Research Article

Risk Evaluation Study of Urban Rail Transit Network Based on Entropy-TOPSIS-Coupling Coordination Model

Fawen Gao 1,2, Zhibin Zhang 1, and Mengxing Shang 3

1 College of Geography and Environmental Science, Northwest Normal University, Lanzhou, China
2 School of Architecture and Urban Planning, Lanzhou Jiaotong University, Lanzhou, China
3 School of Automation and Electrical Engineering, Lanzhou Jiaotong University, Lanzhou 730070, China

Correspondence should be addressed to Fawen Gao; gaofawen@mail.lzjtu.cn and Zhibin Zhang; zbzhang@nwnu.edu.cn

Received 13 November 2021; Revised 29 November 2021; Accepted 7 December 2021; Published 28 December 2021

Copyright © 2021 Fawen Gao et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

As one of the core systems of a city, urban rail transit plays a pivotal role in ensuring the safe, rational, and efficient operation of the city. Therefore, it is of great significance to ensure the safe operation of urban rail transit network to improve the operation efficiency and economic level of the city. The prerequisite to ensure the safety of urban rail transit network is whether the risk situation of urban rail transit network can be reasonably and accurately evaluated. In order to evaluate the risk level of urban rail transit network reasonably and accurately, firstly, with full consideration of the characteristics of urban rail transit, the risk evaluation system of urban rail transit network was established in this paper based on the three levels of regional economy, social resources, and rail transit. Secondly, based on the entropy-TOPSIS-coupling coordination model, the single-factor influence and multifactor coupling influence in the index system are calculated and analyzed, respectively; thus the coupling coordination degree of urban rail transit system is obtained, so as to quantitatively evaluate and analyze the risk situation in urban rail transit network. Finally, based on the actual data of Shanghai from 2000 to 2016, the case simulation and analysis are carried out. The results show that the two indicators of regional economy and social resources are more likely to affect the safety state of urban rail transit. At the same time, the safety factor of urban rail transit coupling system is increasing year by year and gradually develops from disorder to order. This is more in line with current urban rail transit condition, demonstrating the rationality and accuracy of the entropy-TOPSIS-coupling coordination model proposed in this study.

1. Introduction

Urban rail transit is a kind of public transportation that transports a large number of passenger flows in the form of corresponding vehicles through a dedicated track structure, and it occupies a very important position in the urban system. A reasonable and safe urban rail transit network can greatly improve the efficiency and economic level of urban development. The construction of a reasonable and safe urban rail transit network cannot be achieved without an accurate evaluation of the risk of the existing urban rail transit network. Therefore, in order to establish a reasonable risk evaluation system of urban rail transit network, a risk evaluation method of urban rail transit based on the entropy-TOPSIS-coupling coordination model is proposed in this paper, aiming to accurately evaluate the risk situation of urban rail transit network, so as to lay a solid theoretical foundation for optimizing and perfecting urban rail transit network.

Relevant scholars have conducted a series of research on the evaluation of urban rail transit planning and have achieved certain research results. The research content mainly focuses on the exploration, improvement, and optimization of the evaluation model; for example, Yixiu Song [1] used the Analytic Hierarchy Process (AHP) to evaluate the rail transit planning and compared each evaluation index of the transportation planning to obtain its relative importance. Jing Li [2] established a comprehensive evaluation model of traffic network by combining the relative theory of topology and entropy for the shortcomings of the existing
urban rail transit network evaluation index system. Chaoxia Su [3] proposed a comprehensive evaluation method of urban traffic network planning and constructed the comprehensive evaluation model of urban rail transit network by fuzzy evaluation method. Yong Jiang [4] believed that the material element analysis model can provide an operable method for VFM evaluation of urban rail transit PPP projects, reduce the subjectivity in the evaluation process, and improve the scientific and reasonable evaluation results. Xun Liu [5] proposed an evaluation model based on the extension cloud theory for the characteristics of urban rail transit safety evaluation, taking advantage of the uncertain reasoning of the cloud model and the quantitative analysis of the extension theory. Xu XD [6] evaluated the potential benefits and limitations of deploying eco-driving strategies on different transit services, service areas, fleet composition, and road terrain. Bin S [7] proposed a quantitative method to evaluate the performance of urban subway network under different damage scenarios. Hy et al. [8] proposed a vague reasoning of the cloud model and the quantitative analysis of the urban traffic network planning and constructed the comprehensive evaluation model of urban rail transit network and the suitable form of rail network layout, as shown in Table 1.

2. Identification of Evaluation Index

The evaluation index system of the urban rail transit planning network is the key to measuring the results of the traffic system scheme, as well as an important precondition for picking the most reasonable traffic system scheme. This index system needs to comprehensively reflect the traffic system’s economic efficiency, social development, network structure, operation effect, and other rail transit characteristics. Based on an analysis of the related literature’s index system, combined with the characteristics of the city and the needs of social development, and in accordance with the principles of strong purpose, hierarchy, science, rationality, ease of operation, and the quantitative and qualitative combination, the evaluation index system of urban rail transit network is constructed in this paper from three aspects of regional economy, social resources, and urban rail transit, as shown in Table 1.

3. Evaluation Modeling

Step 1. Statistical panel data of three potential variables in Shanghai from 2000 to 2016 are defined as kth, where kth denotes the three subsystems of regional economy (E), social resources (S), and urban rail transit (T), respectively; kth is the kth second index under the subsystem, k = 1, 2, 3, ..., l, l ∈ N∗; jth is the jth year to be evaluated, j = 1, 2, 3, ..., n, n ∈ N∗. The initial matrix of the subsystem \( X_i = [x_{i,k,j}]_{l×n} \) is expressed as

\[
X_i = [x_{i,k,j}]_{l×n} = \begin{bmatrix}
X_{i,1,1} & X_{i,1,2} & X_{i,1,3} & \cdots & X_{i,1,l} \\
X_{i,2,1} & X_{i,2,2} & X_{i,2,3} & \cdots & X_{i,2,l} \\
\vdots & \vdots & \vdots & \cdots & \vdots \\
X_{i,l,1} & X_{i,l,2} & X_{i,l,3} & \cdots & X_{i,l,n}
\end{bmatrix}.
\]

Step 2. For each subsystem separately, the entropy weight method is used to calculate the weight of the kth second index in the jth time period. The smaller the entropy
value, the larger the entropy weight, indicating that the more informative the indicator is, the more important the indicator weight will be. Firstly, the initial matrix is normalized to eliminate the dimension problem, and the normalized matrix of the subsystem is weighted as follows:

$$y_{i,k,j} = \frac{\left( x_{i,k,j}^{\max} - x_{i,k,j} \right)}{\left( x_{i,k,j}^{\max} - x_{i,k,j}^{\min} \right)}, \quad \forall i, k, j,$$

(2)

where $k^{th}$ is the value after normalization and $k^{th}$ and $k^{th}$ are the maximum and minimum values of $k^{th}$, respectively. Calculate the entropy value $e_{i,k}$ of the $k^{th}$ second index under subsystem $i$ as follows:

$$e_{i,k} = -\frac{1}{\ln n} \sum_{j=1}^{n} f_{i,k,j} \cdot \ln(f_{i,k,j}),$$

(3)

when $f_{i,k,j} = 0$; let $f_{i,k,j} \times \ln f_{i,k,j} = 0$. Calculate the entropy weight $\omega_{i,k}$ by using the entropy value of the $k^{th}$ second index under subsystem $i$ as follows:

$$\omega_{i,k} = \frac{1 - e_{i,k}}{\sum_{l=1}^{m} e_{i,l}}, \quad \forall i, k,$$

(4)

Step 3. Using the normalization matrix $Y_i = [y_{i,k,j}]_{m \times n}$ of subsystem $i$ and the entropy weights $\omega_{i,k}$ of the subsystem is weighted as $U = [u_{i,j}]_{m \times n}$:

$$u_{i,j} = y_{i,k,j} \times \omega_{i,k},$$

(5)

Then the probability of system $i$ in the $j$th year is

$$t_{i,j} = \frac{u_{i,j}}{\sum_{j} u_{i,j}}, \quad \forall i, j.$$

(6)

Step 4. Repeat Step 2 and calculate the weight of subsystem $i$ for the $j$th time period using the entropy weight method. Form the normalization matrix $R = [r_{i,j}]_{m \times n}$:

$$r_{i,j} = \frac{\left( u_{i,j}^{\max} - u_{i,j} \right)}{\left( u_{i,j}^{\max} - u_{i,j}^{\min} \right)}, \quad \forall i, j.$$

(7)

Calculate the entropy weight $\omega_i$ by the entropy value of subsystem $i$:

$$\omega_i = \frac{1 - e_i}{m - \sum_{i=1}^{m} e_i}, \quad \forall i.$$

(8)
Step 5. Use the TOPSIS method to solve the comprehensive evaluation index $C_j$ of the urban rail transit system in the $j$th year, first calculating the weighting matrix $O = [\omega_{ij}]_{m \times n}$:

$$o_{ij} = \omega_i \times r_{ij}, \hspace{1em} \forall i, j. \quad (9)$$

Determine optimal $S_i^+$ and inferior solutions $S_i^-$ for the weighted value of subsystem $i$:

$$S_i^+ = \max(o_{i1}, o_{i2}, o_{i3}, \ldots, o_{im}), \hspace{1em} \forall i,$$

$$S_i^- = \min(o_{i1}, o_{i2}, o_{i3}, \ldots, o_{im}), \hspace{1em} \forall i. \quad (10)$$

Calculate the Euclidean distance between the weighted value for the $j$th year and the optimal and inferior solutions:

$$\text{sep}_j^+ = \sqrt{\sum_{i=1}^{m} (S_i^+ - o_{ij})^2}, \hspace{1em} \forall j,$$

$$\text{sep}_j^- = \sqrt{\sum_{i=1}^{m} (S_i^- - o_{ij})^2}, \hspace{1em} \forall j. \quad (11)$$

Calculate the overall evaluation index $C_j$:

$$C_j = \frac{\text{sep}_j^-}{\text{sep}_j^+ + \text{sep}_j^-}, \hspace{1em} \forall j, C_j \in [0, 1]. \quad (12)$$

Step 6. Calculate coupling $B_j$ of multiple factors in the $j$th year. The smaller the deviation between the single factors, the greater the coupling among the factors. Calculate deviation $B_j$ by selecting the formula corresponding to the number of subsystems to be coupled:

$$B_j = S_i \cdot M \cdot \sum t_{i,j} \times \sqrt{2 \left(1 - \frac{\sum (t_{i,j} \times t_{i,j})}{M \cdot \sum t_{i,j}/M} \right)}, \quad (13)$$

where $S_i$ is the standard deviation of accidents caused by a single factor; $M$ is the number of coupled subsystems to be calculated, $2 \leq M \leq 5, M \in N^*$, let $B' = M \cdot \sum (t_{i,j} \times t_{i,j})$, $\sum t_{i,j} \times t_{i,j}$ is the product of the probability of two coupled subsystems, and the larger $B'$, the smaller the deviation. The index is mainly used to evaluate the annual risk coupling strength between the subsystems of urban rail transit coupling model, and at the same time the evaluation results are given to propose decoupling measures. The coupling degree of multifactor risk coupling is calculated by the following formula:

$$B_j = \sqrt{M \cdot \sum (t_{i,j} \times t_{i,j})} / (\sum t_{i,j})^2, \hspace{1em} \forall j. \quad (14)$$

Step 7. Calculate the comprehensive coordination index $V_j$ of probability in the $j$th year; this index is mainly used to evaluate the orderly and disorderly development of urban rail transit system every year. The more orderly the system develops, the more likely it will lead to safety accidents.

$$V_j = \frac{\sum t_{i,j} \times \varpi_i}{\sum_{i=1}^{m} t_{i,j} \times \varpi_i}, \hspace{1em} \forall j. \quad (15)$$

Step 8. Calculate the coupling coordination degree $K_j$ of the urban rail transit system in the $j$th year. This indicator comprehensively considers the characteristics of coupling degree and coordination degree and is mainly used to evaluate the annual coupling strength and orderly and disorderly development between subsystems of urban rail transit coupling model. At the same time, the decoupling method is proposed based on the evaluation results.

$$K_j = \sqrt{|B_j \times V_j|}, \hspace{1em} \forall j. \quad (16)$$

The flow chart of the model is shown in Figure 1.

4. Case Study

Using year as the statistical time period, the panel data of three variables of regional economy ($E$), social resources ($S$), and urban rail transit ($T$) in Shanghai from 2000 to 2016 are counted; the results are shown in Table 2 (see Appendix).

The statistical results of Table 2 show that the economic development of the region is rapid and the investment in infrastructure and transport facilities is increasing, and the growth is increasing over time; in addition, the population density is increasing year by year; the number of times or the number of people using social resources is increasing rapidly; the flow of rail
| Year | Total GDP (E1) | Investment in urban infrastructure (E2) | Investment in traffic service (E3) | Population density along the rail (E4) | Number of hospital beds (S1) | Number of park visitors (S2) | Number of mall patrons (S3) | Total number of jobs along the rail (S4) | Building area of houses along the rail (S5) | Urban rail mileage (T1) | Daily average flow of rail transit (T2) | Peak hourly cross-sectional flow (T3) | Rail Transit Share (T4) |
|------|----------------|-----------------------------------------|-----------------------------------|---------------------------------------|-----------------------------|-----------------------------|-----------------------------|----------------------------------------|-------------------------------------------|---------------------|---------------------------------------|----------------------------------------|------------------------|
| 2000 | 4771.17        | 449.9                                   | 48.83                             | 1575.13                               | 1100.933                    | 3.037235                    | 303690                      | 8917                                   | 62.92                                       | 1100.93             | 26.01                                 | 8917                                   | 9.6                    |
| 2001 | 5210.12        | 510.78                                  | 60.72                             | 1594.793                              | 1141.098                    | 3.378192                    | 41020.2                    | 202.38                                 | 62.92                                       | 1141.09             | 26.41                                 | 21920                                  | 7                      |
| 2002 | 5741.03        | 583.49                                  | 63.01                             | 1627.999                              | 1162.36                     | 3.481151                    | 470640                     | 224.1                                  | 27.0125                                     | 12900               | 27.6125                               | 22900                                  | 8.8                    |
| 2003 | 6694.23        | 604.62                                  | 273.77                            | 1945.152                              | 1183.371                    | 4.681288                    | 693240                     | 240.13                                 | 27.6125                                     | 14123               | 10.865                                | 14123                                 | 11                     |
| 2004 | 8072.83        | 672.58                                  | 316.96                            | 2262.305                              | 1292.254                    | 6.586164                    | 759972.3                    | 244.83                                 | 28.2175                                     | 16729               | 12.123                                | 16729                                 | 10                     |
| 2005 | 9164.1         | 885.74                                  | 385.58                            | 2579.396                              | 1492.024                    | 6.19151                     | 841110                     | 290.53                                 | 28.82                                       | 18333               | 147.9                                 | 18333                                 | 22.5                   |
| 2006 | 10366.37       | 1125.54                                 | 589.52                            | 2699.295                              | 1515.009                    | 6.392849                    | 935715                     | 308.57                                 | 29.4225                                     | 19588               | 169.4                                 | 19588                                 | 15                     |
| 2007 | 12188.85       | 1466.33                                 | 840.46                            | 2793.656                              | 1557.748                    | 8.024164                    | 1068480                    | 355.07                                 | 30.025                                      | 21217               | 234.2                                 | 21217                                 | 18                     |
| 2008 | 14275.8        | 1733.18                                 | 838.91                            | 2786.73                               | 1451.267                    | 10.25247                    | 1210483                    | 374.57                                 | 30.6275                                     | 21920               | 264.3                                 | 21920                                 | 22.5                   |
| 2009 | 15285.58       | 2133.45                                 | 938.24                            | 2880.225                              | 1775.846                    | 10.40956                    | 1775855                    | 374                                  | 31.23                                       | 24819               | 355.05                                | 24819                                 | 32                     |
| 2010 | 17433.21       | 1497.46                                 | 754.66                            | 3066.419                              | 2015.141                    | 12.08282                    | 2071563                    | 377.81                                 | 32                                           | 29188               | 452.57                                | 29188                                 | 31.8                   |
| 2011 | 19533.84       | 1157.34                                 | 595.75                            | 3702.511                              | 2128.829                    | 10.62455                    | 2121357                    | 384.38                                 | 32.82                                       | 29634               | 454.1                                 | 29634                                 | 34.5                   |
| 2012 | 20553.52       | 1038.61                                 | 473.43                            | 3759.09                               | 2350                         | 11.22973                    | 236430                     | 390.042                                | 33.96                                       | 28773               | 510.0                                 | 28773                                 | 37                     |
| 2013 | 22257.66       | 1043.31                                 | 458.7                            | 3817.833                              | 2489.731                    | 11.05788                    | 2509020                    | 465.74                                 | 35.45                                       | 30277               | 528.9                                 | 30277                                 | 38.8                   |
| 2014 | 24060.87       | 1057.25                                 | 422.48                            | 3836.384                              | 2566.667                    | 11.74501                    | 2690280                    | 452.11                                 | 36.02                                       | 31795               | 577.0                                 | 31795                                 | 43                     |
| 2015 | 25643.47       | 1425.08                                 | 759.23                            | 3824.635                              | 2751.32                     | 11.14575                    | 2839740                    | 438.94                                 | 36.02                                       | 33230               | 588.0                                 | 33230                                 | 46.2                   |
| 2016 | 28178.65       | 1551.87                                 | 883.81                            | 3830.881                              | 3078.676                    | 8.887014                    | 3140250                    | 440.19                                 | 36.38                                       | 35436               | 617.0                                 | 35436                                 | 51                     |
Table 3: Results of two-factor and three-factor risk coupling calculations.

| Year | E-S   | E-T   | S-T   | E-S-T  |
|------|-------|-------|-------|--------|
| 2000 | 0.076848266 | 0.70705225 | 0.477653744 | 0.273863504 |
| 2001 | 0.479684364 | 0.727586384 |
| 2002 | 0.476896973 | 0.726825274 |
| 2003 | 0.4750298 | 0.275646204 |
| 2004 | 0.474370190 | 0.274781444 |
| 2005 | 0.472856308 | 0.273784565 |
| 2006 | 0.472108388 | 0.273015559 |
| 2007 | 0.470917514 | 0.271881172 |
| 2008 | 0.468729786 | 0.270321168 |
| 2009 | 0.471217156 | 0.268368082 |
| 2010 | 0.470296768 | 0.266458225 |
| 2011 | 0.468724052 | 0.265600117 |
| 2012 | 0.46885766 | 0.264379497 |
| 2013 | 0.467340377 | 0.263105559 |
| 2014 | 0.467340377 | 0.263105559 |
| 2015 | 0.467340377 | 0.263105559 |
| 2016 | 0.467340377 | 0.263105559 |

Table 4: Integrated coordination of urban rail transit coupled systems, 2000–2016.

| Year | Overall coordination value |
|------|---------------------------|
| 2000 | 0.064319499               |
| 2001 | 0.063911727               |
| 2002 | 0.063578293               |
| 2003 | 0.06276528                |
| 2004 | 0.062219223               |
| 2005 | 0.061646665               |
| 2006 | 0.061083937               |
| 2007 | 0.060285252               |
| 2008 | 0.059427307               |
| 2009 | 0.057899301               |
| 2010 | 0.056771151               |
| 2011 | 0.056293734               |
| 2012 | 0.055560615               |
| 2013 | 0.054835764               |
| 2014 | 0.054052972               |
| 2015 | 0.053268746               |
| 2016 | 0.052080534               |

to 2016, as shown in Table 4, the integrated system coordination maintains a slowly decreasing trend, indicating that the Shanghai urban rail transit system gradually develops from a disorderly state to an orderly state, and the probability of accidents gradually decreases. This is analyzed because the rapid development of Shanghai brings favorable conditions for the improvement of the safety condition of Shanghai’s rail transit system.

The coordination degrees between the two-factor and three-factor risk coupling were measured separately using the evaluation model proposed in Part 2, and the degree of coordination of their evolution toward the common system goal (risk) was further analyzed and evaluated objectively, as shown in Table 5. From Table 5, it can be seen that the two-factor and three-factor risk coupling coordination degrees maintain a steady decreasing trend, which represents a low degree of interaction and synergistic evolution among the factors and a low possibility of risk occurrence in the system. Meanwhile, Table 5 shows that the coupling coordinations of the two-factor E-S as well as E-T, that is regional economy and social resources and regional economy and rail transit, are both larger, while the risk coupling coordination of S-T, that is, social resources and rail transit, is smaller, indicating that both, that is, regional economy and social resources and regional economy and rail transit, are prone to accidents. E-S-T, that is, the smallest risk coupling coordination among the three factors of regional economy, social resources, and rail transportation, indicates that this scenario is the least likely to lead to accidents.

Table 5 shows the annual comprehensive risk index of urban rail transit coupling system based on TOPSIS; the higher the value, the safer the system. The results show that the Shanghai urban rail transit system was the least safe in 2000, and the safety factor of the coupled urban rail transit system is increasing year by year after 2000; that is, the system was gradually safe after 2000.
In the end, the range of the evaluation value obtained by the entropy-TOPSIS-coupling coordination model is 1 and the coefficient of variation is 0.718. The larger the range and coefficient of variation, the greater the dispersion and the higher the degree of discrimination of the evaluation value, where the range reaches the maximum. Therefore, the comprehensive evaluation value of the system obtained by the entropy-TOPSIS-coupling coordination model evaluation method is more beneficial to visually assess the level of urban rail transit risk evaluation.

5. Conclusion

(1) This paper proposes an entropy-TOPSIS-coupling coordination model for urban rail transit by combining the entropy weight method, TOPSIS method, and coupling coordination model. The simulation results show that the risk of urban rail transit system can be reasonably evaluated based on this model, and the conclusions obtained are more in line with the actual situation.

(2) The following results can be obtained from the relevant data of Shanghai from 2000 to 2016: compared with other factors, regional economic and social resources are more likely to cause accidents, so managers need to focus on these two factors for reasonable control.

(3) From Table 5, it can be seen that the E-T two-factor coupling coordination degree is the highest in the factor coupling calculation, so managers should try to avoid the coupling condition of regional economic indicators and rail transit indicators.

(4) From Table 6, it can be seen that the safety factor of urban rail transit coupling system is increasing year by year, gradually developing from disorderly state to orderly state, and the risk is in a gradually increasing situation. Therefore, relevant government departments should pay attention to the urban rail transit problem and increase the strength of urban rail transit safety construction.

Subsequent improvements to the system can be carried out by decoupling methods, and theoretical approaches and practical implementation schemes to decoupling methods for urban rail transit systems should be studied in depth in the future.

Data Availability

Previously reported data are used to support this study and are cited at relevant places within the text as references.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (Grant no. 41961029) and the Natural Science Foundation of Gansu Province, China (Grant no. 20JR5RA398).

References

[1] Y. Song, "Evaluation of rail transportation planning based on hierarchical analysis," Modern Transportation Technology, vol. 8, no. 05, pp. 88–90, 2011.
[2] Li Jing, H. Mou, and L. Wang, "A comprehensive evaluation of urban rail transit network planning based on physical element entropy weight model," Journal of Engineering Management, vol. 27, no. 01, pp. 19–23, 2013.
[3] C. Su, "Model and method for comprehensive evaluation of urban rail transit line network planning," Logistics Science and Technology, vol. 33, no. 06, pp. 143–145, 2010.
[4] Y. Jiang, "Research on VFM Evaluation of Urban Rail Transit PPP Projects Based on Object Element Analysis method," Lanzhou Jiaotong University, Lanzhou, China, 2019.
[5] X. Liu, "Research on urban rail transit safety evaluation based on game theory," Science and Technology Innovation, vol. 23, pp. 138–139, 2017.
[6] X. D. Xu, H. Y. Li, H. B. Liu, M. O. Rodgers, and R. Guensler, "Evaluation of transit ecodriving in rural suburban, and urban environments," Transportation Research Record, vol. 2672, no. 08, pp. 152–164, 2018.
[7] S. Bin and G. Sun, "Optimal energy resources allocation method of wireless sensor networks for intelligent railway systems," Sensors, vol. 20, no. 2, p. 482, 2020.
[8] A. Hy, B. Gg, and B. He, "Risk assessment for construction of urban rail transit projects," Safety Science, vol. 118, pp. 583–594, 2019.
[9] X. Hu, X. Li, and Y. Huang, "Urban rail transit risk evaluation with incomplete information," Procedia Engineering, vol. 137, pp. 467–477, 2016.
[10] N. Aydin, "A fuzzy-based multi-dimensional and multi-period service quality evaluation outline for rail transit systems," Transport Policy, vol. 55, pp. 87–98, 2017.
[11] Y. Wang, M. Li, B. Yang, and C. Yang, "An urban rail transit hazard evaluation methodology based on grey system theory,”

| Year | TOPSIS value | Sorted |
|------|--------------|--------|
| 2000 | 0            | 17     |
| 2001 | 0.032291135  | 16     |
| 2002 | 0.055527455  | 15     |
| 2003 | 0.122951141  | 14     |
| 2004 | 0.164184398  | 13     |
| 2005 | 0.208533961  | 12     |
| 2006 | 0.255951377  | 11     |
| 2007 | 0.323101496  | 10     |
| 2008 | 0.3892544    | 9      |
| 2009 | 0.521650975  | 8      |
| 2010 | 0.612688027  | 7      |
| 2011 | 0.65000222   | 6      |
| 2012 | 0.709916021  | 5      |
| 2013 | 0.766845372  | 4      |
| 2014 | 0.830907081  | 3      |
| 2015 | 0.896998925  | 2      |
| 2016 | 1            | 1      |
[12] Y. Wang, K. Chen, and Y. Zhou, “Evaluation of rail transit line network based on TOPSIS model,” *Highway Transportation Technology*, vol. 32, no. 06, pp. 130–134, 2015.

[13] B. Qian and L. Zhao, “Evaluation of urban rail transit line network planning scheme based on entropy value method,” *Transportation Technology and Economy*, vol. 19, no. 05, pp. 4–8, 2017.

[14] Z. Zhou, *Research on the Evaluation of Service Level of Urban Rail Transit Interchange stations*, Shijiazhuang University of Railways, Shaoxing, China, 2020.

[15] R. Zhao, *Research on Urban Rail Transit Line Network Layout and Scheme evaluation*, Xi’an University of Architecture and Technology, Xi’an, China, 2018.

[16] F. Xie, *Research on Interface Risk Evaluation of Urban Rail Transit PPP Projects Based on ISM-ANP-Fuzzy*, Qingdao University of Technology, Qingdao, China, 2018.

[17] W. Huang, B. Shuai, Y. Sun, Y. Wang, and E. Antwi, “Using entropy-TOPSIS method to evaluate urban rail transit system operation performance: the China case,” *Transportation Research Part A: Policy and Practice*, vol. 111, pp. 292–303, 2018.

[18] H.-W. Wu, J. Zhen, and J. Zhang, “Urban rail transit operation safety evaluation based on an improved CRITIC method and cloud model,” *Journal of Rail Transport Planning & Management*, vol. 16, Article ID 100206, 2020.

[19] M. B. Bouraima, Y. Qiu, and B. Yusupov, “A study on the development strategy of the railway transportation system in the West African Economic and Monetary Union (WAEMU) based on the SWOT/AHP technique,” *Scientific African*, vol. 8, 2020.