Evaluation of High-speed Railway Train Line Plan Based on EMU Routes

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Abstract—EMU route is a fixed turnover section for EMU to take on transportation tasks. As an important transportation resource in high-speed railway transportation, EMU's operation level directly affects the railway transportation cost. Therefore, evaluating the train line plan (TLP) based on EMU routes would be of great significance in further optimization and improvement of the high-speed railway TLP. This paper optimized the evaluation process of TLP by adding EMU routes evaluation stage. After analyzing differences and relations of indicator systems in different evaluation stages, construct evaluation indicator system related to EMU Routes. Therefore, the evaluation system of TLP based on EMU routes is implemented using C#. Eventually the effectiveness about indicators and evaluation system are validated by a case.

1. INTRODUCTION

The train line plan (TLP), which is the carrier of railway passenger transport products, is a technical plan that determines the operating sections (including stops), train categories and operation number of trains. And its quality affects the service level for railway products and the utilization of transportation resources. It also has a profound impact on the benefits performance of railway department.

Currently research on evaluation of TLP is mainly focused on constructed an evaluation indicator system in units of single or multiple trains. Lian Wenbin[1] discussed the factors influencing service quality from four aspects: transportation products, transportation process, combined transportation and image service, and established a three-level indicator system in 2008. In 2013, Goerigk, Schachtebeck & Schöbel[2] did research on the robustness of TLP with travel time as evaluation indicator. In same year, considering adaptability of station organization, Bai Zixi[3] established a comprehensive evaluation indicator system of TLP from the perspective of balance of train timetable and EMU Operation. After that, Ma Chao[4] analyzed and evaluated the TLP of Beijing Shanghai high-speed railway in 2014, also established an evaluation indicator system about single train.

Furthermore, regarding the design of TLP evaluation system, in 2008, Li Jian[5] took the economic benefits of TLP as the main research direction and then developed a TLP evaluation system, which realized the functions of TLP setting and indicator calculation also displayed the various indicators.
about single train in TLP by using a table. Then, Tong Jianan[6] developed a TLP evaluation system based on passenger flow assignment technology in 2016. With continuous development of computer technology, Zhang Yu[7] combined with characteristics of high-speed railway TLP to carry out research about the key technology which is used for evaluation system.

Different from TLP evaluation method only based on single or multi trains in the existing research, this paper optimizes the TLP evaluation process by adding EMU routes evaluation stage. Then the evaluation indicator system of high-speed railway TLP based on EMU routes is constructed and its differences as well as relations with indicator systems of other TLP evaluation stages are analyzed. Finally, a high-speed railway TLP evaluation system based on EMU routes is developed to realize evaluation functions.

2. EVALUATION PROCESS OPTIMIZATION OF HIGH-SPEED RAILWAY TLP

2.1 Evaluation process Optimization

The evaluation of TLP is an important link in the process of line planning. Results can reflect the quality of current TLP and have important guiding significance for its optimization and adjustment. In present research, the evaluation process of TLP is mostly shown in Fig. 1, including single and multi-train evaluation stage. The single-train evaluation stage is mainly from the perspective of passengers, evaluating ticket benefit, service capacity, passenger service level of each train. This stage reflects whether a train in TLP can meets the passengers transport demands. The multi-train evaluation stage evaluates the overall operation effects of TLPs, mainly from the perspectives of economic & social benefit, transport volume, technology level, as well as service diversity. It reflects the quality of line planning at macroscopic level.

![Diagram of Evaluation Process](image)

However, this above evaluation process has some serious limitations. There is a weak linkage between single and multi-train evaluation stage, just statistics and analysis of single train evaluation indicators. There is no necessary linkage between those two stages. Moreover, from the perspective of the entire evaluation process, there is a lack on evaluation process for operation level of the EMUs, which are important resources in the railway transportation. As a result, the evaluation coverage of TLP...
is not comprehensive. Furthermore, in the single-train evaluation stage, due to the difficulty on accounting directly of the train operation cost, comparing the revenue of trains with different departure and terminal stations cannot reflect the real economic benefits of trains.

To solve those aforementioned problems, an EMU routes evaluation stage is added between the single and multi-train evaluation routing stage, to optimize the evaluation process of TLP. The optimized evaluation process is shown in Fig. 2.

2.2 Advantages of adding EMU routes evaluation stage

The main advantages of adding EMU routes evaluation stage are as follows:

- Make the evaluation stages of TLP more tightly connected

  To meet the needs of EMU allocation, the railway department has to run the train at inopportune times or use the EMU formation that does not match the passenger flow. Those trains which must be operated but with lower output, on the other hand, was necessary to ensure the operation of other trains on the whole EMU route. So that, only in the single-train evaluation stage cannot reflect their value. However, an EMU route includes multiple trains running with the same EMU in TLP. Therefore, EMU route is the link between single and multi-trains, which can better reflect the overall operation effect of TLPs. Adding EMU routes evaluation stage makes the evaluation process of TLP more scientific and efficient.

- Convenient to add EMU operation indicators

  EMU Route is a fixed turnover section for EMU to take on transportation tasks. It is more intuitive in EMU routes evaluation stage by adding the EMU operation evaluation which the railway department pays more attention on. It makes up for the lack of EMU aspect in the evaluation process also provides comprehensive and multi-level guidance for the optimization and adjustment of TLP.
Resolution about difficulties on calculating the cost of train operation

The operation cost of high-speed rail train mainly includes line usage fees, traction power fees, EMU operation fees and personnel expenses while the calculation of EMU operation fees is the most complicated among them. Taking EMU route as the basic evaluation unit can turn cost accounting into a unified and measurable standard. Although it is difficult to calculate the specific cost of using the EMU, the operating cost of EMU is roughly the same among EMU routes which using the same type of EMU. By comparing transportation revenue of EMU routes with same EMU, the economic benefit of trains in these routes can be accurately reflected. It is great significance for the railway department to improve their transportation efficiency.

3. CONSTRUCTION AND ANALYSIS OF EVALUATION INDICATOR SYSTEM BASED ON EMU ROUTES

3.1 Construction of evaluation indicator system

Evaluation of TLP involves many factors. In EMU routes evaluation stage, taking EMU route as the basic evaluation unit, three main factors of economic benefit, technology & service level and EMU operation are considered to the evaluation indicator system based on EMU routes as shown in Table 1.

| Elements               | Types       | Indicators                                                                 |
|-----------------------|-------------|-----------------------------------------------------------------------------|
| Economic Benefits     | Revenue     | Ticket revenue of EMU Route                                                  |
|                       |             | Revenue realization rate                                                    |
|                       |             | Ticket revenue per capita of EMU Route                                       |
|                       |             | Ticket revenue per seat of EMU Route                                        |
|                       |             | Ticket revenue per kilometer of EMU Route                                   |
|                       |             | Ticket revenue per EMU                                                     |
| Technology & Service Level | Transportation Quality | Passenger flow                                                            |
|                       |             | Passenger turnover                                                          |
|                       |             | Passenger load factor                                                       |
|                       |             | Transport density                                                           |
|                       |             | Average passenger turnover of trains in EMU Route                           |
|                       |             | Turnover volatility of trains in EMU Route                                  |
|                       |             | Passenger load factor volatility of trains in EMU Route                     |
| Speed Characteristic  |             | Travel speed                                                                |
|                       |             | Technical speed                                                             |
|                       |             | Effective speed ratio                                                      |
|                       |             | Speed ratio                                                                 |
| EMU Operation         | Space-time  | Operation distance of EMU                                                   |
|                       |             | Operation distance per day of EMU                                           |
|                       |             | Operation time of EMU                                                       |
|                       |             | Productive time of EMU                                                      |
|                       |             | Utilization coefficient of EMU                                              |
|                       |             | Space-time utilization level of EMU                                          |

3.2 Comparison of indicator systems between evaluation stages

EMU routes evaluation stage plays a connecting link in the whole evaluation process. The main evaluation elements selected in this stage are similar to single and multi-train evaluation stage, making
the entire evaluation process more tightly connected. On the one hand, the calculation of some indicators in the EMU routes evaluation stage can use the results of previous evaluation which also can be used for calculation in subsequent evaluation process. For example, the ticket revenue of EMU routes, which is the sum of ticket revenue of some single trains at previous stage, can be used when the ticket revenue of multi-trains is calculated at subsequent stage. On the other hand, the calculation method of some indicators in the EMU routes evaluation stage is similar to that in other evaluation stages. For instance, the same calculation method is used for load factor at different evaluation stages in the evaluation process, they only input different data according to different evaluation objects in the calculation.

Although there are some similarities between the EMU routes evaluation stage and other stages, this stage also has its own characteristics which makes the whole evaluation process covers different respects in railway transportation. There are three main characteristics.

- Add economic benefit indicators related to EMU
  
  Because the comparison of transportation income of different routes can directly reflect the economic benefit, the ticket revenue per kilometer and ticket revenue per EMU are increased when evaluating the economic benefit of EMU routes. Between them, the former reflects the revenue per kilometer on the entire operation path of EMU routes, which can analyze profit space of the route by comparing with line usage fees. The latter eliminates the impact of EMU operation time on transportation revenue.

- Add technology & service level indicators related to EMU
  
  Adding turnover volatility and passenger load factor volatility of trains shows the technology & service level of EMU routes. These two indicators mainly reflect the traffic volume fluctuation of different trains in the routes. The smaller the value is, the more stable the traffic volume will be.

- Add EMU operation indicators
  
  EMU routes evaluation stage analyzes the operation time, average operation distance per day and space-time utilization level of EMU by introducing the EMU operation indicators. It mainly reflects the quality of EMU in railway transportation. Among them, the space-time utilization level of EMU refers to the ratio between non-productive time with total operation distance of EMU routes, which measures utilization efficiency of EMU.

In brief, through discussion there is a close connection between EMU routes evaluation stage and other evaluation stages. Meanwhile it also has its own characteristics. The connections and differences of different evaluation stages are shown in Fig. 3. The green dotted line box in the figure shows new indicators added in EMU routes evaluation stage. Indicators in yellow can be calculated using the results of previous stage. Indicators in blue. Calculation methods of indicators in blue are the same as those in other evaluation stages. Other indicators in red require auxiliary data to be calculated using new calculation methods. It can be seen from the figure that evaluation stages are well coordinated and tightly connected.

![Figure 3. Differences and connections of index systems in different stages](image-url)
4. DESIGN AND DEVELOPMENT OF TLP EVALUATION SYSTEM BASED ON EMU ROUTES

4.1 Requirement analysis
Evaluation system needs to implement four main functions: EMU routes importing, data management, calculation of indicators and displays value, as well as human-computer interaction. In terms of system performance, security, stability, easily be maintained and high fault tolerance should be the highest priority. Also, in order to make it easy for users to operate, the system should have a nice human-computer interaction function. In addition, it needs to be fast in processing a large amount of data and can run well on PC.

4.2 System design
1) Structure design

The system is developed with a three-tier structure shown in Fig. 4, including view layer, logic controller layer and data access layer, which are built on entities.

View layer is responsible for evaluation results and interacting with users. Logic controller layer realizes the core module of the system which controls the calculation and statistics of traffic indicators. Data access layer is the bottom module to interact with the database. Using three-tier structure can effectively reduce the coupling and increase the logical reuse between modules. It makes system more conducive to expand and maintain.

![System structure](image)

2) Data organization design

There are many types data involved in the system including railway network, TLP, passenger flow and EMU routes. Therefore, the data organization can be constructed in two directions: "horizontal-vertical", as shown in Fig. 5.

Horizontal data relationships are classified according to data categories. Railway network manager, TLP manager, passenger flow manager and EMU route manager are developed in evaluation system to avoid coupling between each manager. When evaluating a specific TLP, these data managers cooperate with each other to build an evaluation object.

Vertical data management is closely related to system structure. The bottom layer is integrated data manager. Its upper layer is indicator calculation manager, which is mainly responsible for combining and calculating existing data. Then, calculation results can be obtained by indicator result data manager, where the results are transferred to the top-layer display manager after being classified.
4.3 Development and implementation

Evaluation system developed by C# based on .NET Framework. It consists of three modules: EMU route data management, indicator calculation and multi-granularity display module. Each module can be subdivided into several sub-modules, as shown in Fig. 6.

1) Module functions
   a) EMU route data management module
      This module was subdivided into three parts:
      - EMU Route data import and read
      - Train relation construction
      - EMU Route data query and edit.
      The first sub-module interacts with the database while the second construct continuation relationship of trains in TLP based on EMU routes. And the last one implement EMU route data maintenance functions such as query and edit.
b) Indicator calculation module
This module is the core modular that implements evaluation functions and can be subdivided into two parts:
- Indicator calculation
- Calculation of EMU passenger flow matrix
  It can calculate indicators constructed in Chapter III and passenger flow density in different sections of an EMU route.

c) Multi-granularity display module
This is the key module for human-computer interaction which is used to visualize indicators of EMU routes. It can be subdivided into the following parts:
- Information display of EMU routes
- Indicator display
- Passenger flow density display of EMU routes

2) System interface
The system interface is shown in figures below. Fig. 7 is the EMU route data management form, which contains the function of adding, deleting, editing and querying. Fig.8 and 9 illustrate the indicator display forms of which the left side is polyline or column display region and the right side is basic information display region. Fig. 10 is the passenger flow density display form of EMU routes.

Figure 7. EMU route data management form.

Figure 8. Indicator display form with polylines.

Figure 9. Indicator display form with columns.
4.4 Case study
TLP evaluation system runs on Windows 10. The computer uses an Intel Core i5 dual-core four-process CPU clocked at 2.60GHz with 8GB memory capacity. Taking the case of data from the Beijing-Shanghai high-speed railway in 2016, the system can be well achieved the functions of data management, indicator calculation and multi-granularity display for EMU routes. Computer used in this experiment runs smoothly. Indicators can be calculated fast and displayed clearly and effectively.

In short, the case shows that this system can excellently realize the evaluation function of high-speed railway TLP based on EMU route. Taking EMU routes as basic evaluation unit of TLP can better reflect the overall operation effect.

5. CONCLUSION
With development of railway operation and management, it is of great significance to evaluate the TLP from different angles. Firstly, the evaluation process of TLPs was optimized by adding EMU routes evaluation stage in this paper. Then a TLP evaluation indicator system based on EMU routes was also established, which involved indicators of economic benefits, technology & service level and EMU operation, and compared with indicator systems of other stages in evaluation process. Finally, high-speed railway TLP evaluation system based on EMU routes was implemented with C# after system requirements analysis and structure design.

The results show that this evaluation indicators based on EMU routes have good applicability. And evaluation system has following advantages: clear structure, convenient use of core functions, high efficiency of indicator calculation and accurate display of results. In a word, it provides a scientific and reliable assistant decision-making tool for evaluation of high-speed railway TLP.

ACKNOWLEDGMENT
This work was supported and funded by the National Key R&D Plan (No. 2018YFB1201402), the National Natural Science Foundation of China (No. 71971024) and the China State Railway Group Co.,Ltd (No. K2019X007)

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