Evaluation method of effect of marshalling operation process based on DEA

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Abstract. Based on the marshalling station transfer operation process, this paper divides the marshalling transfer operation process into three sub-processes: arriving-disintegrating, disintegrating-marshalling and marshalling-dispatching. Considering the input of the facilities of the marshalling station, the intermediate output of the operating time and the final output of the number of transfer trains, an evaluation index system is constructed and a slacks-based network DEA model is established. For purposes of illustration, the model is applied in a design calculation example, the efficiency of the marshalling station transfer operation process is analysed, and the results show that the model is effective.

1 Introduction

Marshalling station is a station that handles the disintegrating and marshalling of freight trains on the railway network which is equipped with relatively complete shunting equipment. According to the operation process of the trains in the station, the marshalling station system can be divided into three systems: arriving-disintegrating, disintegrating-marshalling and marshalling-dispatching. Each system cooperates with each other and restricts each other, jointly complete a series of work of assignments, disintegration, assembly, marshalling, and departure of the train. In accordance with the requirements of the market-oriented development of transportation enterprises, the marshalling operation process should not only increase the individual operation time and reduce the intermediate waiting time and other indicators that reflect the efficiency of the transfer process, but also reflect the number of final transfer trains. Therefore, the study of the degree of coordination between subsystems starts with the quantitative indicators of inputs and the qualitative indicators of outputs, and analyse the operating efficiency of the entire transit system. Therefore, to increase output with as little input as possible.

Based on the principle of input-output analysis, there are many methods to evaluate the efficiency of the system, most of which are to reduce input while the output is fixed, or to maximize output while the input is fixed. One of the well-known methods is data envelopment analysis (DEA). DEA measures the efficiency of each individual section by calculating a discrete piecewise frontier determined by the set of Pareto-efficient DMUs[1]. There have many applications of DEA in the transportation field, Lewis H. F.[2-3] combined the two-stage DEA and network DEA. The method is applied to the efficiency evaluation of the system, to split the operation process and study the system's interior, to deepen the evaluation efficiency from the overall to the links, and to analyse the input and output effects from a micro perspective, which is more in line with the actual operation process. Gao Ying [4] used the network DEA model to evaluate the internal situation of China's railway transportation. Li Xiamiao [5] divided the wagon operation process into a network of loading and unloading, transit, travel activities, and established an input-output evaluation index system. Hamid [6] consider an IFT system as a multi-division transport chain and calculate its efficiency using a slacks-based DEA model.

This paper uses the network DEA method to design the input and output indicators of each subsystem, and establishes a system evaluation method oriented to the transfer effect of the marshalling station to provide the transfer efficiency evaluation method of the marshalling station.

2 Analysis of marshalling operation process

According to the work completion process in the marshalling station, the work process is divided into three relatively independent links: arriving-disintegrating, disintegrating-marshalling and marshalling-dispatching. These three links are independent but restrict each other, and there will be delays in spreading processes. In the past, the evaluation index was mainly based on the operation time, that is, the average transit time of the train at the technical station. The operation process was not analysed from the internal relationship, and it was impossible to judge which part was in trouble, and it was impossible to evaluate the comprehensive effect of the entire operation process. For example: some trains have longer transit time due to the long arrival operation time, some have long waiting time for disassembly, or long marshalling...
operation time, etc.; and the facilities and equipment conditions of different marshalling stations are different, which will affect the operation to a certain extent, effectiveness.

3 Methodology to evaluate the efficiency of process based on DEA

3.1 Relationship structure

Based on the analysis of the operation process of the marshalling station, the transfer operation process is divided into the sub-processes of arriving-disintegrating, disintegrating-marshalling and marshalling-dispatching (Figure 1). Since the relevant data of the waiting process is difficult to obtain, the intermediate waiting time is not considered. $X_{j1i}, X_{j2i}, X_{j3i}$ indicate resource input for each subsystem, $Z_{j1p}, Z_{j2p}, Z_{j3p}$ indicate intermediate output for each subsystem. At the same time, it is also the input of the transfer operation, and the final output of the whole operation process is obtained through the entire transfer process system $Y_j$.

$$X_{j1i} \xrightarrow{\text{Arriving-disintegrating}} Z_{j1p}$$
$$X_{j2i} \xrightarrow{\text{Disintegrating-marshalling}} Z_{j2p}$$
$$X_{j3i} \xrightarrow{\text{Marshalling-dispatching}} Z_{j3p}$$

Figure 1. Relationship structure of marshalling operation process.

3.2 Model of evaluation

The most important for DEA model is the selection of input-output indicators, which has an impact on the evaluation results on the reliability and practicality. The indicator selection should reflect the reality. As for index of input, the completion of sub-process involves investment in infrastructure, therefore, the number of lines corresponding to infrastructure equipment is the key, which showed in Table 1. As for index of intermediate output, we consider the time of every work. And the index of final output is the total number of transit trains, which showed in Table 2.

| Input categories | Index |
|------------------|-------|
| $X_{j1i}$        | Number of trucks in arriving yard |
|                  | Number of train inspection group-1 |
| $X_{j2i}$        | Number of shunting line |
|                  | Number of Shunter |
| $X_{j3i}$        | Number of trucks in dispatching yard |
|                  | Number of train inspection group-2 |

Table 1. Index of input.

| Output categories | Index |
|-------------------|-------|
| Arriving-disintegrating $Z_{j1p}$ | Number of arriving-disintegrating train |
| Disintegrating-marshalling $Z_{j2p}$ | Time of train inspection |
|                    | Time of disintegrating |
| Marshalling-dispatching $Z_{j3p}$ | Number of marshalling train |
|                    | Time of assembling |
|                    | Time of marshalling |
|                    | Number of dispatching train |
|                    | Time of train inspection |

Table 2. Index of production.
The model is constrained by the input-output relationship of the arriving-disintegrating, disintegrating-marshalling, marshalling-dispatching and the entire transfer process. Taking the operating efficiency value of the $k$-th marshalling station $E_k$ as the goal, a slack-based network DEA evaluation model is established:

$$
\text{min } E_k = e_k^i + e_k^j + e_k^l + e_k^t
$$

subject to:

$$
\sum_{j\in L_k} \lambda_{ij} x_{ij} + s_{ij} = e_i^j x_{ij}, \forall i \in \{1, 2\}
$$

$$
\sum_{j\in L_k} \lambda_{ij} x_{ij} + s_{ij} = e_i^j x_{ij}, \forall i \in \{3, 4\}
$$

$$
\sum_{j\in L_k} \lambda_{ij} x_{ij} + s_{ij} = e_i^j x_{ij}, \forall i \in \{5, 6\}
$$

$$
\sum_{j\in L_k} \lambda_{ij} x_{ij} + s_{ij} = e_i^j x_{ij}, \forall i \in \{7, 8, 9\}
$$

$$
\sum_{j\in L_k} \lambda_{ij} y_j - s_{ij} = y_k, \forall p \in \{1, 2, 3\}
$$

$$
\sum_{j\in L_k} \lambda_{ij} y_j - s_{ij} = y_k, \forall p \in \{4, 5, 6\}
$$

$$
\sum_{j\in L_k} \lambda_{ij} y_j - s_{ij} = y_k, \forall p \in \{7, 8, 9\}
$$

$$
\sum_{j\in L_k} \lambda_{ij} y_j - s_{ij} = y_k, \forall p \in \{1, 2, 3\}
$$

$$
\lambda_{ij} \geq 0, \forall i \in \{1, 2, 3, 4\}
$$

Where $e_k^i$ represents the sub-process of the $i$-th marshalling station, $\lambda_{ij}$ represents the weight coefficient of the sub-process of the $j$-th marshalling station, $s_k^i$ and $s_k^j$ are the corresponding slack variables.

If the optimal solution satisfies $e_k^i \geq 1$, then the sub-process of the $k$-th marshalling station is DEA valid, otherwise, it is DEA invalid.

### 4 Illustrative case

Through the statistics of the existing marshalling stations, the data such as train inspection time are normally distributed or exponentially distributed. Randomly generate data based on this. Based on statistics from existing literature, number and time data are obtained. Table 3 shows the statistics and Table 4 shows the result of the illustrative case.
|                  | 34    | 33    | 30    | 25    | 27    |
|------------------|-------|-------|-------|-------|-------|
| Time of train inspection/min |       |       |       |       |       |
| Number of transfer train       | 2985  | 3398  | 4959  | 5993  | 4582  |

Table 4. Efficiency of transfer operation process

| Station | $e_1^k$ | $e_2^k$ | $e_3^k$ | $e_4^k$ | $E_1^k$ |
|---------|---------|---------|---------|---------|---------|
| A       | 0.934   | 1.034   | 1.276   | 0.877   | 1.098   |
| B       | 0.886   | 0.692   | 1.098   | 1.334   | 0.994   |
| C       | 1.653   | 1.573   | 1.215   | 1.366   | 1.487   |
| D       | 1.367   | 1.467   | 1.196   | 1.198   | 1.365   |
| E       | 0.655   | 0.798   | 0.772   | 1.277   | 0.856   |

From the result, we can know the main factor is the total time. Station C’s total time is shortest and it ranks first. In the arriving-disintegrating, disintegrating-marshalising, marshalling-dispatching and the entire transfer process, Station C and Station D are all DEA valid. Overall, for each station, we can know the shortest sub-process, which mean that the efficiency of input and output is low, and it is time to reduce the transit time of trains at the marshalling station.

5 Conclusion

Based on the traditional time-based evaluation method, this paper divides it into three subsystems considering the transfer operation process of the marshalling station, and uses the network DEA model to evaluate the efficiency of its internal operation process. The results of the calculation example show that the constructed model is effective, the relative efficiency of each operation process can be obtained. The evaluation indicators need to be further refined in the future.

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