Research Journal of Applied Sciences, Engineering and Technology 5(5): 1720-1725, 2013
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: July 27, 2012 Accepted: September 03, 2012 Published: February 11, 2013

The Analysis of Shunting Locomotives' Operating Efficiency Based on Gray-DEA

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Abstract: In order to explore the configuration of the railway freight shunting locomotives, improve the efficiency of locomotive operation; a DEA cross evaluating method based on grey incidence analysis is presented in this paper. This method is based on collecting underlying data of factors that influence the shunting operation efficiency in train service depot, which utilizes grey incidence analysis to establish corresponding evaluation indicators system. Furthermore, the method as well adopts DEA and DEA cross efficiency model to analyze, evaluate and estimate the efficiency of shunting locomotives operation in train service depots. A sorting result of the efficiency of shunting locomotives operation in each train service depot has been acquired with help of programming using MATLAB 7.0. What the result indicates is that the DEA cross efficiency evaluating model based on grey incidence analysis can reflect the actual state of the efficiency of shunting locomotives operation in each train service depot. Eventually, based on a projection analysis of non-DEA's three decision-making units, key factors that influence the efficiency of shunting locomotives operation are identified, which can provide decision support for further improvement of the configuration and operation in train service depots.

Keywords: Cross evaluation, DEA, efficiency of shunting locomotives operation, grey incidence analysis

INTRODUCTION

Shunting operation is one of the main parts of the overall processes of railway transport activities and it is also one of the cores of the organization of the station operation. Shunting locomotives are the major equipments for shunting operation. Therefore, the safety and efficiency of both the organization of train operation and organization of goods loading and unloading could be affected by whether the configuration of shunting locomotives is reasonable, which is the significant influence factor of increasing turnover of cars and reducing operational costs. In order to make rational use of all kinds of human, material and financial resources, it is necessary to evaluate the economic benefit optimization of railway mobile equipment investment with the aim to made the most of the overall economic efficiency with minimal input and the smallest resource consumption. The evaluation mentioned means that, according to various input and output indexes that describe the application effect of shunting locomotives, the analysis work of the main elements that influence the application effect of shunting locomotives would be finished to verify whether the arrangement of the shunting locomotives in technical stations and the terminal is rational and to confirm whether the optimal configuration and utilization have been achieved. As for the study of optimization of the locomotives operation, an ability test system that could test out the equipment ability in the process of shunting was established by Broek and Kroon (2007), a method to select the optimal scheme that takes multiple objectives into consideration from multiple alternative schemes of Taking-Out and Placing-In wagons was proposed by Zhao and Fang (2005) with the use of analytic hierarchy process. A research for the information system for wireless locomotive shunting was conducted (Wei *et al.*, 2006). To improve the automation degree of the railway station shunting system, an intelligent train dispatch system, which could intelligently control the shunting processes, was designed (Yaoguang, 2006). Aimed at the private railway sidings, a mathematical model for optimization of the operation of Taking-Out and Placing-In wagons, based on which a calculation result had been solved by genetic algorithm, was developed (Wang *et al.*, 2007). With consideration of both the shunting operation organization mode within overall relative section and the cost of shunting locomotives, a modified and detailed method to measure the effectiveness of shunting locomotive placement and operation was proposed (Zhu *et al.*, 2011). In this study, we are developing a new approach to evaluate shunting locomotives' operating efficiency. Grey incidence analysis is utilized in that new approach, which is specific to a characteristic that the influence factors of

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shunting locomotives' operating efficiency, contains multi-input and multi-output indexes, to determine what factors mainly influence the shunting locomotives' operating efficiency. Therefore, results made by the new approach can provide reference for improving the arrangement and configuration of shunting locomotives.

METHODS TO EVALUATE

Determination of input and output indexes-gray incidence analysis for evaluation indicator systems: The evaluation of shunting locomotives' operating efficiency could be defined as that under a given investment and engineering technology level, calculating or estimating the maximum degree of satisfaction with adequate use of all resources. What the definition of the evaluation above means that within a certain level of investment, the evaluation could be used to figure out what portion of various input resources should be utilized and how much the maximum output ability is. The evaluation indicator system ought to be as accurate as possible, which can ensure that system to completely reflect and measure the requirements and goals of the application of shunting locomotives in shunting operation. According to resources (human, financial, time and so on) condition for the utilization of railway shunting locomotives and the requirements of manufacturing management, grey incidence analysis is adopted in this study to select input and output indicators with considering the maneuverability of the evaluation indicator system, which aims to reflect the effectiveness of shunting locomotives' operating efficiency with less key indicators.

Grey incidence analysis (Luo *et al*., 2002) is based on the macro and micro geometrical proximity of behavior factors sequence, which is a method to analyze and determine either the influence degree between factors or the contribution measurement to main behavior from factors. Grey incidence analysis can be viewed as a feasible objective weighting method, the basic idea of which is that, the more consistent trend of both reference sequence and comparative sequence, the greater the correlation, vice versa.

Set the reference factors sequence Y = {y (1), y (2), ..., y(n)}; comparative factor sequence Xi = (1), xi (2), ..., xi (n)}, $i \in m$. So in the moment k, the incidence coefficients for comparative factor sequence corresponding to reference factors sequence is:

$$\gamma_{ik} = \frac{\min_i \min_k \left|y(k) - x_i(k)\right| + \xi \max_i \max_k \left|y(k) - x_i(k)\right|}{\left|y(k) - x_i(k)\right| + \xi \max_i \max_k \left|y(k) - x_i(k)\right|} \quad (1)$$

where, ξ is connection weight, $\xi \epsilon [0, 1]$, generally ξ = 0.5, thus, the incidence coefficients for Y and X_i is. $\gamma_i = \gamma(Y, X_i) = \frac{1}{n}\sum_{k=1}^{n} \gamma_{ik}$. Then set Ψ_i as the relative weight measurement for sequence X_i corresponding to sequence Y, so $\Psi_i = \frac{\gamma_i}{\sum_{i=1}^{n} \gamma_i}$.

DEA model: Provided there are n sections or units named Decision Making Unit (DMU) and there are m items of equivalent input and s items of output for those DMU respectively, x_{ij} is the overall input amount of input type I in DMU j; y_{rj} is the overall output amount of type r in DMU j; v_i is the weight of type i input; u_r is the weight of type r output. i = 1, 2, ..., m , r = 1, 2, ..., s, j = 1, 2, ..., n (Wu and Liang, 2006).

Thus, the efficient assessment index for each DMU is the ratio of the total input and total output. That is:

$$h_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}, \quad j = 1,2,\cdots,n \quad (2)$$

Select appropriate weight to satisfy $h_j \leq 1$, j = 1, 2, ..., n.

Now with the decision-making unit efficiency index as the goal, the weight coefficient as a variable, with all the efficiency of decision making units index as constraint, evaluate the efficiency of DMU k and establish an optimization model (C^2R):

$$\begin{aligned} &\max \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \\ &s.t. \quad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \\ &\quad u_r, v_i \geq 0 \\ &\quad i = 1,2,\cdots,m;\ r = 1,2,\cdots,s;\ j = 1,2,\cdots n \end{aligned} \quad (3)$$

The formulas above are a fractional Programming problem. With the use of Charnes-Cooper transformation, make $t = 1/v^T x_k$, ω = tv, μ = tu.

So formula (3) could be equivalently transformed as a linear programming model below:

$$\begin{aligned} &\max \mu^T y_k \\ &\quad \omega^T x_j - \mu^T y_j \geq 0,\ j = 1,2,\cdots,n \\ &s.t. \quad \omega^T x_k = 1 \\ &\quad \omega \geq 0, \mu \geq 0 \end{aligned} \quad (4)$$

Further convert the linear programming model to duality programming model with use of duality theory for linear programming, which introduces slack variables and considers non-Archimedean infinitesimal ε. Then standardize formulation D_{C^2R} and obtain:

$$\begin{aligned} &\min\ \theta - \varepsilon(\hat{e}^T S^- + e^T S^+) \\ &\quad \sum_{j=1}^{n} \lambda_j x_j + s^- = \theta x_k \\ &s.t.\quad \sum_{j=1}^{n} \lambda_j y_j - s^+ = y_k \\ &\quad \lambda_j \geq 0,\ j = 1,2,\cdots,n \\ &\quad s^- \geq 0,\ s^+ \geq 0 \end{aligned} \tag{5}$$

where, S^+, S^-, λ_j, θ are decision variables that are requested.

Cross efficiency matrix (Wang, 2009): Sexton *et al.* (1986) introduced an idea of cross efficiency, while cross efficiency evaluation means evaluating the value of efficiency of each DMU for n times through solving n sets of linear programming and obtain n groups of optimal weight. As shown below:

$$e_{jk} = \frac{\sum_{r=1}^{s} u_{rj} y_{rk}}{\sum_{i=1}^{m} v_{ij} y_{ik}},\ j = 1,2,\cdots,n,\ k = 1,2,\cdots,n$$

where, u_{1j}, u_{2j}, ..., u_{sj} and v_{1j}, v_{2j}, ..., v_{mj} are respectively input and output weight that are calculated with model D_{C^2R}; e_{jk} is the score of DMU_k after running DMU_j. $E_j = \sqrt[n]{\prod_{k=1}^{2} e_{jk}}$ is adopted to be the final score of DMU j. E_j is known as the average cross-efficiency value. All the decision-making units to be sorted according to the size of E_j.

ANALYSIS OF THE CONFIGURATION EFFICIENCY IN TRAIN SERVICE DEPOT

Determination of evaluation indicator systems: Shunting locomotives' operating efficiency evaluation indicator system should reflect the requirements of railway enterprises about economic security. The effect of the operation of shunting locomotives is a multi-dimensional variable, which requires both of the amount and quality guarantee. The evaluation indicator system for the effect of the operation of shunting locomotives is the more comprehensive the more it can reflect the practical application of the conditioners, but subjected to the limitations of quantitative methods and data collection, in practice, it can only select some representative and specific indicators to reflect the effect of the operation of various aspects of shunting locomotives. Therefore, in order to fully reflect the effect of the operation of shunting locomotives, we must follow the principles of comprehensiveness, system integrity, practical applicability, scientificalness, feasibility and operability to select indicators to build the indicators system. This study utilizes the gray incidence analysis method to extract and optimize the system of the indicators as the input and output indicators and finally gets the evaluation of associated indicators of the effect of the operation of shunting locomotives. As the evaluation indicators system has too much indicators and a limited number of decision-making units, it is hard to reflect the relative efficiency of decision-making units truly, which will lead the failure of DEA model evaluation, thus, the analytical data of the selected input and output indicators are condensed in this study. Using the relevant methods to analysis the above indicators system, the input indicators include shunting locomotive cost Module, Transportation Organization, Level of inter-related the job effect, working environment and condition and the output indicators for the job is output module.

The Evaluation System of shunting locomotives' operating efficiency as shown in Fig. 1.

MODEL APPLICATION AND RESULT ANALYSIS

The data in this study comes from Guangzhou Railway Group. We choose 8 train service depots of it as the decision making units, as Table 1 shows. The indicators are standardized in the experiments, because the input and output indicators' dimensions are different. And as the shunting locomotives' operation output indicator has two aspects, operation time and disintegration, marshalling and delivering volume, the output indicator is divided into two parts, time and volume. Based on the Evaluation Indicator System set above and the C^2R model, we can get the analysis result by programming and calculating in MATLAB 7.0 (Table 1).

In Table 2, as a whole, the overall efficiency of the 8 Train Service Depots is generally high relatively, the mean of which reaches 0.929363. Five Train Service Depots have an efficiency of the shunting locomotives equaling to 1. It shows that the effective use of the shunting locomotives in these five Train Service Depots reach a high degree. While each of the operational performance indexes θ of the first and third Train Service Depot are less than 1, which means that their technical efficiency are low and they are not in the overall efficiency of the frontier. The third Train

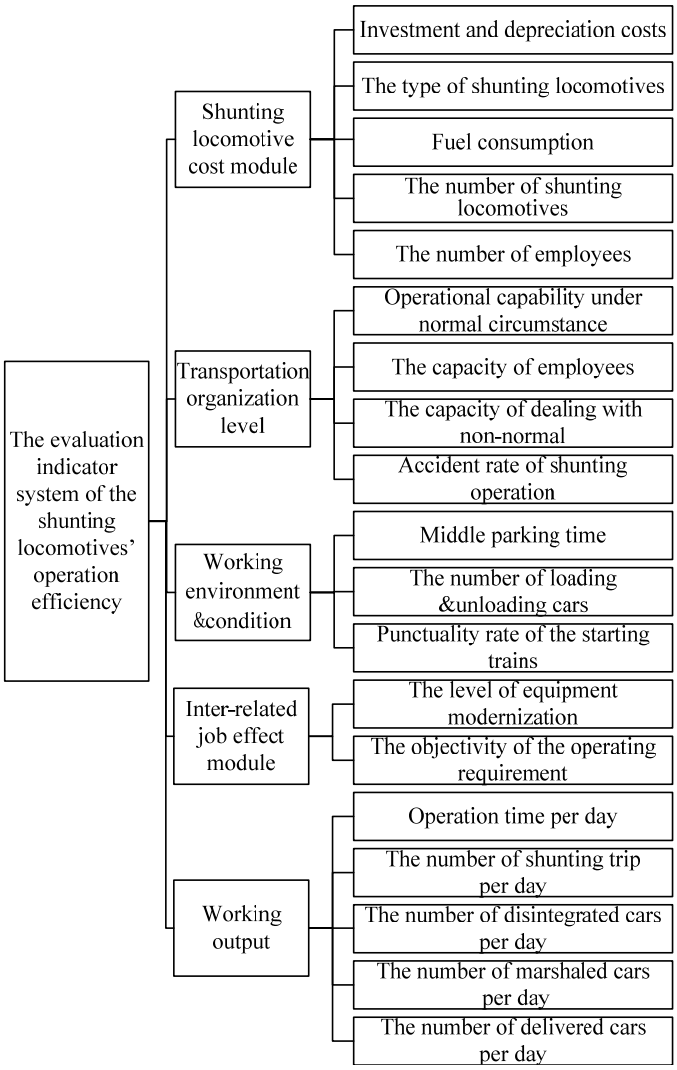

Fig. 1: The evaluation system of shunting locomotives' operating efficiency

Table 1: Comprehensive evaluation of the input and output indicators

	Input indicators				Output indicators	
Train service depot	Shunting locomotive cost module	Transportation organization level	Working environment and condition	Inter-related job effect module	Working output 1	Working output 2
1	0.8003	2.2310	2.2546	4.7686	1.78481	2.6727
2	2.0019	0.7976	4.7906	0.2101	4.72619	6.7416
3	1.0010	0.5725	2.9429	0.1304	4.57123	2.0590
4	0.5001	0.6847	0.4126	0.0103	2.11180	1.1128
5	1.5013	0.8316	3.1538	0.0202	7.20518	3.3697
6	1.1011	0.7547	2.1987	0.0091	6.55169	3.0919
7	1.9101	0.4767	1.6772	1.9143	1.94968	6.4834
8	0.8007	0.4365	1.1326	0.1491	8.72975	3.0265

Service Depot has the lowest efficiency, which is only 0.5907. However, its returns to scale are in the up state, which means that they haven't reached their ideal output scale and have larger potential to explore. The management level and performance of the locomotives should be improved. In contrast, θ of the fifth Train Service Depot is less than 1 and its returns to scale are in the decreasing state, which shows that it has gone

Table 2: The DEA result of the train service depots' shunting locomotives efficient

Train service depot	θ	$\sum \lambda_j$	Scale efficient	S_1^-	S_2^-	S_3^-	S_4^-	S_1^+	S_2^+
1	0.8835	0.8831	irs	0	1.5857	0.9918	4.0816	5.9244	0
2	1	1	-	0	0	0	0	0	0
3	0.5907	0.5849	irs	0	0.0218	0.6854	0	0	0
4	1	1	-	0	0	0	0	0	0
5	0.9607	1.1473	drs	0.2611	0	0.6925	0	0	0
6	1	1	-	0	0	0	0	0	0
7	1	1	-	0	0	0	0	0	0
8	1	1	-	0	0	0	0	0	0

Table 3: Input and output adjusted value of shunting locomotives operation in train service depots

Train service depots	θ	C_1	C_2	C_3	C_4	C_5	C_6
1	0.8835	0.7071	0.3854	1.0001	0.1315	7.7092	-
3	0.5907	1.1837	0.1988	0.4488	0.0503	-	-
5	0.9607	1.1812	0.7989	2.3374	0.0194	-	-

beyond the ideal size of the output. The possible reason may be too many shunting locomotives, which should be solved by reducing the numbers.

In order to sort efficiency of the shunting locomotives of each Train Service Depot and adjust policy and management to correct, this study will get the matrix E of cross efficiency evaluation by using the software MATLAB 7.0, calculating the sample of the efficiency of shunting locomotives of the eight Train Service Depots mentioned above.

Its main diagonal elements are the self-evaluation of values of the efficiency of shunting locomotives of the eight Train Service Depots, while the off-diagonal elements are evaluated by others. The pros and cons of each decision making unit cannot be distinguished only by self-evaluation. As a result, the average cross efficiency evaluation can be calculated using the mentioned method of cross evaluation:

$$e_1 = 0.1429 \quad e_2 = 0.5692 \quad e_3 = 0.3423 \quad e_4 = 0.4377$$

$$e_5 = 0.5384 \quad e_6 = 0.6827 \quad e_7 = 0.3426 \quad e_8 = 0.6954$$

According to the size of e_i, the sort of the pros and cons of the eight Train Service Depots using shunting locomotives efficiency are as follows:

$$DMU_8 > DMU_6 > DMU_2 > DMU_5 > DMU_4 > DMU_7 > DMU_3 > DMU_1$$

As can be seen from the above, in accordance with DEA cross evaluation method, the eighth Train Service Depot is the optimal in using shunting locomotives, while the first is the least efficient.

Through further research and model calculation, as to three non-DEA efficient Train Service Depots, the formula $\hat{X}_k = \theta^k X_k - S^-$, $\hat{Y}_0 = Y_0 + S^+$ are applied to revise the decision-making unit input-output vector, by making quantitative identification of key factors as well as the problems of influencing the operational performance of these Train Service Depots to provide decision support of Configuration and application for the Guangzhou Railway Group. The results are shown in Table 3.

It can be indicated with the chart above that as for depot 3, we should decrease the investment scale, which means cancel one shunting locomotive and 16 employees, relatively curtail the depreciation expense and take measures to reduce energy consumption.

As for depot 5, the shunting locomotive should lessen for 3, the workers for 48, relatively curtail the depreciation expense and take measures to reduce energy consumption. We also can know that 3 depots should immensely improve the overall quality of its staff and their ability to cope with mechanical failure, as well as reduce the accident rate of shunting. Depot 1 should also rationally arrange locomotives, reducing the nonproductive time of shunting locomotives.

CONCLUSION

In this study, the analysis of shunting locomotives' operating efficiency based on Gray-DEA not only improves the traditional DEA model's shortcomings of non-achieving DMU, but also makes some analysis, evaluation and measurements of 2010 locomotive configuration and utilization in the Guangzhou Railway Group, receiving sort results of the shunting locomotive utilization performance in various train service depots. The result can reflect the actual state of efficiency and identify the key factors which influence the shunting locomotive efficiency based on projection analysis of non-DEA's three decision-making units. It also can provide a more accurate decision support for China's railway locomotive configuration and optimization.

$$E = \begin{bmatrix} 0.8835 & 0.8909 & 0.5442 & 0.5887 & 0.5938 & 0.7429 & 0.8980 & 1.0000 \\ 0.0293 & 1.0000 & 0.4280 & 0.2004 & 0.4988 & 0.5053 & 0.1851 & 0.7070 \\ 0.0927 & 1.0000 & 0.5907 & 0.7728 & 0.7913 & 1.0000 & 0.4044 & 1.0000 \\ 0.0036 & 0.1398 & 0.1796 & 1.0000 & 0.3990 & 0.5256 & 0.0097 & 0.2870 \\ 0.0355 & 1.0000 & 0.5672 & 0.3817 & 0.9607 & 1.0000 & 0.2157 & 1.0000 \\ 0.0005 & 0.0312 & 0.0465 & 0.2848 & 0.4910 & 1.0000 & 0.0014 & 0.0597 \\ 0.0881 & 0.3640 & 0.1810 & 0.1195 & 0.2764 & 0.3012 & 1.0000 & 0.5098 \\ 0.0097 & 0.1280 & 0.2015 & 0.1542 & 0.2964 & 0.3866 & 0.0260 & 1.0000 \end{bmatrix}$$

ACKNOWLEDGMENT

The authors wish to thank the helpful comments and suggestions from my teachers and colleagues. This study was supported in part by NSFC under Grant No. 70971140.

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