International Journal of Economics, Commerce and Management
United Kingdom ISSN 2348 0386 Vol. IX, Issue 9, Sep 2021

http://ijecm.co.uk/

MAINTENANCE EFFICIENCY OF FIREFIGHTING EQUIPMENT IN TRANSIT SYSTEM - THE TAIPEI MRT WENHU LINE MUZHA SECTION AS AN EXAMPLE

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Abstract

The Taipei mass rapid transit (MRT) system provides convenient and comfortable commuting alternatives in the greater Taipei metropolitan area with the average ridership of more than two million passengers per day. The well maintenance for the Taipei MRT system is an important issue for the safety and seamless service of passengers. Therefore, this study aims to analyze the maintenance efficiency of the firefighting equipment in the Muzha section of the Metro Taipei Wenhu Line. According to the data envelopment analysis (DEA), this study suggests that the low efficiency station can be improved from better equipment maintenance to reduce "Number of Failure Reports" and better repairing staff scheduling to reduce "Number of Repairers." The result of this study can give the improving references for the present Taipei MRT operations, and then offer better and safer service for passengers.

Keywords: MRT, Firefighting equipment, Maintenance efficiency, DEA

INTRODUCTION

The Taipei MRT system is a mass transit service operated by Metro Taipei corporation. Since the opening of the Taipei MRT Muzha Line (the first MRT line of Taipei city, now renamed Muzha section, part of Wenhu Line) in March 1996, the Taipei MRT system has provided convenient and comfortable commuting options in the metropolitan Taipei area. By March 2019, the accumulated ridership of the Taipei MRT system has reached 10 billion, and daily ridership was more than 2 million (Metro Taipei, 2021). Since the Taipei MRT system is closely integrated with the citizen life, the sound maintenance status of the system is thus an important issue for a smooth and safe service.

Among all the system equipment, the firefighting equipment is one the most important equipment that closely related to passengers' safety. And since the Muzha section of the Taipei MRT Wenhu Line is the first and oldest service section in the Taipei MRT system, its firefighting equipment could be relatively older than other parts of the Taipei MRT system. Therefore, this study aims to explore its maintenance efficiency of firefighting equipment to give safer and more reliable service.

As for the main study steps, this study first collects the data of the Muzha section of the Taipei MRT Wenhu Line, then applies the data envelopment analysis (DEA) method to get the firefighting equipment maintenance efficiencies of all stations of the Muzha section of the Taipei MRT Wenhu Line. Finally, this study remarks some suggestions from the important findings of the study results.

LITERATURE REVIEW

The data envelopment analysis (DEA) for evaluating efficiency has been widely applied to many studies, including the manufacturing, construction, service, farming, and financial industries. This study reviewed some important studies as follows.

For the studies on the fire department or firefighting topics, Chao (2012) used DEA for efficiency analysis on the fire brigades at Banqiao, Zhonghe, Xinzhuang and Sanchong, New Taipei City. From the results of this research, it found that ten of these fire brigades have not achieved relative efficiency rate at present. Similarly, Li (2015) also aimed to use DEA to find out the efficiency of each fire brigade at Yunlin County and help fully use staff and vehicles with limited resources offered by the government. Zeng (2019) made assessment of the fire department, using the poor output model in the DEA to assess the efficiency of the fire department in all counties and cities. The results show that Taipei City, Kaohsiung City, Changhua County, Hsinchu City, and Lianjiang County are the most efficient; while the Pingtung County is the bottom of all counties and cities. Hsu and Tsai (2021) used DEA to analysis the efficiency of government procurement of firefighting equipment. Their study found that due to most firefighters' equipment has special specifications, the use of the Most Advantageous Tender tends to increase year by year. However, the most inefficient one among these three procurement ways is the Most Advantageous Tender, mainly because of the procurement process's long average Time. To improve the Most Advantageous Tender's procurement efficiency, this study suggests that the average Time of the Most Advantageous Tender processes should reduce by 55%.

For the studies in other fields, Thabrani et al. (2018) aimed to analyze the efficiency of health services of all districts/city governments in West Sumatra, Indonesia by DEA. The results showed that the level of efficiency of inter-regional health services in West Sumatra province is 60%. Kosor et al. (2019) used DEA to calculate technical efficiency of public spending on education for EU-28 using the latest higher education statistics available. Focusing on European higher education, conceptual and methodological issues related to the measurement and analysis of efficiency were discussed. Li et al. (2019) used 29 provinces (divided into seven regions) in China as examples, to study the supply-side efficiency of China's real estate market using DEA for the period of 2012-2016. The results showed that the main problem of low supply-side efficiency in the Chinese real estate market is the low land-use efficiency, with a redundancy rate of 60.59% in China's land space pending development.

Moreover, for the non-DEA research related to this study, Stenström (2014) found railway performance and capacity will be enhanced by expanding infrastructure, introducing better technology, and improving the efficiency and effectiveness of operation and maintenance.

METHODOLOGY

The data envelopment analysis (DEA) efficiency evaluating method was originally proposed by Farrell (1957). It uses mathematical programming to evaluate the production efficiency of the decision-making units (DMUs). In DEA, the envelopment curve is used to connect the ratio of input to output with a line called the efficiency frontier, which can also be called the production frontier. If the values of DMUs fall on the line, it means that the unit is efficient; otherwise, the inefficient units will be below the efficiency frontline. To be noticed that the efficiency, analyzed by the DEA method is relative, not absolute efficiency. However, Farrell's efficiency evaluation model can only be used for single input and output options, Charnes, Cooper, and Rhodes (Charnes et al., 1978) then proposed various inputs available called CCR model of DEA. With multiple outputs, and the production boundary obtained by the linear programming method, the relative efficiency of every DMUs will be evaluated.

In addition, the CCR model assumes the constant return to scale, i.e. adding one unit of input can increase one unit of output. Therefore, Banker, Charnes and Cooper (Banker et al., 1984) proposed the BCC model of DEA that does not adopt constant returns assumption. Moreover, the technical efficiency in the BCC model can divided into “pure technical efficiency” and “scale efficiency.” The scale efficiency refers to the advantage of being able to change the scale of its operations and the size of operations in the overall, so that it can meet the most suitable scale.

The DEA efficiency described above are generally expressed in mathematical form as follows (Taylor III, 2015):

$$\text{Technical efficiency} = \frac{\Sigma \text{weighted output}}{\Sigma \text{ weighted input}} \quad (1)$$

After further expression, the mathematical formula (1) expressed as follows:

$$E_k = \frac{\sum_{j=1}^{M} U_j \, O_{jk}}{\sum_{i=1}^{N} V_i \, I_{ik}} \quad (2)$$

Where,

E_k: value of technical efficiency, between 0~1.

k: number of decision units.

N: number of inputs variables.

M: number of output variables.

O_{jk}: value of the output variable j for the decision unit k.

I_{ik}: value of the input variable i for the decision unit k.

V_i: weight of input i.

U_j: weight of output j.

Finally, to solve by linear programming as follows, the technical efficiency (TE) in the target formula may either the maximum output in the known input or the minimum input in the known output.

Max.TE

s.t.

$E_k \leq 1 \quad k=1,2,\ldots K \quad (3)$

Meanwhile, when using the DEA to evaluate the relative efficiency, the first step is to select those DMUs to compare and evaluate relative efficiency. Therefore, when selecting DMUs, factors such as the homogeneity of the DMUs and the number of DMUs should be concerned. In addition, when deciding on the number of DMUs, it is empirically recommended that the number of DMUs is at least twice the sum of the number of input and output variables.

In addition, Dyson et al. (2001) put a stricter standard that the number of DMUs cannot be less than twice the product of the number of input and output variables.

ANALYSIS

The Muzha section of the Taipei MRT Wenhu Line starts at the Taipei Zoo Station and goes to the Zhongshan Junior High School Station, with total of 12 stations, 0.9 kilometers long, as shown in Figure 1. Moreover, the Muzha section belongs to the medium-capacity elevated transit system, with unmanned auto-guided rubber tires transit vehicles, as shown in Figure 2.

Figure 1. Route Map of Muzha Section.

Source: edited from original pngwing.com (https://www.pngwing.com) file.

Figure 2. Taipei MRT Muzha Section in operation.

Source: BToday weekly, 2018.

The firefighting equipment maintenance data of this study ranges from January 2020 to December 2020. In detail, five monthly statistical items as “Number of Failure Reports,” “Severity Scores,” “Repair Time,” “Number of Repairers,” and “Station Volume” are classified, as shown in Table 1.

Table 1. Classified Data for DEA Analysis

Station Code	Input				Output
	No. of Failure Reports	Severity Scores	Repair Time (min)	No. of Repairers	Station Volume (passengers)
BR12	11	475	277	22	9,065,198
BR11	7	325	73	17	25,057,071
BR10	20	975	1,093	43	29,605,500
BR09	15	800	614	30	15,803,653
BR08	2	125	25	5	9,140,339
BR07	9	500	177	19	7,362,604
BR06	4	225	104	9	2,770,420
BR05	5	250	135	10	2,080,332
BR04	0	0	0	0	8,447,619
BR03	2	50	29	4	1,523,307
BR02	5	300	128	10	2,813,718
BR01	9	450	528	20	4,054,577

For the DEA analysis, this empirical study runs MDeap 2 software to calculate the average monthly maintenance efficiency of each station from January 2020 to December 2020. First, to calculate the fixed return to scale efficiencies (i.e., the short-term efficiencies/ the CCR model of DEA analysis), as shown in Table 2 and Figure 3. It is found that the highest short-term efficiency comes to BR04 Wanfang Hospital Station, while the lowest one is BR05 Xinhai Station. Furthermore, Table 3 shows that the improvement direction of BR05 Xinhai Station should reduce the values of “Number of Failure Reports” and “Number of Repairers.”

Table 2. Efficiency Values under Constant Returns to Scale

Station Code	Efficiency
BR12	0.097555
BR11	0.423739
BR10	0.175230
BR09	0.124719
BR08	0.541001
BR07	0.096840
BR06	0.081988
BR05	0.049253
BR04	1.000000
BR03	0.090162
BR02	0.066616
BR01	0.053330

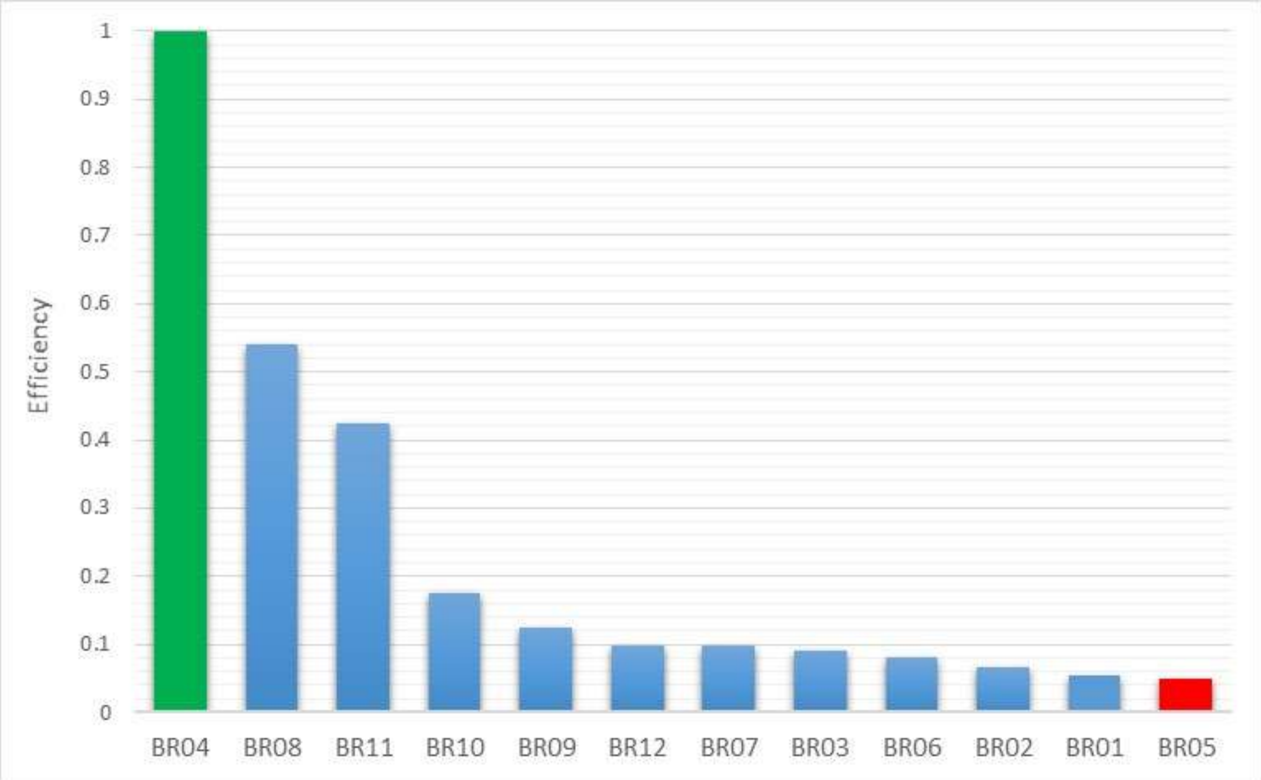

Figure 3. Constant Returns to Scale Efficiency Ranking

Table 3. Improvable Rates under Constant Returns to Scale (%)

Station Code	No. of Failure Reports	Severity Scores	Repair Time (min)	No. of Repairers
BR12	-90.24	-99.77	-99.61	-95.12
BR11	-57.63	-99.09	-95.94	-82.55
BR10	-82.48	-99.64	-99.68	-91.85
BR09	-87.53	-99.77	-99.70	-93.76
BR08	-45.90	-99.13	-95.67	-78.36
BR07	-90.32	-99.83	-99.51	-95.41
BR06	-91.80	-99.85	-99.68	-96.36
BR05	-95.07	-99.90	-99.82	-97.54
BR04	0.00	0.00	0.00	0.00
BR03	-90.98	-99.64	-99.38	-95.49
BR02	-93.34	-99.89	-99.74	-96.67
BR01	-94.67	-99.89	-99.91	-97.60

In addition, to calculate the variable returns to scale efficiencies (i.e., the long-term efficiencies/ the BCC model of DEA analysis), as shown in Table 4. Finally, the CCR results are divided by the BCC results to get the scale efficiency, as shown in Table 5 and Figure 4. It's found that the highest scale efficiency still comes to BR04 Wanfang Hospital Station, while the lowest one is BR10 Zhongxiao Fuxing Station. This means that BR10 Zhongxiao Fuxing Station should try to decrease some maintenance inputs and try to increase its output, i.e., the station volume.

Table 4. Efficiency Values under Variable Returns to Scale

Station Code	Efficiency
BR12	0.111190
BR11	1.000000
BR10	1.000000
BR09	0.269537
BR08	0.625119
BR07	0.111111
BR06	0.250000
BR05	0.200000
BR04	1.000000
BR03	0.500000
BR02	0.200000
BR01	0.111111

Table 5. Scale Efficiency Values

Station Code	Scale Efficiency
BR12	0.877372066
BR11	0.423739
BR10	0.17523
BR09	0.462715694
BR08	0.865436821
BR07	0.871560872
BR06	0.327952
BR05	0.246265
BR04	1
BR03	0.180324
BR02	0.33308
BR01	0.47997048

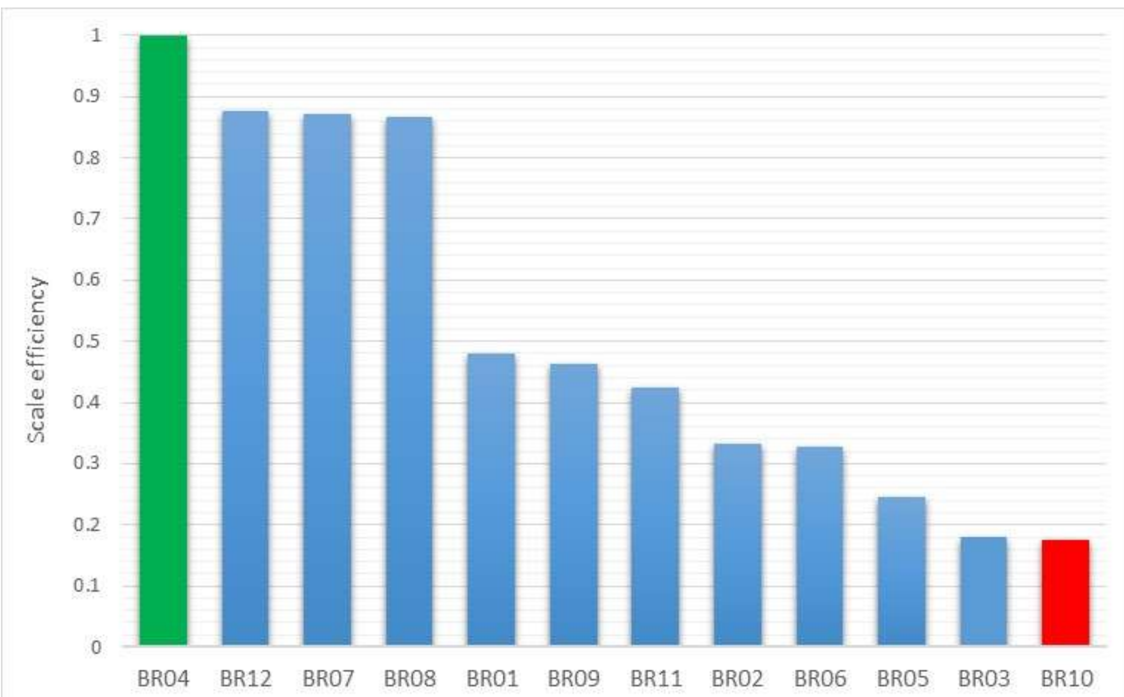

Figure 4. Scale Efficiency Ranking

CONCLUSION

This study applying the data envelopment analysis (DEA) method to explore the maintenance efficiency of the firefighting equipment in the Muzha section of the Taipei MRT Wenhu Line. In addition, the input variables are "Number of Failure Reports," "Severity Scores," "Repair Time" and "Number of Repairers," while the output variable is "Station Volume." Moreover, the short-term/present efficiency is analyzed by the CCR model, and the long-term efficiency is analyzed by the BCC model. Furthermore, using CCR/BCC to get the scale efficiency of each station.

The results show that the highest short-term/present efficiency comes to BR04 Wanfang Hospital Station, while the lowest one is BR05 Xinhai Station. For the lowest maintenance efficiency station, this study suggest that it can improve from two aspects. The first one is strengthening equipment maintenance to reduce chance of equipment damage and therefore to reduce the "Number of Failure Reports." Second, since there is a minimum required repairers for each repair task, if there is no safety concern, the number of maintenance staff must flexibly adjust to reduce the "Number of Repairers."

In addition, the study results also show that the highest scale efficiency still comes to BR04 Wanfang Hospital Station, while the lowest one is BR10 Zhongxiao Fuxing Station. This means that for the long-term, the lowest scale efficiency station should try to decrease some maintenance inputs and in the meantime to increase its output, i.e., the station volume.

Furthermore, the results of this study comes from the current ridership of the Taipei MRT network. However, since the Taipei MRT network is still gradually expanded, the ridership of every transit lines will also change. Therefore, for the future studies, the calculation demonstrated in this study needs to update dynamically, i.e., a regularly updated calculation for the maintenance efficiency of each station is necessary.

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