Operational Performance of the Taiwan Railways Administration First-Class Stations – A Combined AHP and DEA Analytical Approach

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Abstract: This research aims at evaluating the operational performance of the Taiwan Railways Administration (TRA) first-class stations based on both objective and subjective judgments. The demographic and geographic factors significantly vary along a railway line; even for railway stations that share the similar passenger demands could have different service purpose. In order to balance the productivity efficiency and railway station's societal responsibility, this study combines DEA's objective assessment mechanism towards relative efficiency and AHP's subjective integration model on multiple-criteria combination weights to analyze the performance of the target stations. The performance of the TRA's first-class stations is analyzed to demonstrate the applicability of this combined method. The results suggest a more general performance evaluation approach for railway's station operations and also provide the manager with policy directions and operational goals to improve their operational strategies.

Keywords: Performance Evaluation, Railways Station, Data Envelopment Analysis, Analytic Hierarchy Process

1. INTRODUCTION

Increasing awareness that several unique characteristics of railway transportation including

safe, reliable, large capacity, and energy saving has increased interest in the integration of infrastructure utilization and system operation, especially for miscellaneous services at rail stations. Services at rail stations in Taiwan are not only restricted by gate operations, but also affect the patterns of transport and logistic activities and further involved social equality issues. This study first evaluates the performances of the 'First-Class' rail stations in Taiwan Railway Administration (TRA). TRA classified stations into seven classes based on 100 points. The "First-Class" station is the class within the second high score range (50~90 points). This study uses the advantages of Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA) to indicate the directions of system operations that would help managers to re-allocate resources within those stations.

Oum and Yu (1994) pointed out that the output of railway transportation could be considered as the ability to provide and the production utilized by consumers and the derivatives. Not only do the outputs have multi-dimension concerns, the inputs also should also assess multi-criteria factors. Due to the various output features of railway transportation, multiple perspectives must be considered when carrying out efficiency analysis.

However, the railway stations are distributed along the railway line to provide both passenger and freight services; and the demographic and geographic factors may vary significantly between each station. Even for stations that share the similar passenger demands, the transport service criteria for those railway stations could be different. Therefore, to evaluate the performance of railway stations, factors other than the railway station revenue must be taken into account. Indexes such as proper input and output from the perspective of railway station must be chosen for a reasonable and fair assessment. For instance, the performance of railway train stations should include society needs and local community service because the function of a railway system should provide infrastructure services.

This study proposed combined AHP and DEA approach is applied to investigate the operational performance of TRA's first-class stations. From DEA, the objective weights in input and output of every station can be derived. As from AHP, the subjective weight is used to decide which index is given first priority so as to enhance the operational performance of the station.

2. BACKGROUND AND LITERATURE REVIEW

2.1 Current TR Operation Status

TRA is the only public transportation network that has a complete round-island railway coverage in Taiwan. The overall operating mileage is 1094.4 km, including 435.4-km single

track section and 659.0-km double track section. Also, the electronic section is 688.8 km and the non-electrified section is 405.6 km. TRA runs 1,110 trains per day, with a total mileage of 1,014,066 km (807,310 km for passengers and 206,756 km for cargos). TRA carries 464,550 riders per day (20,630,000 passenger-kilometer) and 32,355 tons of cargos.

In the past thirty years, due to changes in international relations, transition of domestic industry structure, transformation of the society life style, and development of transportation system, the demand of TRA's rail services upon long/short trip transportation in different districts has experienced substantial changes. Currently the discrepancy in supply and demand of the train stations' service of the TRA is huge because the performance evaluation system remains unchanged since it was last modified in 1990; the allocation of many operation resources are now in accordance with an outdated system that is not able to meet the concept of advanced service and customers' needs nowadays. Therefore, a new evaluation system for railway stations' operational performance is highly required.

2.2 Data Envelopment Analysis

Data envelopment analysis (DEA) is a nonparametric approach to measure the efficiency of decision making units (DMUs) in organizations. Building on the ideas of Farrell's (1957), developed by Charnes *et al.* (1978), DEA provides a single measure and can be used to handle multi-input and multi-output (Agha *et al.*, 2011). There are two basic types of DEA with CCR and BCC. The CCR (Charnes-Cooper-Rhodes), proposed by Charnes *et al.* (1978), is the most basic model which assumes constant returns to scale (CRS). The model assumes that every DMU is working under an optimized ratio. However, Banker *et al.* (1984) proposed the BCC model with variable returns to scale (VRS) as an extension of the CRS model. Typically, there are two types of measurement techniques: input-orientation model measures the amount of input reduced per DMU and produce output at the same level of the original standard. Alternatively, output-orientation model measures the maximum output per DMU while keeping the input unchanged.

Suppose there are $j(j = 1,….,n)$ DMUs. Each of DMU is using i inputs$(X_{ij} , i = 1,….,m)$ to perform outputs Y_{rj} $(r = 1,….,s)$. The CCR model then is presented as following:

$$E_k = MAX \frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{i=1}^{m} v_i X_{ik}} \qquad (1)$$

$$s.t \; \frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1, \; j = 1,\ldots,n$$

$$u_r, v_i \geqq \varepsilon > 0, \quad i = 1,\ldots,m \quad r = 1,\ldots,s$$

u_r, v_i are the weights for outputs and inputs. The purpose of CCR model is to find the best set of weights of outputs and inputs to maximize the production efficiency. For the detail computation process, readers can refer to Charnes., Cooper, and Rhodes (1978). To release the constraint of assumption of constant return in CCR model, Banker, Charnes and Cooper（1984）modified Equation (1) into Equation (2) by introducing a new parameter $u0$. The $u0$ could indicate the scale of return for each DMU.

$$\text{MAX} \quad h_k = \frac{\sum_{r=1}^{s} u_r Y_{rk} - u_0}{\sum_{i=1}^{m} v_i X_{ik}} \tag{2}$$

$$s.t. \; \frac{\sum_{r=1}^{s} u_r Y_{rj} - u_0}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1, \; j=1,\ldots,n$$

$$u_r, v_{i \geqq \varepsilon} > 0, \quad i = 1,\ldots,m, \quad r = 1,\ldots,s$$

The computation process of BCC, readers could refer to Banker, Charnes and Cooper（1984）.

2.3 Analytical Hierarchical Process

AHP is one of the most widely used multiple-criteria decision making tools. The applications of AHP include different fields such as planning, selecting the best alternative, resource allocations, resolving conflict, optimization, etc. (Vaidya and Kumar, 2006). AHP is a subjective method that applies pairwise comparison matrices, hierarchical structures and ratio scaling to apply weights to attributes (Lee *et al.*, 2008).

The advantage of this method is that experts can reasonably identify the weight index that corresponds to the real problem (Liu, 2003). Thus, despite the different placement of weights on the indices, the AHP method can still determine the order of priority and avoid conflicts between the reality and the index weights (Liu, 2003).

The subjective weights W is obtained by solving in Equation (3). The matrix A is the matrix of the pair comparison among the importance of outputs and inputs from experts'

suggestions. The next step is to calculate the relative weight from systematic point of view. This calculation of relative weight is a standard process in most AHP research. Therefore, the details of computation could refer to Saaty (1980). In short, W is the solution that would satisfy Equation (3).

$$A = \begin{bmatrix} 1 & . & a_{1j} & . & a_{1n} \\ . & . & . & . & . \\ a_{i1} & . & a_{ij} & . & a_{in} \\ . & . & . & . & . \\ a_{n1} & . & a_{nj} & . & 1 \end{bmatrix}_{n \times n} = \begin{bmatrix} w_1/w_1 & . & w_1/w_j & . & w_1/w_n \\ . & . & . & . & . \\ w_i/w_1 & . & w_i/w_j & . & w_i/w_n \\ . & . & . & . & . \\ w_n/w_1 & . & w_n/w_j & . & w_n/w_n \end{bmatrix}_{n \times n} \quad (3)$$

2.4 Integration of AHP and DEA

AHP, which is technically valid and practically useful, does not require large samples (Lam and Zhao, 1998). It can be used in combination with other methods, such as the DEA which produces criteria weights by comparing judging matrices in pairs. So far, there are many studies explaining the integration of AHP and DEA. For instance, Sueyoshi *et al.* (2009) ascertained the decision making infrastructure of the internal audit. Ar and Kurtaran (2013) proposed an integrated AHP/DEA approach to evaluate the efficiency of 13 commercial banks in Turkey. Moreover, it is found that the integrated analyzing values fits better to the operation of banks in reality and performs better in discovering efficiency unit.

Efficiency analysis via a combined method with AHP and DEA can be performed by two approaches. In the first approach, DEA is performed for each pair of units separately, and then the generated pairwise evaluation matrix is used to rank the units via the AHP approach. This approach of integration can be applied to many fields such as the 3PL vendor selection (Zhang *et al.*, 2006).

In the second approach, the subjective weight of AHP is used to determine the sum of input and output of DEA, the BCC analysis method in DEA model is utilized to analyze relative efficiency to find inefficient perspectives in the unit and deal with them (Al-Delaimi and Al-Ani, 2006). This study adopts the second approach because transportation industry is part of the national infrastructure service. Focuses on the society needs and the transport function must be considered in addition to production efficiency.

3. RESEARCH STRUCTURE

There are three main parts of this study. The first step is to select the evaluation criteria from literature reviews and expert interview. In this stage, the scope and scale of this study are determined and the evaluation criteria are listed with clear definition. The second step is using AHP questionnaire to obtain the pair comparison value of those criteria and then to compute the related weights. The third step is to apply the related weights among criteria as new constraints into DEA process. This whole process presents is regarded as the AHP-DEA model (Figure 1).
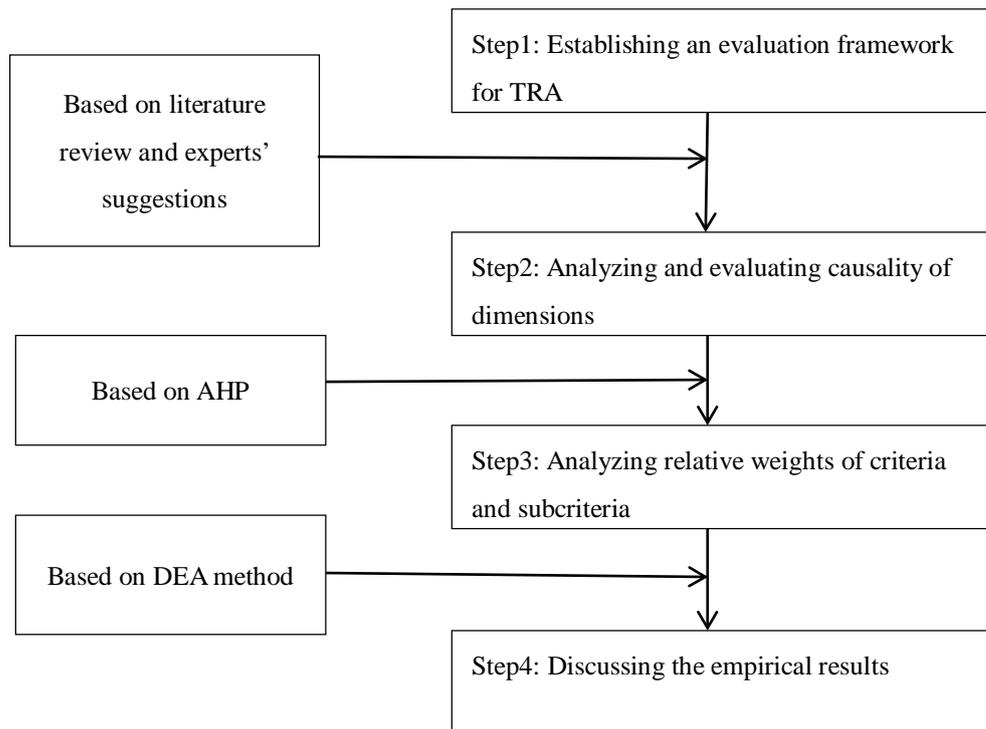
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│ Based on literature │         │ Step1: Establishing an evaluation    │
│ review and experts' │────────▶│ framework for TRA                    │
│ suggestions         │         └─────────────────────────────────────┘
└─────────────────────┘                          │
                                                  ▼
                                 ┌─────────────────────────────────────┐
                                 │ Step2: Analyzing and evaluating      │
┌─────────────────────┐         │ causality of dimensions              │
│ Based on AHP        │────────▶└─────────────────────────────────────┘
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                                 │ Step3: Analyzing relative weights of │
┌─────────────────────┐         │ criteria and subcriteria             │
│ Based on DEA method │────────▶└─────────────────────────────────────┘
└─────────────────────┘                          │
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                                 │ Step4: Discussing the empirical      │
                                 │ results                              │
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Figure 1. Proposed evaluation model of Taiwan Railways Administration

The study investigates all the TRA's first-class stations, and uses actual annual statistics of 2013 from every unit as the criterion. The input factors are the number of employees, number of stopped/service trains, business area, number of platform sides, and automatic equipment; output factors include delivery revenue, number of passengers getting on and off, number of trains dispatched, and number of disabled passengers served.

The selection of inputs is discussed in this section. Location size represents the business area of the station: including main hall, baggage room, ticket office, staff room, and offices and so on. Regarding the contributed capital, the number of cars stopped at the station is used because the main revenue of a station comes from selling tickets for seats. For input factors, the number of workers is used as the indicator for labor force. The input variables and other

variables are described in the following:

(1) Number of employee (I1): average number of employees of every individual station in year 2013.

(2) Number of stopped passenger trains (I2): average number of passenger trains stopping daily.

(3) Business area (I3): station area used for operation including main hall, ticket office, staff room, baggage room and offices and so on.

(4) Automatic equipment (I4): mainly refers to the vendor machine and the automatic gate.

(5) Number of platform sides (I5): platforms can be divided into two types, side platform (one side) and island platform (two sides).

The outputs are discussed in this section. Generally speaking, station revenue can be classified as "non-delivery revenue" and "delivery revenue". The non-delivery revenue section is mainly composed of rent draw from investment fairs arranged by TRA's affiliated units, (catering service department and freight department) and authorized by the station in which the area of the stations are used for sites planning. The train working/running routine (especially the switchyard) is also a type of output that should be concerned; hence, "number of trains dispatched" is used to represent the contribution of the employee in operation.

The delivery revenue of the station, on the other hand, differs in correspondence to "trips" and "traveling distance". The "number of passengers getting on and off" is used as another output besides delivery revenue; "number of disabled passengers served" at the station is recognized as a standard by the number of services the station staff applies at every station per day. Each variable is defined as follows:

(1) The number of passengers getting on and off (O1): total number of passengers who enters the station to take the train and leave the station.

(2) Number of trains dispatched (O2): the daily average of total number of dispatched passenger trains and cargo trains.

(3) Number of disabled passengers served at the station (O3): the daily average of the number of disabled passengers served at the station.

(4) Delivery revenue (O4): sum of the daily passenger and cargo revenue.

4. RESULTS ANALYSIS

This study applies input-based efficiency model of DEA to carry out a performance evaluation analysis of AHP model objectively. Additionally, interviews with experts and questionnaires on TRA's operations are used as subjective input/output indexes and weights.

4.1 Correlation Analysis

The greatest advantage of the DEA model is the prevention of using production function. For that, the input and output factors must have sufficient explanatory power. Such power can be further confirmed by the correlation analysis in statistics to verify its isotonicity.

From Table 1, the study can see a correlation between inputs and outputs. For example, the number of stopped passenger trains (I2) and automatic equipment (I4) is positively correlated (0.69); number of trains dispatched (O1) and number of employees in the input category (I1) is positively correlated (0.03); number of disabled passengers served (O3) and delivery revenue (O4) in the output category are positively correlated (0.71). Judging from the above-mentioned relations, the study propose that the input and output categories conform to the priori standard of isotonicity.

Table 1. Correlation analysis of inputs and outputs

	I1	I2	I3	I4	I5	O1	O2	O3	O4
I1	1.00	0.57	0.59	0.42	0.59	0.48	0.72	0.44	0.59
I2	0.57	1.00	-0.01	0.69	0.21	0.59	0.30	0.55	0.32
I3	0.59	-0.01	1.00	-0.24	0.61	-0.13	0.59	0.11	0.31
I4	0.42	0.69	-0.24	1.00	0.00	0.92	-0.03	0.66	0.48
I5	0.59	0.21	0.61	0.00	1.00	0.00	0.49	-0.10	0.09
O1	0.48	0.59	-0.13	0.92	0.00	1.00	0.03	0.70	0.69
O2	0.72	0.30	0.59	-0.03	0.49	0.03	1.00	0.14	0.15
O3	0.44	0.55	0.11	0.66	-0.10	0.70	0.14	1.00	0.71
O4	0.59	0.32	0.31	0.48	0.09	0.69	0.15	0.71	1.00

4.2 Weight Restrictions

The study investigates TRA first-class stations' operational performance related questions via AHP questionnaires. This study calculates the relative weight of inputs and relative weight of outputs using the AHP model and shows the results in Table 2.

As mentioned in Section 2.3, the AHP evaluation is a process of pair comparison then to compute the relative weights. Therefore, the result of AHP give subjective relationship among outputs as $v_2=0.929v_1$, $v_3=0.312v_1$, $v_4=0.238v_1$, $v_5=0.142v_1$, and the relationship among inputs as $\mu_2=0.446\mu_1$, $\mu_3=1.073\mu_1$, $\mu_4=0.207\mu_1$. This study then applies those constraints obtained from AHP into the DEA model. Therefore, the DEA model can be modified as AHP-DEA model which using the relative weight constraints.

Table 2. Pairwise comparison matrix for inputs and outputs

Factor	Inputs					Outputs			
	(I1) (v_1)	(I2) (v_2)	(I3) (v_3)	(I4) (v_4)	(I5) (v_5)	(O1) (μ_1)	(O2) (μ_2)	(O3) (μ_3)	(O4) (μ_4)
Relative weight	0.381	0.354	0.119	0.091	0.054	0.367	0.164	0.394	0.076
Based on μ_1, v_1 weight ratio	1	0.929	0.312	0.238	0.142	1	0.446	1.073	0.207

The results of efficiency are listed in Table 3.For the overall average relative efficiency value of TR, BCC model has greater efficiency than CCR while the average efficiency of the original CCR and BCC models is greater than the average efficiency of the AHP modified AR-I-C and AR-I-V models respectively. Hence, if the study adopts previous data and adjust the relative range with respect to weight, the evaluation result in terms of the efficient DMU is reduced. In other words, when the subjective train-driving and training environment is taken into account, the modification of DEA model using weight constraint will result in an overall decrease of the efficiency value of every factor as well as the DMU.

In DEA analysis, the efficiency value of a DMU equals to one, then the DMU is efficiency unit, otherwise, the DMU is called inefficiency. Table 3 shows that there are 14 stations reaching efficient frontier in the CCR model (fixed returns to scale). In contrast, through integrated analysis of the combined AHP-DEA CCR model (the AR-I-C model) has only one station that reaches efficient frontier. After weights rearrangement, Changhua station turns out to be the exemplary role model. Via the integration model, it is obvious that most of the TRA's units fail to reach efficiency frontier and therefore this study can recommend TRA how to improve those stations' performance.

In the technical efficiency analysis of BCC model (variable returns to scale), it is found that 23 units reach efficiency frontier. After performing the AR-I-V integration analysis (via the combined AHP-DEA BCC model,), this study discovers that only 3 units reach the efficiency frontier. The integration analysis table provides a hint to determine the main source of the inefficiency; and factors that may cause technical flaw for factors of production portfolio.

Table 3. Efficiency value and rank of original and correction models

DMUs	DEA Model				AHP-DEA Model			
	CCR Model		BCC Model		AR-I-C Model		AR-I-V Model	
	Efficiency	Rank	Efficiency	Rank	Efficiency	Rank	Efficiency	Rank
Keelung (DMU1)	0.901	21	1.000	1	0.109	19	0.173	18

Qidu(DMU2)	0.949	16	1.000	1	0.023	22	0.034	22
Songshan (DMU3)	1.000	1	1.000	1	0.466	6	0.554	7
Wanhua (DMU4)	0.445	27	1.000	1	0.945	2	0.984	4
Banqiao (DMU5)	1.000	1	1.000	1	0.782	3	0.815	6
Shulin (DMU6)	1.000	1	1.000	1	0.509	4	0.525	8
Taoyuan (DMU7)	1.000	1	1.000	1	0.156	16	0.191	17
Zhongli (DMU8)	0.895	22	0.891	25	0.370	8	0.446	9
Beihu (DMU9)	1.000	1	1.000	1	0.159	15	0.195	16
Zhunan (DMU10)	0.932	20	1.000	1	0.129	18	0.140	19
Fengyuan (DMU11)	0.948	17	1.000	1	0.194	13	0.206	15
Miaoli (DMU12)	0.946	19	1.000	1	0.269	10	0.359	12
Changhua (**DMU13**)	**1.000**	**1**	**1.000**	**1**	**1.000**	**1**	**1.000**	**1**
Yuanlin (DMU14)	0.861	24	0.942	24	0.502	5	0.837	5
Douliu (DMU15)	1.000	1	1.000	1	0.325	9	0.434	11
Chiayi (DMU16)	1.000	1	1.000	1	0.375	7	0.440	10
Xinying (**DMU17**)	**0.987**	**15**	**1.000**	**23**	**0.222**	**12**	**1.000**	**1**
Tainan (DMU18)	1.000	1	1.000	1	0.077	20	0.133	20
Gangshan (DMU19)	0.695	25	0.842	26	0.066	21	0.072	21
Xinzuoying(DMU20)	0.666	26	0.671	27	0.187	14	0.326	14
Pingtung (DMU21)	1.000	1	1.000	1	0.247	11	0.354	13
Hualien (**DMU22**)	**1.000**	**1**	**1.000**	**1**	**0.140**	**17**	**1.000**	**1**
Yuli(DMU23)	0.888	23	1.000	1	0.109	19	0.173	18
Taitung (DMU24)	1.000	1	1.000	1	0.023	22	0.034	22
Ruifang (DMU25)	1.000	1	1.000	1	0.466	6	0.554	7
Yilan (DMU26)	0.947	18	1.000	1	0.945	2	0.984	4
Su'ao (DMU27)	1.000	1	1.000	1	0.782	3	0.815	6

*AR-I-C is the combined AHP-DEA CCR model；AR-I-V is the combined AHP-DEA BCC model

5. SUMMARY AND RECOMMENDATION

This research provides an AHP-DEA approach to probe into the operational performance of TRA's first-class stations. One of the research limitations is the evaluating of the operational performance only for the case of operational viewpoints. It not only analyzes the relative efficiency of each unit under evaluation using DEA objectively as well as the exemplary role model for learning, but also offers information related to the direction and scale for inefficient units to improve. Using expert's subjective evaluation of the priority on TRA's station functions to modify DEA weight relationships of inputs and outputs, this study proves that the modified performance evaluation results are indeed closer to the reality.

This study considers the evaluation criteria based on literature reviews and experts' suggestions. The scope of the criteria focuses on the train station performance but without consider the performance of rail management (including the train delay, service in train carts,

safety and security, etc). For future study, this study would extend to the performance of whole railway system such as the study in Burdett (2015) And Erdős (2014).

The individual efficiency value, average efficiency value, and number of efficient DMU for CRS and VRS analyzed using a modified AHP model decreased overall. When subjective factors about current environment of the station are taken into account, efficient DMU decreases considerably. Consequently, using the analysis model as proposed to understand the trend of the industry and to acquire a closer-to-reality TRA's operational efficiency value, this research provides the manager with policy directions and operational goals for managers by improving their operational strategies.

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