Journal of the Eastern Asia Society for Transportation Studies, Vol.7, 2009

A DEA Approach for Evaluating the Efficiency of Exclusive Bus Routes

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Abstract: This study presumes the efficiency of each route by utilizing data of Seoul's exclusive bus routes for the first half of 2008 and the DEA model. In the estimation, it is assumed that the number of passengers and profits of each route is calculated by considering the number of buses and stops, travel distance, intervals and management cost. This study computed the efficiency scores of each bus line in Seoul based on the data for the first half of 2008 and one of the DEA models, namely the BCC model.
After analysis using the input-oriented BCC model, out of a total of 18 lines of interest, there were 2 CRS lines and 16 IRS lines. Also, the Tobit Regression Analysis that helps identify the impact of the elements used in the analysis on efficiency scores proved that the most influential element to exclusive buses is the length of intervals.

Key Words: *DEA(Data Envelopment Analysis), DMU(Decision Making Unit), efficiency, Tobit regression*

1. INTRODUCTION

Buses as a typical means of transportation today plays a crucial role as a means of transportation in most downtowns except for in the metropolitans that have city rail networks like Seoul city. In the case of Seoul, most traffic volumes are related to metropolitan area and, especially, due to the increase in traffic volume caused by neighboring new city development and high dependency on automobiles specific measures that can evaluate the effect of the policies are required as preparing policies for activation of means of transportation. although running costs of buses as means of public transportation has dramatically increased because of traffic congestion caused by distribution of automobiles and increase in using them after 1990, the revenue of running buses has not been largely increased because of extension of downtown rail network infrastructure and constant growth of automobiles despite of rises in annual bus fees.

The City of Seoul, in order to resolve this problem, reorganized general bus system by implementing policies including introduction of quasi-public management based on co-management of the revenue in July, 2004, revision of charging system and implementation of bus only lane. As a result, more people use buses and subways as the usefulness to public transportation users increases and, especially, in the case of buses, expansion of service areas with reorganization of bus routes, decrease in financial burden on users with free transfer between public transportations and correctness of bus timetables resulted from implementation of c bus only lane are considered to be the competitive factors of buses. In addition, as implementing semi-public management system, bus companies ensure revenues even when they have deficit due to less revenue than running cost because the City of Seoul support them financially so that they ensure stability of management and are able to provide constant services. However, despite an increase in the number of public transport users, the City of Seoul's financial burden has not been eased for the last four years since implementation of bus system reorganization so it is in the financial trouble as the support for public transportation subsidizing deficit of bus companies occurred every year.

In this respect, the City of Seoul plans to implement policies for reinforcement of competitiveness of buses and improvement of efficiency and in order to evaluate these polices objectively, we require presuming the efficiency of routes that are the foundation of competitiveness of buses as a means of transportation and analyzing factors that are influence on it, but the current operating bus evaluation system is not appropriate to measuring future policies because the system aims at distributing revenues according to the results of the evaluation.

This study newly interprets the concept of Farrell's relative efficiency (1957) promoted by Banker and others (1984), and calculates efficiency points of current but routes by using data envelopment analysis (DEA) which is a nonlinear programming extended to the BCC Ratio with a multitude of inputs and outputs and presents measures to reinforce competitiveness of buses as a means of transportation by analyzing the factors that impact on the efficiency of bus routes by estimating Tobit regression equation of the efficiency points. This analysis helps to grasp the problems of buses as a means of transportation that are not dealt with by the current operating bus service evaluation system and by complementing the problems, it is also assumed that we can expect a decrease in public transportation support in the long term.

2. BACKGROUND

2.1. Current bus service evaluation system

The current service evaluation system provides the reasons for incentives that are different amount of payments according to management results through the evaluation results and urban bus companies are evaluated in order to promote them to improve services by encouraging competition between excellent companies and changing the patterns of drivers' consciousness. Such evaluation conducted to all the 68 Seoul urban bus companies every year and the evaluation includes three categories; management, and service and management improvement. Each category has various standards for evaluation as the following Table 1.

In the case of current bus evaluation system, there are incentives but the big problem is that there are not disincentives and penalties and some evaluation criteria need to be added, including improvement of transportation fees, number of passengers per hour, the rate of revenue per hour and comparative evaluation of subsidies by route. In addition, there is a possibility that using excessive criteria may lead to confusion and currently there are many objections to evaluation criteria for bus companies.

Table1 The Categories and Criteria of the Current Bus Evaluation

Evaluation Categories	Evaluation Criteria
Management	Safe driving index The level of worker's welfare Application and management of BMS
Service improvement	Service quality evaluation Assessment of the degree of pollution
Management improvement	Introduction of the CNG bus Improvement of transportation revenue and expenditure Strong financial condition Transparentness of revenue and expenditure Internal improvement

Source: Transportation department of the City of Seoul

Therefore, it is difficult to understand the problems of bus companies and bus routes by the current evaluation system and even we understand the problems, it is difficult to expect that efficiency of buses as a means of transportation will improve because there is no penalty on the problems and the bus companies do not have strong will to correct them.

2.2. Literature Review

In the case of the traffic sector in Korea, researches evaluating efficiency by using DEA model are applied to rail, bus, aviation and logistics, but there is no preceding research on analysis of the efficiency of bus routes and generally current evaluation on buses is performed by using evaluation categories and standards on the subject of bus companies.

Taking a look at the precedent researches on the bus sector, Kim and others (2000) produced economical scale and minimum efficiency scale after calculating efficiency points by company of 69 Seoul urban bus companies by using the DEA model. In addition, Oh and others (2002) calculate efficiency points of 69 Seoul urban bus company by using the DEA model and analyse factors that have an influence on efficiency by estimating Tobit regression equation. Oh and others (2005) analyse changes in productivity by company by applying Malmquist index measurement, after estimating efficiency by company with the DEA model by using materials by urban bus company before and after the reorganization of Seoul public transportation system. They (2009) examine correctness of Seoul blue bus time table by using the bus management system (BMS) and DEA model.

Meanwhile, reviewing the preceding studies on transportation other than the bus sector, Kim and others (2003) calculates efficiency values reflecting only internal factors by removing external factors, including organization types, by using the results of estimation with Tobit regression equation from the values estimated efficiency values of different city rail management institution. In addition, Kim and others (2004) estimates the rate of increase in total factor productivity of city rail management institutions by estimating Malmquist total productivity index by using the DEA. Kim and others (2005) analyse the effect of the features of the approach on the estimation results by comparing it with the estimation results by using the DEA after presuming efficiency and productivity of city rail management institutions by using Ctochastic Cost Frontier Approach.

Besides, the DEA model is used in various ways in the area of aviation, logistics and other sections of traffic, and precedent studies by using the DEA model in the transportation area of Korea is as the following Table 2.

Table 2 Precedent studies related to the DEA model in the transportation sector of Korea

Classifi-cation	Author (Year)	Subject of analysis	Input Elements	Output Elements
Bus	Kim, Seong-su (2002)	urban Bus companies	labor, oil, vehicles, maintenance	city bus, seat bus
	Oh, Miyeong (2002)	urban Bus companies	labor, oil, vehicles, maintenance	travel distance, number of passengers
	Oh, Miyeong (2005)	urban Bus companies	driving, maintenance, management, vehicles, fuel	Travel distance, number of passengers, travel distance & number of passengers
	Oh, Miyeong (2009)	correctness of urban bus timetables	-	-
Rail	Kim, Minjeong (2003)	city rail management institutions	labor, energy, electric rail cars, orbit (or capital)	electric rail car-km
	Kim, Minjeong (2004)	city rail management institutions	labor, energy, electric rail cars, orbit (or capital)	electric rail car-km
	Kim, Minjeong (2005)	city rail management institutions	labor, energy, electric rail cars, orbit (or capital)	electric rail car-km
Aviation	Hong, Seokjin (2005)	aviation	cost and number of employees, annual processing capacity of airports WLU	sales revenue and WLU results value
	Kim, Minjeong (2008)	emigration and immigration procedure	-	-
Logistics	Ha, Heongu (2007)	logistics industry	number of employees, fixed assets, total capital, management cost	sales, current term net profit
Others	Hong, Seokjin (2005)	education for professional logistics human resources	-	-

3. DATA ENVELOPMENT ANALYSIS AND TOBIT REGRESSION ANALYSIS

3.1. Definition of efficiency

Efficiency generally means ratio between the amount of input elements used by a production organization and production output.

$$Efficiency = \frac{Output\ production}{Used\ amount\ of\ input\ elements} \tag{1}$$

Efficiency is fairly simple to calculate when a production organization produces only one output by using only one input element but most of the organizations use a number of input elements and produces a multitude of outputs. In order to calculate theses organization's efficiency, a process to calculate aggregated input that sums up by adding weights to many input elements and aggregated output that is calculated by using many output weights.

Farrell (1957) distinguishes efficiency into three types including technical, price, and overall efficiency and defines them as follows;

Technical efficiency shows the relations between output and input that are used to produce the output and means the capacity to produce the maximum output within the range of given input. Therefore, technically, the word efficient means that when the input reduces, output has to be reduced and the word inefficient means that although input is reduced, we can maintain the existing output. In other words, technical inefficiency occurs because input elements are overused. Price efficiency is related to optimizing compounding of input elements that can be produced output with minimum expenses and inefficiency in terms of price means that input elements are overused compared to the optimized compounding amount and it also occurs when they are used much less than that.

Overall efficiency is a multiple of technical and price efficiency, which means that in order to provide overall economic efficiency, technical and price efficiency has to be considered at the same time.

3.2. Data Envelopment Analysis

Data Envelopment Analysis (DEA) is measuring relative efficiency of decision making unit with the linear programming by using plentiful output ratio with many inputs which is presented for the first time by Charnes, Cooper, and Rhodes in 1978. This is a nonparametric method, which is largely advantageous in terms of the fact that it does not set up any assumption about model and parameter of production function.

3.2.1. The concept of efficiency in the DEA model

Efficiency in the DEA model is the concept of technical efficiency, which is the concept of relative efficiency that is determined through comparison with the most efficient frontier. In other words, since it is impossible to measure absolute efficiency that is evaluated according to ideational datum point, it measures the degree of efficiency through comparison with reference set that has similar input and output structure.

3.2.2. DEA Basic Model

DEA models that are applied the most in general are CCR model of Charnes, Cooper and Rhodes (1978) and BCC Model of Banker, Charnes and Cooper (1984).

3.2.2.1. CCR Model

The CCR model presented by Charnes, Cooper, and Rhodes in 1978 is a fractional linear programming model to maximize the efficiency of each measure unit by adding up many input elements and outputs by the optimized weight. In the model, the condition of efficiency is $\theta^* = 1$ and all the slack variables are assumed to be zero (0). Under such condition, DMU_0's many output maximized values against many inputs, which are the subject to evaluation is assumed to be θ_0, θ_0 is as follows.

$$Max\theta_0 = \frac{\sum_{r=1}^{s} u_r y_{r_0}}{\sum_{r=1}^{s} v_i x_{i_0}} \tag{2}$$

s.t.

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1, \qquad j = 1, \cdots, n$$

$$u_r \ge \varepsilon \ge 0, \qquad r = 1, \cdots, s$$

$$v_i \ge \varepsilon \ge 0, \qquad i = 1, \cdots, m$$

Where:

θ_0 : efficiency of DMU_0

u_r : weight of output in r position, v_i : weigh of input in i position

y_{rj} : the amount of output in r position of DMU_j

x_{ij} : the amount of output in i position of DMU_j

y_{r0} : the amount of output in r position of DMU_0, the subject to evaluation

x_{i0} : the amount of output in i position of DMU_0, the subject to evaluation

ε : non-Archimedean constant, n : the number of DMU

m : the number of input, s : the number of input,

In the equation above, the ratio of weight sum total of output elements on all the DMU's input elements should not have to be over 1, and under that simple condition that the weight value of each input and output elements is more than zero (0), this is the function that maximizes the ratio of output element weight sum and input elements weight sum of DMU_0 which is a subject to evaluation.

3.2.2.2. BCC Model

BBC model presented by Banker, Charnes, and Cooper in order to estimate the total efficiency of DMU is adding the assumption of Variable returns to scale (VRS) by easing Constant returns to scale (CRS) assumed in CCR. BBC model understands revenue effect of scale and enables to distinguish DMUs according to pure technical efficiency except for scale efficiency by separating the revenue effect of scale from technical efficiency.

$$Min\theta_0 = \frac{\sum_{i=1}^{m} v_i x_{i_0} + v_0}{\sum_{r=1}^{s} u_r y_{r_0}} \qquad (3)$$

s.t.

$$\frac{\sum_{i=1}^{m} v_i x_{ij} + v_0}{\sum_{i=1}^{s} u_r y_{rj}} \geq 1, \qquad j = 1, \cdots, n$$

$$u_r \geq \varepsilon > 0, \qquad r = 1, \cdots, s$$

$$v_i \geq \varepsilon > 0, \qquad i = 1, \cdots, m$$

Where:

θ_0 : efficiency of DMU_0

u_r : weight of output in r position, v_i : weigh of input in i position

y_{rj} : the amount of output in r position of DMU_j

x_{ij} : the amount of output in i position of DMU_j

y_{r0} : the amount of output in r position of DMU_0, the subject to evaluation

x_{i0} : the amount of output in i position of DMU_0, the subject to evaluation

ε : non-Archimedean constant, n : the number of DMU

m : the number of input, s : the number of input,

If we compare CCR model with BCC model, there is no difference between them except for introducing the variable, v_0, which is not limited by sign. v_0 in BCC model is used to understand economy on scale and if there is plural roots, different results on economies of scale are produced. In other words, the value of v_0 changes according to the unit of measurement so this does not mean the absolute value on economy (non-economy) of scale, but this is only used to analyze whether it is economy or non-economy.

$v_0 = 1$ - Constant returns to scale (CRS)

$v_0 > 0$ - Increasing returns to scale (IRS)

$v_0 < 0$ - Decreasing returns to scale (DRS)

For example, if $v_0 > 0$, the size is expanded to λ times and the output is increased to more than λ times, this means that by extending the size we can increase efficiency. On the other hand, if the size of $v_0 < 0$ is expanded to λ times, output increases less than λ. In this case, if we adjust the size by reducing output forcefully to the degree of more than that ratio, we can save output.

3.3. Tobit Regression Analysis

It is not easy to examine how such materials influence on efficiency points because it is difficult to understand the relations between input and output elements in the analysis of efficiency by the DEA model. This study analyzes the effect of each input and output element on efficiency through Tobit regression analysis in order to complement the limitation caused by DEA model.

Tobit regression analysis is appropriate to estimate regression equation that the range of dependent variable is limited and because in this study the range of efficiency estimated is limited to 0 and 1, when we compose regression equation by using efficiency points as dependant variables, it is reasonable to estimate parameter through Tobit regression analysis. Therefore, this study composes Tobit regression equation that has efficiency points of each route as dependant variables and the elements that are considered to influence on the efficiency points as independent variables

In order to grasp multicollinearity of independent variables included in Tobit regression equation, we conducted an analysis of correlation between efficiency points calculated through the DEA model and all the input and output elements and the result is as the following Table 3.

As a result of conducting an analysis on correlations of estimated efficiency points and all the input and output elements, the variable that shows the biggest correlations with efficiency points among input elements is travel distance and the variables among input elements that has low correlations with each variables are intervals and the number of passengers. Therefore, this study composes Tobit regression equation with efficiency points as dependent variable by the DEA model and travel distance, interval and the number of passengers as independent variables and analyzes influential power of variables that contributes to efficiency by estimating parameter of regression equation by using LIMDEP 7.0.

Table 3 Correlation between independent variables

Classification	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
number of cars (A)	1.000	-	-	-	-	-	-	-
route distance (B)	0.753	1.000	-	-	-	-	-	-
number of stops (C)	0.728	0.771	1.000	-	-	-	-	-
Intervals (D)	-0.635	-0.263	-0.046	1.000	-	-	-	-
operating costs (E)	0.966	0.764	0.772	-0.544	1.000	-	-	-
number of passengers (F)	0.869	0.529	0.688	-0.543	0.885	1.000	-	-
profit (G)	0.932	0.648	0.758	-0.557	0.956	0.970	1.000	-
efficiency (H)	-0.200	-0.404	-0.339	-0.196	-0.227	0.160	0.021	1.000

4. ASSESSMENT OF EXCLUSIVE BUS ROUTE EFFICIENCY

4.1. Data and estimation method

Data used in the evaluation of efficiency is cross-sectional data of 18 bus routes in Seoul during the first half of 2008 obtained from the Seoul City Administration. These bus routes are operated by 4 companies (Company 1: DMU1-DMU3, Company 2: DMU4-DMU7, Company 3: DMU8-DMU14, Company4: DMU15-DMU18) where it is possible to analyze the effects and problems of adopting a BRT line by analyzing the efficiency of the current lines because Seoul is considering the idea of adopting it as a part of its congestion reduction scheme.

In this study, each line was set as a unique DMU where each DMU was assumed to have 5 input elements, including number of buses, distance of routes, number of stops, length of bus intervals, and operating costs and two output elements, namely number of passengers and profit. Current bus lines are not in operation under optimized production capacity and Seoul will need to decrease the input or increase the output of each DMU. Also, since it is not feasible to define the production property of bus lines as CRS state, using the CCR model, which assumes CRS, to evaluate bus lines is not applicable. Thus, the efficiency of bus lines was evaluated using the BCC model, which assumes VRS. The efficiency of each line was analyzed using the input-oriented BCC model, which minimizes the input while fixing the output, because control over inputs, such as the number of cars and interval between buses was much easier for bus companies than it is to control the output elements.

Table 4 DEA Properties of Input and Output Data used in the Analysis

classification	inputs					outputs	
	number of cars	route distance	number of stops	intervals	operating costs	number of passengers	profits
		km		min	10 thou. Won	Thou. persons	10 thou. Won
DMU1	31	50.61	101	8	48,528	535	38,350
DMU2	33	55.21	78	7.5	52,646	613	43,932
DMU3	30	49.9	70	6.5	27,559	329	23,166
DMU4	41	64.6	115	8.5	60,851	801	56,422
DMU5	36	43.9	110	8.5	52,111	762	55,341
DMU6	17	44	78	12.5	25,832	214	15,981
DMU7	34	66.1	107	9	55,838	670	49,155
DMU8	65	74	122	5	91,438	1,226	85,557
DMU9	41	69.9	113	8.5	60,583	816	57,322
DMU10	32	44.1	92	9.5	46,082	512	35,378
DMU11	31	47.7	98	9.5	44,445	513	36,473
DMU12	25	35.1	55	6	35,097	419	28,148
DMU13	12	43.1	76	10	17,445	227	13,988
DMU14	12	45	81	10.5	17,819	214	14,826
DMU15	26	37	63	7	38,609	489	35,664
DMU16	41	76.9	107	8	61,336	310	40,454
DMU17	38	55.3	96	7.5	61,964	750	53,756
DMU18	44	72.5	105	7.5	63,116	641	45,789

Based on this data, this study compose Eq. 2 for 18 exclusive bus routes and produce the values of the linear programming, which are technical efficiency points of each route. Efficiency points of each route are estimated by using EnPAS (Efficiency and Productivity Analysis System) which is an analysis system for efficiency and productivity.

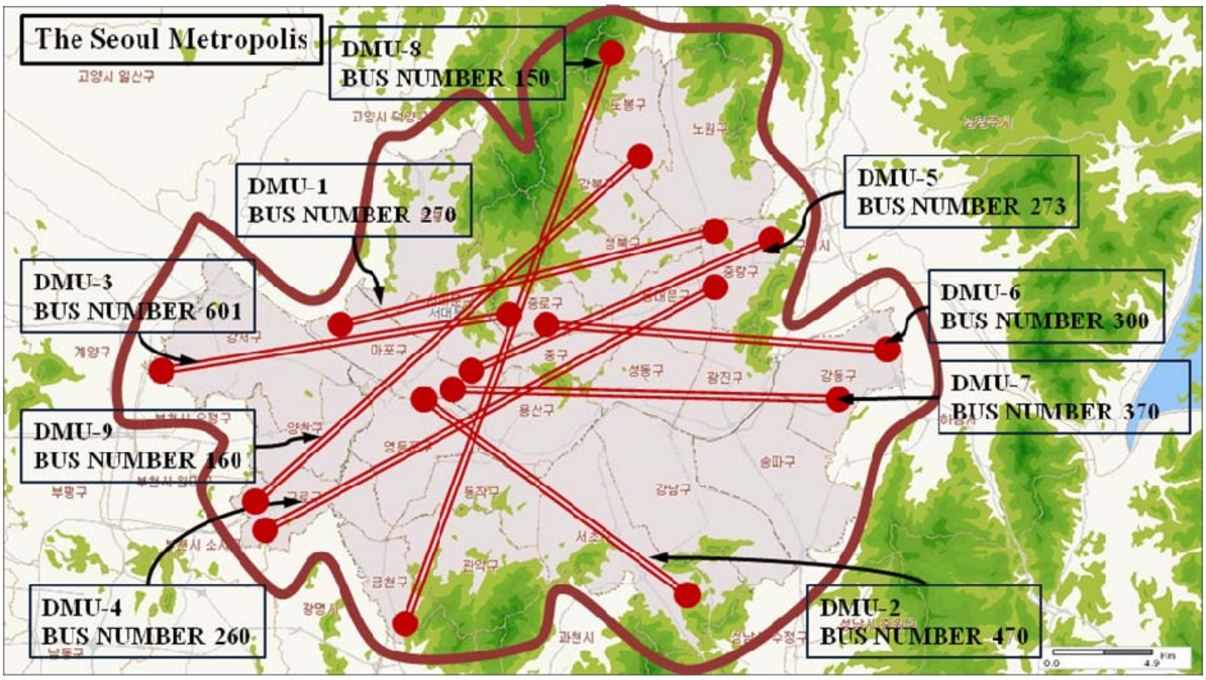

Figure 1 Transit Lines-1

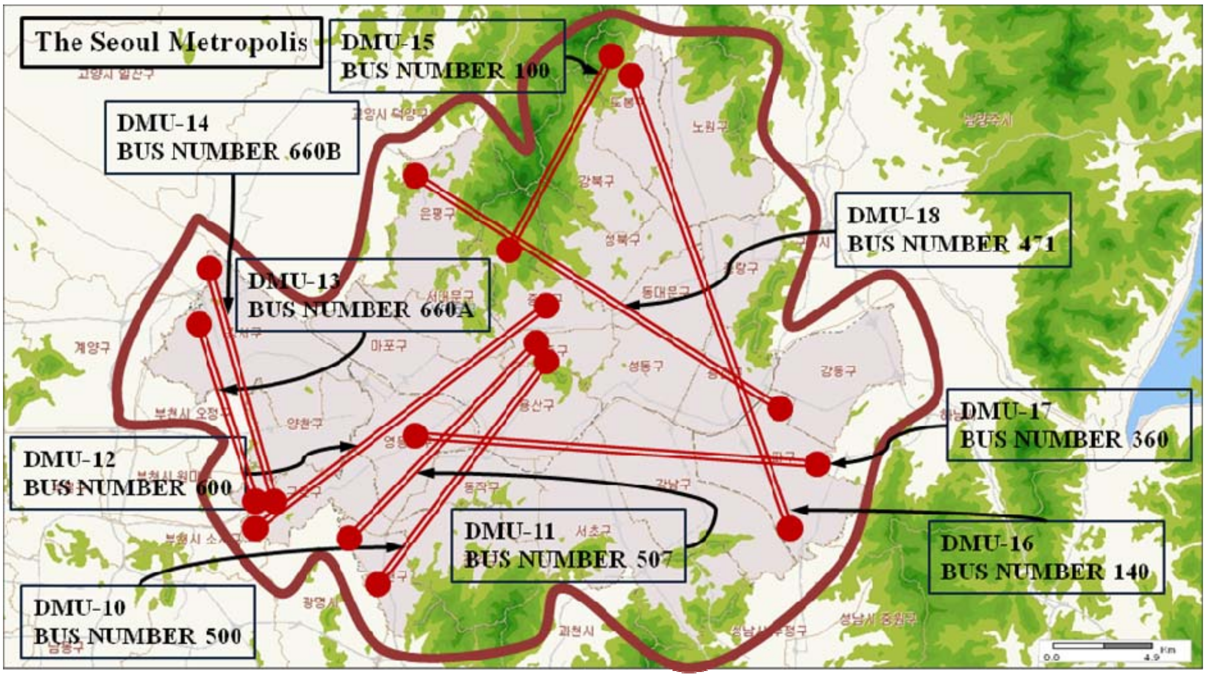

Figure 2 Transit Lines-2

4.2. Estimation result and interpretation

4.2.1. Estimation results of efficiency by data envelopment analysis
The results of estimating efficiency of the City of Seoul's blue bus routes with input oriented BBC model is as the following Table 5.

Table 5 The results of analyzing efficiency of the City of Seoul's blue bus routes.

Classification		Efficiency			Reference	
Bus Number	DMU	CRS	VRS	Scale Revenue	Reference group	Reference frequency
270	DMU1	0.8153	0.8976	IRS	5,8,15	0
470	DMU2	0.9458	0.9715	IRS	5,8,15	0
601	DMU3	0.8164	1	IRS	3	1
260	DMU4	0.9449	0.9467	IRS	5,8,15	0
273	DMU5	1	1	CRS	5	8
300	DMU6	0.6115	0.927	IRS	12,13	0
370	DMU7	0.9405	0.9559	IRS	5,14,15	0
150	DMU8	1	1	CRS	8	7
160	DMU9	0.967	0.9687	IRS	5,8,15	0
500	DMU10	0.7692	0.8578	IRS	5,12,13,15	0
507	DMU11	0.7893	0.8521	IRS	3,5,12,13,15	0
600	DMU12	0.8668	1	IRS	12	5
660A	DMU13	0.8937	1	IRS	13	3
660B	DMU14	0.8425	1	IRS	14	1
100	DMU15	0.9669	1	IRS	15	10
140	DMU16	0.6788	0.7785	IRS	8,12,15	0
360	DMU17	0.9837	0.994	IRS	5,8,15	0
471	DMU18	0.7371	0.813	IRS	8,12,15	0

CRS: Constant returns to scale
VRS: Variable returns to scale
Reference set: A set of efficient DMUs, which indirectly notifies of the inputs that need to be reduced and the outputs that have to be increased in order to make a particular DMU efficient where the reference set of efficient DMUs is itself.
Reference Frequency: number of times included in its own or in the reference set of another DMU.

Analysis results are classified as either CRS status or VRS status because the efficiency of blue buses was analyzed using the BCC model where the efficiency score of VRS turned out to be slightly higher than CRS. Also, since the volume of input elements and output elements was different for each line, the efficiency score of each line resulted differently from one another where there were two Constant Returns to Scale (CRS) DMUs (11.1%) out of a total of 18 lines, namely line 5 (route number 273) and line 8 (route number 150), and 16 Increasing Returns to Scale (IRS) DMUs (88.9%). The efficiency of most IRS DMUs will need to be improved by increasing the size of input elements.

Also, a high reference frequency does not necessarily mean the particular DMU is highly efficient because a DMU with high efficiency score included in the reference set is not necessarily included in the reference frequency. However, the reference set is meaningful in that inefficient DMUs should set it as their benchmark in terms of input and output elements where DMU 15 with route number 100, DMU 5 with route number 273, and DMU 8 with route number 150 turned out to have higher reference frequencies.

4.2.2. Estimation results of Tobit regression analysis

The results of estimating efficiency points through DEA model and parameter of Tobit regression analysis composed of variables of travel distance, interval, and number of passengers are as the following Table 6.

Table 6 The results of parameter estimation through Tobit regression anaysis

Independent Variables	Coefficient	Standard error
Travel distance	-0.00024468	0.00532165
Intervals	-0.09574666	0.02011354
Number of passengers	0.00043828	0.00029745

As result of parameter estimation, the sign of all independent variables turned out to be reasonable where the most influential factor on exclusive buses in Seoul turned out to be interval between buses. The length of intervals between buses must be reduced in order to improve the efficiency of exclusive buses, which will also influence the operation of BRT lines, which is expected to be introduced in the future.

5. CONCLUSIONS

This study estimates efficiency of each route by using data of Seoul blue bus routes for the first half of 2008 and DEA model. When estimating efficiency, each route sets as a DMU and each DMU is assumed to produce number of passengers and revenue by inputting the number of vehicles and stops, travel distance, intervals and management fees. As a result of analyzing input oriented BCC-model, DMUs in CRS among 18 routes as the subject to evaluation is a total of two (11.1%), and the rest of 16 DMUs are all IRS routes, which account to 88.9%. DMUs in IRS should increase efficiency of each route by extending the scale of input elements and inefficient DMU should benchmark DMU 15, DMU 5, and DMU 8.

Also, Tobit Regression Analysis was conducted in order to analyze the effect of the elements used in the analysis on the efficiency score. After parameter estimation, the sign of all variables turned out to be reasonable and the element that has the most impact on blue buses in Seoul came out to be the length of intervals between buses. Based on such results, improvement schemes focused on the length of intervals between buses, distance of routes, and number of passengers must be devised in order to improve the efficiency of bus lines with a special emphasis on improving intervals between buses.

ACKNOWLEDGEMENTS

This research is funded by Engineering Research Institute and BK21 Safe and Sustainable Infrastructure Research Group in Seoul National University.

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