國立交通大學

交通運輸研究所

碩 士 論 文

考慮非意欲產出下之公車營運效率分析

Analyzing the Operation Efficiency for Bus Transit with Undesirable Output

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中 華 民 國 一百 年 六 月

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考慮非意欲產出下之公車營運績效分析之研究

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摘要

本研究提出考慮非意欲產出之公車營運績效分析方法，並探討考慮非意欲產出與否對於績效分析結果之影響。不包含非意欲產出的績效分析結果往往高於納入非意欲產出的績效分析結果，顯示出忽略非意欲產出可能造成高估整體績效。

以往衡量運輸服務的績效是利用投入產出比，具有較多的產出與較少的單位被視為有效率的單位。然而，在執行生產活動時，除了獲得意欲產出外，非意欲產出也伴隨產生，例如污染排放，造成了外部成本。在環保議題受到重視的現今，運輸服務所帶來的外部成本必須內部化，以促使營運單位為了追求效率，必須要盡可能減少非意欲產出。

資料包絡分析常被用於衡量多投入與多產出的績效，但無法處理非意欲產出。本研究採取差額式評量模式之改良模式—不可分割好/壞產出模式去衡量台北十四家民營公車業者之績效，分析業者在納入非意欲產出與否的不同狀況下，其效率的變化情形，並在管理意涵上有所詮釋。

關鍵字：績效分析、非意欲產出、資料包絡分析、公車

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Abstract

The purpose of this research is to investigate how undesirable outputs influence performance. The efficiency scores are overestimated under considering without undesirable output, which shows that ignoring undesirable output may cause bias when estimating efficiency. As the environmental issues are taken seriously, undesirable outputs should be taken into the efficiency model, which urges the firms concern not only increasing good outputs but also decreasing bad outputs.

Data envelopment analysis (DEA) is an approach applied to measure multiple input-output efficiency of decision making units (DMUs). However, classical DEA model cannot deal with undesirable outputs, this research introduces SBM model (non-separable inputs/outputs model) to estimate the efficiency.

The data of Taipei bus transit firms over 2007 to 2010 is used for the case study, wherein the CO emission is selected as undesirable output. Our findings indicate that many efficiency DMUs become inefficiency if involving undesirable output into the DEA model. Furthermore, this research give some suggestions to improve efficiency.

Keywords: efficiency, undesirable output, data envelopment analysis (DEA), Taipei bus transit

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Chapter 1 Introduction

1.1 Motivation and background

Bus transit is one of the main public transportation all over the world. Due to the small dimensionality, bus transit has become the most important transportation in Taiwan. However, as the income growing, there are more and more private vehicles which significantly influenced the demand of bus transit. Also the problems of the operating administration rose, such as great employee expenses, inefficient production, and improper route managing, therefore the bus transit operators sank to scrapes and can't better the service level, bringing a vicious circle. Thus, the operation of bus transit became difficult, and deficit appeared. The operational performance and service quality went worse. The way to skip the bad condition is to find out the causes of inefficiency and improve the efficiency.

Quantities of researches are proposed to measure performance, and Data Envelopment Analysis (DEA) is a commonly used measure of efficiency. However, DEA usually assumes that producing more outputs relative to less input resources is a criterion of efficiency (Cooper et al., 2007). Producing the desirable outputs sometimes accompanies with undesirable outputs, such as pollutions. Undesirable outputs damage the environments the properties, therefore inefficiency arises. As the environmental issues are taken seriously, undesirable outputs should be taken into the efficiency model, which urges the firms concern not only increasing good outputs but also decreasing bad outputs.

A variety of opinions have been proposed in dealing with the undesirable outputs. A common approach is to treat undesirable outputs as inputs (Lansink and Reinhard, 2004). As inefficient firms want to improve performance, the objective is minimizing inputs and undesirable outputs. However, treating undesirable outputs as inputs doesn't reflect the true production process (Seiford and Zhu, 2002). Some researchers treat undesirable outputs as weak disposable, which emphasizes reducing undesirable outputs must accompany decrease in desirable outputs or increase in inputs. That is to say, it needs cost to lessen undesirable outputs (Färe et al, 1989).

The purpose of this research is to investigate how undesirable outputs influence performance, using the data of Taipei bus transit. The research is organized as follow: Chapter 2 reviews literature on undesirable outputs and DEA; Chapter 3 explains the research methodology; Chapter 4 analyzes the research data; Chapter 5 discusses the results and Chapter 6 concludes and recommends the research.

1.2 Research objectives and scope

Based on the motivation and background, the purposes of this research are as follows.

1. To Review and summarize the related papers in investigating how to deal with undesirable outputs by different DEA models.
2. Using adjusted DEA model—Slacks-based measure of efficiency in DEA to analysis the data to evaluate the efficiencies of different bus transit operators.
3. To give a recommendation to eliminate inefficiency and ameliorate performance.

1.3 Framework and procedures

The research flowchart of this study is depicted in Figure 1.1.

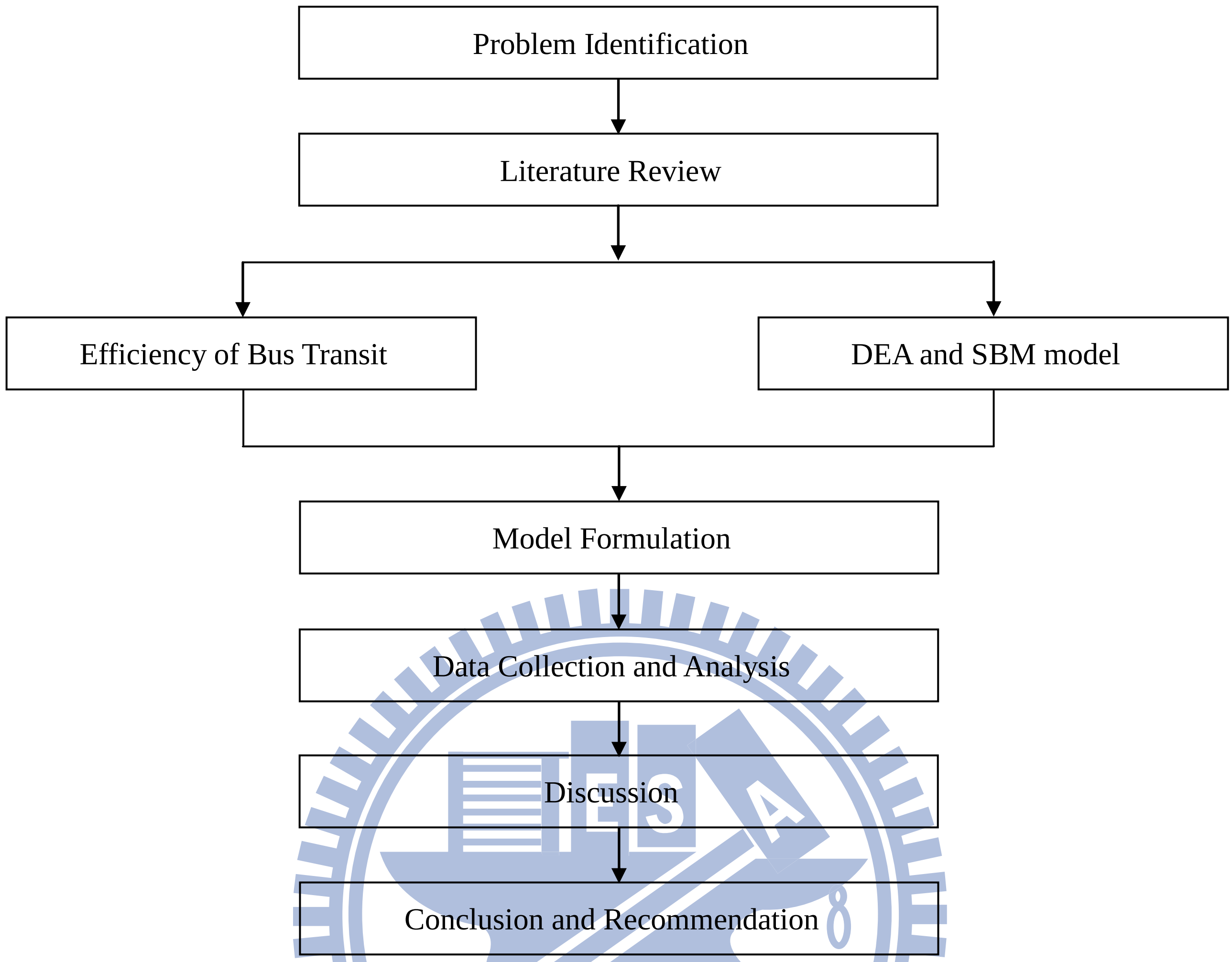

Figure 1.1 Research flowchart

Following the research purposes and the flowchart in Figure 1.1, the research procedure of this study is designed below:

1. Problem Identification

Define the research target and scope and confirm the objectivities of this study. Furthermore, determine the methodologies to resolve the problem.

2. Literature Review

Review the studies related to measuring the efficiency of bus transit, undesirable outputs, DEA, and SBM model.

3. Model formulation

Based on the literatures, develop a multi objective programming model to evaluate performance.

4. Data Analysis

Analyze the inputs, desirable outputs and undesirable outputs to identify which operator is efficient and which is inefficient.

5. Conclusions and Recommendations

Based on the results of analysis, to make conclusion and give recommendation to inefficient operator to improve performance.

Chapter 2 Literature Review

2.1 Measuring the efficiency of bus transit

There is a basic definition of efficiency which uses the relationship between input and output. Labor, capital, and energy are three common input variables for measuring the efficiency of bus transit. In the early studies, desirable outputs are generally used as the output variables to measure the efficiency of bus transit, such as vehicle-kilometers, seat-kilometers, and passenger-kilometers.

Kerstens (1996) measured the efficiency of French urban transit sector by using DEA and FDH two methods. In this case, inputs are set as the number of vehicles, the number of employees, and the fuel consumption, while outputs are presented by vehicle-kilometers and seat-kilometers. The study confirmed the significance of the choice between deterministic nonparametric reference technologies for technical efficiency measurement. However, this research cannot identify whether DEA or FDH is better due to the lack of information.

Yu and Fan (2009) proposed a mixed structure network data envelopment analysis (MSNDEA) model which can be used to simultaneously estimate the production efficiency, service effectiveness and operational effectiveness of multimode transit firms. In this research, inputs are the number of drivers, the number of vehicles, fuel, and network length, while outputs are vehicle-kilometers, passenger-kilometers. This paper presents different results obtained from MSNDEA model and conventional DEA model.

Fielding et al. (1985) analyzed the performance of bus transit in U.S. (based uses FY 1980 Section data 15) by using labor, capital, and fuel as input variables and using vehicle hour, vehicle miles, capital miles, and services reliability as output variables. The objectives of this research are finding the minimum amount of data necessary to provide soli and stable performance evaluation capability, and testing the validity of the methodology developed from the previous analysis of FY 1979 data.

Lao and Liu (2009) combined DEA and geographic information systems (GIS) to examine the operational efficiency and spatial effectiveness of a public transit system in Monterey-Salinas area. Operation time, round-trip distance, and number of bus stops are used as inputs, and the number of passengers is output. After evaluating the performance of bus line, this research suggested ways to improve the performance of bus lines.

Kuo and Kao (1992) used DEA to measure the relative efficiency of public versus private municipal bus forms in Taipei. Taipei Municipal Bus (TB) is publicly owned, while Hsin-Hsin, Ta-Yao, Ta-Nan, and Kuang-Hua are privately owned. Data of the five bus firms in 1970-1988 are adapted. Inputs include capital (the number of buses in operations), labor (the number of fulltime employees), and diesel fuel. And outputs combine vehicle-kilometers, revenue and the number of bus traffic trip on routes. The result shows TB had lower efficiency scores than the private firms.

Table 2.1 summarizes the previous research using desirable output.

Table 2.1 Summarization of bus transit efficiency research

Author	Input Variables	Output Variables
K. Kerstens (1996)	Vehicles, employees, fuel consumption	Vehicle-kms, seat kms
Yu and Fan (2009)	No. of drivers, No. of vehicles, fuel, network length	Vehicle-kms, passenger-kms
Fielding et al. (1985)	Labor, capital, fuel	Vehicle hour, vehicle miles, capital miles, services reliability
Lao and Liu (2009)	Operation time, Round-trip distance, Number of bus stops	Total number of passengers
Chang and Kao (1992)	Capital, Labor, diesel fuel	Vehicle kilometers, revenue, bus traffic trips on routes
Wei (1996)	Labor, vehicles, fuel	Vehicle kilometers, total number of passengers, services frequency
Chen and Hsiao (1994)	Labor, vehicles, fuel	Vehicle kilometers, total number of passengers, services frequency
Hsieh（2007）	Employees, drivers, vehicles, Total network length, fuel	services frequency, Total number of passengers, passenger-kms, revenue, total trip length

To economists, efficiency means obtaining the maximum of output that can be produced under a given unit of input. In fact, bus transits produce not only beneficial outputs (such as passenger-kilometers or vehicle-kilometers), but also undesirable outputs (such as vehicle emissions or accidents). In the past two decades, the effects of undesirable outputs are significantly recognized, and a number of researchers proposed to integrate undesirable outputs into efficiency measurement models.

McMullen and Noh (2007) uses a directional distance function approach to demonstrate the importance of considering reducing vehicular emissions as well as production of passenger or vehicle-miles, when measuring agency efficiency. The analysis includes 43 single mode US bus transit agencies for the year 2000. The emissions of HC, CO, and NO_x from fuel are defined as undesirable outputs which are simultaneously produced with transit outputs of vehicle- or passenger-miles. The result shows that considering undesirable outputs changes the efficiency score.

Yu and Fan (2006) employed the directional graph distance function and the multi-activity data envelopment analysis (DEA) approach, which incorporates both desirable and undesirable outputs, for the purpose of providing a more complete representation of the multimode bus production technology from which environmentally and risk-sensitive cost effectiveness measures can be generated. In order to make sense of wishing to decrease risky outputs, this research treats accident cost as the risky output. This paper measures the cost effectiveness of 24 bus companies in Taiwan, and indicates that the conventional DEA cost effectiveness measure may be seriously misleading if it ignores the cost effectiveness of organizations that carry out various activities whilst sharing common resources.

Lin et al. (2010) used stochastic frontier analysis (SFA) approach to analysis the data of ten Taipei Bus Transit firms over 2001 to 2006 in order to investigate if the productive efficiency of a bus transit is significantly influenced by accidents involved. Accidents are divided into four levels by severity and correspond to different weighted score. The findings indicate that there exists significant inefficiency in the Taipei bus transit industry as a whole. The productive efficiency with adjustment of undesirable accidents is significantly different from that measured without adjustment of accident effects.

Those studies are summarized as Table 2.2.

Table 2.2 Summarization of bus transit efficiency research integrating undesirable output

Author	Input Variables	Output Variables	
		Desirable	Undesirable
McMullen B. Starr and D.-W. Noh(2007)	Labor hours, fuel consumption, and total vehicle seats	Passenger-miles and vehicle-miles	Emissions of HC, CO, and NO_x from fuel
Yu and Fan(2006)	No. of transportation workers, No. of vehicles, fuel, network length	Passenger-kms	The amount of accident
Lin et al. (2010)	Capital, labor, fuel	Vehicle-kilometers	No. of fatalities, No. of injuries (serious/slight), No. of accidents without any fatality or injury

2.2 Incorporating undesirable outputs in DEA

Data envelopment analysis (DEA) is an approach applied to measure multiple input-output efficiency of decision making units (DMUs), which uses a linear programming based model. Dealing with multiple input-output problem, the efficiency of DMUs are defined as follows: outputs multiply relating weights and divided by inputs multiply relating weights. High relative efficiency comes from high outputs and low inputs. That is to say, DEA uses inputs and outputs to evaluate the efficiency of DMUs.

DEA is a non-parametric approach which means it doesn't need assumption about the weight of the underlying production function. Farrell (1957) proposed frontier production function method, using technical efficiency to measure productive efficiency. Given the input set, the maximum output level is an efficient point. Link all the efficient points and become production frontier. Every point on the production frontier is efficient, and other points under the frontier are inefficient.

Based on the production frontier, Charnes et al. (1978) proposed CCR model to measure efficiency under constant returns to scale. The DEA model is developed then. The DMUs on the efficient frontier are those with maximum output level for given inputs or with minimum input level for given outputs. Later Banker et al. (1984) proposed BCC model, adding a convexity constraint to relax the assumptions of CCR model. BBC can evaluate multi inputs and outputs under variable returns-to-scale.

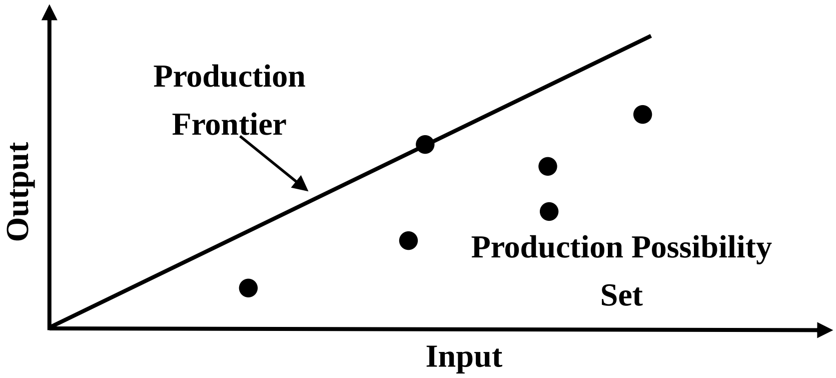

Figure 2.1 Production frontier of the CCR model (adapted from Cooper, W.W., Seiford, L.M. and Tone, K., 2007. Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software)

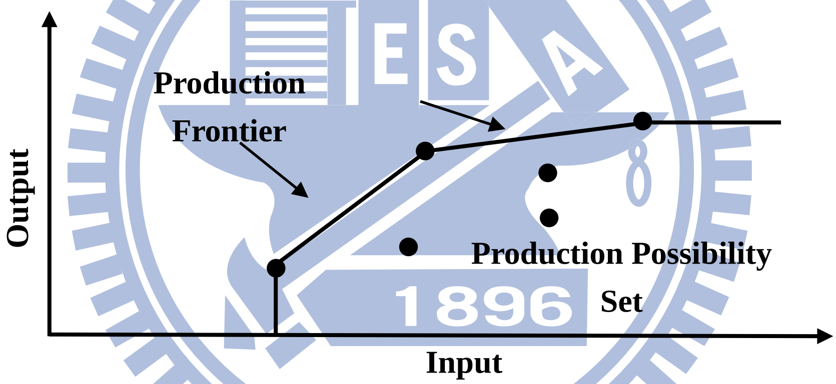

Figure 2.2 Production frontier of the BCC Model (adapted from Cooper, W.W., Seiford, L.M. and Tone, K., 2007. Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software)

As Charnes et al. (1978) described, the classical DEA models rely on the assumption that maximizing outputs and minimizing inputs. However, it's not in accordance with current situation. Sometimes the production process may also generate by products which we don't like, and it's called undesirable outputs such as waste, water pollution or smoke pollution. Those undesirable outputs have been reduced as possible to achieve the best efficiency, while traditional DEA model supposes that outputs should be increased as more as possible. Apparently classical DEA model is not suitable for dealing with undesirable outputs.

Cooper et al. (2007) classified DEA into four types— radial, non-radial and oriented, non-radial and non-oriented, and radial and non-radial. Conventional DEA models are radial and oriented, and they cannot take account the slackness of input and output. Thus, Tone (2001) proposed a non-radial and non-oriented SBM model.

2.3 Incorporating undesirable outputs in SBM model

Based on slack variables, Tone (2001) proposed SBM model, using slack variables to evaluate performance. The SBM model is non-radial and non-oriented, and directly utilizes input and output slacks in producing an efficiency measure. The model provides the fully efficiency score 1 to a DMU if and only if the DMU is efficient and gives a score less than 1 to inefficient DMU.

Cooper et al. (2007) introduced a separable and non-separable inputs/outputs model. The model extends to cope with co-existence of non-separable desirable and undesirable outputs. Sometimes a certain bad outputs are closely related with a certain inputs, therefore reducing bad outputs is accompanied by reducing good outputs. For instance, producing paper is accompanied with water and air pollution, and electric industries emit Nitrogen Oxides (NOa) and Sulfur Dioxides (SO2).

In this model, it proposed to decompose the set of good and bad outputs (Y^g, Y^b) into (Y^{Sg}) and (Y^{NSg}, Y^{NSb}) denote the separable good outputs, and non-separable good and bad outputs respectively.

2.4 Summary

The issue which concerns about the performance of bus transit has been proposed in the past decades. However, most of the research ignored the effects of undesirable outputs, which may cause external cost and may lead to a biased result.

In previous studies, labor, capital, and fuel are commonly used as input variable, vehicle-kms, passengers, and revenue are desirable output variable, while accidents and emission are the indicators of undesirable output.

With the advantage which can deal with separable and non-separable input/output, SBM model which incorporates undesirable outputs (Cooper et al. 2007) will be used as the methodology in this research.

Chapter 3 Methodology

3.1 The development of data envelopment analysis

DEA was developed as a method for evaluating the comparative efficiencies of DMUs, and it can simultaneously consider multiple inputs and outputs. DEA can identify the benchmark members of the efficient set and also identify these sources of inefficiency.

This approach was developed by Charnes et al. (1978) who extended the single-output/single-input ratio to multiple-inputs / multiple-outputs. Based on the CCR model, Banker et al. (1984) proposed a new model to estimate technical efficiency and scale inefficiency in DEA by adding a convexity constrain. The BCC model relaxed the constant returns-to-scale assumption to be variable returns-to-scale. Tone (2001) proposed a slack-based measure (SBM) model to treat the slacks (the input excesses and output shortfalls) directly in the objective function.

3.2 The CCR model

The CCR model is the basic DEA model. It can be used in CRS situation only. The original model is showed in formula 3.1. The model assumes n DMUs, and each $\mathrm{DMU_i}(i = 1,2,\ldots,n)$ utilizes m kinds of inputs $x_{ij}(j = 1,2,\ldots,m)$ and produces s kinds of outputs $y_{ir}(r = 1,2,\ldots,s)$. The efficiency of DMU k can be estimated by (3-1).

$$\underset{u,v}{Max} \quad h_k = \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{j=1}^{m} v_j x_{jk}} \tag{3-1}$$

$$s.t. \quad \frac{\sum_{r=1}^{s} u_r y_{ri}}{\sum_{j=1}^{m} v_j x_{ji}} \leq 1 \quad , \quad i = 1,2,\cdots,n$$

$$v_j \geq 0 \quad , \quad j = 1,2,\cdots,m$$

$$u_r \geq 0 \quad , \quad r = 1,2,\cdots,s$$

Then, Charnes et al. transform model (3-1) into linear problem to simplify the problem. The linear model is as follows:

$$\underset{u,v}{Max} \quad h_k = \sum_{r=1}^{s} u_r y_{rk}$$

$$s.t. \quad \sum_{r=1}^{s} u_r y_{ri} - \sum_{j=1}^{m} v_j x_{ji} \leq 0 \, , \quad i = 1,2,\cdots,n \tag{3-2}$$

$$\sum_{j=1}^{m} v_j x_{jk} = 1 \quad ,$$

$$v_j \geq 0 \quad , \quad j = 1,2,\cdots,m$$

$$u_r \geq 0 \quad , \quad r = 1,2,\cdots,s$$

Since the number of constraints is greater than the number of variables, one can transform it into dual problem as follows:

$$\underset{z,\lambda_i}{Min} \quad z$$

$$s.t. \quad z x_{jk} - \sum_{i=1}^{n} x_{ji} \lambda_i \geq 0 \, , \quad j = 1,2,\cdots,m \tag{3-3}$$

$$-y_{rk}+\sum_{i=1}^{n} y_{ri}\lambda_i \geq 0 \quad , \quad r=1,2,\cdots,s$$

$$\lambda_i \geq 0 \quad , \quad i=1,2,\cdots,n$$

z is a scalar, which is the efficiency of kth firm, and it ranges from zero to unity. If z=1, the firm is efficient. And if z is less than one, the firm is inefficient.

3.3 The BCC model

The CCR model is constructed under the assumption of CRS production technology. However, production technology changes with environment or human factors in reality. Banker et al. (1984) relaxed the CRS constraint to VRS technology by adding a convexity constraint, so that the returns to scale of DMU can be separated to increasing, decreasing, and constant returns to scale. The BCC input oriented model as follows:

$$\underset{z,\lambda_i}{Min} \quad z$$

$$s.t. \quad zx_{jk}-\sum_{i=1}^{n} x_{ji}\lambda_i \geq 0 \, , \quad j=1,2,\cdots,m \qquad (3\text{-}4)$$

$$-y_{rk}+\sum_{i=1}^{n} y_{ri}\lambda_i \geq 0 \quad , \quad r=1,2,\cdots,s$$

$$\lambda_i \geq 0 \quad , \quad i=1,2,\cdots,n$$

$$\sum_{i=1}^{n} \lambda_i = 1$$

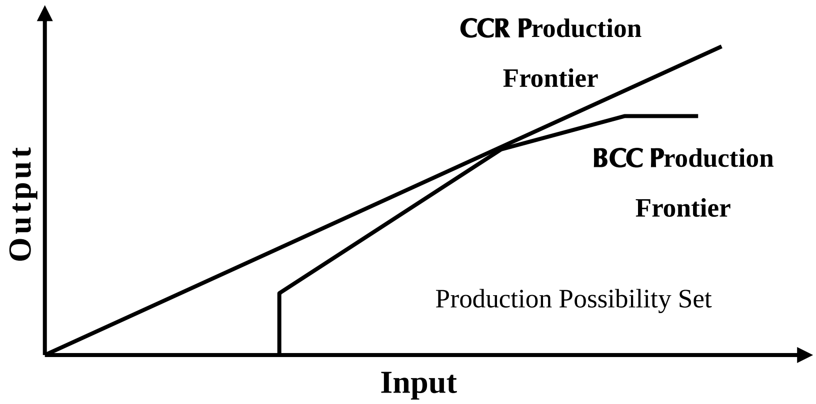

Figure 3.1 The relationship between CCR model and BCC model (Adapted from Cooper, W.W., Seiford, L.M. and Tone, K., 2007. Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software)

3.4 The SBM model

Conventional DEA models evaluate performances by ratio efficiency which assumes that there exists ratio between input and output. However the assumption is not suitable some conditions. Tone (2001) proposed a slack-based measure (SBM) of efficiency in DEA. SBM model deals directly with the input excesses and output shortfalls of the DMU concerned. The following properties are satisfied by SBM model.

1. Units invariant: The measure should be invariant with respect to the units of data.
2. Monotone: The measure should be monotone decreasing in each slack in input and output.
3. Reference-set dependent: The measure should be determined only by consulting the reference-set of the DMU concerned.

Describe the DMU (x_0, y_0) as

$$x_0 = X\lambda + s^- \quad (3\text{-}5)$$

$$y_0 = Y\lambda - s^+ \quad (3\text{-}6)$$

and define an index ρ as follows:

$$\text{Min } \rho = \frac{1-\left(\frac{1}{m}\right)\sum_{i=1}^{m} s_i^- / x_{i0}}{1+\left(\frac{1}{s}\right)\sum_{r=1}^{s} s_r^+ / y_{r0}} \quad (3\text{-}7)$$

with $\lambda \geq 0, s^- \geq 0$ and $s^+ \geq 0$

m and s are the number of input and output items; ρ is a non-radial slack index and s^- and s^+ respectively stand for input excesses and output shortfalls. Multiply a scalar variable t (>0) to both the denominator and the numerator of (3.7) which causes no change in ρ.

$$\text{Min } \tau = t - \frac{1}{m}\sum_{i=1}^{m} S_i^- / x_{i0} \quad (3\text{-}8)$$

$$\text{s.t.} \quad 1 = t + \frac{1}{s}\sum_{r=1}^{s} S_r^+ / y_{r0}$$

$$t x_0 = X\Lambda + S^-$$

$$t y_0 = Y\Lambda - S^+$$

$$\Lambda \geq 0,\ S^- \geq 0,\ S^+ \geq 0, t > 0$$

A DMU is SBM-efficient if $\rho^* = 1$. The condition is equivalent to $S^{-*} = 0$ and $S^{+*} = 0$, i.e., no input excesses and no output shortfalls.

3.5 Non-separable ‘good’ and ‘bad’ output model

It is usually observed that bad outputs co-existence with good outputs. Cooper et al. (2007) proposed to decompose the set of good and bad outputs. It is reasonable that the slacks in non-separable (non-radial) bad outputs and non-separable inputs should affect the overall efficiency, since even the radial slacks are sources of inefficiency. The following model is used to evaluate overall efficiency.

$$\rho^* = min \frac{1-\frac{1}{m}\sum_{i=1}^{m_1}\frac{s_i^{S-}}{x_{io}^{S}}-\frac{1}{m}\sum_{i=1}^{m_2}\frac{s_i^{NS-}}{x_{io}^{NS}}-\frac{m_2}{m}(1-\alpha)}{1+\frac{1}{s}(\sum_{r=1}^{s_{11}}\frac{s_r^{Sg}}{y_{ro}^{Sg}}+\sum_{r=1}^{s_{22}}\frac{s_r^{NS_b}}{y_{ro}^{NS_b}}+(s_{21}+s_{22}(1-\alpha))} \quad (3\text{-}9)$$

S.t.

$$x_o^S = X^S\lambda + s^{S-}$$

$$\alpha x_o^{NS} = X^{NS}\lambda + s^{NS-}$$

$$y_o^{S_g} = Y^{S_g}\lambda - s^{S_g}$$

$$\alpha y_o^{NS_g} \leq Y^{NS_g}\lambda$$

$$\alpha y_o^{NS_b} = Y^{NS_b}\lambda + s^{NS_b}$$

$$\sum_{r=1}^{s_{11}}(y_{ro}^{S_g} + s_r^{S_g}) + \alpha\sum_{r=1}^{s_{21}} y_{ro}^{NS_b} = \sum_{r=1}^{s_{11}} y_{ro}^{S_g} + \sum_{r=1}^{s_{21}} y_{ro}^{NS_g}$$

$$\frac{s_r^{S_g}}{y_{ro}^{S_g}} \leq U \ (\forall r)$$

$$s^{S-} \geq 0, s^{NS-} \geq 0, s^{S_g} \geq 0, s^{NS_b} \geq 0, \lambda \geq 0, 0 \leq \alpha \leq 1$$

Then decompose the inefficiency into respective inefficiencies as follows:

$$\rho^* = \frac{1-\sum_{i=1}^{m_1}\alpha_{1_i}-\sum_{i=1}^{m_2}\alpha_{2_i}}{1+\sum_{r=1}^{s_{11}}\beta_{1r}+\sum_{r=1}^{s_{21}}\beta_{2r}+\sum_{r=1}^{s_{22}}\beta_{3r}} \quad (3\text{-}10)$$

Where

$$\alpha_{1i} = \frac{1}{m}\frac{s_i^{S-*}}{x_{io}^{S}} \quad (i = 1, \ldots, m_1) \quad \text{(Separable Input)} \quad (3\text{-}11)$$

$$\alpha_{2i} = \frac{1}{m}(1-\alpha^*) + \frac{1}{m}\frac{s_i^{NS-*}}{x_{io}^{NS}} \quad (i = 1, \ldots, m_2) \quad \text{(Non-Separable Input)} \tag{3-12}$$

$$\beta_{1r} = \frac{1}{s}\frac{s_r^{S_g *}}{y_{ro}^{S_g}} \quad (r = 1, \ldots, s_{11}) \quad \text{(Separable Good Output))} \tag{3-13}$$

$$\beta_{2r} = \frac{1}{s}(1-\alpha^*) \; (r = 1, \ldots, s_{21}) \quad \text{(Non-Separable Good Output)} \tag{3-14}$$

$$\beta_{2r} = \frac{1}{s}(1-\alpha^*)\frac{1}{s}\frac{s_r^{NS_b *}}{y_{ro}^{NS_b}} \quad (r = 1, \ldots, s_{22}) \quad \text{(Non-Separable Bad Output)} \tag{3-15}$$

Chapter 4 Data Analysis

4.1 The data

As a developed public transport, Taipei bus transit is used as the case study in the thesis. In the earlier periods, there was only one bus operator in Taipei, which belonged to Taipei City Bus Administration, with 51routes and 651 buses. From 1969, the Taipei City Government opened more opportunities to privately-owned firms for operating buses, including Shin-shin Bus, Air Bus, Da-nan Bus, and Kuang-hua Bus, with 90 routes and 847 buses. Up until 1976, Taipei Bus System included only a few private companies and was managed by the Taipei City Government.

Currently there are in total 14 privately-owned bus operators (listed on Table 4.1), serving for almost seven-million people inhabited in Taipei metropolitan area. With 308 routes and 3,898 buses (until 2010 Dec.), these bus operators provided 243,900 thousand vehicle-kilometers and carried 647,479 thousand passenger-trips in 2010.

Table 4.1 Current Companies of Taipei Bus System

Companies	
Metropolitan Bus (MP)	Capital Bus (CP)
Shin-shin Bus (SS)	Zhinan Bus (ZN)
Air Bus(AB)	Chung-shing Bus (CS)
Da-nan Bus(DN)	Xindian Bus (XD)
Kuang-hua Bus (KH)	Southeast Bus (SE)
Taipei Bus (TP)	Tanshui Bus (TS)
San-chung Bus (SC)	Hsin-ho Bus (HH)

Following previous studies, several authors have studied the efficiency performance of bus transit. Most of these studies utilized service inputs (such as labor, vehicle, and fuel) as input variables, while utilized service outputs (such as vehicle hours, vehicle miles, and capacity miles) and service consumption (such as passengers, passenger miles, and operating revenue) as desirable output variables. On the other hand, bus transit industry produces several kinds of undesirable outputs such as air pollution. Diesel is generally used as fuel in bus transit industry, and there are several emissions from the buses, e.g., carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NO_x), particulate matters (PM), which are causes for acid rain and smog.

The variables which are used in this research are described as follow:

Table 4.2 The Variables Description

Set	Variable	Description
Input	**Labor (x1)**	Drivers, managements, and maintenance technicians
	Vehicle (x2)	Referring to the number of passenger vehicles registered and authorized to provide passenger service within a given time, including active vehicles and those suspended for unspecified causes.
	Fuel (10^3) (x3)	Consumption of diesel
Desirable output	**Vehicle-kilometers (10^3) (y1)**	The summation of all vehicle mileages in a particular period
	Revenue (10^6) (y2)	The revenue from passenger transport
Undesirable output	**CO Emission (z)**	Total emission of CO accompany with all vehicles traveling at a specific time

The data used in this research is provided by Public Transportation Office in Taipei City. Firms with incomplete data or unreasonable data are deleted. As such, two firms have been excluded from this empirical analysis because of small scale of market share (less than 1% of all). There are fourteen firms over a four-year horizon from 2007 to 2010. Totally, there are 48 observations (DMUs) in this research.

1. Input

(1) Labor: Drivers, managements, and maintenance technicians are included in labors. The maximum number of labors is 1,419 in MP2010. The minimum number 81 shows at SE2007. The average of labor is about 536, and the standard deviation is 364.

(2) Vehicle: The number of passenger or freight transport vehicles registered and authorized to provide passenger service or freight delivery within a given time. MP2010 has the most vehicle, 800, and AB2009 has the least number, 165. The average of vehicle is about 344, and the standard deviation is 183.

(3) Fuel: The consumption of diesel is used as the variable. MP2007 consumes 24,626 kilo litre, being the maximum, while SE 2010 consumes 2598 kilo litre, being the minimum. The average of fuel is about 9,638 kilo litre, and the standard deviation is 6,217.

2. Desirable output

(1) Vehicle-kms: The summation of all vehicle mileages in a particular period is described as vehicle-kms. The maximum is 47,707 thousand vehicle-kms, MP2007; while the minimum is 5615 thousand vehicle-kms, SE 2010. The average of vehicle-kms is about 20,564 and the standard deviation is 12592.

(2) Revenue: The revenue from passenger transport is defined as revenue. MP2008 has the most revenue, 2,254 million NT dollar; while SE2009 has the least revenue, 147 million NT dollar. The average of revenue is about 846 million NT dollar, and the standard deviation is 570.

3. Undesirable output

In this research we use total emission of CO accompany with all vehicles traveling at a specific time as undesirable output. MP2008 emits 488,201 kg CO and SE2010 emits 57499 kg CO. The average of emission is about 211,098 kg, and standard deviation is 129,073.

The descriptive statistics of the 56 observations are summarized as Table 4.3 and the correlation coefficient of the variables are list in Table 4.4.

Table 4.3 Descriptive Statistics of the observations

Variable	Max.	Min.	Average	Std. Dev.
(x1)	1419	81	536	364
(x2)	800	165	344	183
(x3)	24626	2598	9638	6217
(z)	488201	57499	211098	129073
(y1)	47707	5615	20564	12592
(y2)	2254	147	846	570

Table 4.4 Correlation of the Variables

	(x1)	(x2)	(x3)	(z)	(y1)	(y2)
(x1)	1.000	0.920	0.933	0.924	0.923	0.932
(x2)	0.920	1.000	0.978	0.968	0.968	0.975
(x3)	0.933	0.978	1.000	0.995	0.996	0.995
(z)	0.924	0.968	0.995	1.000	0.999	0.991
(y1)	0.923	0.968	0.996	0.999	1.000	0.991
(y2)	0.932	0.970	0.995	0.991	0.991	1.000

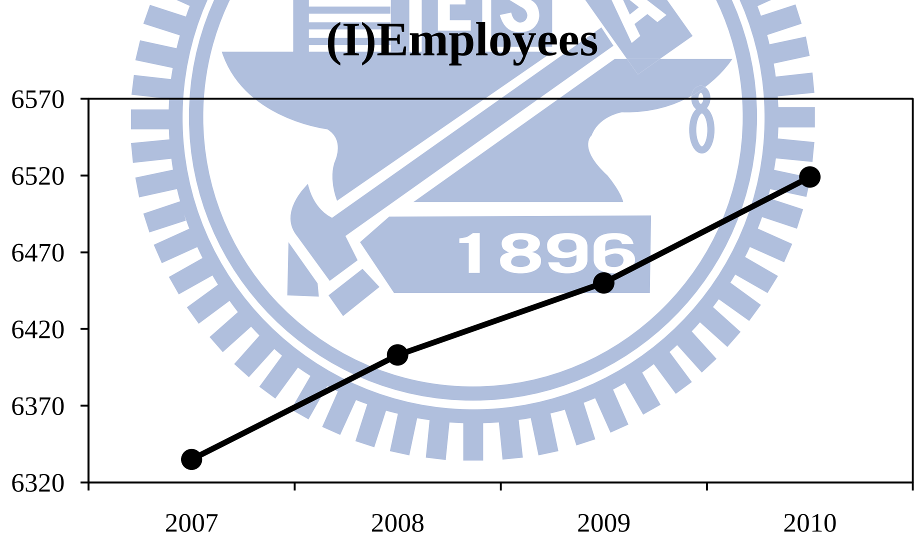

Figure 4.1 Trend of employees by year

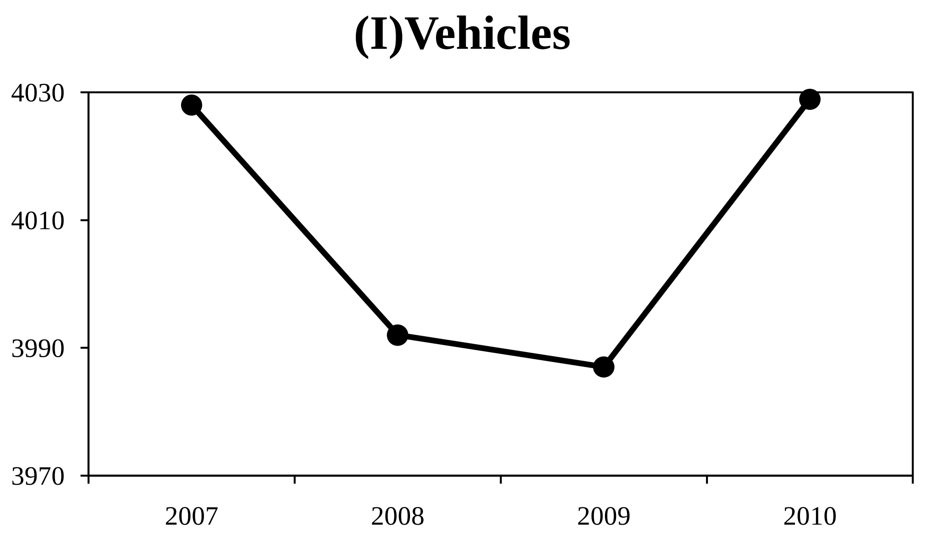

Figure 4.2 Trend of vehicles by Year

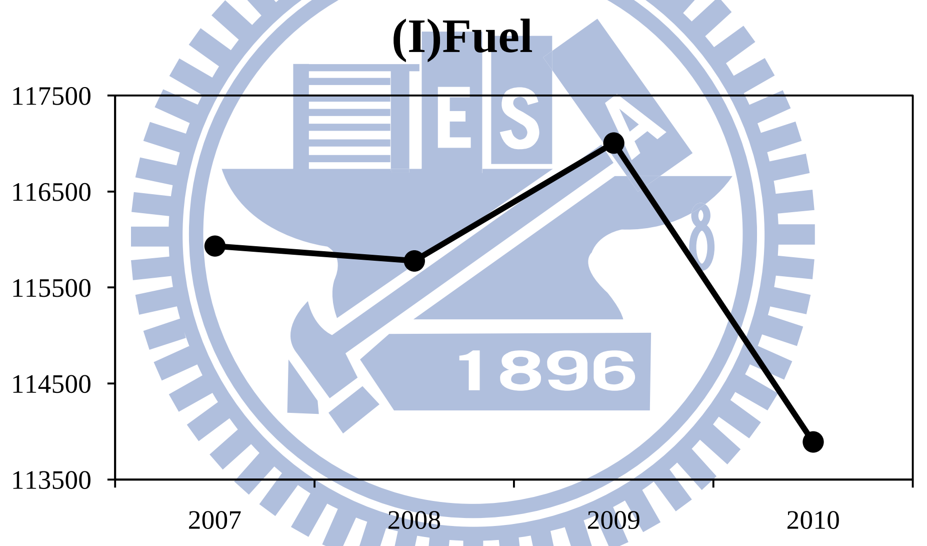

Figure 4.3 Trend of fuel consumptions by Year

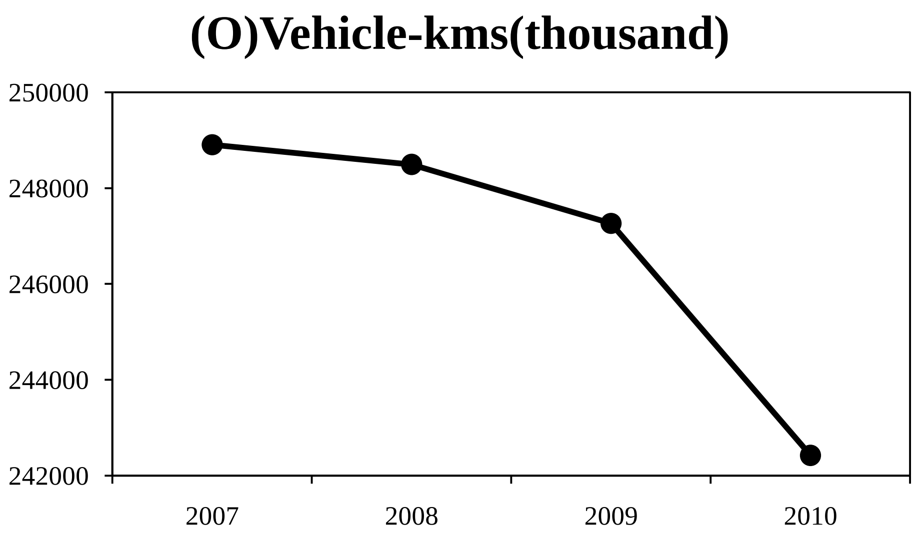

Figure 4.4 Trend of vehicle-kms by Year

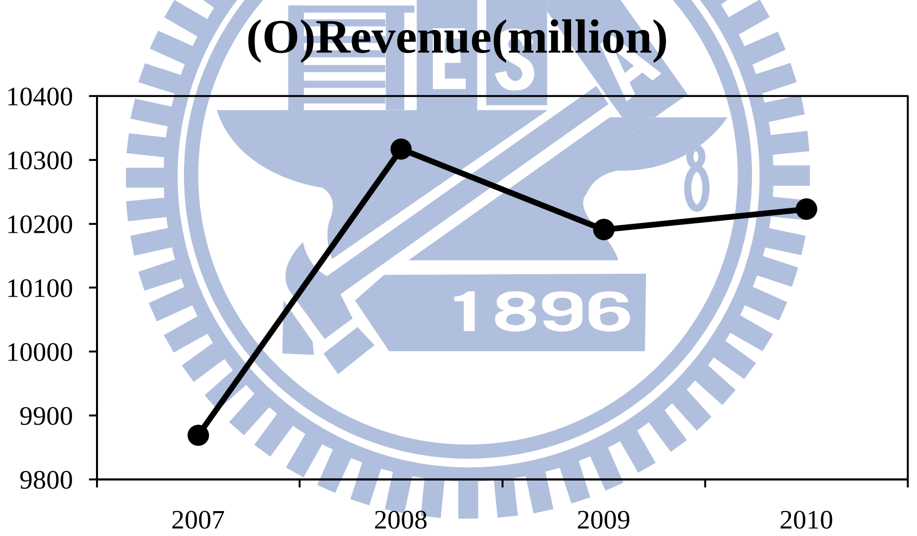

Figure 4.5 Trend of revenue by Year

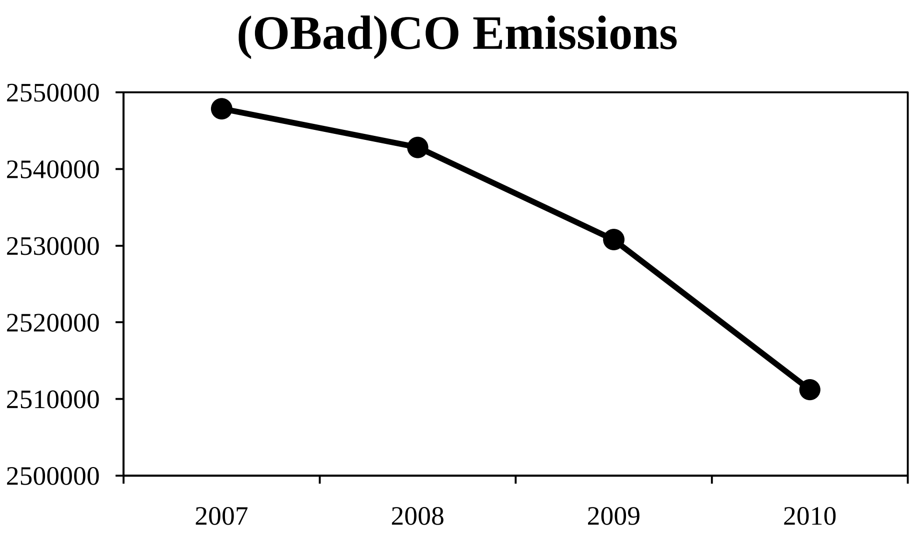

Figure 4.6 Trend of CO emissions by Year

4.2 Empirical results

According to Fielding et al. (1985), there are two categories relating to desirable outputs—service outputs, and service consumption. Therefore, in this section we set three scenarios to estimate the efficiency scores with and without undesirable outputs respectively. In scenario one, service output (vehicle-kms) is used as desirable output. In scenario two, service consumptions (passengers and revenue) are used as desirable outputs. In scenario three, both service output and service consumptions are discussed as desirable outputs.

4.2.1 Scenario one

This scenario discusses the relationship amount inputs, service outputs, and undesirable outputs.

Table 4.5 Statistics on input and output data

Variable	Max.	Min.	Average	Std. Dev.
(x1)	1419	81	536	364
(x2)	800	165	334	183
(x3)	24626	2598	9638	6217
(z)	488201	57499	211098	129073
(y1)	47707	5615	20564	12592

We applied the SBM model and undesirable output model in Section 3.5 to the 48 DMUs respectively, and got the scores and ranks as Table 4.6. As applying SBM model and considering without undesirable outputs, there are 6 DMUs which meet ρ*=1, i.e. the 6 DMUs are efficient. However, using undesirable output model with undesirable outputs, there are only 4 DMUs are efficient. There are two firms become unefficient after consider undesirable outputs.

Table 4.6 The results of considering without/ with undesirable outputs

DMU	Without Undesirable Outputs		With Undesirable Outputs	
	Score	Rank	Score	Rank
AB 2007	1.000	1	1.000	1
XD 2007	1.000	1	1.000	1
SC 2008	1.000	1	1.000	1
XD 2008	1.000	1	0.945	10
SE 2008	1.000	1	0.856	19
SC 2009	1.000	1	1.000	1

Table 4.7 The score and rank without/with consideration of undesirable outputs

DMU	Without Undesirable Outputs						With Undesirable Outputs					
	2007	**2008**	**2009**	**2010**	**Av.**	**Rank**	**2007**	**2008**	**2009**	**2010**	**Av.**	**Rank**
MP	0.891	0.896	0.878	0.869	0.884	4	0.951	0.896	0.879	0.870	0.899	7
SS	0.797	0.818	0.806	0.809	0.807	7	0.802	0.825	0.813	0.768	0.802	6
AB	1.000	0.743	0.726	0.725	0.799	8	1.000	0.774	0.756	0.754	0.821	4
DN	0.849	0.676	0.674	0.682	0.720	10	0.876	0.704	0.709	0.710	0.750	9
KH	0.646	0.662	0.641	0.630	0.645	12	0.681	0.688	0.665	0.654	0.672	12
TP	0.983	0.966	0.971	0.931	0.963	2	0.989	0.987	0.973	0.935	0.971	3
SC	0.950	1.000	1.000	0.935	0.971	1	0.954	1.000	1.000	0.939	0.973	2
CP	0.848	0.836	0.836	0.831	0.838	6	0.853	0.840	0.839	0.832	0.841	5
ZN	0.739	0.741	0.733	0.703	0.729	9	0.772	0.774	0.745	0.729	0.755	8
CS	0.690	0.704	0.697	0.672	0.691	11	0.726	0.732	0.725	0.697	0.720	11
XD	1.000	0.945	0.938	0.946	0.957	3	1.000	1.000	0.990	0.996	0.997	1
SE	0.874	0.856	0.845	0.846	0.855	5	0.806	1.000	0.701	0.696	0.801	10
Av.	0.867	0.852	0.816	0.798	0.833		0.856	0.820	0.812	0.798	0.822	

4.2.2 Scenario two

This scenario discusses the relationship amount inputs, service consumption, and undesirable outputs.

Table 4.8 Statistics on input/ output data

Variable	Max.	Min.	Average	Std. Dev.
(x1)	1419	18	536	364
(x2)	800	165	334	183
(x3)	24626	2598	9638	6217
(z)	488201	57499	211098	129073
(y2)	2254	147	846	570

The same as scenario one, we applied the SBM model and undesirable output model to measure the efficiency with and without undesirable outputs respectively, and got the scores and ranks as Table 4.9.

Table 4.9 Results of considering without/ with undesirable outputs

DMU	Without Undesirable Outputs		With Undesirable Outputs	
	Score	Rank	Score	Rank
XD 2007	1.000	1	1.000	1
SC 2008	1.000	1	1.000	1
AB 2010	1.000	1	1.000	1
XD 2010	1.000	1	1.000	1

Without considering undesirable outputs, there are 4 DMUs which meet ρ*=1, i.e. the 4 DMUs are efficient. With considering undesirable outputs, there are still 4 DMUs are efficient.

Table 4.10 The score and rank without/with consideration of undesirable outputs

DMU	Without Undesirable Outputs						With Undesirable Outputs					
	2007	2008	2009	2010	Av.	Rank	2007	2008	2009	2010	Av.	Rank
MP	0.921	0.961	0.912	0.919	0.928	4	0.930	0.982	0.922	0.935	0.942	5
SS	0.725	0.750	0.765	0.797	0.760	7	0.692	0.719	0.744	0.750	0.726	7
AB	0.612	0.907	0.975	1.000	0.873	5	0.553	0.848	0.973	1.000	0.844	4
DN	0.740	0.701	0.667	0.669	0.694	8	0.705	0.700	0.651	0.650	0.677	8
KH	0.586	0.592	0.573	0.547	0.575	12	0.551	0.554	0.536	0.506	0.537	11
TP	0.913	0.954	0.948	0.976	0.948	2	0.867	0.928	0.918	0.974	0.922	3
SC	0.924	1.000	0.947	0.918	0.947	3	0.910	1.000	0.933	0.908	0.938	2
CP	0.759	0.790	0.794	0.810	0.788	6	0.721	0.768	0.774	0.798	0.765	6
ZN	0.664	0.691	0.676	0.659	0.672	10	0.615	0.650	0.632	0.615	0.628	10
CS	0.670	0.683	0.664	0.675	0.673	9	0.649	0.660	0.637	0.664	0.652	9
XD	1.000	0.987	0.972	1.000	0.990	1	1.000	0.982	0.963	1.000	0.986	1
SE	0.580	0.647	0.688	0.706	0.655	11	0.347	0.360	0.354	0.358	0.355	12
Av.	0.758	0.805	0.798	0.806	0.792		0.712	0.763	0.753	0.763	0.748	

4.2.3 Scenario three

This scenario discusses the relationship amount inputs, service outputs, service consumption, and undesirable outputs.

Table 4.11 Statistics on input/ output data

Variable	Max.	Min.	Average	Std. Dev.
(x1)	1419	81	536	364
(x2)	800	165	344	183
(x3)	24626	2598	9638	6217
(z)	488201	57499	211098	129073
(y1)	47707	5615	20564	12592
(y2)	2254	147	846	570

The same as previous one, we applied the SBM model and undesirable output model to measure the efficiency with and without undesirable outputs respectively, and got the scores and ranks as Table 4.11.

Without considering undesirable outputs, there are 11 DMUs which meet ρ*=1, i.e. the 11 DMUs are efficient. With considering undesirable outputs, there are only 7 DMUs are efficient. The score of SE2008 decreases from 1 to 0.742.

Table 4.12 Results of considering without/ with undesirable outputs

DMU	Without Undesirable Outputs		With Undesirable Outputs	
	Score	Rank	Score	Rank
MP 2007	1.000	1	0.912	18
AB 2007	1.000	1	1.000	1
XD 2007	1.000	1	1.000	1
AB 2008	1.000	1	1.000	1
SC 2008	1.000	1	1.000	1
XD 2008	1.000	1	0.987	8
SE 2008	1.000	1	0.742	32
AB 2009	1.000	1	0.972	13
SC 2009	1.000	1	1.000	1
AB 2010	1.000	1	1.000	1
XD 2010	1.000	1	1.000	1

Table 4.13 The score and rank without/with consideration of undesirable outputs

DMU	Without Undesirable Outputs						With Undesirable Outputs					
	2007	2008	2009	2010	Av.	Rank	2007	2008	2009	2010	Av.	Rank
MP	0.912	0.941	0.902	0.904	0.915	5	1.000	0.990	0.952	0.975	0.979	6
SS	0.767	0.789	0.790	0.809	0.789	7	0.776	0.798	0.797	0.781	0.788	8
AB	1.000	1.000	0.972	1.000	0.993	1	1.000	1.000	1.000	1.000	1.000	1
DN	0.896	0.704	0.676	0.681	0.739	9	0.900	0.712	0.701	0.696	0.752	9
KH	0.621	0.631	0.611	0.591	0.613	12	0.650	0.651	0.629	0.612	0.635	12
TP	0.977	0.979	0.979	0.977	0.978	3	0.982	0.984	0.981	0.978	0.981	3
SC	0.939	1.000	1.000	0.928	0.967	4	0.943	1.000	1.000	0.932	0.969	4
CP	0.806	0.815	0.817	0.822	0.815	6	0.817	0.821	0.823	0.824	0.821	7
ZN	0.706	0.722	0.709	0.686	0.706	10	0.731	0.746	0.721	0.702	0.725	10
CS	0.686	0.699	0.685	0.680	0.687	11	0.711	0.715	0.703	0.691	0.705	11
XD	1.000	0.987	0.964	1.000	0.988	2	1.000	1.000	0.986	1.000	0.997	2
SE	0.708	0.742	0.766	0.777	0.748	8	0.883	1.000	0.817	0.816	0.879	5
Av.	0.835	0.834	0.823	0.821	0.828		0.866	0.868	0.842	0.834	0.853	

4.2.4 Summary

In section 4.2, three scenarios are introduced under considering service outputs, service consumptions, or overall outputs respectively. The results are compiled and separate according to different cases and years in Table 4.14. From this table, we can see there are more efficient DMUs in 2007 than in other years.

In scenario 1, service output (vehicle-kms) is used as output variable. There are 12 DMUs efficient as consider without undesirable output; while only 4 DMUs are efficient if undesirable output is involved. In scenario 2, service consumption (passengers and revenue) is the output variable. There are 10 efficient DMUs under considering without undesirable output. If taking undesirable output into account, there are 4 DMUs which are efficient. In scenario 3, both service output and service consumption are involved in the model. There are 18 efficient DMUs and 6 efficient DMUs respectively as considering without and with undesirable output.

According to the results, over half of DMUs which are efficient as considering undesirable output are not efficient if considering it.

Table 4.14 Efficient DMUs without/with undesirable output from 2007 to 2010

		Scenario 1	Scenario 2	Scenario 3
2007	Without	AB, XD	XD	MP, AB, XD
	With	AB, XD	XD	AB, XD
2008	Without	SC, XD, SE	SC	AB, SC, XD, SE
	With	SC	SC	AB, SC
2009	Without	SC		AB, SC
	With	SC		SC
2010	Without		AB, XD	AB, XD
	With		AB,XD	AB, XD
Total	Without	6	4	11
	With	4	4	7

4.3 Slack analysis

The DMUs have already classified as efficiency or inefficiency. To improve the inefficient DMUs, slack values for the factors are computed. According to the three scenarios, we have different results of slack analysis. The following analyses take undesirable output into account.

Table 4.15 Slack analysis in scenario one

DMU	Score	(x1)	(x2)	(x3)	(y1)	(z)
MP 2007	0.951	75.631	41.484	1002.496	0.000	0.000
SS 2007	0.802	376.680	5.089	764.335	0.000	0.000
AB 2007	1.000	0.000	0.000	0.000	0.000	0.000
DN 2007	0.876	124.908	0.000	0.000	0.000	0.000
KH 2007	0.681	273.175	75.821	0.000	0.000	0.000
TP 2007	0.989	15.822	2.112	0.000	0.000	0.000
SC 2007	0.954	74.387	0.000	689.849	0.000	0.000
CP 2007	0.853	255.998	54.417	581.711	0.000	0.000
ZN 2007	0.772	294.553	0.000	18.771	0.000	0.000
CS 2007	0.726	242.897	32.551	0.000	0.000	0.000
XD 2007	1.000	0.000	0.000	0.000	0.000	0.000
SE 2007	0.806	17.065	63.882	0.000	0.000	0.000
MP 2008	0.896	136.073	110.557	1764.523	0.000	0.000
SS 2008	0.825	367.686	0.000	249.684	0.000	0.000

Table 4.15 Slack analysis in scenario one (continued)

AB 2008	0.774	142.895	20.084	0.000	0.000	0.000
DN 2008	0.704	229.447	42.501	6.720	0.000	0.000
KH 2008	0.688	305.620	55.998	5.097	0.000	0.000
TP 2008	0.987	19.502	0.000	23.577	0.000	0.000
SC 2008	1.000	0.000	0.000	0.000	0.000	0.000
CP 2008	0.840	259.103	74.695	848.379	0.000	0.000
ZN 2008	0.774	288.846	0.000	83.247	0.000	0.000
CS 2008	0.732	265.099	18.631	0.113	0.000	0.000
XD 2008	1.000	0.000	0.000	0.000	0.000	0.000
SE 2008	1.000	0.000	0.000	0.000	0.000	0.000
MP 2009	0.879	167.316	132.031	1817.272	0.000	0.000
SS 2009	0.813	388.235	9.663	4.262	0.000	0.000
AB 2009	0.756	186.725	5.265	113.567	0.000	0.000
DN 2009	0.709	230.949	36.499	50.910	0.000	0.000
KH 2009	0.665	317.312	66.889	60.734	0.000	0.000
TP 2009	0.973	29.164	0.000	375.541	0.000	0.000
SC 2009	1.000	0.000	0.000	0.000	0.000	0.000
CP 2009	0.839	248.127	77.748	1036.474	0.000	0.000
ZN 2009	0.745	324.270	0.000	133.711	0.000	0.000

Table 4.15 Slack analysis in scenario one (continued)

CS 2009	0.725	268.431	20.452	53.198	0.000	0.000
XD 2009	0.990	1.372	1.104	58.054	0.000	0.000
SE 2009	0.701	33.500	83.123	27.689	0.000	0.000
MP 2010	0.870	198.843	139.841	1796.582	0.000	0.000
SS 2010	0.768	278.267	74.184	0.000	0.000	29840.976
AB 2010	0.754	178.012	7.819	120.081	0.000	0.000
DN 2010	0.710	232.243	37.067	26.804	0.000	0.000
KH 2010	0.654	326.673	78.807	0.000	0.000	0.000
TP 2010	0.935	67.019	24.236	295.216	0.000	0.000
SC 2010	0.939	98.726	0.000	932.244	0.000	0.000
CP 2010	0.832	247.230	93.779	1007.299	0.000	0.000
ZN 2010	0.729	351.962	4.229	37.637	0.000	0.000
CS 2010	0.697	289.381	34.894	16.668	0.000	0.000
XD 2010	0.996	0.292	0.575	24.641	0.000	0.000
SE 2010	0.696	35.974	83.852	6.946	0.000	0.000

Table 4.16 Slack analysis in scenario two

DMU	Score	(x1)	(x2)	(x3)	(y2)	(z)
MP 2007	0.930	96.695	77.662	2174.209	0.000	0.000
SS 2007	0.692	318.858	83.757	943.437	0.000	0.000
AB 2007	0.553	169.952	116.208	0.000	0.000	18539.951
DN 2007	0.705	226.472	39.288	0.000	0.000	10666.941
KH 2007	0.551	320.792	90.568	0.000	0.000	1836.989
TP 2007	0.867	0.000	74.917	36.235	0.000	0.000
SC 2007	0.910	112.663	7.655	622.780	0.000	0.000
CP 2007	0.721	359.211	87.396	438.130	0.000	0.000
ZN 2007	0.615	207.076	33.149	0.000	0.000	3127.647
CS 2007	0.649	277.016	36.764	0.000	0.000	1650.983
XD 2007	1.000	0.000	0.000	0.000	0.000	0.000
SE 2007	0.347	48.972	114.538	0.000	0.000	539.749
MP 2008	0.982	47.804	53.183	1387.831	0.000	0.000
SS 2008	0.719	310.500	76.380	496.371	0.000	0.000
AB 2008	0.848	158.384	16.836	0.000	0.000	4494.991
DN 2008	0.700	230.448	43.392	0.000	0.000	201.169
KH 2008	0.554	322.244	85.026	0.000	0.000	299.691
TP 2008	0.928	0.000	34.103	142.867	0.000	0.000

Table 4.16 Slack analysis in scenario two (continued)

SC 2008	1.000	0.000	0.000	0.000	0.000	0.000
CP 2008	0.768	317.900	93.460	753.641	0.000	0.000
ZN 2008	0.650	195.531	27.041	0.000	0.000	2337.869
CS 2008	0.660	272.672	31.588	0.000	0.000	408.281
XD 2008	0.982	1.836	2.294	0.000	0.000	334.170
SE 2008	0.360	51.380	115.270	0.000	0.000	80.712
MP 2009	0.922	122.336	101.729	1708.532	0.000	0.000
SS 2009	0.744	307.984	76.866	292.983	0.000	0.000
AB 2009	0.973	13.234	0.000	0.000	0.000	99.465
DN 2009	0.651	237.956	49.274	34.332	0.000	0.000
KH 2009	0.536	332.936	94.444	32.773	0.000	0.000
TP 2009	0.918	0.000	35.374	251.586	0.000	0.000
SC 2009	0.933	37.605	0.000	982.627	0.000	0.000
CP 2009	0.774	301.863	94.895	941.250	0.000	0.000
ZN 2009	0.632	203.245	29.619	0.000	0.000	1620.675
CS 2009	0.637	277.916	36.614	32.584	0.000	0.000
XD 2009	0.963	3.448	4.392	36.562	0.000	0.000
SE 2009	0.354	53.012	118.198	8.899	0.000	0.000
MP 2010	0.935	130.302	94.706	1547.466	0.000	0.000

Table 4.16 Slack analysis in scenario two (continued)

SS 2010	0.750	296.337	74.405	0.000	0.000	32642.869
AB 2010	1.000	0.000	0.000	0.000	0.000	0.000
DN 2010	0.650	238.732	47.878	9.327	0.000	0.000
KH 2010	0.506	347.240	109.260	0.000	0.000	527.946
TP 2010	0.974	0.000	26.564	185.879	0.000	0.000
SC 2010	0.908	117.632	8.627	902.020	0.000	0.000
CP 2010	0.798	276.211	101.196	932.408	0.000	0.000
ZN 2010	0.615	225.076	38.949	0.000	0.000	1589.181
CS 2010	0.664	293.100	40.950	0.000	0.000	44.087
XD 2010	1.000	0.000	0.000	0.000	0.000	0.000
SE 2010	0.358	54.808	117.832	0.000	0.000	95.649

Table 4.17 Slack analysis in scenario three

DMU	Score	(x1)	(x2)	(x3)	(y1)	(y2)	(z)
MP 2007	1.000	0.000	0.000	0.000	0.000	0.000	0.000
SS 2007	0.776	246.831	63.094	1146.642	0.000	89.676	0.000
AB 2007	1.000	0.000	0.000	0.000	0.000	0.000	0.000
DN 2007	0.900	67.041	23.221	0.000	0.000	0.000	0.000
KH 2007	0.650	273.813	76.641	0.000	0.000	54.658	0.000
TP 2007	0.982	15.843	2.627	0.000	0.000	22.977	0.000
SC 2007	0.943	76.415	0.000	679.678	0.000	38.580	0.000
CP 2007	0.817	260.963	55.250	563.631	0.000	132.274	0.000
ZN 2007	0.731	296.949	0.111	0.000	0.000	61.901	0.000
CS 2007	0.711	243.160	32.902	0.000	0.000	23.258	0.000
XD 2007	1.000	0.000	0.000	0.000	0.000	0.000	0.000
SE 2007	0.883	4.801	17.353	0.000	0.000	31.400	0.000
MP 2008	0.990	15.849	7.787	195.418	0.000	0.000	0.000
SS 2008	0.798	244.161	55.175	609.254	0.000	88.057	0.000
AB 2008	1.000	0.000	0.000	0.000	0.000	0.000	0.000
DN 2008	0.712	222.505	42.162	0.549	0.000	0.000	0.000
KH 2008	0.651	306.185	56.997	0.000	0.000	70.780	0.000
TP 2008	0.984	19.975	0.000	22.331	0.000	9.946	0.000

Table 4.17 Slack analysis in scenario three (continued)

SC 2008	1.000	0.000	0.000	0.000	0.000	0.000	0.000
CP 2008	0.821	261.684	75.269	840.580	0.000	73.697	0.000
ZN 2008	0.746	291.263	0.000	72.124	0.000	44.138	0.000
CS 2008	0.715	265.343	19.067	0.000	0.000	27.814	0.000
XD 2008	1.000	0.000	0.000	0.000	0.000	0.000	0.000
SE 2008	1.000	0.000	0.000	0.000	0.000	0.000	0.000
MP 2009	0.952	76.037	56.353	456.246	0.000	0.000	0.000
SS 2009	0.797	265.393	63.772	360.783	0.000	55.229	0.000
AB 2009	1.000	0.000	0.000	0.000	0.000	0.000	0.000
DN 2009	0.701	231.063	36.704	50.853	0.000	12.678	0.000
KH 2009	0.629	317.746	67.632	44.625	0.000	70.493	0.000
TP 2009	0.981	21.877	0.000	32.888	0.000	15.309	0.000
SC 2009	1.000	0.000	0.000	0.000	0.000	0.000	0.000
CP 2009	0.823	250.461	78.282	1029.294	0.000	67.201	0.000
ZN 2009	0.721	326.030	0.000	122.506	0.000	37.443	0.000
CS 2009	0.703	268.708	20.936	48.357	0.000	37.555	0.000
XD 2009	0.986	1.262	0.876	43.457	0.000	7.059	0.000
SE 2009	0.817	14.176	33.517	19.616	0.000	29.400	0.000
MP 2010	0.975	56.105	27.184	0.000	0.000	0.000	0.000

Table 4.17 Slack analysis in scenario three (continued)

SS 2010	0.781	266.132	80.400	0.000	0.000	1.623	29886.186
AB 2010	1.000	0.000	0.000	0.000	0.000	0.000	0.000
DN 2010	0.696	232.401	37.339	22.391	0.000	23.662	0.000
KH 2010	0.612	327.356	79.991	0.000	0.000	75.480	0.000
TP 2010	0.978	11.348	17.707	126.837	0.000	0.000	0.000
SC 2010	0.932	95.895	1.829	940.963	0.000	26.374	0.000
CP 2010	0.824	248.558	93.926	1001.033	0.000	32.761	0.000
ZN 2010	0.702	352.153	4.536	20.863	0.000	44.082	0.000
CS 2010	0.691	289.381	34.873	7.035	0.000	12.867	0.000
XD 2010	1.000	0.000	0.000	0.000	0.000	0.000	0.000
SE 2010	0.816	15.366	33.295	0.000	0.000	29.600	0.000

4.4 Discussion

This study was designed to measure the operation efficiency of bus transit with consideration of undesirable output and compare with the efficiency without considering undesirable output. The findings indicate that many efficiency DMUs become inefficiency if involving undesirable output into the DEA model. Therefore, ignoring undesirable outputs may cause bias in evaluation of efficiency.

Figure 4.7 displays the trends of six average efficiency scores over time, without and with undesirable output in the three scenarios, indicating the following: (1) in the three scenario, the efficiency scores estimated without undesirable output are generally higher than the scores estimated with undesirable output; (2) the efficiency scores in scenario one and scenario three are higher than the scores in scenario two; (3) the efficiency scores in scenario three are steadier than those in scenario one and two. The above time trends show: (1) the efficiency scores are overestimated under considering without undesirable output; (2) the efficiency scores are steadier as both service outputs and service consumption are involved in the model.

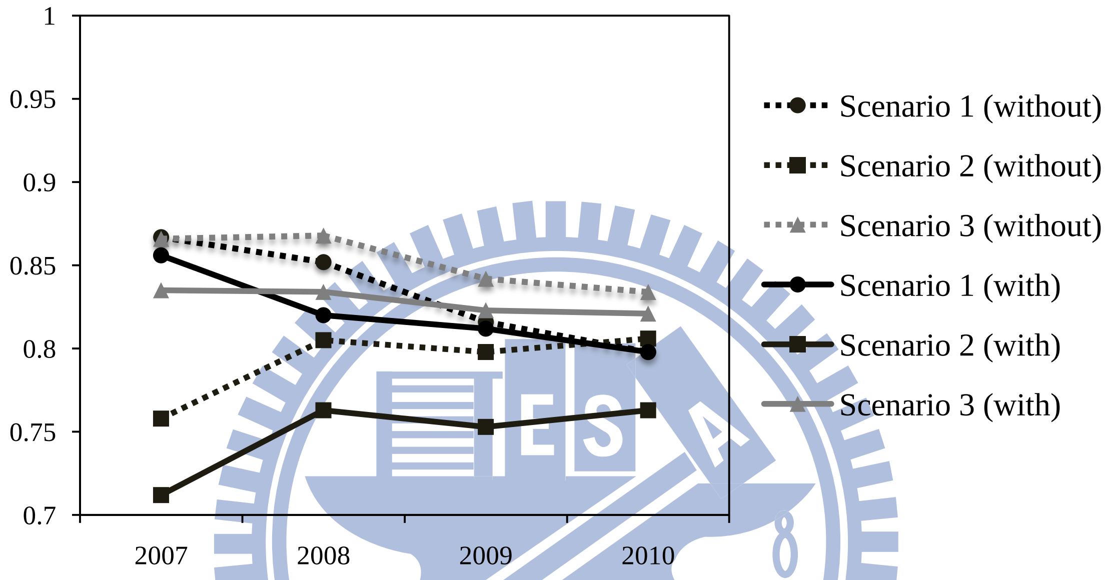

Figure 4.7 Time trends of annual average of efficiency scores from 2007 to 2010, without and with undesirable in the three scenarios

Table 4.18 summarizes the average efficiency scores of the 12 firms from 2007 to 2010 in the three scenarios. The table shows that in scenario three, AB has ρ *=1, being the most efficient firm. Following are MP, TP, SC, and XD have ρ *>0.95, which means the four firms are respectively efficient to others. Those efficient firms totally operating 992,956 thousand vehicle-kms (55% of total) and carrying 2,567,696 thousand passengers (57% of total) in the period of 2007-2010. The operational universalities of the five efficiency firms are (1) (y1) > 10,000; (2) (y2) > 30,000; (3) (y3)> 500, which indicate that the scales of firms have relationship with the efficiency.

Table 4.18 Averages of efficiency scores in the three scenarios

Firm	Scenario 1	Scenario 2	Scenario 3
MP	0.899	0.942	0.979
SS	0.802	0.726	0.788
AB	0.821	0.844	1.000
DN	0.750	0.677	0.752
KH	0.672	0.537	0.635
TP	0.971	0.922	0.981
SC	0.973	0.938	0.969
CP	0.841	0.765	0.821
ZN	0.755	0.628	0.725
CS	0.720	0.652	0.705
XD	0.997	0.986	0.997
SE	0.801	0.355	0.879
Average	0.833	0.748	0.853

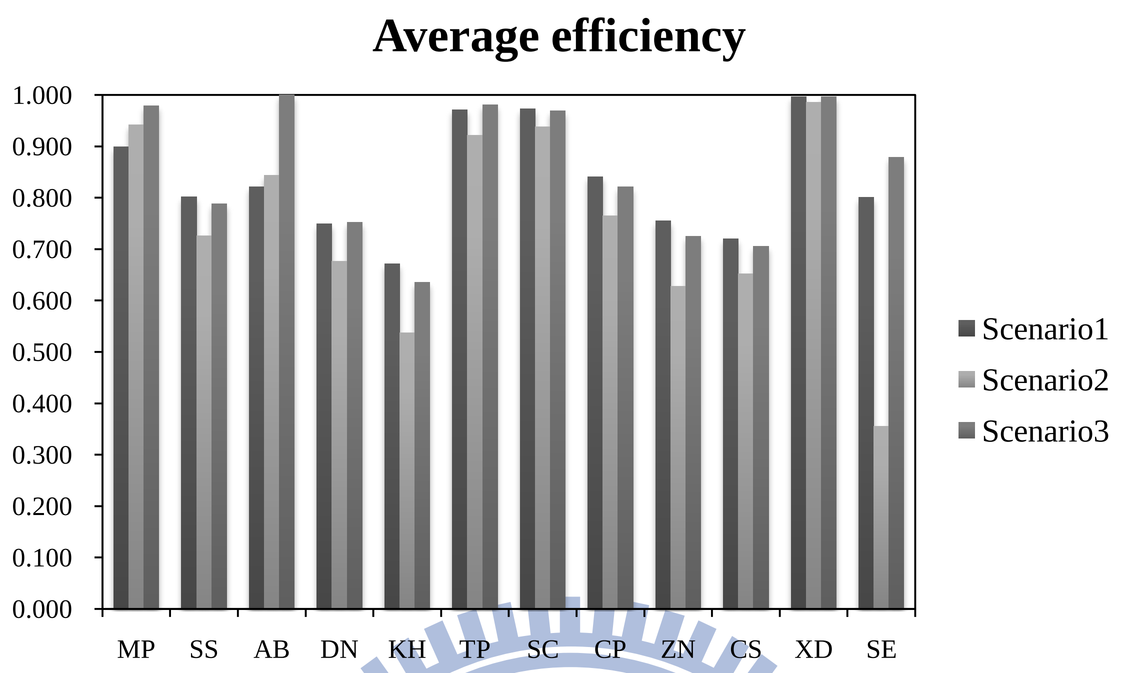

Figure 4.8 Average efficiency scores of the 14 firms for three scenarios

Based on the results, target values of the variables are provided. The following is the potential input and output values in scenario three. According to the potential values, the DMUs can improve the efficiency by increasing desirable outputs and decreasing inputs and undesirable output.

Table 4.19 Potential input and output values

DMU	Score	(x1)	(x2)	(x3)	(y1)	(y2)	(z)
MP 2007	1	1389	785	24626	2189	47707	488045
SS 2007	1	477	333	11186	1071	25367	259782
AB 2007	1	254	267	4720	412	12111	123923
DN 2007	1	268	211	5602	532	13104	134088
KH 2007	1	139	179	5445	507	11942	122241

Table 4.19 Potential input and output values (continued)

TP 2007	1	514	509	15192	1280	33411	341870
SC 2007	1	729	414	14472	1407	33238	340105
CP 2007	1	654	394	13579	1316	31050	317704
ZN 2007	1	135	174	5282	495	11550	118216
CS 2007	1	125	167	5051	469	11062	113232
XD 2007	1	89	169	5127	458	11237	115699
SE 2007	1	76	155	3051	188	6673	68309
MP 2008	1	1371	783	23863	2254	47699	488196
SS 2008	1	485	338	11308	1087	25600	261999
AB 2008	1	251	183	4271	454	9586	98200
DN 2008	1	107	180	5259	488	11366	116300
KH 2008	1	116	207	6064	560	13113	134196
TP 2008	1	504	502	15029	1301	32523	332753
SC 2008	1	807	414	14827	1450	34317	351093
CP 2008	1	700	409	14187	1377	32523	332756
ZN 2008	1	144	177	5396	505	11838	121138
CS 2008	1	106	189	5535	510	11980	122607
XD 2008	1	102	182	5325	491	11520	117870
SE 2008	1	83	172	2825	155	6116	62490

Table 4.19 Potential input and output values (continued)

MP 2009	1	1317	739	23327	2159	47111	482040
SS 2009	1	460	329	10967	1052	24789	253725
AB 2009	1	276	165	4795	507	10134	103720
DN 2009	1	101	181	5194	474	11237	114973
KH 2009	1	110	197	5790	536	12502	127955
TP 2009	1	505	505	15350	1311	32979	337543
SC 2009	1	806	414	16023	1419	34384	351808
CP 2009	1	716	414	14391	1397	33014	337772
ZN 2009	1	111	176	5349	487	11715	120340
CS 2009	1	105	188	5507	509	11906	121837
XD 2009	1	102	182	5343	495	11536	118073
SE 2009	1	69	138	2605	176	5626	57599
MP 2010	1	1363	773	23639	2184	46986	480775
SS 2010	1	457	313	10628	1012	24196	248020
AB 2010	1	267	167	4794	514	10120	103588
DN 2010	1	102	181	5314	491	11488	117558
KH 2010	1	110	190	5595	515	12127	124120
TP 2010	1	521	489	14470	1314	31387	321200
SC 2010	1	711	412	14327	1390	32864	336230

Table 4.19 Potential input and output values (continued)

CP 2010	1	724	415	14509	1407	33329	341135
ZN 2010	1	98	175	5145	477	11103	113648
CS 2010	1	101	180	5274	488	11394	116608
XD 2010	1	102	183	5379	500	11597	118725
SE 2010	1	70	139	2584	178	5585	57196

To decrease undesirable output, firms may perform maintenance or renew the parts of vehicles. According to the data provided by Metropolitan Bus Company covering the period of 2007-2010, the intermediate input expenditure is highly negative correlative with the emission of CO_2. The correlation coefficient is -0.96885.

Table 4.20 Intermediate input expenditure and CO emission covering the period 2007-2010, provided by Metropolitan Bus Company

Year	Expenditure	CO emission
2007	231,463	488,045
2008	265,874	486,201
2009	298,954	482,040
2010	327,102	480,775

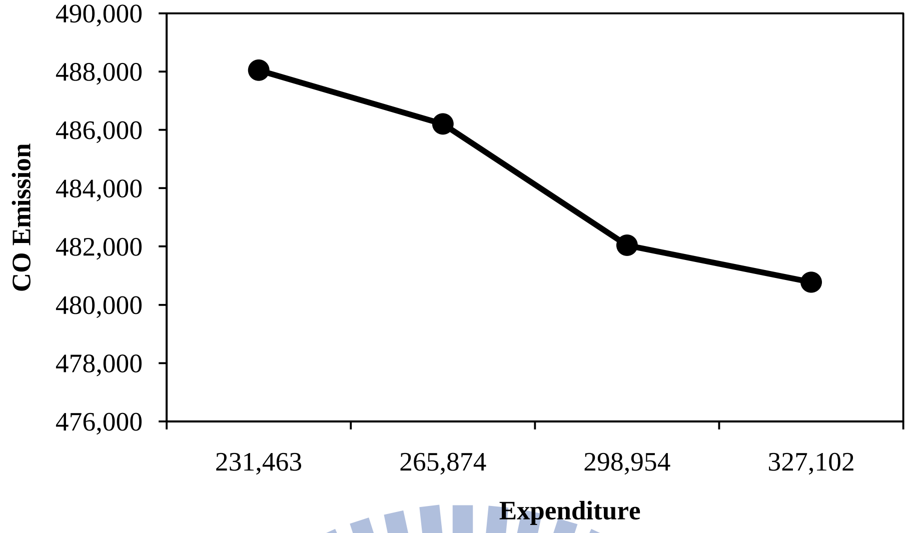

Figure 4.9 Relationship between expenditure and emission of CO

Chapter 5 Conclusions and Recommendations

5.1 Conclusions

In accordance with the recent environmental issues, the pollution which accompany with production activities cause the external cost. However, the external cost should be internalization. Therefore, firms should eliminate pollution as possible to achieve efficiency. This research applies non-separable 'good' and 'bad' output model to intake undesirable output. There are three scenarios with different output combinations discussed before. Some major findings can be concluded as follows:

(1) Compared with conventional DEA model, the results from non-separable model are significantly different. Undesirable output causes some efficient firms to be inefficient. If the undesirable output accompany with production activities, it should be involved in the estimate model.

(2) The case study shows that there are approximately half of the firms efficient in the period of 2007-2010. Those firms operate 55% of total vehicle-kms and carry 57% of total passengers. Therefore, Taipei bus transit should be continuously improved.

(3) Firms may improve the efficiency by decreasing undesirable output. Two promising strategies are to periodically renew the parts related to emissions, such as exhaust system or catalytic converter, and introduction of green fuel.

Nevertheless, there is a limitation in this research—the data of undesirable output. The emission of CO is estimated by the bus firms, which may lead to a bias.

5.2 Recommendations

Further research could focus on the following:

(1) The undesirable output is probably decreased by increasing some intermediate inputs, such as expenditure of maintenance and parts. To search related literatures to support certain intermediate inputs influence undesirable outputs, then including to the model. In addition, other types of undesirable outputs exist, e.g. noise and accidents. Those could be used as undesirable output variable. However, the more variables need the more DMUs.

(2) Investigating the efficiency of bus transit industry in different countries is another idea. Compare with other advanced countries and follow the efficient ones.

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