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Osaka University
Doctoral Dissertation

Indicator-based Analysis on Achievement Efficiency of Transport Energy Consumption

Jiang Jian

Dec. 2012

Graduate School of Engineering
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1. INTRODUCTION
1.1 Backgrounds

With the unprecedented high-speed development of the world's modernization in the recent years, people are enjoying a more and more comfortable life. However, due to the tremendous and excessive development of the society, the human activity is drawing the earth under such a stress that the ability of the planet's ecosystems to recover and sustain the needs for the coming generations can no longer be taken for granted. Nowadays, more and more serious attentions are paid to sustainable issues by the human beings, and the importance of sustainable development gradually turns to be realized as the resources existed are limited on the only one earth. Sustainability means to meet the needs of the present without compromising the ability of future generations to meet their own needs. Particularly, for the human beings, sustainability is the long-term maintenance of responsibility, and it has three dimensions for environmental, economic, and social. In this research, we would like to deal with the problem of sustainability at all its dimensions.

Energy issue is one of the crucial problems in the corresponding research of sustainability because it is strongly related to the environmental dimension and economic dimension. And what's more, this issue also concerns social problems: Almost every corner of our everyday life cannot work without energy. The incident of twice world oil crisis showed that energy is indispensible. However, most of the energy being consumed is non-renewable; furthermore, the consumption of energy all over the word is increasing year by year, and is estimated to keep on increasing in the near future as is shown in Fig.1-1. Nowadays, the rapid growth of the economic in the world is driving the energy consumption grew up rapidly. So especially because of the existence of developing regions which are at a high speed of economic growth, if this pace continues, many types of energy will exhaust in decades.

In this case, before we find out the resource of new energy, it is more practical to improve the efficiency of energy consumption, which will contribute much to the sustainability development of the world. There are many literatures that involved in the issue for transport sustainability. The consumption of energy and the emission of carbon dioxide in transport sector are usually considered to be the representative of the
transport sustainability (S. Okushima 2007 and D. Yoshino 2010). As there are some potential relationship between the consumption of energy and the emission of carbon dioxide for positive correlation, researchers always focus on the variable of environmental issue.

![Fig.1-1 World energy consumption (International energy outlook 2011)](image)

Energy consumption can generally be divided into sectors: the commercial and residential sector, the transport sector and the industrial sector. In the field of civil engineering, energy corresponding research for the transport sector is mostly concerned. Energy use in the transport sector includes the energy consumed in moving people and goods by road, rail, water, air and pipeline. More precisely, the road transport component includes light-duty vehicles, such as automobiles, sport utility vehicles, minivans, small trucks, and motorbikes, as well as heavy-duty vehicles, such as large trucks used for moving freight and buses for passenger travel (International energy outlook 2011). Compare the energy consumption in transport sector all over the world in the year 2010 to the year 1973, when the first oil crisis happened, we can find that in the absolute amount, the value in the 2010 is nearly 2.2 times of that in the year 1973, and the ratio transport sector accounts for also rises from 23.1% in 1973 to 27.3% in 2010 (Key world energy statistics 2012).
Although it is estimated that in OECD countries, the transport energy demand will grow slowly as a result of high motorization levels, relatively slow growth of GDP and population, sustained high world oil prices and continuing improvements in transport energy efficiency, we cannot believe that the energy demand in transport sector will calm down because the group of developing countries is now strengthening rapidly. With this rapid development, the energy demand for transport is a steadily rising demand for personal travel in both the developing and developed countries. In the developing countries, with gains in urbanization and personal incomes, demand for air travel and motorized personal vehicles increases. In addition, strong GDP growth in the developing countries leads to modal shifts in the transport of goods, and freight transport by trucks leads the growth in developing demands for transport energy. Furthermore, as the volume of trade grows, energy use for freight transport by air and marine vessels also increases in the projection. What’s more, the vehicle ownership in developing countries increases in an astonishing pace, which is also a heavy burden on the world energy. In summary, the energy consumption in transport sector will continue increasing for a long time in the future.

It is no doubt that the transport sector consumes more and more energy which is not so ideal from appearance. But on the other hand, such transport energy consumption brings in more and more transport achievement as well when we can feel it is more convenient and comfortable for people to travel and the logistics is far more improved to contribute to the modernized society. Therefore, we cannot predicate the increasing of transport energy consumption should be restricted toughly. The great achievement caused by the consumption should also be taken into consideration. Fig.1-2 and Fig.1-3 shows the tendency of transport energy consumption and typical achievement made by the transport sector in Japan in recent years. The two figures infer the fact that the great quantity of energy consumption brings in more achievement of transport activity which contributes to the economic development, but it's hard to evaluate whether this achievement deserves such amount of consumption. In other words, we expect to make simultaneous improvement both at the achievement of transport activity which leads to economic growth and the transport energy consumption.
The energy consumption in transport sector in Japan (Year 1973=100)

Fig.1-2 The energy consumption in transport sector in Japan
(Source: Yearbook of economic statistics. Cabinet Office in Japan)

The tendency of GDP, Passenger kilometers and Freight kilometers in Japan (Year 1973=100)

Fig.1-3 The tendency of GDP, Passenger kilometers and Freight kilometers in Japan (Source: Yearbook of economic statistics. Cabinet Office in Japan)
In many OECD countries such as Japan, environmentally sustainable transport is advocated in many regions which are called EST model cities. It is hoped that the achievement contributed by the transport sector be attained without too much accompanying increase in energy consumption. Therefore, a balance is required for evaluating the coordination between the two, to have compatible between the transport achievement and transport energy consumption. Consequently, we are facing a problem that how to evaluate this coordination between the two in order to find out whether a region does well for the balance. In other words, we want to solve whether the consumption of energy in transport sector is well converted into its achievement or some of it is wasted for some reason. In addition, if some region does not perform well on this balance between the two, what is the problem or what is the key point that should be picked out for the improvement is another issue we concern. Quantitative analysis is needed to make the evaluation convincing.

1.2 Points of issues and purposes of the research

In the last section, we reached a conclusion that it is urgent to establish an evaluation system to evaluate how a region performs on the balance between transport energy consumption and the achievement supported by this consumption. Corresponding discussions and countermeasures are also necessary for improvement on the efficiency to reach transport sustainability based on the evaluation result. Here we decided to propose a variable for the concept which calls “achievement efficiency” to measure this balance between transport energy consumption and its achievement. Before we define the formula on calculating “achievement efficiency”, we should make it clear what “efficiency” is in advance.

Efficiency in general describes the extent to which time or effort is well used for the intended task or purpose. Here we use “input variable” to represent the time or effort and “output variable” to represent the intended task or purpose. Therefore, “efficiency” can be expressed by the quotation of the amount of the output variable and the input variable to represent the extent how the output reveals by the effort of the input.
Efficiency = \frac{\text{output variable}}{\text{input variable}}

For the issue which is wanted to be solved in this research, “efficiency” refers to the “achievement efficiency in transport energy consumption”, it is the variable we want to calculate, and the denominator “input variable” apparently refers to the “transport energy consumption” it is a definite amount which can be got easily from data sources. In order to improve the amount of the efficiency, we should find out proper way to analyze this item to minimize it as much as possible. On the other hand, we should try to maximize the numerator- output variable; however, it seems unclear how to make the achievement countable. In this case, the remained problem is what variables can represent the output variable in this issue-the transport energy consumption achievement. This is the initial point of the issue chains for the following research. To solve this problem, we should scan over the literatures to find a proper way to determine the indicators to represent the output variable. After the indicators that can indicate appropriately the output variable are determined, we are supposed to find a proper way using selected indicators for calculating the achievement efficiency in various regions to see whether the achievement efficiency of some specific region is good. Next, if the achievement efficiency is not as good as other regions, we want to analyze the reason that leads to the low efficiency quantitatively for the relatively inefficiency region and give corresponding suggestion for improvement.

The purposes of the research are described as follows:

1. Perform quantitative analysis to find out the importance of each factor that affects the amount of transport energy consumption.
2. Select proper indicators convincingly for the output variable for the achievement due to transport energy consumption.
3. Perform quantitative analysis on regions to calculate the achievement efficiency of the transport energy consumption.

In addition, this research will not cease at the level of theoretical calculation but move forward to policy implications for policy-makers to improve the achievement efficiency of the transport energy consumption based on the quantitative analysis result.
This research initially proposes the concept of “achievement efficiency” by transport energy consumption which will pay attention to the result on how well the energy converts into the achievement of transport activity, and perform quantitative analysis on the evaluation of the efficiency. Owing to the quantitative evaluation result, a standard will reveal on evaluating whether a region perform well on the converting from consumed energy in transport related field into the achievement of transport activity. Regions fit this standard well will be an example for the other regions. We will also observe the reason and way of improvement in this point of view. Furthermore, this research links the three independent researches together as a package to observe the issue of transport energy consumption from different points of view. The research finding out proper indicator for the achievement of transport activity observes from macro viewpoint to get an abstract impression, and the analysis for the achievement efficiency evaluation for regions observes from meso viewpoint to investigate the transport energy consuming circumstance in region level, and which is done at the first, the research on analyzing the importance of factors that leads to transport energy consumption looks into the phenomenon from micro viewpoint in order to find the interior relationship between energy consumption and its factors.

1.3 Previous researches

In order to fulfill the purposes we proposed in the last section, a lot of related literatures are reviewed as a reference. Here we lay out the previous researches for references and the hits we got from the literatures for our three purposes respectively.

At the beginning, we review literatures for the first purpose on finding out the importance of each factor which contributes to transport energy consumption. T. Lakshmanan in 1997 introduced the method of decomposition analysis to decompose the change of the environmental variables. Okushima in 2007, Papagiannaki in 2009 and Zha in 2010 decomposed the amount of carbon dioxide emission for environmental policy suggestions. Researcher B. Ang is the most contributive one to give thorough classification for the application on environmental issue of the mathematics methodology of decomposition analysis. He published many literatures from theoretical
to practical on decomposition analysis for analyzing factors for policymaking in energy. He did a survey of index decomposition analysis in energy and environmental studies in 2000 to overview the historical related researches. His summary is sufficient enough for the reference on choosing proper methodology. By the way, these literatures also gave their policy suggestions according to the result of their own research for us to reference, and many other researchers devote to this issue and publish some valuable works to apply on many fields for environmental policy making.

The next purpose is to find proper variables that can indicate the output variable for the “achievement efficiency” of transport energy consumption. Consequently, in this paper, indicator analysis is introduced for resolving the issue of environmentally sustainability in transport sector and the indicator related researches are reviewed. As we can read the meaning of “indicator” from its root, indicator can indicate something to supply information on other variables which are difficult to access and can be used as bench marker to take a decision (Gras, 1989). In the 1990s, the development of indicators at the national, regional, local or field level, has become a commonly approach to meet the crucial need for assessment tools. Such tools are a prerequisite to the implementation of the concept of sustainability, and especially its environmental component (Hansen, 1996). From here, we can infer that the search of indicators is very fit for our hope to find variables to indicate the output of “achievement efficiency” of transport energy consumption. Many researchers applied the study of indicator on the field of environmental sustainability issues. C. Bockstaller in 2003 managed to validate environmental indicators in his work. D. Niemeijer in 2008 set a conceptual framework for selecting environmental indicator sets. T.Litman in 2011 developed indicators for comprehensive and sustainable transport planning. The most related work which is in the transport field is R.Joumard in 2010; he applied indicators on the field of environmental sustainability in transport.

The core issue of indicator related researches is how to identify appropriate indicators or choose well among possible candidates. The way to select specific indicators using criteria is important when applying indicators to practical use. There are various contributions by many researchers and organizations on this problem. The methodology on the criteria on the selecting of indicators is advanced thanks to Rice
and Rochet in 2005, Bockstaller and Girardin in 2003, Mendoza and Macoun in 1999, and so on. Especially, in the transport field, Zietsman and Rilett in 2002, Marsden in 2005 also got some useful achievement for the indicator selecting criteria. What’s more, Dale and Beyeler in 2001, Eyles and Furgal in 2002, OECD in 2003, Niemeijer and de Groot in 2008, Litman in 2011 revealed such accomplishment in the area of environmental, sustainability assessment, which is more deserving for this research to reference. These literatures showed different numbers and names of categories and criteria to their own field of studies, and of course some of criteria in different literatures are more or less the same. In this research, we are making contempt to find an appropriate system of criteria to evaluate whether a variable should be an indicator for the achievement efficiency of transport energy consumption.

For the third purpose, we review the literature that related to the efficiency evaluation. WBCSD in 2000 did research on eco-efficiency and suggested eco-efficiency brings together the two eco dimensions of economy and ecology to relate product or service value to environmental influence. In addition, it suggested the progress in eco-efficiency can be achieved by providing more value per unit of environmental influence or unit resource consumed, which is a good hint for calculation of efficiency to support this research, issues on the evaluation of the “achievement efficiency” of transport energy consumption of regions. Farrell in 1957 showed many theoretical methods to measure the productive efficiency and Charnes et al in 1978 measured the efficiency of decision making unit which is developed into an important mathematical methodology later on.

For practical application, D. Yoshino, A. Fujiwara, and J. Zhang in 2010 applied this methodology on energy efficiency evaluation among object regions based on the contribution by Ahmed in 2009. This innovation solves many difficulties on the inconvenience of other methodology. Besides, Senbil in 2005 and Feng in 2007 also did similar efficiency evaluations to get results. However, in these previous researches listed above, some problem remains unsolved. On the hypothesis of the affecting factors that result in energy consumption efficiency, no convincing evidence is shown for the reason of the variables selection. In the data envelopment analysis done for environmental efficiency analysis, the input and output variables are chosen subjectively by the
researchers in spite of the fact that huge differ probably occurs in the analysis result based on a different choice of variables. Moreover, at least whether the selected variables can indicate the evaluation object also has not been solved. As a result, the credibility of the quantitative result based on variables be selected at will is hard to say. This research intends to decide the variables for evaluation based on indicator criteria to ensure the correctness of this selection. There are some other improvements on the application of the methodology as well due to some reality in the transport sector, detailed illustration are intended to be shown in the chapters afterwards.

1.4 Research framework

This dissertation is made up of six chapters. The process and framework of the whole paper is shown in Fig.1-4.

This first chapter gives a brief introduction on the importance and significance of this research and presents the flow of the whole paper to show the backgrounds, points of issue and the purposes of the research.

Chapter 2 focuses on finding the key factors which contribute huge share to the change of the transport energy consumption. Decomposition analysis will be used for quantitative analysis, and the result will be laid out in detail on how much share each factor contributes to the total change of energy consumption. Policy proposals and suggestions will be given based on the result.

In the next chapter, the definition of indicator and the basic theory of indicator analysis are presented. The functions and applications of indicators will also be revealed in detail. After that, the criteria and methods for indicator assessment and selection are laid out in detail.

Chapter 4 applies the selection of indicators from candidates into the field of transport energy consumption achievement. In this chapter, the criteria of indicator selection will be applied on the domain of transport energy consumption for output variables of achievement efficiency. Furthermore, developed scoring system for indicator selection is also shown exactly.
Chapter 5 is the application of selected indicators on the issue of transport energy achievement efficiency evaluation. It will work on the selection of output variables for data envelopment analysis to make the analysis convincing. For the result, inefficient regions are picked up for proposing countermeasures for improvement.

Finally, Chapter 6 summarizes all the work and achievement done in this paper. Besides, we also give outlook to discuss the deficiency in this paper for this research to stretch on in the future.

![Fig.1-4 The framework of this research](image)
References


Sustainable Transport Indicators Subcommittee of the Transportation Research...
Board, 2008. Sustainable Transport Indicators—A Recommended Research Program For Developing Sustainable Transport Indicators and Data


Yoshino, D., Fujiwara, A., and Zhang, J. 2010. Environmental efficiency model based on data envelopment analysis and its application to environmentally sustainable transport policies, the 89th Annual meeting of the transportation research board CD-ROM


Zietsman J. and Rilett L.R., 2002. Sustainable Transportation: Conceptualization and Performance Measures. Research Report SWUTC/02/167403-1, Texas Transportation Institute, Univ. of Texas, Austin, USA, pp.163.
2. FACTOR DECOMPOSITION
ANALYSIS OF TRANSPORT
ENERGY CONSUMPTION
2.1 Introduction

In the last chapter, the achievement efficiency of transport energy consumption was defined to measure one aspect of the transport sustainability among various object regions. From the definition formula, we could see that in order to improve this efficiency mathematically, the first thing we should do is to study into the amount of the transport energy consumption and contempt to reduce it as much as possible. Therefore, we need to find out the interior reason for the tendency of the transport energy consumption. However, the reasons for the change of the energy consumption in the transport sector are sophisticated and hard to distinguish into factors at appearance completely. This is because the traffic demand, the energy efficiency, the kilometers in both passenger transport sector and freight transport sector are changing all the time. Furthermore, the breakdown of each means of transport has been varying continuously as well and also plays an important role. Among all the factors that possibly affect the energy consumption in the transport sector, ones which give positive and negative effect remain a problem. Moreover, the proportion these factors actually account separately need to be studied at the same time. In this case, quantitative research is necessary for the analyzing the factors and corresponding policy suggestions.

This chapter mainly identifies the factors behind the changes of energy consumptions in the transport sector during the recent decades in Japan and how much effect each factor contributes. For this purpose, we improve the method of decomposition analysis to make it suitable for the characteristic on the variety means of transport. The details of this method will be explained in the next section, while the result of the decomposition together with the analysis and policy suggestions will be given in the last section of this chapter.

As we stated before, the amount of energy consumption in the transport sector is affected by many factors such as the energy intensity of vehicles, travel distance and so on. Therefore, there is a certain relationship between the change of energy consumption and the changes of these factors mathematically. That is to say, the amount of change of each factor decides the amount of total change. Decomposition analysis mainly focuses on the decomposition of the change in total amount and distributes the change into the
effects of its factors under certain rules. Accordingly, in decomposition analysis, changes in an energy-related aggregate indicator of interest are decomposed and distributed among a number of pre-defined factors (Ang, B.W. et al. 2003). In this chapter, we decompose the energy consumption changes in the transport sector in Japan into some factors. The result will show the contribution by the each factor to the energy consumption. Based on the result, the policy-makers can find out the key factors and emphasize on the key factors' improvement, so the balance between the energy conservation and the economic development can be grasped.

Index decomposition methodology was used to study the impact of changes in product mix on industrial energy demand at first and now it is widely used not only in industrial fields but also in the environmental fields in general. It is first developed not long after the 1970s world oil crises and has continued to be studied until today with more and more papers presented every year (Ang, B.W. et al. 2000). It mainly deals with the issues whose total amount can be expressed by the factors multiplied together. Based on the number of studies reported, index decomposition analysis is now widely accepted as an analytical tool for policymaking on national energy and environmental issues (Ang, B.W., 2004). With the development of the method, a lot of mathematics algorithms are applied to the calculation of the decomposition. Scanning over the studies done by various researchers in recent years, we could find that the most widely used decomposition methods are apparently the Laspeyres method and the Divisia method, which are able to give decomposition results easily and reasonably. But the trouble these two initial methods may bring in is that a factor left unexplained always exists, and this unexplained factor could be beyond imagination and lead to improper results. Consequently, two other methods were developed separately to achieve perfect decomposition. Refined Laspeyres index method and Logarithmic mean Divisia index method do not left any factors unexplained. At present, most of the decomposition studies are based on these improved methods. In this section, we show the results of decomposing a three-factor case, for the sake of simplicity, by the two methods discussed by Ang, B.W et al. in 2003. Under the principle of these methods, the decomposition with more factors can be done in the similar way.
2.2 Methodology

In this section, we will explain the methodology of decomposition analysis, the basic thought of this method is to decompose the change of the total value into the effects by the change of factors that affect the total amount in order to find out how much effect each factor does by the share it accounts in the total change.

Assume that $V$ is the aggregate of interest and it is determined by three independent factors $x_1, x_2, x_3$, where $V = x_1 * x_2 * x_3$. Consider the problem studied temporally and discretely, we assume the absolute change in $V$ from year 0 to $T$, $\Delta V$, will be decomposed to give effects associated with factors $x_1, x_2, x_3$. We have

$$V^0 = x_1^0 * x_2^0 * x_3^0, V^T = x_1^T * x_2^T * x_3^T,$$

$$\Delta V = V^T - V^0 = x_1^T * x_2^T * x_3^T - x_1^0 * x_2^0 * x_3^0$$

The purpose of this decomposition is to evaluate the effects imposed on $V$ by each factor. That is to have $\Delta V_{x_1}, \Delta V_{x_2}, \Delta V_{x_3}$, calculated to separately show the changes of $V$ caused by factors $x_1, x_2, x_3$ respectively.

Note that $\Delta x_1 = x_1^T - x_1^0, \Delta x_2 = x_2^T - x_2^0, \Delta x_3 = x_3^T - x_3^0,$ therefore

$$\Delta V = (\Delta x_1 + x_1^0) * (\Delta x_2 + x_2^0) * (\Delta x_3 + x_3^0) - x_1^0 * x_2^0 * x_3^0 = \Delta x_1 * \Delta x_2 * \Delta x_3 + \Delta x_1 * \Delta x_2 * x_3^0 + \Delta x_2 * \Delta x_3 * x_1^0 + \Delta x_3 * \Delta x_2 * x_2^0 + x_1^0 * x_2^0 * \Delta x_3$$

According to the rule of the Refined Laspeyres index method, the item which has only one factor changed is obviously considers the effect is caused by the changed factor alone. The item which has two factors changed will be divided into two averagely and distributes each effect to the changed factors, and in the same manner, the item $\Delta x_1 * \Delta x_2 * x_3^0$ is to be divided into three parts averagely and each part is distributed to all the three factors.
The decomposition result of this three-factor case is as follows:

\[
\Delta V_{x_1} = \Delta x_1 \times x_1^0 \times x_3^0 + \frac{1}{2} \Delta x_1 \times \Delta x_2 \times x_3^0 + \frac{1}{2} \Delta x_1 \times x_2^0 \times \Delta x_3 + \frac{1}{3} \Delta x_1 \times \Delta x_2 \times \Delta x_3
\]

\[
\Delta V_{x_2} = x_1^0 \times \Delta x_2 \times x_3^0 + \frac{1}{2} \Delta x_1 \times \Delta x_2 \times x_3^0 + \frac{1}{2} x_1^0 \times \Delta x_2 \times \Delta x_3 + \frac{1}{3} \Delta x_1 \times \Delta x_2 \times \Delta x_3
\]

\[
\Delta V_{x_3} = x_1^0 \times x_2^0 \times \Delta x_3 + \frac{1}{2} x_1^0 \times \Delta x_2 \times \Delta x_3 + \frac{1}{2} \Delta x_1 \times x_2^0 \times \Delta x_3 + \frac{1}{3} \Delta x_1 \times \Delta x_2 \times \Delta x_3
\]

The Logarithmic mean Divisia index method also gives perfect decomposition as the refined Laspeyres index method. Here is the decomposition result of the refined Laspeyres index method.

\[
\Delta V_{x_1} = \ln \frac{x_1^T}{x_1^0} * L(V^T, V^0)
\]

\[
\Delta V_{x_2} = \ln \frac{x_2^T}{x_2^0} * L(V^T, V^0)
\]

\[
\Delta V_{x_3} = \ln \frac{x_3^T}{x_3^0} * L(V^T, V^0)
\]

In the expressions above, \( L(V^T, V^0) = \frac{V^T - V^0}{\ln V^T - \ln V^0} \), which represents the mean weight function defined as the logarithmic average of two positive numbers.

Moreover, the results of the decomposition can be achieved in two ways: the multiplicative decomposition and the additive decomposition. In the multiplicative decomposition, the change in an aggregate given as a ratio is decomposed, while in the additive decomposition, the change in an aggregate is decomposed in absolute changes (Ang, B.W. et al, 2003). These two ways have almost the same meaning basically, except that the additive decomposition can calculate the ratio of each factor occupied in the gross.

2.3 Applications

Now we come back to the issue this chapter is discussing. Generally speaking,
the energy consumption in transport sector is mainly related to the turnover of transport, the energy intensity of transport, the economic growth, the breakdown of each transport mode and so on. The factors chosen for the energy consumption decomposition should fulfill the following conditions:

1. The energy consumption can be decomposed by all the factors multiplied together;

2. All of the factors should be available for mathematical calculation;

3. The factors should make sense for the analysis and policy-making based on the calculation result.

First, we start with the multiply equation: \( E = O \cdot e \)

In this equation, \( E \) is the energy consumption in the transport sector; \( O \) is the turnover of transport (per capita kilometer in passenger transport and per ton kilometer in freight transport); \( e \) is the energy intensity in transport sector (energy consumption per turnover). It is noted, by Lakshmanan, T.R. et al. in 1997, that the passenger and the freight transport always show different characteristics and then we decide to do decomposition analysis in passenger transport and freight transport separately. In passenger transport, turnover \( O \) is decomposed into the number of trips and average travel distance; in freight transport, turnover \( O \) is decomposed into gross domestic product and transport intensity of gross domestic product. The data of all the factors for both the passenger and the freight transport are sufficient enough for calculation.

After that, we try to decompose the energy intensity \( e \): normally, the factors are always described as figures to be analyzed and calculated. However, the transport sector is made up from many kinds of transport vehicles such as trains, cars, airplanes and so on. The different vehicles have their own unique energy intensity so they cannot be integrated. To deal with this specialty, this research introduces vector variables into the field of factors. The vector variable factors appear in the shape of n-dimension row vector \( l \cdot n \) and n-dimension column vector \( n \cdot 1 \) to represent every means of transport to be studied. We decompose the energy intensity \( e \) into a \( l \cdot n \) vector variable \( e \) and an \( n \cdot 1 \) vector variable \( w \) for a collection of all the transport means. The meaning of \( w \) is the breakdown of turnover each transport sector accounts. The result that \( e \) multiplies \( w \) comes to the comprehensive energy intensity \( e \). (Lakshmanan, T.R. et al., 1997) also
used the vector variables for index decomposition methodology, however, they contributed all the expressions that include more than one factor change to the factor effect of interaction among other factors, which may lead to excessive unexplained factors and so is not considered as a perfect decomposition. In contrast, this research intends to decompose every expression to the end to thoroughly analyze the effect of each factor.

In this way, the decomposing equation is as follows:

\[
\begin{align*}
\text{Passenger transport: } E_P &= e^*w^*C^*L = \begin{bmatrix} e_r & e_c & e_s & e_p \end{bmatrix} \begin{bmatrix} W_r \\ W_c \\ W_s \\ W_p \end{bmatrix} \\
\text{Freight transport: } E_F &= e^*w^*G^*T = \begin{bmatrix} e_r & e_c & e_s & e_p \end{bmatrix} \begin{bmatrix} W_r \\ W_c \\ W_s \\ W_p \end{bmatrix} 
\end{align*}
\]

In the equation above, \( E_P \) is the total energy consumed in the passenger transport sector, and \( E_F \) is the total energy consumed in the freight transport sector. \( e \) is a vector made up of energy intensity elements with the dimension \( l*n \), where \( n \) is the number of modes in the transport sector, and \( w \) is a vector made up of mode share elements with the dimension \( n*l \), where \( n \) is the number of modes in the transport sector. \( C \) stands for the number of trips and \( L \) stands for the average distance of each trip. \( G \) stands for the gross domestic product in Japan, which is considered to directly affect the turnover of the freight transport, and \( T \) stands for transport intensity of the gross domestic product, which measures the synergetic effects of all the factors that are influencing the demand for freight transport. The result of the all the factors multiplied together leads to the energy consumption indeed. Therefore, the changes of the energy consumption in the transport sector can be deduced from the factors explained above as follows:

The mode energy intensity effect \( \Delta E_e \), reflects the effect of the change in the energy intensity of each transport mode. \( \Delta E_{eP}, \Delta E_{eF} \) represent the effect in passenger transport and freight transport, respectively.
The mode share effect \( \Delta E_w \), reflects the effect of the change in the breakdown of each transport mode (\( \Delta E_{wp} \), \( \Delta E_{wf} \) represent the effect in passenger transport and freight transport respectively).

The trip number effect \( \Delta E_c \), reflects the effect of the change in the trip numbers.

The trip distance effect \( \Delta E_L \), reflects the effect of the change in the average distance of each trip.

The GDP effect \( \Delta E_G \), reflects the effect of the change in the GDP of Japan.

The transport intensity of GDP effect \( \Delta E_T \), reflects the effect of the change in the transport intensity of GDP of Japan.

Therefore, the changes of the energy consumption in the passenger transport and the freight transport can be decomposed into the factors stated above:

\[
\Delta E_P = \Delta E_{ep} + \Delta E_{wp} + \Delta E_C + \Delta E_L,
\]

\[
\Delta E_F = \Delta E_{ef} + \Delta E_{wf} + \Delta E_G + \Delta E_T,
\]

The introduction of the vector variable makes it impossible to decompose the changes in the multiplicative decomposition, and the Logarithmic mean Divisia index method cannot be used as well, just because vector cannot be divided by another vector with the same dimension although the Logarithmic mean Divisia index method is robust and gives perfect decomposition very easily. In this case, we have no other choice than to use the refined Laspeyres method to decompose the changes in the additive decomposition. Note the precondition that vector variables also satisfy the condition: \((e+\Delta e) \cdot (w+\Delta w) = e \cdot w + e \cdot \Delta w + \Delta e \cdot w + \Delta w \cdot \Delta e\). In this case, to treat the vectors as normal figures in calculation and the refined Laspeyres method is suitable for the decomposition with vector factors all the same.

Here we lay out the universal solution to the Refined Laspeyres index method according to Shapely.L, in 1953:

From the year 0 to the year T, the effect of each factor is calculated through the
equation summarized below:

\[
\Delta E_x = \sum_{s=1}^{4} \frac{(s-1)!}{4!} \frac{(4-s)!}{4!} \sum_{s \in S, |S|=s} \left[ E(S) - E(S - x) \right]
\]

Here \( S \) is a set made up with some of the four factors and \( x \) is the one element in the set \( S \). \( E(S) \) is a function where the factor included in \( S \) uses the data in year \( T \), while for all the other factors use the data in year 0. \(|S|\) stands for the number of elements set \( S \) includes. \( S - x \) stands for the set \( S \) without its element \( x \).

2.4 Data and results

The data used in this research is from Statistics of EDMC Energy and Economy (2009) by The Energy Data and Modeling Center in Japan, and The statistics Data of Transportation (2009) by the Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry of Japan. Besides, the Japan Statistical Yearbook provides the data of GDP. As for the vector variables, according to the data provided, the dimension of the vector is set to four, indicating the transport means of road transport, railway transport, ship transport and air transport for both the passenger transport and the freight transport.

With the original data supplied for every year recently, we could find that the data figures are continuous without obvious fluctuations. So it is feasible to pick up any groups of data from these years for the analysis and there is no need to worry about essentially revising the results due to some special data in the database. In this research, we use ten years as one period and inspect three periods from the year 1975 to 2005, with which we trace back to the years of the oil crisis till recent years. Therefore, we pick up the data of the years 1975, 1985, 1995 and 2005 to do a three-period decomposition analysis. All the data picked up are shown as figures as follows:
Energy Consumption of Transport Sectors in Japan (unit: $10^{10}$ kcal)

**Fig. 2-1** The energy consumption of transport sectors in Japan

The energy intensity of passenger transportation
unit: kcal/(cap.km)

**Fig. 2-2** The energy intensity of passenger transport in Japan
Fig. 2-3 Number of passengers in Japan

Fig. 2-4 Average distance of each passenger in Japan
Fig. 2-5 Proportion of passenger transport mode in Japan

Fig. 2-6 The energy intensity of freight transport in Japan
Fig. 2-7 GDP in Japan

Fig. 2-8 Transport intensity of GDP in Japan
From the data selected, we can get some intuitive image and the trends of data can be described as follows: The turnover breakdown of car and airplane are increasing gradually both in the passenger and the freight transport sector all the periods. On the other hand, the turnover breakdown of railway and ship are decreasing as the time going on both in the passenger and the freight transport sector. The GDP and the number of trips are also increasing year by year, and at the same time, the average trip distance is vibrated and the GDP intensity keeps going down. Despite the report of the improving fuel efficiency in vehicles year by year, the energy intensity does not show decreasing trend in all means of transport across the period, which is more or less beyond the ordinary opinion of people. The energy intensity of airplane is decreasing all the time but the other three transport means do not have any clear trend of the change in energy intensity. In particular, the energy intensity of car and ship in passenger transport become much higher in the year 2005 than that in the year 1995. Maybe the popularization of high-emission vehicles consumes much energy in spite of the enhancing of the fuel efficiency can explain this fact.

The decomposition result based on the refined Laspeyres method is shown by the effect of every factor and every period studied as shown in Tab.2-1. The percentages each factor occupies are also shown for convenience to read and analyze.
Tab.2-1 Decomposition result of energy consumption in the transport sector in Japan
(Unit of the energy consumption amount: \(10^{10}\) kcal)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>Amount</td>
<td>Percentage</td>
<td>Amount</td>
<td>Percentage</td>
<td>Amount</td>
<td>Percentage</td>
</tr>
<tr>
<td>Effect of mode energy intensity ((\Delta E_{eP}))</td>
<td>1488</td>
<td>11.8</td>
<td>-6475</td>
<td>-23.3</td>
<td>3046</td>
<td>74.8</td>
</tr>
<tr>
<td>Effect of mode share ((\Delta E_{wP}))</td>
<td>3321</td>
<td>26.4</td>
<td>5755</td>
<td>20.7</td>
<td>766</td>
<td>18.8</td>
</tr>
<tr>
<td>Effect of trip number ((\Delta E_c))</td>
<td>4396</td>
<td>34.9</td>
<td>19346</td>
<td>69.7</td>
<td>2663</td>
<td>65.4</td>
</tr>
<tr>
<td>Effect of trip distance ((\Delta E_l))</td>
<td>1006</td>
<td>8.0</td>
<td>1550</td>
<td>5.6</td>
<td>-1703</td>
<td>-41.8</td>
</tr>
<tr>
<td>Changes in passenger transport energy consumption ((\Delta E_p))</td>
<td>10211</td>
<td>81.1</td>
<td>20176</td>
<td>72.7</td>
<td>4772</td>
<td>117.2</td>
</tr>
<tr>
<td>Effect of mode energy intensity ((\Delta E_{eF}))</td>
<td>-7343</td>
<td>-58.4</td>
<td>-1613</td>
<td>-5.8</td>
<td>-3691</td>
<td>-90.7</td>
</tr>
<tr>
<td>Effect of mode share ((\Delta E_{wF}))</td>
<td>5064</td>
<td>40.2</td>
<td>2213</td>
<td>8.0</td>
<td>2304</td>
<td>56.6</td>
</tr>
<tr>
<td>Effect of GDP ((\Delta E_G))</td>
<td>24819</td>
<td>197.2</td>
<td>7564</td>
<td>27.2</td>
<td>3686</td>
<td>90.6</td>
</tr>
<tr>
<td>Changes in freight transport energy consumption ((\Delta E_F))</td>
<td>2373</td>
<td>18.9</td>
<td>7584</td>
<td>27.3</td>
<td>-702</td>
<td>-17.2</td>
</tr>
<tr>
<td>Changes in total transport energy consumption ((\Delta E))</td>
<td>12584</td>
<td>100.0</td>
<td>27760</td>
<td>100.0</td>
<td>4070</td>
<td>100.0</td>
</tr>
</tbody>
</table>

From the result of the decomposition, it is easy to find that the passenger transport energy consumption accounts more in total energy consumption. Furthermore,
most of the factors analyzed in the passenger transport sector were driving up the total energy consumption across these years. In the freight transport, some factors give positive effects to the energy consumption and others give negative. Then we discuss all the contributing factors one by one in detail as follows. For convenience of discussion, we call the period 1975-1985 as Period 1 and the period 1985-1995 and 1995-2005 are called Period 2 and Period 3 respectively.

The effect of trip number occupies a large proportion among the factors at any time. In Period 1, it contributes 43960 trillion calories to the energy consumption, the largest share in the passenger transport energy consumption. In Period 2, its contribution surges into 193460 trillion calories, 4 times greater than Period 1. Not only in the passenger transport energy consumption, but also in the total transport energy consumption, it is the principal factor which is much larger than the second largest effect. In Period 3, although the breakdown is still large, it is not prevailing anymore and the absolute value calms down. From the decomposition analysis, we can find that the trip number in passenger transport is the factor which effectively affects the energy consumption in the transport sector in all the three periods. It seems that Japanese people highly care for traveling in these years and something has to be done, in the case the energy consumption in the transport sector should be reduced.

In contrast, the factor of average trip distance does not have much impact on the passenger transport. It accounts for 8.0% and 5.6% of the total in Period 1 and 2 respectively, which are the slightest impact among the factors in passenger transport. In Period 3, it impact on the energy consumption became further smaller. The average trip distance increased in Period 1 and Period 2 and decreased in Period 3, but the range of the change remains stable.

The decomposition of energy consumption in the freight transport found the impact of the GDP factor enormous. In Period 1, which considered with the final stage of the high-speed growth of Japan’s economy, the GDP grew significantly and greatly promoted the development of transport meanwhile stimulated the energy consumption naturally. Its contribution is almost twice the amount of change in transport energy consumption. In Period 2, the speed of economic growth slowed down but the effect remained positive, and it contributes 27.2% of the change in transport energy
consumption where the whole contribution done by freight transport is only 27.3%. So it still plays an important role on the energy consumption. Period 2 and 3 are the period with moderate-speed growth of Japan’s economy. The absolute contribution by GDP in Period 3 decreased to half of that in Period 2, but the share climbed to 90.6%, and remained the dominant factor. It can be seen that the relationship between the GDP and the development of freight transport is very strong.

On the other hand, transport intensity of GDP always contributes negative impact to the energy consumption. The trend of its share is opposite to GDP’s contribution: in Period 1, the percentage of its contribution reached -160.1%, the most negative factor of all; and in Period 2, it climbed up to -2.1%, however, it returned to -73.7% in Period 3 and retained its significant impact on the decrease of energy consumption. As explained in the previous section, transport intensity of GDP is a synergetic factor which contains all factors influencing the demand for the freight transport. It is the supplement for the factor of GDP on the demand of freight transport.

The analysis in this research emphasizes the effect of factors in vector form in decomposition result, i.e. the effect of mode energy intensity and transport mode share. The effect of mode energy intensity greatly varied from Period 1 to 3, and between the passenger transport sector and the freight transport sector. This proves that it really shows the different characteristics between the passenger transport sector and the freight transport sector and it is right to discuss them separately. In the passenger transport sector, the effect of mode energy intensity contributes 11.8% of the total in Period 1. The increased energy intensity is that of cars’, despite the decreased intensity of ship and airplane. The energy intensity increases the energy consumption. In Period 2, the effect of mode energy intensity contributes -23.3% of the total, mainly due to the improvement of the energy intensity of car. The effect of mode energy intensity recovers in Period 3 to 74.8% and this should be attributed to the increasing energy intensity of car and ship. From the point of absolute amount, the largest change occurs in Period 2, where the change of car’s energy intensity is also the largest. The improvement of airplane’s energy intensity hardly affects, because its breakdown of turnover is very small. The railway’s breakdown of turnover is not small but the energy intensity remains same along these periods, so to change the car’s energy intensity is the key to
control the change of energy consumption caused by the energy intensity in the passenger transport sector. In the freight transport sector, the effects in three periods are all negative, and the effect is not driven only by the car’s energy intensity. Particularly in Period 2, the car’s energy intensity increased a little but the effect is still negative, because there is a great improvement on the energy intensity of the railway and ship. But we have to admit that the breakdown of cars in the freight transport is rather high, so the change of the car’s energy intensity is still in the prevailing position in affecting the absolute amount of the energy consumption’s change. Although the energy intensity of the airplane is high, the breakdown is too little to affect the result. The effect of improving the energy intensity of railway and ship is limited, too.

The analysis of the factor of mode share mainly inspects how the ways of transport structure affects the energy consumption. It is a pity that we find in all the three periods at both the passenger transport sector and the freight transport sector, the effect of mode share contributes positive amount of energy consumptions. Therefore, the structure is changing all the way adversely to the reduction of energy consumptions. Comparing with the initial data and the decomposition results, it can be concluded that the increase of the car’s breakdown is the main reason for the increase of the energy consumption. The passenger transport sector in Period 2 and the freight transport sector in Period 1 are where the surge of car’s breakdown and the eminent increase of the absolute amount occur. Therefore, in this analysis, the breakdown of car in the means of transport expresses the characteristic of the mode share affect most of all.

2.5 Policy implications

The transport sector is one of the principal sources of energy consumption. Its contribution to the energy consumption increased constantly during the last few decades and is estimated to grow continually in the near future. Therefore we should pay more attention to controlling energy consumption in the transport sector. To inhibit the development of transport is a direct and valid method, but is apparently far from our real intention and will shock the economy heavily at the same time. The key point is to find a balance between the energy consumption and the economic development so that we
can keep the sustainability of resource and the economic growth at the same time.

In this chapter, we decompose the change of energy consumption into the effects of several factors by the method of decomposition analysis with vectors. According to the result, it is found that the effect of trip number and the effect of GDP are the most influential effects to the energy consumption in both the passenger transport sector and the freight transport sector. It is a clear conclusion that the effect of the mode share is always giving positive contribution in both the passenger transport sector and the freight transport sector. The effect of energy intensity gives irregular contribution across all over the periods. The effect of average trip distance is small but not trivial. In the end, the decomposition result shows that there is no doubt that the passenger transport and the freight transport really have different characteristics about energy consumption. The policy implications are as follows.

Firstly, the reduction of energy intensity is the fundamental method to control energy consumption in the transport sector. In the freight transport sector, the intensity is decreasing and becoming the least factor to contribute to energy consumption, on the other hand, in the passenger transport sector, the effect of energy intensity is getting worse. Comparing the initial data and the decomposition result, we found out the energy intensity of passenger cars is the largest factor for energy consumption. Therefore, it is effective to reduce the energy intensity of passenger cars. Recently, more and more people buy cars for their own use and there is a surge of ownership of cars. From the view point of energy saving in the long run, it is suggested that car owners should use environmental cars. Environmental cars are consuming less energy than conventional cars with the reduced energy intensity, or can run on new type energy. The policy the government should emphasize is the one to encourage the use of environmental cars. The Japanese government is giving allowance for the purchase of environmental car right at the moment it is necessary to promote environmental cars’ market share. Besides, the government restricts the sales of the cars with less fuel efficiency by means of administrative force. Furthermore, in some of the environmental model cities set up by the government, environmental public vehicles are running instead of the conventional ones.

Secondly, the effect of the transport mode share always brought positive
influence during the periods analyzed. It is the very factor which should be regulated. It seems that the structure of the transport sector is becoming more and more unreasonable from the viewpoint of reducing energy consumption. Examining the data of the transport mode share in recent years, we found that the breakdown of the turnover by cars went higher and higher, consuming more energy per transport amount unit than the other transport means. In order to reduce energy consumption, there is no doubt policies should encourage other transport means than cars, such as railway, bicycle and others which consume less energy. Japan has built extensive railway and subway systems in major cities, supplying punctual, inexpensive and comfortable services to the citizens for travelling, but as to the long distance trip across the country, especially the trip for which the Shinkansen is not available, people are tend to use cars or high-speed bus because they are more convenient. It is recommended for JR companies to offer new train service plans for long journey across the nation based on the conventional railway lines. With the advantage of cheap price, punctuality and reliability, this new rail way service will attract many passengers who would otherwise travel by their own cars or high-speed bus. Besides, the Shinkansen or other railway lines can be further developed for freight transport, which can release the high energy intensity trucks carrying cargos from their work. Still more, the encouragement on riding bicycles and walking is also important. The policy could focus on creating bicycle parking lots, the bicycle lanes and rental-bicycle centers. Meantime, the government should try to advocate the healthy life style by riding bicycles or walking via Medias.

With the rapid construction of the transport facilities and the growth of communications among people around the country, the turnovers of both the passenger and freight transport will keep growing into the future and be of great importance to the financial benefit of the country. Besides, GDP has the biggest impact on the energy consumption in the freight transport sector. It is found that the amount of GDP and the freight turnovers are in direct proportion with each other. That is to say, GDP is the dominant factor which affects freight turnovers deeply. As for the energy consumption, it may be no exaggeration to say that GDP is also the dominant factor in energy consumption on basis of the decomposition result. By the way, the GDP in Japan had grown rapidly in the past and has been stable in recent years, and is estimated to stay so
in the near future. It is apparently unwise to restrict the development of the GDP growth or trip number just for the purpose of controlling the energy consumption in the transport sector. The policy implication for the government is to pay much attention to the sustainable development of economy with proper energy consumption.

Finally, the result shows that the effect of average trip distance is decreasing although the trip number is very large. Perhaps it is because in many cases the travel purpose can be easily satisfied in the short distance for the travelers all over the country. It is suggested that the government encourage people to work at home or a place nearby, and build convenient centers around the residential areas to satisfy the residents' needs. It is already taken into consideration in city planning for the future. Besides, there is an indirect way to develop and widely apply the technology of logistics to the freight transport, in order to reduce the empty miles by trucks and the average trip distance at the same time.

2.6 Summary

In this chapter, we introduced decomposition analysis to solve the problem on the importance of each factor on their contribution to the change of transport energy consumption. In order to reveal the variety of means of transport, we introduced the vector variable to analyze the effect of transport mode share, which will lead to the importance on converting ways of transport. And to fit the general knowledge, we analyzed the passenger transport and freight transport respectively for the policy implications each. As a result, we found that average trip distance contributes most to the change of energy consumption on the passenger transport and GDP contributes most to the change of energy consumption on the freight transport after the calculation of data in Japan. Corresponding suggestions were given based on the whole result.
References


3. INDICATOR AND ITS CRITERIA FOR SELECTION
3.1 The concept of indicator

In order to find the variables that properly indicate the phenomenon of the achievement efficiency in transport energy consumption, the theory of indicator analysis should be studied for finding the reasonable indicators for the issue. In the last decade, the development of the research on indicators at the national, regional, local or the field level, has become a commonly approach to meet the crucial need for assessment tools, which are a prerequisite to the implementation of the concept of sustainability and especially its environmental component (Hansen, 1996). The concept of indicator should be specified so that the necessity for the introduction of indicator related analysis could be explained. Here the literatures concerning the concept of indicator are to be reviewed to provide a brief explanation of indicators, and to establish a practical definition intended to be used in this paper.

The word 'indicator' is obviously be defined as something that indicates some phenomenon. For scientific research report, there are many literatures in many fields to define indicators in many ways. Here are some examples:

- A substance (as litmus) used to show visually (as by change of color) the condition of a solution with respect to presence of a particular material (such as a free acid or alkali) (Webster's dictionary).
- An organism or ecological community so strictly associated with particular environmental conditions that its presence is indicative of the existence of these conditions (Webster's dictionary).
- Whose presence is directly related to a particular quality in its environment at a given location (McGraw-Hill Encyclopedia of Science and Technology).
- Any of a group of statistical values (such as level of employment) that taken together give an indication of the health of the economy (Webster's dictionary).
- A variable that is directly associated with a latent variable, such that difference in the values of the latent variable mirror difference in the values of the indicator (Bollen, 2001).
• A common term used to refer to the variables that we use to detect concepts empirically (Bollen, 2001).

• At a more concrete level, indicators are variables (not "values", as they are sometimes called). A variable is an operational representation of an attribute (quality, characteristic, property) of a system (Gallopin, 1996, 1997).

• A variable selected and defined to measure progress towards an objective (Gudmundsson, 2001)

In summary, an indicator can be generally understood to be a tool or a method which can be used to mirror or measure something in a way that adequately represents what is being measured. By the way, these general definitions are often defined with respect to different measures based on different scientific domains. As to the application of indicator analysis on the domain of transport energy consumption, particular and detailed analysis will be given in the next chapter.

3.2 The function of indicator

Indicators have a number of functions regard to various domains of scientific research, such as measurement, policy, plan, programme and project assessment, or public debates (Joumard and Gudmundsson, 2010). It is necessary to grasp the functions of indicator for the practical research of indicating the achievement efficiency in transport energy consumption. Generally speaking, the function of indicator has two sets of distinctions: measurement function and policy/decision-making function.

3.2.1 Measurement function of indicators

According to one of the definition of indicator "a variable representing a phenomenon", one function of indicator can be given that measures a phenomenon. There are three aspects of measurement to be cleared: (Joumard and Gudmundsson, 2010).

• What should be measured?
The first step of evaluation of indicator is to describe in detail on what has to be evaluated. Ordinarily, indicators have to be agreed and discussed at the end by the stakeholders for evaluation, and usually measure large range of problem such as some effect, some phenomenon, and some change that appears obviously in the world. At the same time, some human activity concerned or considered is also the object for measurement of indicators.

- Why is it necessary to measure?

This question is equivalently to ask why it is necessary to do indicator analysis rather than analyze the impact itself. That depends on what we concentrate on, the impact itself or the reason of the impact. It is important to know who is interested for the answer of the analysis. For the latter one, we have to grasp the reason for parameters to explain the change of the impact, and be understood for reasoning the problem.

- How to measure?

On the problem of how the indicators conduct the measurement on the phenomenon, here we only discuss the measurement of quantitative calculation method indicators can be applied on. Indicators are supposed to measure the phenomenon accurately, proportionally and properly on quantitative analysis. They mainly measure by finding proper models and variables for practical issues. When the phenomenon is complex to be measured, indicators can introduce the full process on modeling taking into account as far as possible all the influencing parameters of the process for indirectly measurable problems.

The advantage of quantitative analysis is to reduce the uncertainties quality analysis brings in. For the accuracy of quantitative analysis, evidence is needed to state the reasonability on the calculation result. Selection of a set of convincing indicators is just for this purpose.

3.2.2 Policy-implication function of indicators

Most research being done nowadays is focusing on the practical significance. There is no exception for this research as well. The ultimate purpose for quantitative
analysis for practical research is planned to lead to policy implications for
decision-makers. This is a very important function of indicators.

Briguglio (2003) summarized the functions of indicators for policy implications
as follows: Indicators are analyzed to support decision-making, to set targets and
establish standards, to disseminate information, to focus the discussion, to promote the
idea of integrated action, to monitor and evaluate developments and so on. By means of
indicator analysis, we expect to find out during the procedure of the phenomenon, what
is important, how we are doing, what is wrong, who is to blame, how we can improve.
And this will make the analysis sensitive.

3.3 The criteria of selecting indicators

3.3.1 Overview of literatures for selecting criteria

As stated in the last section, indicators have many useful functions to help
measuring proper phenomenon. However, how to identify appropriate indicators from
possible candidate indicators remains a problem. This section will summarize the
criteria to select proper indicators for specific domain of quantitative analysis. By the
way, the word ‘criteria’ here refers to the general notion of a principle, or a standard on
which a judgment may be used.

In fact, criteria for indicator selection are driven by the problem that indicators
are supposed to solve. Here, we just build the universal framework for the criteria and
apply it for particular use on problems in detail.

Indicators are widely used in most fields of researches and the criteria for
indicators selection are developing particularly advanced year by year. Many
organizations like OECD, WTO and NCHOD decided the criteria for indicator
selections on their own field. However, scan over the lists of criteria for use in the
selection of indicators, the number of criteria varies from 4 to over 30. Some criteria are
well mentioned across many fields while some other only applied on specific field. It is
not so common to find it in detail to reveal how indicators are accessed and selected by
such criteria.

There is not totally agreed in all the corresponding literatures for criteria that are needed to sufficiently assess indicators, each reference keeps its own lists criteria despite of the existence of the redundancy and overlaps over criteria. The categories for criteria are analyzed in the following section.

3.3.2 Categories and their criteria of indicators selection

There are such a number of differences among the literatures for the indicators on indicators selection. However, the categories of the criteria are more or less the same across different fields of research. They are classified into three levels of categories for three groups of indicator functions as in Fig.3-1 (Joumard and Gudmundsson, 2010).

![Fig.3-1 Tentative linkage of criteria to categories](image)

**Management:**
- Policy relevance
- Usefulness
- Connected threshold
- Relevance to objectives
- Comparability across jurisdictions
- Linkable to economic models etc.

**Monitoring:**
- Measurability
- Quantifiability
- Applicability
- Ease of handling
- Data availability
- Integrativity
- Accessibility
- Understandability
- Ethical acceptability

**Measurement:**
- Validity
- Reliability
- Sensitivity
- Specificity
- Representativity

Level 1: Indicators treated as units measuring particular system properties or
endpoints (Cryer et al., 2002). The criteria for level 1 should emphasis on the basic requirements of accurate quantitative analysis regardless of practical issues or policy concerns. The key point in this level is the accuracy for methodology.

Level 2: Indicators considered as reporting units in monitoring programmes (Strobel, 2000). The criteria for level 2 involve concerns if indicators are to be actually used for reporting. Meanwhile, the measurements of indicators of practice, the availability of data are also important. The key point in this level is to make sense from the analytic point of view.

Level 3: Indicators treated as decision making units in policy or management strategies (van der Loop, 2006). The criteria for level 3 are lead to practical applicant for decision making, which related to the possibility of interpretation, transparency to provide legitimacy of the information, relations to policy or management objectives. It can draw implications for action, which is the key point in this level.

In other words, the criteria on level 1 can be considered to be basic level criteria that always to be considered if indicators are to be accepted from a scientific point of view, while systematic application of criteria on level 2 or 3 must be added in case indicators are have to used in monitoring or decision support or management respectively.

After three categories are classified for the indicator criteria selection in detail, it is convenient for overview the criteria selection literatures. We use these review to look at which criteria are most frequently mentioned in the reviews and to see if some criteria are generally considered as more fundamental or important than others, redundancy and overlaps between criteria should also be noticed in the selection.

3.3.3 The list of criteria selected for indicators

Given the importance and necessity for doing indicator analysis, the next problem is how to determine which factor can be one of the indicators to do further analysis. According to the reference the criteria of indicator selecting can be defined as follows as most researchers agreed. We also believe that the three categories with ten criteria are the most reasonable ones as follows at the moment. Notice it should be kept in mind that the criteria are only forming a list, and not yet be considered in the context
of a procedure for application. (Journard and Gudmundsson, 2010)

1. **Validity.** A valid indicator must actually measure the issue or factor it is supposed to measure (WHO, 2006). A valid indicator must be based on a conceptual model justifies how the indicator and the issue are causally connected. The model should fit the scientific community in the particular field very well. It is a basic requirement for an indicator that it makes no sense for one without conceptual validity, which could mislead the analysis result.

2. **Reliability.** A reliable indicator must give the same value if its measurement were repeated in the same way on the same population and at almost the same time (WHO, 2006). It means the achievement of information for the phenomenon should be repeatable. Same result should be obtained even by different operators when operating the indicator many times. This criterion is particularly important when obtaining data for quantitative analysis.

3. **Sensitivity.** A sensitive indicator must be able to reveal important changes in the factor of interest (WHO, 2006). Indicators should generally react clearly and promptly to significant changes in the phenomenon being indicated. For statistics variables, the data should be meaningful and identify the phenomenon quite well.

4. **Measurability.** A measurable indicator should be straightforward and relatively inexpensive to measure (Dale and Beyeler, 2001). It is important that indicator can be measured or calculated using easy tools and using simple data that are easily achievable and at a raw level (Goger et al, 2009). It is a criterion of the category in operation. Simple indicators are always considered to be more measurable than that combined by many others. For example, support rate for some policy is more measurable than average opinion on the policy.

5. **Data availability.** Data available indicators are indicators based on input data that should be readily available or made available at reasonable cost and time (OECD, 2003). The data should be accurate, comparable over time,
complete with historical information and covering sufficient geographic area (Boyle, 1998). It is especially important for calculation of quantitative analysis. If key data are not available, calculations cannot be done, let alone the analysis by operating the indicator for the phenomenon.

6. Ethical concerns. An indicator must comply with fundamental human rights and require only data that are consistent with morals, beliefs or values of the population (WHO, 2006). This is to ensure that no human right is violated during the acquisition of some information to operate the indicator. It is usually applied on survey or questionnaire to investigate some personal information. Privacy or other ethical concerns should not be violated during data collection.

7. Transparency. A transparent indicator is one which is feasible to understand and possible to reproduce for intended users. This means an indicator must describe in an understandable way on how the indicator is constructed. The source of the origin for the data of indicator should also be opened to readers to check the calculation. It would be more attractive for readers to know the procedure of the way indicator produced.

8. Interpretability. An interpretable indicator allows an intuitive and unambiguous reading. Indicator should be clearly understood that whether it is a positive variable or a negative variable. For example, energy consumption, number of traffic accidents are the less the better while the turnover of the transport could be easily understood for it is the more the better. On the other hand, at the field of sustainability, it is ambiguous whether the speed of vehicle is a positive variable because the emission by the vehicle and the speed of vehicle do not act synchronously.

9. Target relevance. A target relevant indicator must measure performance with regard to articulated goals objectives, targets or thresholds. This criterion means that the selection of indicator should meet the need of the objective and goal for the phenomenon analysis. Indicators that do not or cannot measure performance with regard to any goals or targets are less supportive of management and decision making function of indicators.
10. **Actionability.** An actionable indicator is one which measure factors that can be changed or influenced directly by management or policy action. Actionability refers to the role of indicators as tools to support decisions and management. The point of actionability is that follow-on action to the indicator should be immediately apparent (WHO, 2006).

### 3.4 The framework of selecting indicators

In this section, the way of how criteria stated in the last section are applied for assessing and developing indicators. Generally speaking, some candidate indicators are proposed at first, and evaluate them under the summarized criteria. Finally, the candidate indicators with high evaluations are considered to be the formal indicators.

Rice and Rochet in 2005 drew out the framework for selecting indicators as follows is one of the most detailed reports of approaches to the selection of indicators.

1. Determine user needs
2. Develop a list of candidate indicators
3. Determine screening criteria
4. Score indicators against criteria
5. Summarize scoring results
6. Decide how many indicators are needed
7. Make final selection
8. Report on the suite of indicators

We would like to follow these steps to find proper indicators for the issue in this research. Among all the steps, the way of scoring the indicator candidates is the key step and of the most importance which should be clarified in detail.

Here we introduce a 5-level evaluation system to score the degree that each indicator candidate satisfies the criterion. If the indicator candidate under evaluation satisfies the criterion excellently, it will get 9 points; and if the indicator candidate under evaluation satisfies the criterion well, it will get 7 points; and so on, fairly candidate will get 5 points, limited candidate will get 3 points, and finally, the candidates satisfies the criterion poorly will only get 1 point. By the way, intermediate evaluation is also
acceptable between adjacent levels when necessary, and at the same time, the point of 2, 4, 6, 8 could be given as its evaluation for the fitness of the candidate. After all the candidates get their points respectively for each criterion, we summarize the points together and ranking the total points of each, the candidates with more points are tend to be considered as more appropriate indicators.

The process of giving points to the candidate indicators is subjective: different deciders may give different evaluations base on their own opinion regardless of the same occasion. But we still consider this method effective because what we want to get from the evaluation scores is the ranking of each candidate among all ones, rather than the absolute total score. Therefore it doesn’t matter whether we give scores from 1 to 9 or other evaluation systems such as the 1, 2, 3, 4, 5 points evaluation system. As long as the deciders scoring the points under the criterion strictly and with his same opinion impartially, the ranking of the candidates will be the same. By the way, small margins of total scores between candidates will be considered at the same level on the probability of the candidates be chosen, for the slight differences on scoring should be thought over.


Briguglio L., 2003. The Usefulness of Sustainability Indicators. Symposium ‘Sustainability Indicators for Malta’, Valletta, Malta.


NCHOD, 2005. Compendium of Clinical and Health Indicators User Guide. National Centre for Health Out-comes Development (NCHOD), London School of Hygiene and Tropical Medicine, London.


Sustainable Transport Indicators Subcommittee of the Transportation Research Board, 2008. Sustainable Transport Indicators—A Recommended Research Program For Developing Sustainable Transport Indicators and Data


4. INDICATOR SELECTION FOR THE OUTPUT VARIABLES OF ACHIEVEMENT EFFICIENCY IN TRANSPORT ENERGY CONSUMPTION
4.1 Indicators for environmental, sustainable transport

This research focused on the issue of transport energy consumption efficiency. It could be considered as a branch of environmental, sustainable research which is applied on the domain of transport. In order to find out proper indicators for the output of transport energy consumption based on the criteria in the last section, review should be done on the research for indicator analysis, specialists of indicator analysis defined the application on the domain of environmental, sustainable transport in particular in many ways from different angles. Here are some examples among the literature.

Environmental indicators:

- A parameter- or a value derived from parameters- which points to, provides information about, or describe the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value (OECD, 2003).
- A numerical value derived from actual measurements of a pressure, ambient condition, exposure, or human health or ecological condition in a specified geographic domain, whose trends over time represent or draw attention to underlying trends in the condition of the environment (USEPA, 2006).
- A parameter- or a value derived from parameters- that describe the state of the environment and its impact on human beings, ecosystems and materials, the pressures on the environment, the driving forces, and the responses steering that system. An indicator is established through a selection and/or aggregation process to enable it to steer action (EEA, 2009).

Sustainability indicators:

- Reflect the reproducibility of the way a given society utilizes its environment (Opschoor and Reinders, 1991).
Quantitative measures of human wellbeing, economic activity, and natural processes and conditions, needed to sense the degree to which human activity may continue or expand in the future (Lee, 2001).

Statistical measures that give an indication of the sustainability of social, environmental and economic development (OECD, 2005).

Sustainable transport indicators:

- Selected, targeted, and compressed variables that reflect public concerns and are of use to decision-makers (Gilbert et al, 2002)

- Regularly updated performance measures that help transport planners and managers to take into account the full range of economic, social and environmental impacts of their decisions (Lee et al, 2003)

- General principles regarding indicators in any urban mobility system: Indicators should support the decision-making capacity, in particular enabling proactive action to correct the performance path of a specific element or agent whenever signs of potential underperformance are identified... (Macario, 2005)

- A forecastable, quantifiable variable, usually with target value representing an objective, which symbolizes environmental or other impacts of transport infrastructure plans. (Fernandez, 2009)

In general, these definitions mainly focus on the indicator function of representation, and are much focused on objectives, plans, policies, measures, rather than simple implication. The definition also emphasize on the context of decision making. Here, the definition of indicator on environmental sustainability in transport given by Joumard and Gudmundsson in 2010 is adopted in this research for the selection of indicators on the output of transport energy consumption: An indicator of environmental sustainability in transport is a variable, based on measurements, which represents potential or actual impacts due to environmental transport as accurately and necessary.
4.2 Candidate indicators on the output variables of this issue

There are many literatures involving the issue for environmental, sustainable transport or other fields which connected with the issue of transport energy consumption. The variables usually mentioned in the literatures, which are the classical statistics, should be emphasized for investigated on whether they are proper to be the output of transport energy consumption. As the input variable, which is represented by total energy consumption in transport sector, is not divided by capita, the output variable will also be represented by the variables which are not divided by capita, but the total amount.

These variables of statistics are always expressed by passenger transport and freight transport respectively, for they behave differently on the phenomenon of transport. At the same time, the data of private transport and public transport in a city are also collected respectively, for they undertake different responsibilities of urban transport. Besides, for the very issue being discussed in this research, private transport contributes more to the energy consumption because vehicles supporting private transport are more possible to be high energy consuming vehicles than that of public transport. These facts should also be taken into consideration for indicator selection.

Output variables for transport energy consumption achievement can be divided into two groups: direct output variables and indirect output variables. They are listed and stated as follows.

4.2.1 Direct variables indicate the output of transport energy consumption achievement
Direct variables for the output of transport energy consumption achievement refer to the variables which can directly express the achievement in the transport activity while consuming energy. Main statistics variables can be listed as follows:

**V.K.T.:** Abbreviation of Vehicle Kilometers Travelled. This variable reports is the total in kilometers travelled by motor vehicles on any particular road systems during a given period of time. VKT is a widely used international proxy for the pressures of road transport on the environment, and also can be used to measure the phenomenon of transport safety and human health from another point of view sometimes. It is a variable focuses on the issue of road transport both for passengers and cargos. It is an output variable that satisfies the more the better, so there is no need to deal with the data for the calculation of efficiency if selected.

**Passenger kilometers in public transport:** It is calculated by dividing total distance travelled, in kilometers, in a given period, by the number of passengers in public system of transportation. It is also a basic unit used by transport department for calculating profit levels etc. Public transport system plays an important role on carrying a large number of passengers to destinations, sharing responsibilities of the burden by road vehicles. ‘Passenger kilometers’ is also an important variable to evaluate the transportation capacity and achievement. It is also an output variable that satisfies the more the better.

**Average trip length:** It represents the average distance each trip travels. It can reveal the achievement of consumed energy to a certain extent because it is affected by the number of trips. This variable is always used to measure the mode of transport in one region for it can reveal the distance of travel number for passengers. It is also an output variable that the more the better.

**Average speed of vehicle:** This variable measures the velocity and fluency for the vehicles in the region. High velocity of vehicles can be considered to be a symbol of convenient region of communication. Furthermore, the energy consumption has something to do with the speed of vehicle. In the same distance, the energy consumption can be much different due to different speeds of the same vehicle. It is not clear whether absolutely better if the speed is high on the issue of energy consumption.
4.2.2 Indirect variables indicate the output of transport energy consumption achievement

Indirect variables for the output of transport energy consumption achievement are not variables represent clearly for the achievement of transport activity, but efficiency can be connected between indirect output variables and input variables from other points of view. The relationship will be explained separately.

**Road network length:** It means the total length of road network in a region and shows the degree of road development for the region. Highly developed road network can promote and stimulate the use of vehicles, which leads to energy consumption. Region with highly developed road network and common transport energy consumption can be explained as a model for encouraging public or environmental transport, which can be interpreted for a special way of high efficiency. It is also considered as one the more the better variable for this research.

**Number of vehicles on register:** It is a common statistics variable for many transport literatures which means the number of vehicles registered in a region. With the same nature of the former variable, high ownership of vehicles can promote and stimulate the use of vehicles and leads to energy consumption. Besides, big number of vehicles on road also brings in traffic jam, which consumes extra energy. Therefore, as to the same transport energy consumption, large number of vehicles on register can be considered a way of high efficiency more or less.

**Area of parking places:** It is a statistics in the capacity of a city for its convenience of car using. Insufficient area of parking places is a restriction for people using vehicles for trip. Large area of parking place promotes and stimulates the use of vehicles and leads to energy consumption as well.

**GDP:** It is the abbreviation of Gross Domestic Product. It is widely accepted as the most comprehensive measure of the size of an economy. Transport activity, as a component of the economy, naturally is often measured against GDP. In popular press as well as in policy discussions, measures of transport in relation to GDP are often cited to illustrate the importance or contribution of transport activity to the economy.
However, there is a problem that the relationship between transport activity and the economy is a complicated one and measures of transport in relation to GDP are not always based on a conceptual framework that explicitly and accurately reflects the underlying relationship. This has resulted in both incorrect measures and incorrect interpretations of correct measures. Consequently, although GDP contributed by transport activity is one the more the better achievement by consumed energy, the accurate relationship for their direct relationship remains unclear.

**Employment rate:** It is also an economic statistics and seems have not such direct relationship with transport energy. It is taken into consideration because transport circumstance is always bad at rush hours in many regions, when much extra energy is consumed. Therefore some kind of relationship can be concluded to connect with the employment rate. It is treated as an affecting variable for efficiency of energy consumption tentatively.

### 4.3 Evaluation of the candidate indicators on the output variables of this issue

In this section, we will evaluate the candidate indicators listed in the last section by the selecting criteria respectively and calculate the total score for selection. First, we should check whether all the ten criteria are necessary for this practical issue of the output variables of the transport energy consumption achievement.

The criteria category ‘representation’ inspects how well the candidates can represent the phenomenon, which is rather important and is just the very purpose we intended to fulfill by introducing the indicator selection. Therefore, this category should be adopted completely. Meanwhile, the criteria category ‘policy application’ also inspects the purpose of this research- for the improvement of the transport energy efficiency and the policy suggestion and application, so this category will be adopted as well. The criteria category ‘operation’ inspects how well the candidates can be operated as an indicator for further use. In this category, the criteria ‘Data availability’ and ‘Ethical concerns’ cannot perform well for their responsibility because this research
performs quantitative analysis and it is necessary for every candidates to be available of data, and at the same time, this research relates nothing connected for ethical problem, so there is no need to evaluate the candidate by this two criteria. Furthermore, the criterion 'Transparency' also makes no sense in this research because all the candidate indicators are transport statistical variables and have clear meaning for every other user to understand. In this way, we eliminate these three criteria and adopt the rest seven criteria for the selection of formal indicators. All the candidates are evaluated by the seven criteria one by one as follows.

4.3.1 Vehicle kilometers travelled

Validity: This variable is based on conceptual model indeed and casually connected with the issue being discussed. The definition is also accepted all over the world. 9 points

Reliability: This variable is highly reliable for its value is constant even be measured for another time. 9 points

Sensitivity: This variable is sensitive for the distance high energy consuming vehicles travelled but ignores the existence of the vehicle with high energy efficiency. Vehicles are considered all the same when travelling. 5 points

Measurability: This variable can be measured straight-forward and easily achievable. 9 points

Interpretability: It is drawing a clearly conclusion for this issue that based on constant energy consumption, this variable is the more the better. 9 points

Target relevance: This variable measures the most target relevantly output for the achievement of transport activity when consuming energy. 9 points

Action ability: This variable can be influenced by management or policy action, but not directly. 7 points

4.3.2 Passenger Kilometers in public transport
Validity: This variable is based on conceptual model indeed and casually connected with the issue being discussed. The definition is also accepted all over the world. 9 points

Reliability: This variable is highly reliable for its value is constant even be measured for another time. 9 points

Sensitivity: Similar to the variable of V.K.T., this variable ignores the means of public transport passengers’ select, which vary on the energy efficiency. 6 points

Measurability: This variable can be measured straight-forward and easily achievable. 9 points

Interpretability: It is drawing a clearly conclusion for this issue that based on constant energy consumption, this variable is the more the better. 9 points

Target relevance: This variable measures the most target relevantly output for the achievement of transport activity when consuming energy. 9 points

Action ability: This variable can be influenced by management or policy action, but not directly. 7 points

4.3.3 Average trip length

Validity: This variable is also based on conceptual model indeed and casually connected with the issue being discussed. The definition is also accepted all over the world. 9 points

Reliability: This variable is highly reliable for its value is constant even be measured for another time. 9 points

Sensitivity: This variable also ignores the differences among different means of transport when the average trip length is calculated. But it is not the point this variable wants to measure. 7 points

Measurability: It is a little difficult to measure the word “average”, for there are many ways to solve average. 5 points

Interpretability: It is drawing a clearly conclusion for this issue that based on constant energy consumption, this variable is the more the better. 9 points
Target relevance: It is hard to say this variable measures the output for the achievement of transport activity when consuming energy target relevantly because the trip length made by passengers or freight may most probably related to the distance between origin and destination. 3 points

Action ability: This variable is a little difficult to be influenced by management or policy action. 3 points

4.3.4 Average speed of vehicle

Validity: This variable is used, but not such widely used for quantitative analysis because the kind of vehicle is hard to manage. And the way to get the average value has no international standard. 5 points

Reliability: This variable is reliable by the technology of measuring speed; however, vehicle may show different speed at every periods of running. 8 points

Sensitivity: It can hardly reveal the changes of the output for energy consumption. 3 points

Measurability: It is a little difficult to measure the word “average”, for there are many ways to solve average. 5 points

Interpretability: It is drawing conclusion for this issue that based on constant energy consumption, this variable is the more the better only in a certain range. 5 points

Target relevance: It is hard to say this variable measures the output for the achievement of transport activity target relevantly when consuming energy because the vehicle speed is also affected by many other complicated factors. 5 points

Action ability: This variable is a little difficult to be influenced by management or policy action. 3 points

4.3.5 Road network length

Validity: This is a basic parameter for a region. Its definition is clear and of course widely admitted all around the world. 9 points
Reliability: This variable is highly reliable for its value is constant even be measured for another time. 9 points

Sensitivity: This variable reflects the change of energy consumption output rather passively. 4 points

Measurability: This variable can be measured straight-forward and easily achievable. 9 points

Interpretability: It is drawing conclusion for this issue that based on constant energy consumption, this variable is the more the better, although a little strange. 7 points

Target relevance: This variable does not measure the phenomenon target relevantly for its indirect relation with the output for energy consumption. 3 points

Action ability: This variable is easily be influenced by management or policy action. 9 points

4.3.6 Vehicle number on register

Validity: This is a basic parameter for a region. Its definition is clear and of course widely admitted all around the world. 9 points

Reliability: This variable is highly reliable for its value is constant even be measured for another time. 9 points

Sensitivity: This variable reflects the change of energy consumption output passively at a certain degree. 6 points

Measurability: This variable can be measured straight-forward and easily achievable. 9 points

Interpretability: It is drawing conclusion for this issue that based on constant energy consumption, this variable is the more the better, although a little strange. 7 points

Target relevance: This variable does not measure the phenomenon target relevantly for its indirect relation with the output for energy consumption. 3 points

Action ability: This variable is be influenced by management or policy action at a certain range. 7 points
4.3.7 Area of parking place

Validity: This is a basic parameter for a region. Its definition is clear and of course widely admitted all around the world. 9 points

Reliability: This variable is highly reliable for its value is constant even be measured for another time. 9 points

Sensitivity: This variable hardly reflects the change of energy consumption output rather passively. 2 points

Measurability: This variable can be measured straight-forward and easily achievable. 9 points

Interpretability: It is drawing conclusion for this issue that based on constant energy consumption, this variable is the more the better, although a little strange. 5 points

Target relevance: This variable does not measure the phenomenon target relevantly for its indirect relation with the output for energy consumption. 1 point

Action ability: This variable is easily be influenced by management or policy action. 9 points

4.3.8 GDP

Validity: There is slight argument at some tiny items on whether it should be counted as an element of GDP, but not affect much. 7 points

Reliability: This variable is not an objective parameter of a region, but with some little subjective elements for analysis. It may slightly change due to different way of census. 7 points

Sensitivity: The total amount of GDP merely reveals its relationship between the changes of the output for energy consumption. 1 point

Measurability: This variable can be measured straight-forward and easily achievable. 9 points
Interpretability: It is drawing a clearly conclusion for this issue that based on constant energy consumption, this variable is the more the better. 9 points

Target relevance: It is hard to say this variable measures output for the achievement of transport activity target relevantly when consuming energy because GDP is also affected by many other factors. 4 points

Action ability: This variable is difficult to be influenced by transport management or policy action. 2 points

4.3.9 Employment rate

Validity: This is a basic parameter for a region. Its definition is clear and of course widely admitted all around the world. 9 points

Reliability: This variable is highly reliable for its value is constant even be measured for another time. 9 points

Sensitivity: This variable hardly reflects the change of energy consumption output rather passively. 2 points

Measurability: This variable can be measured straight-forward and easily achievable. 9 points

Interpretability: It is drawing conclusion for this issue that based on constant energy consumption, this variable is the more the better, although a little strange. 5 points

Target relevance: This variable does not measure the phenomenon target relevantly for its indirect relation with the output for energy consumption. 1 point

Action ability: This variable is difficult to be influenced by transport management or policy action. 2 points

All the candidate indicators are scored by the seven selected criteria and after that, we will summarize the result and decide the formal indicators for the issue of transport energy consumption achievement.
4.4 Summary

We summarized all the evaluation scores of every candidate indicator by all the seven criteria and calculated the total scores in Tab.4-1.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>V.K.T</th>
<th>Passenger kilometer</th>
<th>Average trip length</th>
<th>Average speed</th>
<th>Road length</th>
<th>Vehicle number</th>
<th>Parking place</th>
<th>GDP</th>
<th>Employment rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Validity</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>5</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Reliability</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Measurability</td>
<td>9</td>
<td>9</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Interpretability</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>5</td>
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<tr>
<td>Target relevance</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Action ability</td>
<td>7</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>7</td>
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<tr>
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<td>45</td>
<td>34</td>
<td>50</td>
<td>50</td>
<td>44</td>
<td>39</td>
<td>37</td>
</tr>
</tbody>
</table>

From the result of the evaluation, it can be concluded that the candidate indicators vehicle kilometer travelled and passenger kilometer in public transport are two of the formal indicators out of question. Road length of network and vehicle number on registered also get a high score, but not as high as the former two, what’s more, they are indirect output indicators, so they should be adopted as former indicators with limitation. By the way, both passenger transport and freight transport have indicators of its own, and the indirect output indicators are for road transport, which is crucial on contributing energy consumption. Therefore, this set of indicators is acceptable for further analysis of the issue of transport energy consumption.

In this chapter, we applied the criteria of selecting indicators on the field of transport, and for solving the problem on finding proper indicators that indicate the output of transport energy consumption. We classified the output variables into direct output variables and indirect output variables initially to satisfy the situation of transport.
After that, we evaluated the candidate indicators by the ten criteria one by one seriously. The total score of the evaluation by the criteria expressed how the candidates perform on indicating the phenomenon. Based on the result, vehicle kilometer travelled and passenger kilometer in public transport are selected as indicators for the achievement of transport energy consumption. Road length of network and Vehicle number on register are limited indicators for the achievement of transport energy consumption. They should be adopted with limitation and should not share the same importance with the former indicators.
References


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Sustainable Transport Indicators Subcommittee of the Transportation Research Board, 2008. Sustainable Transport Indicators—A Recommended Research Program For Developing Sustainable Transport Indicators and Data.


5. ACHIEVEMENT EFFICIENCY EVALUATION ON TRANSPORT ENERGY CONSUMPTION BASED ON SELECTED INDICATORS
5.1 Introduction

In the last chapter, the indicators for the output variables of transport energy consumption achievement have been successfully selected by the criteria. And in this chapter, we will solve the problem proposed at the beginning of this paper to analyze the achievement efficiency of energy consumption in transport sector based on the selected indicators.

The variable “efficiency” is expressed by the quotation of “output variable” and “input variable”, which is determined to be represented by transport energy consumption. The problem remains is to determine the expression formula for the output variable made up by the indicators. There are some main points on the formula we have to pay attention to.

1. For the integration of the indicators into one output, we do not know the weight of each indicator respectively, nor is the importance of each indicator determined or clearly presented at all times.
2. The unit of each indicator does not unified at all. Therefore, it is difficult to unite them together as one variable for calculation.
3. The ratio between output and input itself makes no sense. The quotation could only be meaningful when comparing with other quotations. Therefore, the methodology which supports relative evaluation would be helpful. The efficiency could be expressed by a variable under the same evaluation system and could tell the order for efficiency.

Among piles of quantitative analysis methods, we find out that DEA (Data Envelopment Analysis) method has its advantages to fit all the requirements listed above so well for this evaluation analysis issue in this research. We will apply this method for practical use to calculate the relatively achievement efficiency in transport energy consumption of each region. In the next section, the methodology of DEA method will be explained in detail.
5.2 Brief knowledge of DEA method

Data Envelopment Analysis (DEA for short) is a relatively new ‘data- oriented’ approach for evaluating the performances of a set of entities that called Decision Making Units (DMUs for short) which convert multiple inputs into multiple outputs. This method has been used in evaluating the performances of many different kinds of entities engaged in many different kinds of activities in many different contexts. (William W. Cooper et al, 2004). It is now considered to be a very useful operational research tool and becoming more and more popular on the field of quantitative evaluation analysis. It has been recognized as a valuable analytical research instrument and a practical decision support tool and is a linear programming methodology to measure the efficiency of multiple decision-making units when the production process presents a structure of multiple inputs and outputs.

DEA method is proposed by Charnes, Cooper & Rhodes initially, they describe DEA as a ‘mathematical programming model applied to observation data that provides a new way of obtaining empirical estimates of relations- such as the production functions and/or efficient production possibility surfaces’ (Charnes A. et al, 1978). After that, this method is developed into some other models with the years went by for different kinds of needs by users to measure productive efficiency of decision making units. Now it is spread and used widely in many fields for efficiency evaluation. For this reason, it can be also adopted for the evaluation of the efficiency by environmentally sustainable transport policies.

DEA method focuses on the evaluation given some input variables and output variables. There is no need to set weight on each variables but only consider the mathematical relationships of the variables. It can be used for both production and cost data. Utilizing the selected variables such as unit cost and output, DEA method searches for the points with the lowest unit cost for any given output, connecting those points to form the efficiency frontier. It is also useful because it takes into consideration returns to scale in calculating efficiency, allowing for the concept of increasing or decreasing efficiency based on size and output levels. A drawback of this technique is that model specification and inclusion/exclusion of variables can affect the results.
Compared with other evaluation methods, some of the main advantages of DEA are as follows: There is no need to explicitly specify a mathematical form for the production function; and is proven to be useful in uncovering relationships that remain hidden for other methodologies; and it is capable of handling multiple inputs and outputs and of being used with any input-output measurement. At last, the sources of inefficient can be analyzed and quantified for every evaluated unit.

Now we will explain the basic idea and methodology of DEA to reveal the mechanism to solve the problem. As we stated before, the concept of efficiency can be expressed by the output and input of the unit which is under measurement and this measurement can be stated by the form of a ratio between the output and input. If there is only one output and one input, while they are apparently in the direct relationship of cause and effect, the efficiency could be got easily by the ratio of the two. However, in most of the complicated cases, more than one output or input are necessary to represent all the linkage between cause and effect to calculate the efficiency. Consequently, we need to find out some criteria to squeeze the outputs or inputs into the comprehensively single output and single input in order to calculate the efficiency. That is to say, we need to put on weights to the outputs or inputs respectively according to their importance on the contribution to the effect. So it is rather confusing when the importance of each output or input is obscure or hard to tell, for no accurate calculation can be done anyway.

Based on the thought of Data Envelopment Analysis, weights to be attached to each output and input are not required to prescribe, as in the usual index number approaches, and it also does not require prescribing the functional forms that are needed in statistical regression approaches to these topics. In fact, DEA allows any choice on set of weights to every Decision Making Unit as long as the same set of weights is applied to any other Decision Making Units at the same time. It is allowed to every DMU to appeal for the set of weight of its own to maximize its efficiency. For better understanding, when evaluating the efficiency of one DMU, this DMU can propose a set of weights to every output and input at will to apply for its advantage to exert to its excellent output/input and avoid too much effect on its inadequate output/input in order to maximize its efficiency. This is the basic thought and principle of the DEA method.
Based on this principle, the methodology of DEA method can be expressed by the model like this:

$$\max \theta_o = \frac{\sum_{i=1}^{s} u_i y_{i0}}{\sum_{i=1}^{m} v_i x_{i0}}$$

subject to.

$$\sum_{i=1}^{s} u_i y_{ij} \leq 1 \quad (j = 1, 2, \ldots, n)$$

$$\sum_{i=1}^{m} v_i x_{ij} \quad v_1, v_2, \ldots, v_m \geq 0$$

$$u_1, u_2, \ldots, u_s \geq 0$$

Where

- $n$: the number of DMU
- $o$: the DMU under evaluation
- $m$: the number of input variables
- $s$: the number of output variables
- $x$: input variables
- $y$: output variables
- $v$: weight of input variables
- $u$: weight of output variables

Here we assume the maximum value of the efficiency is 1, the probably efficiency value of any DMU is between 0 and 1. The degree on how well a DMU perform can be interpreted by the value of efficiency. In the formula above, $x$ and $y$ are known positive variables while $u$ and $v$ are unknown positive variables. What we want to do is to find out proper set of all the $u$ and $v$ to make the efficiency $\theta$ as much as possible with the constraint that there is not any other efficiency of DMUs exceeds 1.
It can be proved that this fractional program problem is equivalent with a linear program problem (William W. Cooper et al, 2005) and we could find that the number of constraints is more than the number of unknown variables so that the optimum solution of this problem is existed.

Next, we will give an intuitive graph for a better understanding of the basic mechanism of DEA method. The practical problem in this paper is determined to be a one-input-four-output case, so we should pay more attention to the scenario of one input and multiple output case. For the convenience of explanation, we assume that there are only two output variables. An illustration of the case for two outputs is shown in Fig.5-1 which is drawn in the two dimension space in order to be understood easily. The case that with four outputs is in the same principle but only should be expressed in a four dimension space.
The two output variables are represented by X and Y, the amount of X and Y are both the more the better in this issue. The spot A–G are the Decision Making Units to be evaluated and their positions are located by their value of X and Y index of output divided by their input variables respectively. It is apparent that the DMU of B is better than E affirmatively as the amount of both X and Y of B is better than that of E, but for the other pairs in the DMU, it is hard to tell which one is better because we don’t know the relatively relationship of the importance between the output variables X and Y. By the basic theory of DEA, it is considered that a DMU which has any largest output is an effective DMU (A, B, C, D in the figure above), and the lines connecting them is called the efficient frontier (dotted line in the figure above), every DMU should not beyond the range of the frontier line. DMUs on the efficient line are considered to be the efficient DMU and its efficiency is 1, draw a line from O to the inefficient spot of DMU (e.g. F in the figure) and intersect to the efficient frontier in a spot (F’ in the figure), this spot is the imagined destination for the inefficient DMU, the ratio by the two spots from O is considered the efficiency of the DMU (OF/OF’). Obviously, the closer a DMU to the efficient frontier, the higher its efficiency is. B and C are the referring efficient DMU for the inefficient DMU F to follow. By the way, if a DMU is on the efficient frontier but is left to A or under D, the efficiency is 1 but it would also be considered as an inefficient DMU for A or D is apparently better. If there are many outputs for the decision, the diagram should be drawn in an n-dimension space. Case that contains multiple input variables can be explained in the same way.

As this method is initially proposed by Charnes, Cooper and Rhodes, the initial model of this method is called the CCR model. After that, for other practical use, the models were improved into many other shapes such as BCC model which adjoins the constraint that the total of all the weights be fixed. BCC model is proposed by Banker, Charnes and Cooper and is considered to be another very crucial model in the DEA methodology. It seems that the CCR model and the BCC model are very much alike for there is only one constraint different between the two. However, their significances and applications are in much difference (Sueyoshi, 2000). The most obvious difference is the shape of the efficiency frontier line. Comparing the two models and we find in this paper, a more reasonable frontier line is required for each decision making unit to refer
to, which is the function and characteristics of the BCC model, so we choose the BCC model for the analysis to solve the problem of the achievement efficiency in the transport energy consumption for Environmentally Sustainable Transport.

5.3 Data and analysis result

In this research, we make use of the data in the publication by Peter NEWMAN, Jeffrey KENWORTHY (1989): Cities and automobile dependence— An international sourcebook. Thirty-two principle cities of North America, Europe, Asia and Australia were collected for the city transport data in the year 1960, 1970 and 1980. These cities are Adelaide, Amsterdam, Boston, Brisbane, Brussels, Chicago, Copenhagen, Denver, Detroit, Frankfort, Hamburg, Hong Kong, Houston, London, Los Angeles, Melbourne, Moscow, Munich, New York, Paris, Perth, Phoenix, San Francisco, Singapore, Stockholm, Sydney, Tokyo, Toronto, Vienna, Washington, West Berlin, and Zurich.

They are all developed cities at the time being studied and all the cities from the third world are neglected in this book. This is because according to the writers of the book, the comparison of the cities is to promote cities follow the good example from their similar companions, while cities in the third world countries are in a totally different shape on such as the city planning. And in this research, this consideration is taken as well as the DEA method also expects the similar DMUs to be evaluated under the same frame. It is such a pity that the data we selected in this book are rather old for the analysis nowadays. However, no new follow-up for a later data is done till today and no other data books can provide such detailed data as we could find. What need to be emphasized is that this section is just a case study of the evaluation method for the transport energy achievement efficiency. For the impartiality of evaluation, we have to ensure the sufficient number of object cities and apply the data of cities for the same period, although it is rather old.

Since DEA method needs all the data available for calculation in detail, we checked the data availability of the 32 cities for selected input and output indicators--transport energy consumption, vehicle kilometer travelled, passenger kilometers in public transport, road network length, and number of vehicle on register.
As a result, 24 of the cities have all the data for indicators available: Adelaide, Brisbane, Brussels, Chicago, Copenhagen, Denver, Detroit, Hong Kong, Houston, London, Los Angeles, Melbourne, New York, Paris, Perth, Phoenix, San Francisco, Stockholm, Sydney, Tokyo, Toronto, Vienna, Washington, and West Berlin.

In order to ensure the reasonability and readability for the DEA result, it is not acceptable that too many DMUs get the evaluation of efficient. Therefore, the number of DMU and the number of input/output variables should satisfy this empirical formula (K. Kone, 2006):

\[ n \geq \max\{m \times s, 3(m + s)\} \]

Here "n" represents the number of DMU, "m" represents the number of input variables, and "s" represents the number of output variables.

In the case study for this research, the number of DMU- number of objected cities \( n=24 \), the number of input variables \( m=1 \), the number of output variables \( s=4 \), we can conclude that this set of numbers satisfies the empirical formula. Consequently, the number of variables ensures it possible to get appropriate result for this analysis.

The initial data in the data book for the input and output variables of the 24 object cities are listed in the tables below. It seems that the significant figures in each item among the object cities are different due to the different data origins. The analysis result will not be affected much by the slight change so we just input what the data source loaded.
Tab.5-1 Data for input variables of the object cities

<table>
<thead>
<tr>
<th>City</th>
<th>Energy use per capita (MJ)</th>
<th>Population</th>
<th>Total energy use (10^15KJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>35207</td>
<td>931886</td>
<td>32.8</td>
</tr>
<tr>
<td>Brisbane</td>
<td>37303</td>
<td>1028527</td>
<td>38.4</td>
</tr>
<tr>
<td>Brussels</td>
<td>22793</td>
<td>997293</td>
<td>22.7</td>
</tr>
<tr>
<td>Chicago</td>
<td>53380</td>
<td>7103624</td>
<td>379.2</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>17283</td>
<td>1379860</td>
<td>23.8</td>
</tr>
<tr>
<td>Denver</td>
<td>77202</td>
<td>1593308</td>
<td>123.0</td>
</tr>
<tr>
<td>Detroit</td>
<td>68968</td>
<td>4043633</td>
<td>278.9</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>5404</td>
<td>4986560</td>
<td>26.9</td>
</tr>
<tr>
<td>Houston</td>
<td>83907</td>
<td>2905353</td>
<td>243.8</td>
</tr>
<tr>
<td>London</td>
<td>18721</td>
<td>6713200</td>
<td>125.7</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>65515</td>
<td>7477503</td>
<td>489.9</td>
</tr>
<tr>
<td>Melbourne</td>
<td>34243</td>
<td>2722817</td>
<td>93.2</td>
</tr>
<tr>
<td>New York</td>
<td>52090</td>
<td>15590274</td>
<td>812.1</td>
</tr>
<tr>
<td>Paris</td>
<td>19733</td>
<td>10094000</td>
<td>199.2</td>
</tr>
<tr>
<td>Perth</td>
<td>40248</td>
<td>898918</td>
<td>36.2</td>
</tr>
<tr>
<td>Phoenix</td>
<td>78932</td>
<td>1509052</td>
<td>119.1</td>
</tr>
<tr>
<td>San Francisco</td>
<td>66275</td>
<td>3250630</td>
<td>215.4</td>
</tr>
<tr>
<td>Stockholm</td>
<td>22754</td>
<td>2494450</td>
<td>56.8</td>
</tr>
<tr>
<td>Sydney</td>
<td>34658</td>
<td>3204696</td>
<td>111.1</td>
</tr>
<tr>
<td>Tokyo</td>
<td>16829</td>
<td>11597211</td>
<td>195.2</td>
</tr>
<tr>
<td>Toronto</td>
<td>48622</td>
<td>2137395</td>
<td>103.9</td>
</tr>
<tr>
<td>Vienna</td>
<td>12138</td>
<td>1531346</td>
<td>18.6</td>
</tr>
<tr>
<td>Washington</td>
<td>54342</td>
<td>2988100</td>
<td>162.4</td>
</tr>
<tr>
<td>West Berlin</td>
<td>16465</td>
<td>2001000</td>
<td>32.9</td>
</tr>
</tbody>
</table>
Tab.5-2 Data for output variables of the object cities

<table>
<thead>
<tr>
<th>City</th>
<th>Road network length (km)</th>
<th>Vehicle number on register</th>
<th>VKT $(10^9)$</th>
<th>Passenger kilometers $(10^9)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>8506</td>
<td>245273</td>
<td>6.53</td>
<td>1.347</td>
</tr>
<tr>
<td>Brisbane</td>
<td>7084</td>
<td>669068</td>
<td>8.199</td>
<td>0.766</td>
</tr>
<tr>
<td>Brussels</td>
<td>1651</td>
<td>406681</td>
<td>4.624</td>
<td>1.392</td>
</tr>
<tr>
<td>Chicago</td>
<td>35698</td>
<td>3682453</td>
<td>56.577</td>
<td>6.898</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>7435</td>
<td>515337</td>
<td>7.248</td>
<td>2.885</td>
</tr>
<tr>
<td>Denver</td>
<td>12752</td>
<td>1358225</td>
<td>13.422</td>
<td>0.347</td>
</tr>
<tr>
<td>Detroit</td>
<td>23485</td>
<td>2794284</td>
<td>46.798</td>
<td>0.479</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>1141</td>
<td>330472</td>
<td>4.485</td>
<td>10.184</td>
</tr>
<tr>
<td>Houston</td>
<td>30674</td>
<td>2315652</td>
<td>33.507</td>
<td>0.373</td>
</tr>
<tr>
<td>London</td>
<td>12850</td>
<td>2386700</td>
<td>22.451</td>
<td>11.526</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>33829</td>
<td>4985527</td>
<td>74.799</td>
<td>2.868</td>
</tr>
<tr>
<td>Melbourne</td>
<td>21381</td>
<td>1437869</td>
<td>19.029</td>
<td>2.12</td>
</tr>
<tr>
<td>New York</td>
<td>83559</td>
<td>8230989</td>
<td>117.66</td>
<td>23.039</td>
</tr>
<tr>
<td>Paris</td>
<td>9427</td>
<td>3864230</td>
<td>32</td>
<td>18.442</td>
</tr>
<tr>
<td>Perth</td>
<td>11923</td>
<td>552325</td>
<td>7.523</td>
<td>0.532</td>
</tr>
<tr>
<td>Phoenix</td>
<td>15763</td>
<td>1141572</td>
<td>14.86</td>
<td>0.996</td>
</tr>
<tr>
<td>San Francisco</td>
<td>15825</td>
<td>2213410</td>
<td>33.814</td>
<td>3.01</td>
</tr>
<tr>
<td>Stockholm</td>
<td>1480</td>
<td>855359</td>
<td>3.43</td>
<td>3.246</td>
</tr>
<tr>
<td>Sydney</td>
<td>19812</td>
<td>1619913</td>
<td>21.326</td>
<td>4.84</td>
</tr>
<tr>
<td>Tokyo</td>
<td>22098</td>
<td>3090734</td>
<td>32.065</td>
<td>134.133</td>
</tr>
<tr>
<td>Toronto</td>
<td>5815</td>
<td>1189888</td>
<td>15.864</td>
<td>4.384</td>
</tr>
<tr>
<td>Vienna</td>
<td>2650</td>
<td>572328</td>
<td>4.9</td>
<td>2.8</td>
</tr>
<tr>
<td>Washington</td>
<td>15186</td>
<td>1927890</td>
<td>27.069</td>
<td>1.841</td>
</tr>
<tr>
<td>West Berlin</td>
<td>2943</td>
<td>612104</td>
<td>6.187</td>
<td>4.32</td>
</tr>
</tbody>
</table>

The total energy consumptions of the cities are derived from the initial data and we decided to accurate the number by 0.1 of the unit above. The other data are kept as noted in the data book. From the data in the tables, we could find that the value of the same statistics data in different cities varies very much from each other, and there is no
exception for the indirect output variables. The value of indirect output variable in some
city can even reach many times of that in other city. According to the DEA method, if
we do nothing to deal with the data, the direct output variables and the indirect output
variables will affect the result with the same importance and it will make the analysis
result unreasonable. Therefore, the next problem we want to resolve which is also
proposed in the last chapter is to give restriction at the importance of indirect output
indicators. The reason why we do the treatment here in this section rather than the last
chapter is that we have to find an effective way to set restriction based on the
characteristic of the analysis model we have selected. And now, we have found the
analysis method and will analyze the characteristic of the DEA method to find out an
appropriate methodology for restricting the importance of the indirect output variables.

From the methodology of DEA method, we can conclude that all the output
variables are considered to be equal on calculation. The factor affects the analysis result
is not the mathematic relationship between output variables but the mathematic
relationship for one output variable between DMUs. The output variables are
independent from each other for the analysis. Therefore, it is no use to minify the data
of indirect output variables into a smaller amount. The most important thing is to
squeeze the multiple between DMUs for the indirect output variables so that the indirect
output variables will affect less than before.

Here we attempt to introduce natural logarithm function to squeeze the multiple
between DMUs for the same indirect output variable. Before that, we have to prove that
the natural logarithm function will squeeze the multiple indeed first. Now we will show
the process of the proof:

First we assume a function \( f(x) = \frac{\ln(x)}{x}, x > 0 \)

Then \( \frac{df(x)}{dx} = \frac{1-\ln(x)}{x^2} \)

Therefore when \( x > e \), we have \( \frac{df(x)}{dx} < 0 \),

That is to say for any \( a, b \), if \( a > b > e \), then \( f(a) < f(b) \)

Which means \( \frac{\ln(a)}{a} < \frac{\ln(b)}{b} \), therefore \( \frac{\ln(a)}{\ln(b)} < \frac{a}{b} \) is correct
Consequently, we can see that if any amount of the indirect output variables is more than the base of natural logarithm e (the letter e in this section always represents the base of natural logarithm), the function of natural logarithm will squeeze the multiple between the output values successfully.

This is the procedure to deal with the data for the indirect output variables: First, find the minimum value of the indirect output variable of all DMUs and calculate the multiple between it and the constant number e-- the base of the natural logarithm function. And then deal all the data with the same multiple got just now. Finally replace the original data with new data. Indirect output variables are set to be made less important by this treatment. The adopted data for calculation are listed in Tab.5-3. The values are accurate to 0.01 of the unit. It shows the multiple of data values among object cities are no more than 5 which is much less than the multiple of the original data and not so large. By this way, the effects of the indirect output variables are successfully cut down. This treatment is considered to be able to lead to a more reasonable analysis result.
Tab.5-3 Data for indirect output variables after squeeze treatment

<table>
<thead>
<tr>
<th></th>
<th>Road network length</th>
<th>Vehicle number on register</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>3.01</td>
<td>1.00</td>
</tr>
<tr>
<td>Brisbane</td>
<td>2.83</td>
<td>2.00</td>
</tr>
<tr>
<td>Brussels</td>
<td>1.37</td>
<td>1.51</td>
</tr>
<tr>
<td>Chicago</td>
<td>4.44</td>
<td>3.71</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>2.87</td>
<td>1.74</td>
</tr>
<tr>
<td>Denver</td>
<td>3.41</td>
<td>2.71</td>
</tr>
<tr>
<td>Detroit</td>
<td>4.02</td>
<td>3.43</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>1.00</td>
<td>1.30</td>
</tr>
<tr>
<td>Houston</td>
<td>4.29</td>
<td>3.25</td>
</tr>
<tr>
<td>London</td>
<td>3.42</td>
<td>3.28</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>4.39</td>
<td>4.01</td>
</tr>
<tr>
<td>Melbourne</td>
<td>3.93</td>
<td>2.77</td>
</tr>
<tr>
<td>New York</td>
<td>5.29</td>
<td>4.51</td>
</tr>
<tr>
<td>Paris</td>
<td>3.11</td>
<td>3.76</td>
</tr>
<tr>
<td>Perth</td>
<td>3.35</td>
<td>1.81</td>
</tr>
<tr>
<td>Phoenix</td>
<td>3.63</td>
<td>2.54</td>
</tr>
<tr>
<td>San Francisco</td>
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<td>3.20</td>
</tr>
<tr>
<td>Stockholm</td>
<td>1.26</td>
<td>2.25</td>
</tr>
<tr>
<td>Sydney</td>
<td>3.85</td>
<td>2.89</td>
</tr>
<tr>
<td>Tokyo</td>
<td>3.96</td>
<td>3.53</td>
</tr>
<tr>
<td>Toronto</td>
<td>2.63</td>
<td>2.58</td>
</tr>
<tr>
<td>Vienna</td>
<td>1.84</td>
<td>1.85</td>
</tr>
<tr>
<td>Washington</td>
<td>3.59</td>
<td>3.06</td>
</tr>
<tr>
<td>West Berlin</td>
<td>1.95</td>
<td>1.91</td>
</tr>
</tbody>
</table>

Now all the data and the approach for dealing the data are ready for the calculation of energy consumption achievement efficiency. Here we have to state in advance that there are two types of BCC models which are called output-oriented model and input-oriented model with different purposes. The purpose of input-oriented model is to minimize inputs while producing at least the given output levels, on the other hand, output-oriented model attempts to maximize outputs while using no more than the observed amount of any input. The application of BCC model uses only one of them at
one time, because in business field which DEA method usually applied on, the object of improvement is focused on either the output variables or the input variables. In this research, we want to inspect all the values of the output variables and the input variables so we will apply both two methods in the BCC model of DEA method. The detailed calculation result of efficiency is listed in Tab.5-4 as below:

Tab.5-4 Energy achievement efficiency results for object cities (BCC input-oriented model)

<table>
<thead>
<tr>
<th>City</th>
<th>Energy achievement efficiency</th>
<th>Real energy consumption (10^5KJ)</th>
<th>Optimum energy consumption (10^5KJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>0.834</td>
<td>32.8</td>
<td>27.4</td>
</tr>
<tr>
<td>Brisbane</td>
<td>0.992</td>
<td>38.4</td>
<td>38.1</td>
</tr>
<tr>
<td>Brussels</td>
<td>0.818</td>
<td>22.7</td>
<td>18.6</td>
</tr>
<tr>
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<td>1.000</td>
<td>379.2</td>
<td>379.2</td>
</tr>
<tr>
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<td>1.000</td>
<td>23.8</td>
<td>23.8</td>
</tr>
<tr>
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<td>123.0</td>
<td>86.6</td>
</tr>
<tr>
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<td>1.000</td>
<td>278.9</td>
<td>278.9</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>1.000</td>
<td>26.9</td>
<td>26.9</td>
</tr>
<tr>
<td>Houston</td>
<td>1.000</td>
<td>243.8</td>
<td>243.8</td>
</tr>
<tr>
<td>London</td>
<td>1.000</td>
<td>125.7</td>
<td>125.7</td>
</tr>
<tr>
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<td>1.000</td>
<td>489.9</td>
<td>489.9</td>
</tr>
<tr>
<td>Melbourne</td>
<td>1.000</td>
<td>93.2</td>
<td>93.2</td>
</tr>
<tr>
<td>New York</td>
<td>1.000</td>
<td>812.1</td>
<td>812.1</td>
</tr>
<tr>
<td>Paris</td>
<td>1.000</td>
<td>199.2</td>
<td>199.2</td>
</tr>
<tr>
<td>Perth</td>
<td>1.000</td>
<td>36.2</td>
<td>36.2</td>
</tr>
<tr>
<td>Phoenix</td>
<td>0.646</td>
<td>119.1</td>
<td>76.9</td>
</tr>
<tr>
<td>San Francisco</td>
<td>0.900</td>
<td>215.4</td>
<td>193.9</td>
</tr>
<tr>
<td>Stockholm</td>
<td>0.858</td>
<td>56.8</td>
<td>48.7</td>
</tr>
<tr>
<td>Sydney</td>
<td>0.991</td>
<td>111.1</td>
<td>110.1</td>
</tr>
<tr>
<td>Tokyo</td>
<td>1.000</td>
<td>195.2</td>
<td>195.2</td>
</tr>
<tr>
<td>Toronto</td>
<td>0.749</td>
<td>103.9</td>
<td>77.8</td>
</tr>
<tr>
<td>Vienna</td>
<td>1.000</td>
<td>18.6</td>
<td>18.6</td>
</tr>
<tr>
<td>Washington</td>
<td>0.919</td>
<td>162.4</td>
<td>149.2</td>
</tr>
<tr>
<td>West Berlin</td>
<td>0.769</td>
<td>32.9</td>
<td>25.3</td>
</tr>
</tbody>
</table>
According to the calculation result based on DEA method BCC input-oriented model, thirteen of the twenty-four object cities are considered to be efficient cities, they are: Chicago, Copenhagen, Detroit, Hong Kong, Houston, London, Los Angeles, Melbourne, New York, Paris, Perth, Tokyo, and Vienna. Other eleven cities are not so efficient compared with the former ones. Brisbane and Sydney have the efficiency near 1 and could also be treated as the efficient city; while on the other hand, Phoenix has the efficiency at 0.646, which is the lowest of all. Denver, Toronto and West Berlin are also less efficient cities that need improvement urgently. The detailed ways for improvement are discussed afterwards. The optimum energy consumptions of each city are listed in the right column in Tab.5-4 to set up goals for each city to reach.

Besides the efficiency value of each city, there are also other results got at the same time. Tab.5-5 shows the reference category of the relatively inefficient cities. As to every inefficient city, the efficient cities in the reference set are the cities with the similar structure of input and output variables. It is considered wise for this inefficient city to follow the examples of its reference set cities as their structure of city parameters are close. It may be intuitive to describe this in Fig.5-1, as to the inefficient DMU F, it will reference the DMU B and C rather than A or D because the output variables of F is close to B and C rather than A or D so it is easy for F to improve the output variables to catch B or C or anywhere else to the efficient line. In the four-dimension space, the DMU in the reference set will be four at most. The numbers in the brackets after the cities in the reference set mean the ratio of distance to each reference city. Take the example in Fig.5-1 again, the number after B means the ratio of the length of CF' to the length of BC, and the number after C means the ratio of the length of BF' to the length of BC in the two-dimension space, the large this number is, the example of this efficient DMU should be more important to be referenced.
### Tab.5-5 Reference set for object cities (BCC input-oriented model)

<table>
<thead>
<tr>
<th>City</th>
<th>Reference set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>Copenhagen(0.715), Perth(0.285)</td>
</tr>
<tr>
<td>Brisbane</td>
<td>Copenhagen(0.496), Melbourne(0.226), Vienna(0.278)</td>
</tr>
<tr>
<td>Brussels</td>
<td>Vienna(1.000)</td>
</tr>
<tr>
<td>Chicago</td>
<td>Chicago(1.000)</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>Copenhagen(1.000)</td>
</tr>
<tr>
<td>Denver</td>
<td>London(0.234), Melbourne(0.576), Vienna(0.190)</td>
</tr>
<tr>
<td>Detroit</td>
<td>Detroit(1.000)</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>Hong Kong(1.000)</td>
</tr>
<tr>
<td>Houston</td>
<td>Houston(1.000)</td>
</tr>
<tr>
<td>London</td>
<td>London(1.000)</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Los Angeles(1.000)</td>
</tr>
<tr>
<td>Melbourne</td>
<td>Melbourne(1.000)</td>
</tr>
<tr>
<td>New York</td>
<td>New York(1.000)</td>
</tr>
<tr>
<td>Paris</td>
<td>Paris(1.000)</td>
</tr>
<tr>
<td>Perth</td>
<td>Perth(1.000)</td>
</tr>
<tr>
<td>Phoenix</td>
<td>Copenhagen(0.172), Melbourne(0.769), Vienna(0.059)</td>
</tr>
<tr>
<td>San Francisco</td>
<td>Detroit(0.510), London(0.183), Melbourne(0.307), Tokyo(0.000)</td>
</tr>
<tr>
<td>Stockholm</td>
<td>London(0.281), Vienna(0.719)</td>
</tr>
<tr>
<td>Sydney</td>
<td>Detroit(0.060), London(0.139), Melbourne(0.789), Tokyo(0.011)</td>
</tr>
<tr>
<td>Tokyo</td>
<td>Tokyo(1.000)</td>
</tr>
<tr>
<td>Toronto</td>
<td>London(0.064), Melbourne(0.675), Tokyo(0.011), Vienna(0.250)</td>
</tr>
<tr>
<td>Vienna</td>
<td>Vienna(1.000)</td>
</tr>
<tr>
<td>Washington</td>
<td>Detroit(0.260), London(0.237), Melbourne(0.502)</td>
</tr>
<tr>
<td>West Berlin</td>
<td>Copenhagen(0.061), Melbourne(0.058), Tokyo(0.012), Vienna(0.869)</td>
</tr>
</tbody>
</table>

Tab.5-6 shows the analysis result based on the BCC output-oriented model. Comparing with that of the BCC input-oriented model, we can find that the efficient cities are completely the same and the energy achievement efficiency numbers and reference set for the inefficient cities are different. The inefficient cities can refer the cities in its set at its demand for the improvement of either input variable or output variable.
<table>
<thead>
<tr>
<th>City</th>
<th>Energy achievement efficiency</th>
<th>Reference set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>0.938</td>
<td>Copenhagen(0.294), Perth(0.705), Tokyo(0.002)</td>
</tr>
<tr>
<td>Brisbane</td>
<td>0.998</td>
<td>Copenhagen(0.493), Melbourne(0.230), Vienna(0.277)</td>
</tr>
<tr>
<td>Brussels</td>
<td>0.799</td>
<td>Copenhagen(0.078), Melbourne(0.050), Vienna(0.872)</td>
</tr>
<tr>
<td>Chicago</td>
<td>1.000</td>
<td>Chicago(1.000)</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>1.000</td>
<td>Copenhagen(1.000)</td>
</tr>
<tr>
<td>Denver</td>
<td>0.890</td>
<td>London(0.204), Melbourne(0.569), Tokyo(0.227)</td>
</tr>
<tr>
<td>Detroit</td>
<td>1.000</td>
<td>Detroit(1.000)</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>1.000</td>
<td>Hong Kong(1.000)</td>
</tr>
<tr>
<td>Houston</td>
<td>1.000</td>
<td>Houston(1.000)</td>
</tr>
<tr>
<td>London</td>
<td>1.000</td>
<td>London(1.000)</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>1.000</td>
<td>Los Angeles(1.000)</td>
</tr>
<tr>
<td>Melbourne</td>
<td>1.000</td>
<td>Melbourne(1.000)</td>
</tr>
<tr>
<td>New York</td>
<td>1.000</td>
<td>New York(1.000)</td>
</tr>
<tr>
<td>Paris</td>
<td>1.000</td>
<td>Paris(1.000)</td>
</tr>
<tr>
<td>Perth</td>
<td>1.000</td>
<td>Perth(1.000)</td>
</tr>
<tr>
<td>Phoenix</td>
<td>0.908</td>
<td>Houston(0.172), Melbourne(0.828)</td>
</tr>
<tr>
<td>San Francisco</td>
<td>0.934</td>
<td>Detroit(0.421), London(0.186), Melbourne(0.021), Tokyo(0.372)</td>
</tr>
<tr>
<td>Stockholm</td>
<td>0.955</td>
<td>London(0.356), Vienna(0.644)</td>
</tr>
<tr>
<td>Sydney</td>
<td>0.996</td>
<td>Detroit(0.050), London(0.129), Melbourne(0.778), Tokyo(0.043)</td>
</tr>
<tr>
<td>Tokyo</td>
<td>1.000</td>
<td>Tokyo(1.000)</td>
</tr>
<tr>
<td>Toronto</td>
<td>0.864</td>
<td>London(0.797), Vienna(0.203)</td>
</tr>
<tr>
<td>Vienna</td>
<td>1.000</td>
<td>Vienna(1.000)</td>
</tr>
<tr>
<td>Washington</td>
<td>0.950</td>
<td>Detroit(0.217), London(0.353), Melbourne(0.259), Tokyo(0.171)</td>
</tr>
<tr>
<td>West Berlin</td>
<td>0.942</td>
<td>London(0.112), Melbourne(0.017), Tokyo(0.006), Vienna(0.865)</td>
</tr>
</tbody>
</table>

From the table of reference set above, first we could find the relatively efficient cities are completely the same compared with the previous model, but the efficiency of
the inefficient cities are a little different. Here Brussels performs worst on this efficiency, while Brisbane and Sydney are nearly perfect. Which efficiency number is more reliable is depending on which aspect we focus on. Output-oriented model focuses on the improvement of the output variable, while of course input-oriented model focuses on the improvement of the input variable. However, the inefficient cities are remains the same so we should analyze the reasons for them to improve respectively. The significance of the reference set is advising examples for the inefficient cities, according to the algorithm of the calculating model, the example cities usually have the similar city structures for transport and is easier to follow and catch up.

Tab.5-7 shows the insufficient output values for inefficient cities by BCC output-oriented model. It means as to the inefficient cities, if they improve the insufficient output variables by the numbers in the table, the inefficient cities will turn into efficient cities if others remain unchanged. The insufficient numbers in the column of the indirect output variables means the insufficient values after the measurement of the natural logarithm function. We don’t converse them into the initial value because what we really want is not to increase the value of the road network length or the vehicle number, we just want to get some hint given by the indirect output variables.
Tab.5-7 Insufficient output values for inefficient cities (BCC output-oriented model)

<table>
<thead>
<tr>
<th>City</th>
<th>Road network length</th>
<th>Vehicle number on register</th>
<th>VKT</th>
<th>Passenger kilometers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>0.000000</td>
<td>0.727707</td>
<td>0.517500</td>
<td>0.000000</td>
</tr>
<tr>
<td>Brisbane</td>
<td>0.000000</td>
<td>0.000000</td>
<td>1.094045</td>
<td>1.917732</td>
</tr>
<tr>
<td>Brussels</td>
<td>0.312785</td>
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<td>1.029688</td>
</tr>
<tr>
<td>Chicago</td>
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<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Denver</td>
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<td>0.000000</td>
<td>7.612433</td>
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</tr>
<tr>
<td>Detroit</td>
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<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Houston</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>London</td>
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<td>0.000000</td>
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<td>0.000000</td>
</tr>
<tr>
<td>Melbourne</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
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<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Paris</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
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<tr>
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<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Phoenix</td>
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<td>0.055876</td>
<td>5.153868</td>
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</tr>
<tr>
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<td>0.000000</td>
<td>49.085239</td>
</tr>
<tr>
<td>Stockholm</td>
<td>1.085214</td>
<td>0.000000</td>
<td>7.562434</td>
<td>2.509622</td>
</tr>
<tr>
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<td>0.000000</td>
<td>0.000000</td>
<td>4.025961</td>
</tr>
<tr>
<td>Tokyo</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Toronto</td>
<td>0.058453</td>
<td>0.000000</td>
<td>0.524742</td>
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</tr>
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<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
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<td>25.674904</td>
</tr>
<tr>
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<td>0.703963</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

From this result, we can find three cities Denver, San Francisco and Washington lack passenger kilometers seriously, and this insufficient is the main reason for the three to be classified into inefficient cities. Besides, Denver, Phoenix and Stockholm lack vehicle kilometers seriously, which leads them to be classified into inefficient cities. Denver performs badly at both direct outputs and it should be considered as the worst
city at transport energy achievement efficiency of all without a doubt. The indirect output variables seem to be not so insufficient.

Tab.5-8 shows the weights chosen by each object city for maximizing its efficiency by this method. It indicates the advantage and disadvantage of the output variables for each object city. It would be a good material for discussion.

Tab.5-8 Weights for output variables to compose the comprehensive output of object cities (BCC output-oriented model)

<table>
<thead>
<tr>
<th></th>
<th>Road network length</th>
<th>Vehicle number on register</th>
<th>VKT</th>
<th>Passenger kilometers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>0.985277</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.014723</td>
</tr>
<tr>
<td>Brisbane</td>
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<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Brussels</td>
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<td>0.721692</td>
<td>0.278308</td>
<td>0.000000</td>
</tr>
<tr>
<td>Chicago</td>
<td>0.556357</td>
<td>0.175935</td>
<td>0.267708</td>
<td>0.000000</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>0.734314</td>
<td>0.000000</td>
<td>0.254035</td>
<td>0.011651</td>
</tr>
<tr>
<td>Denver</td>
<td>0.389376</td>
<td>0.610624</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Detroit</td>
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<td>0.999830</td>
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</tr>
<tr>
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<td>0.000000</td>
<td>1.000000</td>
</tr>
<tr>
<td>Houston</td>
<td>0.715518</td>
<td>0.195387</td>
<td>0.089094</td>
<td>0.000000</td>
</tr>
<tr>
<td>London</td>
<td>0.197753</td>
<td>0.802247</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>0.000000</td>
<td>0.014284</td>
<td>0.985716</td>
<td>0.000000</td>
</tr>
<tr>
<td>Melbourne</td>
<td>0.096385</td>
<td>0.903615</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>New York</td>
<td>0.000000</td>
<td>0.386412</td>
<td>0.610513</td>
<td>0.003076</td>
</tr>
<tr>
<td>Paris</td>
<td>0.043502</td>
<td>0.412694</td>
<td>0.543804</td>
<td>0.000000</td>
</tr>
<tr>
<td>Perth</td>
<td>0.471037</td>
<td>0.527246</td>
<td>0.000000</td>
<td>0.001717</td>
</tr>
<tr>
<td>Phoenix</td>
<td>1.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>San Francisco</td>
<td>0.091354</td>
<td>0.314310</td>
<td>0.594336</td>
<td>0.000000</td>
</tr>
<tr>
<td>Stockholm</td>
<td>0.000000</td>
<td>1.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Sydney</td>
<td>0.128405</td>
<td>0.375446</td>
<td>0.496149</td>
<td>0.000000</td>
</tr>
<tr>
<td>Tokyo</td>
<td>0.469580</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.530420</td>
</tr>
<tr>
<td>Toronto</td>
<td>0.000000</td>
<td>1.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Vienna</td>
<td>0.160719</td>
<td>0.839281</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Washington</td>
<td>0.104191</td>
<td>0.346942</td>
<td>0.548867</td>
<td>0.000000</td>
</tr>
<tr>
<td>West Berlin</td>
<td>0.105512</td>
<td>0.882151</td>
<td>0.000000</td>
<td>0.012337</td>
</tr>
</tbody>
</table>
We can see from the result in Tab.5-8 that each city expressed their ability stretching to its advantage for a better efficiency. The items with high weights are the relatively high values of energy efficiency of all the cities. We can see it clearly for the advantages of each city compared with others. The cities with the best performance for efficiency of each output variable apparently give all the weight to that variable.

**Tab.5-9 Weights for output variables to maximize the efficiency of object cities (BCC output-oriented model)**

<table>
<thead>
<tr>
<th>Cities</th>
<th>Road network length</th>
<th>Vehicle number on register</th>
<th>VKT</th>
<th>Passenger kilometers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide</td>
<td>0.327458</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.010930</td>
</tr>
<tr>
<td>Brisbane</td>
<td>0.075405</td>
<td>0.392766</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Brussels</td>
<td>0.000000</td>
<td>0.479320</td>
<td>0.060188</td>
<td>0.000000</td>
</tr>
<tr>
<td>Chicago</td>
<td>0.125216</td>
<td>0.047435</td>
<td>0.004732</td>
<td>0.000000</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>0.255476</td>
<td>0.000000</td>
<td>0.035049</td>
<td>0.004038</td>
</tr>
<tr>
<td>Denver</td>
<td>0.114060</td>
<td>0.225193</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Detroit</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.021365</td>
<td>0.000355</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.098193</td>
</tr>
<tr>
<td>Houston</td>
<td>0.166729</td>
<td>0.060210</td>
<td>0.002659</td>
<td>0.000000</td>
</tr>
<tr>
<td>London</td>
<td>0.057798</td>
<td>0.244939</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>0.000000</td>
<td>0.003560</td>
<td>0.013178</td>
<td>0.000000</td>
</tr>
<tr>
<td>Melbourne</td>
<td>0.024522</td>
<td>0.326386</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>New York</td>
<td>0.000000</td>
<td>0.085616</td>
<td>0.005189</td>
<td>0.000134</td>
</tr>
<tr>
<td>Paris</td>
<td>0.013980</td>
<td>0.109842</td>
<td>0.016994</td>
<td>0.000000</td>
</tr>
<tr>
<td>Perth</td>
<td>0.140752</td>
<td>0.291012</td>
<td>0.000000</td>
<td>0.003228</td>
</tr>
<tr>
<td>Phoenix</td>
<td>0.275804</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>San Francisco</td>
<td>0.025169</td>
<td>0.098224</td>
<td>0.017577</td>
<td>0.000000</td>
</tr>
<tr>
<td>Stockholm</td>
<td>0.000000</td>
<td>0.444613</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Sydney</td>
<td>0.033314</td>
<td>0.130013</td>
<td>0.023265</td>
<td>0.000000</td>
</tr>
<tr>
<td>Tokyo</td>
<td>0.118474</td>
<td>0.000000</td>
<td>0.000000</td>
<td>0.003954</td>
</tr>
<tr>
<td>Toronto</td>
<td>0.000000</td>
<td>0.387711</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Vienna</td>
<td>0.087222</td>
<td>0.454318</td>
<td>0.000000</td>
<td>0.000000</td>
</tr>
<tr>
<td>Washington</td>
<td>0.029035</td>
<td>0.113313</td>
<td>0.020277</td>
<td>0.000000</td>
</tr>
<tr>
<td>West Berlin</td>
<td>0.054177</td>
<td>0.460766</td>
<td>0.000000</td>
<td>0.002856</td>
</tr>
</tbody>
</table>
Tab.5-9 shows the slack variables for each city to satisfy the inequalities at their optimum efficiency respectively. This table shows the strength and weakness of each city at each of their variable at a different angle which helps to make a better understanding.

The DEA method is a very useful analysis method that it can give many results from many aspects. Many other models can be applied at the user’s willings. In this research, we just selected the analysis results that can lead to useful discussions for the issue of transport sustainability.

5.4 Discussion on the analysis result

Now we will give some discussions on the analysis result listed above. As is stated in advance, the data we adopted is too old to give reasonable suggestions for references of the cities nowadays. We just analyze the situation at that time point of the objected cities to show the application of the DEA method on the evaluation of transport energy achievement efficiency.

According to the analysis result by BCC model of DEA method, among the 24 object cities, 13 of them are relatively efficient; the other 11 cities are not so efficient comparing with the former efficient cities. In this section, discussion will mainly be made based on the result of the transport energy achievement efficiency value and the excess or inadequate of the variables.

First we discuss on the relatively efficient cities. Although their efficiencies are all the perfect number 1, the advantage output variable and the extent of excess are all different from each other. Meanwhile, due to the limitation of the DEA method, DMUs with each of the highest output variables is considered to be efficient regardless of the amount of other outputs. In this research, object city with the perfect efficiency is not certainly the ideal transport sustainable city as well especially for the cities that have advantage of the indirect output variables. The result should be analyzed case by case. Tokyo, whose value of passenger kilometers in public transport is far more exceeded
than any other cities, shows its strong ability of public transport system on carrying passengers. The complicated railway lines in and around the city offers enormous transport capacity under punctual schedule. As a cosmopolitan, Tokyo set a good example on satisfying the travel number of passengers mainly by public transport system and it should be evaluated as an energy efficient city out of question. Similarly, Hong Kong is another good example on its excellence of public transport system. In fact, the average amount of output variable for passenger kilometers by energy consumption in Hong Kong is the most of all. It is also a good example for the cities with this scale for the public transport system supporting transport capacity. Copenhagen shows its excessive output on the road network length, it can be understood easily that Copenhagen encourages the use of bicycle rather than vehicles by planning bicycle-only lanes and add special taxes on the purchase of cars. Bicycles consume no energy while satisfying the transport number so they are more ideal than vehicles on the aspect of energy consumption. San Francisco, Denver and Washington are the cities which lack the most value of the output of passenger kilometers travelled. It may be attributed to the low rate of passengers in each vehicle in these cities. San Francisco, Denver and Stockholm lack vehicle kilometers travelled which means the energy intensity is not so ideal. Adelaide has the most excessive indirect output of vehicle number on register. As to the reason, low utility of vehicle, or high efficiency of logistics may explain. In summary, each city could find out the evaluation respectively for evaluating and adopting corresponding policy.

The DEA method developed initially is expected to show the easiest way for the inefficient DMUs to reach the efficient frontier, because in the business field, it aims to improve an inefficient DMUs up to the frame of efficient DMU with the smallest cost. In this research, we are tending to find out the worst output variable for an inefficient city to improve at first to catch up with the efficient cities. Toronto lacks passenger kilometers in public transport most, so it is suggested that Toronto should make more effort on encouraging the trips by public transport. Phoenix acts bad on the output of vehicle kilometers travelled. It may be explained by the low efficiency of fuel consuming. Eco-cars and other low energy consumption means of transport should be strongly encouraged and advocated.
5.5 Summary

In this chapter, we proposed the requirement for solving the problem on evaluating the transport energy achievement efficiency, and found out the method of data envelopment analysis which satisfies our requirements so well. Consequently, we applied the output indicators selected in the last chapter to the DEA method to analyze the relative transport energy efficiency among many cities with the help of the data book for detailed data of many cities. During the application of DEA method, we improved the method on the utilization of data to give different importance between direct output variables and indirect output variables by using natural logarithm function to squeeze the multiple between values of indirect output variables. The analysis result gave comprehensive conclusions in many aspects. Corresponding discussions were done based on the analysis result for both the efficient cities and the inefficient cities.
References


Kaoru Tone., 2006. The Evaluation and Improvement of Business Efficiency- by the method of Data Envelopment Analysis.

M. Fukui. College Analysis Software Ver. 4.0.


William W. Cooper, Lawrence M. Seiford, Kaoru Tone., 2005. Introduction to
Data Envelopment Analysis and Its Uses with DEA-Solver Software and References. Springer.


Yoshino D., Fujiwara A., and Zhang J., 2010. Environmental efficiency model based on data envelopment analysis and its application to environmentally sustainable transport policies, the 89th Annual meeting of the transportation research board CD-ROM.
6. CONCLUSIONS
6.1 Summary of the dissertation

In this paper, the concept of "achievement efficiency in transport energy consumption" was initially proposed for the evaluation of one aspect on transport sustainability and the following related research was continuously done around this issue. First, we focused on the direct factor that affect the energy efficiency, which is the total energy consumption in transport sector, the crucial factors that lead to the excess energy consumption were found by the method of decomposition analysis. For one certain time period, the amount of change in transport energy consumption was completely decomposed into the effect of the change of every factor mathematically. Consequently, which factor contributed to the change of the consumption most was revealed and the corresponding measures were suggested to be taken with priority. The same research done in continuous periods could obtain the tendency in these periods for the change of each factor. On the other hand, in order to calculate the transport energy achievement efficiency of the regions to evaluate the degree on transport sustainability of each region, the indicators that can represent the achievement of transport energy consumption should be convincingly found out. At the beginning, we scanned over a lot of literatures connected with indicator theory and then focused concentration on the transport related indicators. Thanks to these previous researches, the method of indicator selection by the criteria was applied on the issue of finding out proper indicators represent output variables of transport energy consumption. Proper indicators were picked up from the candidate indicators, which were the affecting factors to the issue. After that, using the selected indicators, we introduced the method of data envelopment analysis to do quantitative analysis to get the achievement efficiency of transport energy among regions. The analysis result told the efficient regions and the inefficient regions apart. What's more, the detailed efficiency value of each region was also laid out clearly. For improvement, the inadequate output or input variables of the inefficient regions were listed compared with the efficient regions so that corresponding transport policy implications can be resulted for the inefficient regions to reach sustainability. In summary, this paper arranged the issue of achievement efficiency in transport energy consumption from many points of view to do related quantitative
analyses. The evaluation of regions on this issue and policy implication and suggestions for improvement were got as well.

The achievement and novelty of this research can be summarized as follows:

1. This research proposed the concept and its calculation formula of “achievement efficiency in transport energy consumption” initially. Based on this evaluation index, it was available to measure how regions perform on the degree of transport sustainability from one aspect.

2. This research gave perfect decomposition result for factors on their contribution to the change of transport energy consumption during the periods in order to get more precise result. Meantime, vector variables represented different means of transport were introduced as one of the factors to describe the characteristics of the variety means of transport.

3. This research introduced the method of indicator analysis into the field of transport sustainability for quantitative analysis to select the proper variables to represent the output variables for the achievement in transport energy consumption. It solved the problem in the previous research for the subjectivity and uncertainty of the variables selection and made the quantitative analysis result robust.

4. This research applied the theory of indicator analysis on the very field of transport energy consumption for determining the way to choose from the candidate indicators into the indicators in transport energy consumption. Based on the practical situation, indirect output variables were classified for representing the achievement by transport energy consumption.

5. This research introduced the method of data envelopment analysis to do quantitative analysis for calculating the achievement efficiency of transport energy among regions. On the process of applying this method, we had succeeded on solving the problem to give different weight on the data with different importance, for we utilized natural logarithm function to compress the multiple between data to make the effect by the indirect indicators less important. Furthermore, both output-oriented model and input-oriented model were applied to give comprehensive analysis for every inadequate variable.
6.2 Further researches prospect

We have tried very hard to make this research perfect as we could; however there are nevertheless certain limits in this research due to some confinement from many aspects. Some elements were not taken into consideration and sometimes we didn’t spread out more widely to get more information for further research. They are listed in the following for the convenience of further study to make this research perfect.

1. The evaluation by the criteria for indicator selection: In this research, ten criteria were considered to be of the same importance on the evaluation. In fact, the importance of each criterion is probably different due to the emphasis of the indicators concentrate on. Therefore, according to the requirement of the indicator, setting a group of importance weights to each criterion may be more reasonable. On the other hand, at the step of scoring the candidates to each criterion, it would be more convincing to show evidence on the scoring. Furthermore, some researchers did study on multi-criteria evaluation method for joint consideration of indicators, which is also considered to be a method with better understanding, although it is much more complex.

2. The application of indicator selection for practical problem: When choosing the candidate indicators for the output variable, it seems to be more fluent if giving the choice of the candidates. After the total of evaluation scoring comes out for each candidate, it is better to make it clear for the division line between the selected indicators and others.

3. In chapter 4 when we did the efficiency evaluation, the data we used for the 24 cities is in the year 1980, which is really old for today. We didn’t find a later data with this precise by numbers of cities and indicators. It is apparently more ideal to do this analysis with contemporary data to get applicable result for policy implication. Besides, performing analysis for various periods and in other DEA models for contrast may also make this research more interesting.
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How time flies! It’s time that my life in Osaka University as an international student comes to the end. Looking back these three years, I’ve learnt much in many aspects and now I believe I really grow up after walking off the campus. I’d like to express my sincere gratitude here to everyone who gives me support for my study in Osaka University.

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