UNIVERSITY OF SOUTHAMPTON
School of Civil Engineering and the Environment

THE EQUITY AND EFFICIENCY IMPACTS OF CONGESTION CHARGING MEASURES: THE CASE OF SEOUL, KOREA

By

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ABSTRACT

FACULTY OF ENGINEERING, SCIENCE & MATHEMATICS

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Doctor of Philosophy

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Congestion charging has been floated as an efficient way of managing travel demand in urban areas, reducing traffic congestion and externalities as well as raising revenues to fund transportation improvements. Moreover, the policy maker who faces heavy traffic congestion now considers it as a promising policy alternative. This situation has led to an encouraging evaluation methodology that analyses the impact of the congestion charging scenarios. However, in contrast with substantial studies on evaluation of congestion charging, comprehensive assessment, namely, trade-off between equity and efficiency, has attracted little attention so far. In addition, although studies have argued about the generated revenue for managing equity, little attention has been paid to assess the impact of revenue return as a compensating policy.

The main objective of this study is to investigate and identify the impact of congestion charging measures in terms of equity and efficiency based on full implementation scenarios for Seoul in Korea. In order to achieve the objectives, the evaluation criteria has been explored in terms of equity and efficiency with the theoretical background of congestion charging, and the impacts of congestion charging have been analyzed through case studies such that charging on CBD, 2nd CBD and both. The equity is analyzed on the basis of the compensating variation measure for three income groups which can provide an index of political acceptability. The efficiency is analyzed in terms of net social welfare and traffic improvement that can be used to assess the practicability of congestion charging implementation. Finally, the revenue return which is substantially related to acceptability is examined. It is noteworthy that estimating the compensating variation by income group and expanding it to social-welfare change in a whole system in conjunction with cost-benefit analysis is a substantial advance in measuring the equity impact within the efficiency outline.

Through this study, some empirical findings can be drawn; Congestion charging provides an efficiency improvement as congestion relief, increases net social welfare, but there are equity impacts as user benefit varies by toll level across the income groups. Determination of congestion charging scheme is heavily relied on not only the characteristics of charging area such as mode share, parking facilities, road network and public transport but also the traffic pattern such as traffic volume of inner, inbound, outbound, and go through in duo-centric city. It is also found that the optimal toll that is deemed to maximize social welfare is much higher than the existing toll level, so an applicable toll level has to be determined by policy objectives that maximise either social welfare or revenue. Furthermore, reduced fare of public transport as a compensating policy makes an improvement of equity as a fairer distribution whereas the economic efficiency does not make an additional improvement as a social welfare change. However, considering the limitations of the model, including use of fixed demand O/D and static short run analysis, further study would lead to an analysis of a dynamic model, variable demand and longer-term view, with more realistic assumptions.

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DECLARATION OF AUTHORSHIP

I, **Yongwook Lee** declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

[The Equity and Efficiency Impacts of Congestion Charging Measures: The Case of Seoul, Korea]

I confirm that:

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3. Where I have consulted the published work of others, this is always clearly attributed;
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7. Either none of this work has been published before submission.

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Date : ....

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ABBREVIATIONS USED

ANPR	Automatic Number Plate Recognition
bn	Billion
Br	Bridge
CBD	Central Business District
CC	Congestion Charging
CEC	Commission of the European Communities
CfIT	Commission for Integrated Transport
CV	Compensating Variation
CVPP	Compensating Variation Per Person
EAC	Expected Accident Costs (₩/km)
ECMT	European Conference of Ministers of Transport
ERP	Electronic Road Pricing
ETC	Electronic Toll Collection
Eq	Equation
Fig	Figure
IVTT	In Vehicle Travel Time
IRTAD	International Road Traffic Accident Database
ITS	Intelligent Transport System
KOSIS	Korea Statistical Information Service
KOTI	Korea Transport Institute
KPA	Korea Petroleum Association
KRIHS	Korea Research Institute of Human Settlements
MCPF	Marginal Cost of Public Fund
mn	Million
MNL	Multinomial Logit model
MPC	Marginal Private Cost
MSC	Marginal Social Cost
Mt	Mountain
OC	Operating Cost
OD	Origin Destination

OVTT	Out of Vehicle Travel Time
PCU	Passenger Car Unit
PCE	Passenger Car Equvalent
POA	Probability of Accident
PT	Public Transport
PRMSE	Percent Root Mean Square Error
RMSE	Root Mean Square Error
ROCOL	Road Charging Option for London Working Group
TfL	Transport for London
tn	Trillion
TRG	Transportation Research Group, at the University of Southampton
SDI	Seoul Development Institute
SMG	Seoul Metropolitan Government
VHT	Vehicle Hours Travelled
VKT	Vehicle Kilometres Travelled
VOT	Value of Time
VOC	Vehicle Operating Cost
WTP	Willingness To Pay

INTRODUCTION

1.1. STUDY BACKGROUND

Due to the rapid growth in travel demand, which is associated with the growth in car ownership, urban transport is faced with the problem of external social diseconomies, such as severe traffic congestion and air and noise pollution. Thus, the major cities in the world have endeavoured to cope with the problem through the construction of new infrastructure facilities, such as roads, or via reinforced demand management. The transport supply policies, however, such as the building of new roads, increasing the capacity of the existing road network, and providing additional parking spaces, have reached their limits because they require enormous funds and land. Moreover, the transport supply policy in urban areas has been in a vicious circle; that is, infrastructure expansion makes it difficult to meet the increasing demand due to the additional potential demand as well as the high cost.

Congestion charging has recently been considered an efficient way to manage the transport demand in urban areas, reducing traffic congestion and externalities as well as raising revenues for fund transportation improvement efforts (Ho et al., 2005; Yang and Zhang, 2002). The principles of congestion charging assume that a toll equal to the user externalities, or the difference between the marginal social cost and the marginal private cost, is charged on each link so that the optimal network traffic flow condition can be obtained. The traditional best pricing theory, marginal cost pricing, is well established and widely advocated by economists (Knight, 1924; Pigou, 1920) and has been proposed as a practical means of reducing the externalities arising from road use since the Smeed Report (Ministry of Transport, 1964).

Moreover, substantial traffic growth is forecasted over the next decades, unless the demand for car use is managed in a number of cities (CfIT, 2006a). With the traffic growth and the increasing concern over the external costs of traffic congestion, it is likely that there will be greater use of congestion charging as an effective traffic management tool (Glaister and Graham, 2003). Policymakers in cities with heavy traffic congestion are increasingly considering congestion charging as a transport policy. This has generated many studies, ranging from those that aim to develop methods of obtaining optimal pricing system designs (Verhoef, 2002a, 2002b; Yang and Zhang, 2002; Ho et al., 2005) to those that aim to evaluate the effects of congestion charging implementation (Zhang and Yang, 2004; Santos and Fraser, 2006; De Palma and Lindsey, 2006; De Palma et al., 2006). Investigations have also been made into why road pricing should be introduced to cope with the traffic congestion (Button and Verhoef, 1998; Rouwendal and Verhoef, 2006), how the economic principle will work on a general congested road network (Yang and Huang, 1997), and the nature that the congestion charging policy must adopt to reduce the external costs imposed by traffic congestion (De Palma et al., 2006; Walters, 1961; Vickrey, 1969; Yang and Huang, 1997). In spite of the contributions of these studies, congestion pricing has been rarely implemented in reality due to the following reasons:

- It is not easy to determine the optimal toll in reality, based on marginal cost pricing, which is the theoretical background of congestion charging. Further, the toll is generally determined to be exceedingly high. This situation leads to the second-best pricing.
- As most of the proposed charging areas are situated in the socioeconomic centres of cities (Eliasson & Mattsson, 2006), there is a general concern that charging will cause reductions in travel to such areas, which will affect their economic performance.
- The increased traveller costs due to charging can affect land use (e.g., housing and industry) in the long run, with less desirable outcomes of the dispersion of activities.
- There is a possibility that congestion charging will generate higher benefits for the high-income groups, who value time highly. The resulting equity issue will pose an obstacle to the implementation of the policy.
- The people and politicians strongly object to the implementation of the policy as it will require them to pay for road use, which is typically free.

Despite these concerns, empirical evidences indicate that congestion charging will generate social-welfare improvement (May, 1992; Santos, 2004a, 2004b; De Palma and Lindsey, 2006; Chung et al., 2006). Politicians, however, have been reluctant to make a decision to implement road pricing due to the problem of public acceptability due the potential discontent of the vehicle users, who are already paying for road use through a variety of taxes. In addition, the welfare of the poor has a relatively high weight in the evaluation of policies with potential undesirable regressive effects in the society (Santos, 2004).

This situation necessitates congestion charging implementation impact analysis with respect not only to efficiency for social-welfare improvement but also to equity in terms of fair distribution. *Efficiency* refers to the extent to which the implementation of the policy yields the highest possible net social benefits, defined as the difference between the social benefits and the social costs, whereas *equity* refers to the distribution of the effects of the policy implementation and whether they are considered fair and appropriate. The conventional assessments of the effects of congestion charging implementation that can be found in the related literature focus on efficiency, measured in terms of time and money (Lo and Hickman, 1997). Potentially, effectiveness is measured in terms of contribution to efficiency and revenue generation, and the focus is on the conventional economic-efficiency analysis of the policy's benefits.

From the related literature, however, which will be described in greater detail later in this paper, it is evident that road users have difficulty identifying the equity and efficiency effects of congestion charging implementation. Moreover, the empirical evidences and policy experiences from the limited congestion charging implementation cases mainly addressed efficiency improvement. Moreover, as congestion charging implementation can be foiled by equity concerns, most policymakers sincerely want to address such equity concerns and will be happy to incorporate equity into their analysis (Litman, 2002). In contrast, however, to the substantial studies on the evaluation of congestion charging, a comprehensive assessment, such as of the trade-off between equity and efficiency, has received very limited attention so far. In addition, studies have argued about the revenue generated by equity management (e.g., Small, 1992; Litman, 2005; Morrison, 1986; Harington et al., 2001), and little attention has been paid to the assessment of the impact of revenue return as a compensating policy.

This necessarily leads to two issues when assessing congestion charging implementation: the trade-off between efficiency in the use of resources and equity as fair distribution effects on each income and user group, and the fair distribution of revenue so as to reduce the regressive impact of congestion charging and to improve the social efficiency. It is expected that the trade-off between equity and efficiency will not only lead to practical guidelines for congestion charging implementation but will also generate further work in the field of congestion charging evaluation.

1.2. RESEARCH OBJECTIVES

The evaluation of congestion charging for the policy implementation is potentially divided into two issues: efficiency, defined as the difference between the social benefits and the social costs, and equity, defined as the distribution of the effects of the policy and whether they can be considered fair and appropriate. A successful congestion charging policy has to be well matched in a social system but must also be acceptable to each affected user group, corresponding to efficiency and equity. This necessary leads to must meet a range of criteria related to impact assessment and analysis before the implementation of the policy.

The objectives of this study are to investigate and identify the impact of congestion charging measures in terms of equity and efficiency. To achieve this objective, evaluation criteria corresponding to equity and efficiency were explored along with the theoretical background of congestion charging, and the effects of the policy were analysed through a case study, with the South Korean city of Seoul as the subject. This process may provide not only a better understanding of the effects of congestion charging, including the trade-off between equity and efficiency, but also practical guidelines for the implementation of the policy. The specific aims and objectives of this research are summarized as follows:

i. to investigate and identify the evaluation criteria in terms of equity and efficiency for the congestion charging policy;

ii. to examine the impact of equity and efficiency in accordance with congestion charging by considering its full implementation in Seoul, Korea;

iii. to examine the variation of the impact of equity and efficiency by the toll revenue return in accordance with the reduced fare of public transport; and

iv. to examine the trade-off between the equity and efficiency of congestion charging.

1.3. OUTLINE OF THE THESIS

This thesis is organised as follows:

The general background of the study, and its specific objectives and outlines, are presented in Chapter 1.

Chapter 2 starts with a review of the theoretical background of congestion charging, leading to the establishment of a basis for governmental intervention in the transport market. The key reasons for congestion charging are outlined, and reviews of the congestion charging research practice are made to capture the research trend and emerging issues with regard to congestion charging.

The efficiency of congestion charging is discussed in Chapter 3, and the theoretical background and measurement methods of, as well as the evaluation criteria for, the efficiency of congestion charging are reviewed. Investigations are also made into how the policy's effects are incorporated into the evaluation of the policy's efficiency, taking into account the assessment methods used, to obtain more information and to increase the reliability of such information. Particular emphasis was placed on the social-welfare changes, which could serve as the bases of the selection of the assessment indicators, and of their use.

The equity of congestion charging is discussed in Chapter 4. The equity of the policy is reviewed by identifying the equity-related issues arising from congestion charging as well as how the evaluation criteria and the methods of measuring the equity effects were derived. Moreover, to attain the study's objective, this chapter provides an overview of the current transport equity issues, defines the various types of transport equity, discusses the methods of evaluating the equity effects, and describes ways of incorporating equity analysis into a congestion charging policy.

Model application for the evaluation of congestion charging is considered in Chapter 5. This chapter provides a data description of the model corresponding to the mode choices and traffic assignments, and provides an evaluation methodology with respect to equity and efficiency. In addition, it provides an overview of the transport in Seoul and of its 10-year experience of implementing congestion charging. Then, the charging regimes for the case study are described following their selection based on travel and socioeconomic data.

The case study is discussed in Chapter 6, following a description of the impact analysis model that was used in the study, including the framework of the model, the scenario, and the evaluation criteria, and an analysis of the effects of the policy implementation in terms of equity and efficiency, along with the trade-offs. In addition, as a further equity issue, the revenue return effects analysed based on the reduced fare of public transport are introduced. The results that were obtained from the case study, and the discussion that was drawn based on these, are presented towards the end of the chapter.

Finally, the conclusions and research findings of this study are presented in Chapter 7. The relevant issues that should be explored in the further research are also listed therein.

THEORETICAL BACKGROUND OF CONGESTION CHARGING

1.4. INTRODUCTION

Congestion charging is considered as an efficient way of managing transport demand in urban area, reducing traffic congestion and externalities as well as raising revenues to fund transportation improvements. The justification for congestion charging is an economic one that is well accepted and its explanation is plentiful in the literature (Ho et al., 2005; Yang and Zhang, 2002). The principles of congestion charging were advanced by economists in the 1920's (e.g. Pigou, 1920; Knight, 1924). In 1960's interest in this topic surged (Walters, 1961, Vickrey, 1969), particularly, a government study (Ministry of Transport, 1964) provided the first major policy analysis of congestion charging as a UK landmark. Since then, a great deal of research has been done and a number of attempts to introduce congestion charging have been made such as Singapore, Norway, London and recently Stockholm.

Congestion charging is used as various terminologies such as road user charging, road pricing, congestion pricing, road tolling, variable pricing, etc, all of which generally reflect the same principle. In the UK, the term of road pricing was introduced (Ministry of Transport, 1964) to cover any fiscal form of traffic measures including both direct and indirect charges on road users in the early 1960s. During the 1990s, the term of road user charging was widely used to specify direct charging schemes, but since 2000, congestion charging has become more popular (Saleh, 2005). Although the principle of congestion charging has been debated for many years, there are still quite a few policy applications in practice.

The objective of this chapter is review the theoretical background of congestion charging in order to justify the charging for a transport policy. A particular emphasis is on the feasibility of congestion charging implementation as a policy. Thus, the main concern in the review is why congestion charging should be implemented, and so the equilibrium of demand and supply curve in economic perspective is introduced to explain marginal cost pricing in congestion charging. An additional objective of the chapter is exploring the key issues of congestion charging to catch up the recent research trend and emerging issue of congestion charging. Moreover, why the equity and efficiency is significant in congestion charging scheme will be investigated.

This chapter is organized as follow. Section 2.2 briefly reviews the theoretical background of congestion charging and section 2.3 explores key issues of congestion charging with recent research trends and emerging. Finally, a summary of the review and a discussion is given at section 2.4.

1.5. NECESSITY OF CONGESTION CHARGING

Increased social cost of private car use such as congestion, noise, air pollution has become a significant problem to be solved in densely populated areas. Policy makers are increasingly turning toward strategies that attempt to control or reduce congestion by controlling traffic demand (Mun et al., 2005) and hence it has been applied for many years in a large number of cities, proving to be very effective in reducing traffic flows in the congested areas and increasing the speed and reliability of public transport vehicles (Meyer, 1999; Giuliano, 1992b; Garling et al., 2002). And congestion charging is considered as an efficient way to managing transport demand in urban area. In general, congestion charging aims to reduce private traffic in specific areas, normally the city centre, mitigating congestion and improving public transport performance. Traditional economic theory suggests that external costs can be internalized by introducing taxation to equal the externality. The feasibility of congestion charging policy starts from breaking the vicious circle for in efficient transport system. In addition, it reviews the theoretical background of congestion charging leading to a basis for governmental intervention in transport market.

1.5.1. Breaking the transport vicious circle

Economic growth provides the first momentum to increase car ownership. More car owners means more people want to transfer from public transport to car; this in turn means fewer public transport passengers, to which operators may respond by increasing the fares, reducing the frequency level of service or both. These measures make the use of the car even more attractive than before and induce more people to buy cars, thus accelerating the vicious circle of car and public transport (See **Fig**. **2-1**). After a few cycles, car drivers face an increased level of congestion, and buses are also delayed and thus become increasingly more expensive and run less frequently. These repeated actions by individual decisions result in a final state in which almost everybody is worse off than originally.

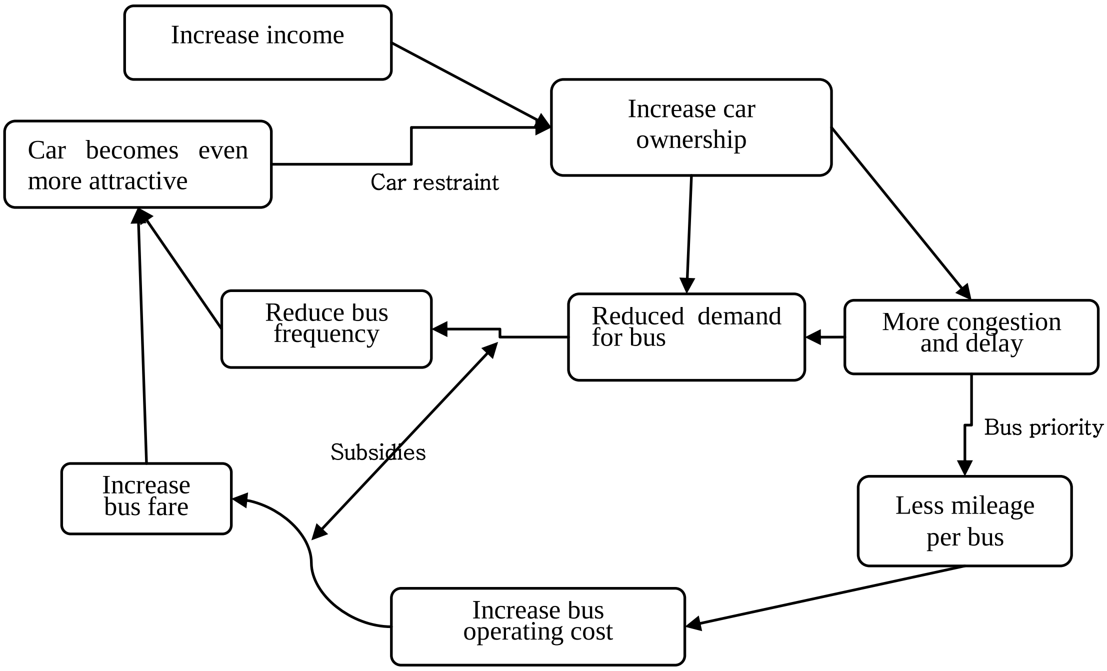

Figure 0-1 Car and public transport vicious circle
Source: Ortuzar & Willumsen (2001)

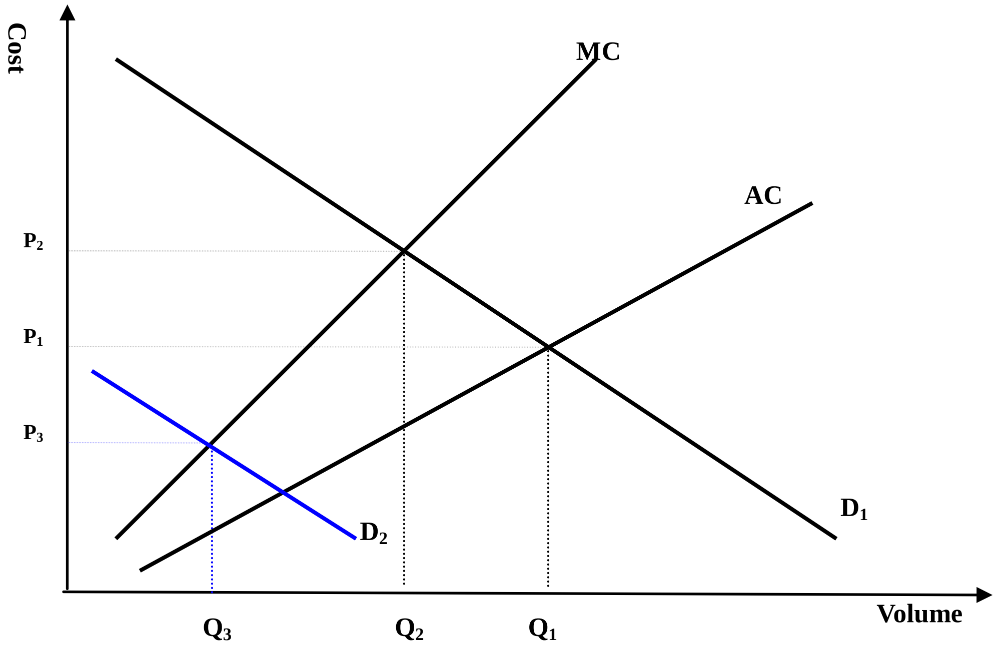

Figure 0-2 Edgeworth Paradox

The effect of policies for restraining car use by charging for it was explained by the Edgeworth paradox (Mogridge, 1995). It states that introduction of a toll on individual transport can reduce the equilibrium trip cost. In transport market, as shown **Fig. 2-2**, the demand-supply reaches to a equilibrium initially at Q_1,P_1 , which is the intersection point of the demand curve (D_1) and the average cost curve (AC). If the marginal cost pricing is introduced, however, the equilibrium point is moved to Q_2,P_2. This causes the original demand curve (D_1) shift inwards to D_2 as supply of public transport increases. As a result, the traffic equilibrium will be reached at (Q_3,P_3) where MC and D_2 intersect, and where paradoxically P_1, >P_3. Note it may need a big shift if demand is inelastic. Likewise, a differentiated charge between the average and marginal cost leads to a new equilibrium with a shift away from individual transport to public transport and a lower trip cost. The introduction of a congestion charging could therefore reduce equilibrium trip cost.

According to the Edgeworth paradox[1], if the car users were charged for road use, they will be changing to public transport mode, creating a new point of equilibrium with lower trip cost in the overall context of the system. That is meant to bring about the convergence to a lower equilibrium trip cost by imposing congestion charges. The same is true with the phenomenon of mode shift from individual to public transport as the suppressed demand of individual transport in the Downs-Thomson paradox is converted to public transport demand on account of imposition of congestion charges. These approaches can break the car and public transport vicious circle shown in **Fig. 2-1.** On the other hand, traffic congestion has often neither fallen in the long run nor travel speed increased in spite of increased road capacity to reduce traffic congestion. In the short run, this enlarged capacity is quickly filled up with more road traffic. Therefore, the transport authorities expand roads capacity more, but again they are quickly filled with more traffic.

Viewed from a long run perspective, it is apparent that traffic congestion does not fall. It is addressed that the expected effects of road projects are negated by insatiable road travel demand (Romilly, 2004). Downs (1962) and Thomson (1977) maintain that the enlargement of road capacity for personal transportation will increase the transportation costs of the entire city rather than helping to alleviate road congestion. In other words, expansion of road network will help to ease road congestion in the short run, but this will result in encouraging the public transportation users to use their own cars. This feedback effect can be so large in certain cases that when the system reaches equilibrium the performance on the roadway system is even worse

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[1] Note that Edgeworth's 's original work was an first and second class rail travel (Edgeworth, F.Y, 1925)

than before the capacity was added. This is commonly called the ‘Downs-Thomson Paradox’. When the capacity of the road network is increased, the supply curve for individual transport shifts to the right. The new point of intersection in **Fig. 2-3** implies a shift away from public transport toward individual transport and a higher equilibrium trip cost. Note the introducing marginal cost pricing would be similar to shifting from AC_1 to AC_2.

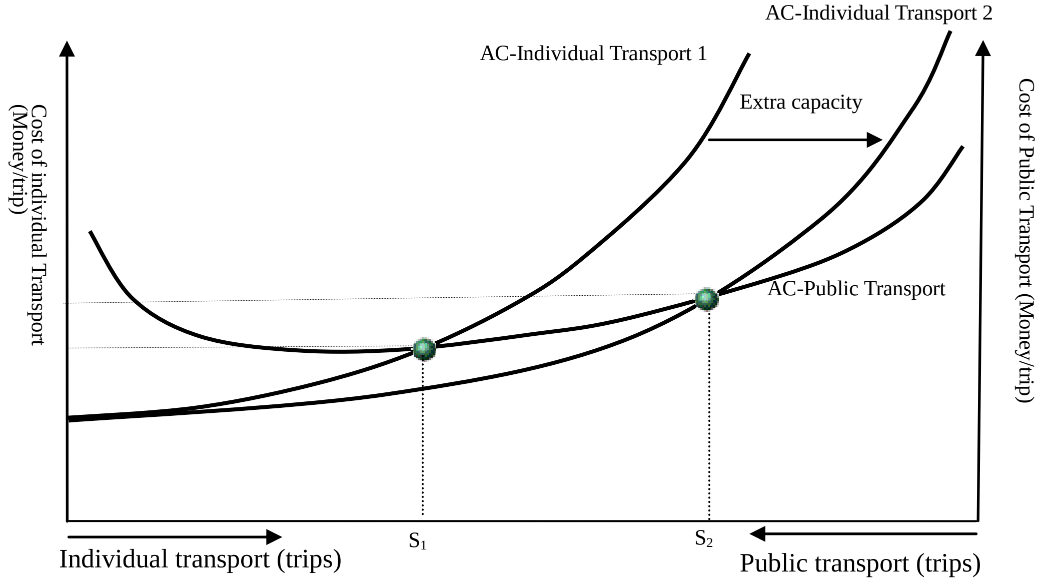

Figure 0-3 Downs - Thomson paradox
Source: Bell & Iida (1997)

According to the Downs-Thomson paradox, the use of personal and public transportation modes will be balanced out at the level of public transportation mode with passenger vehicle users responding more sensitively to the fluctuation of transportation costs than to variation of traffic volume given that the transportation cost curves of public transportation modes and personal passenger vehicles are basically different. This addresses that the travel time or travel speed of each mode is attributable to mode shift, therefore yields the principle of an argument that modal change from personal to public transportation is to be caused to reach the state of balance by levying congestion charges. The Edgeworth paradox is similar to the Downs-Thomson paradox, which is a phenomenon that occurs due to the difference between the individual transport cost curve and public transport cost curve, excepting for the difference that the Downs-Thomson paradox increases the individual trip cost by enlarging the road capacity, rather than charging a toll or tax.

As seen at a new direction for UK transport policy with the publication of the government's transport White Paper (DETR, 1998), one of the key directives of this policy was that the government would no longer attempt to accommodate traffic growth through a strategy of "predict and provide." That is, road construction would not continue to meet forecast traffic growth. The level of forecast infrastructure needed to meet an unconstrained growth assumption was seen as unsustainable both environmentally and financially. Goodwin (1999) states that this allows the recognition that alternative options, such as increased public transport and non-motorized modes are increasingly important. Integration of all modes of transport was seen as a key goal while simultaneously reducing the need for motorized transport. An emphasis on maintaining existing road infrastructure, rather than increasing its capacity, was another key element. The recognition that some road pricing options would be desirable, both for moderating demand, and for raising revenue for alternatives was another key conclusion.

1.5.2. Marginal cost pricing of congestion charging

The theoretical background of congestion pricing has relied on the fundamental economic principle of marginal cost pricing, which states that road users using congested roads should pay a toll equal to the difference between the marginal social cost and the marginal private cost in order to maximize social net benefit. As Pigou (1920) introduced the concept of an externality, the congestion charging began to surface as the centre of attention, with a congested road used as an example providing a theoretical basis for congestion charging. Pigou's basic concept is that congestion tolls, in which social cost brought about by congestion are reflected, would eventually make the drivers realize that the tolls are true social costs incurred by themselves. Through this, only cost-justified trips would be available, and as a result, only those who find using them to be of the highest value will use roads.

Let us consider the diagram representing the quantity of road usage on X-axis and the unit costs of road usage on Y-axis in **Fig. 2-4**. This can be applied to a given road or area, and road usage can be measured in vehicle km. It is presumed that the supply of road is fixed and social cost is the generalized cost as short-run marginal cost that takes account of both the travel time and travel cost. D(X) is a demand curve of road usage, as a function of the unit cost of using the road. MSC(X) stand for the social marginal cost curve of road section, and ASC(X), which could be called as supply curve, is the individual average cost curve of road usage.

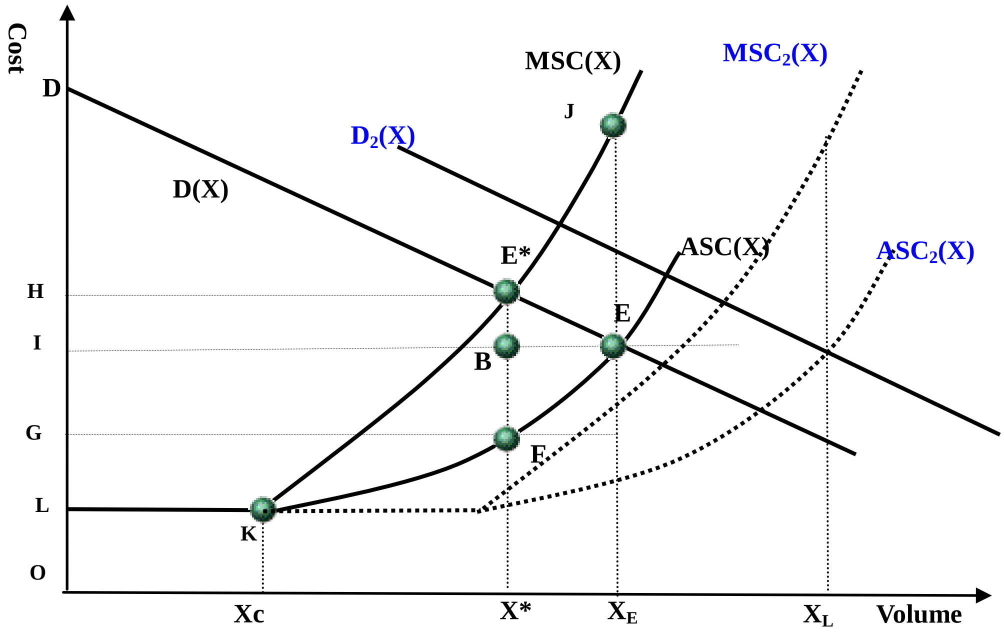

Figure 0-4 Congestion charging by utilizing demand and supply curve

For section (O-Xc) where all users can use the road at optimum operation speed because there is no congestion, travel cost per car is the same. However, once the free flow traffic volume Xc is exceeded, traffic congestion occurs causing the marginal cost to exceed the individual average cost, contributing to the occurrence of external diseconomies. An equilibrium will be reached at E, where ASC(X) and D(X) intersect, with X_E vehicle km driven in the zone, and a unit cost of I. At this point, the marginal driver bears a cost equal to the benefit he/she derives from road usage. Beyond, he/she would bear a cost greater than the benefit derived, and thus would not use the road. This natural equilibrium is suboptimal.

This is easy to see when we consider MSC(X), the unit social cost created by a vehicle as a function road usage. This social cost is equal to the individual cost ASC(X), plus the cost of the additional time spent by all other vehicles due to one extra vehicle on the road. At X_E , marginal social costs (X_EJ) are considerably in excess of marginal benefits (X_E E) and overall a dead weight loss of E*FE occurs. Point E*, where D(X) and MSC(X) intersect, with X* vehicle km, and a unit cost H, is the optimal solution for society. Beyond that point, an additional vehicle generates a social cost greater than the social benefit it creates. This optimal situation can be reached by the imposition of a congestion charge equal to E*F that will reconcile the private cost and the social cost. At this point, the social surplus can be identified in **Fig. 2-4** as follows.

Consumers surplus is DEI and DE*H, before and after charging respectively. Thus, the consumers loss is HE*EBI. On the other hand, suppliers' gain is HE*BFG and net gain is IBFG-E*EB.

- Consumers surplus (before charging) : DEI
- Consumers surplus (after charging) : DE*H
- Consumers loss : HE*EBI
- Government surplus gain : HE*BFG
- Net gain : IBFG - E*EB

Alternatively, at X_E, net social benefit can be calculated as follow.

- Benefit to supplier : LKFED
- Congestion externality : KFEJE*
- Net social benefit : LKE*D - E*JE (i.e. Marginal benefit-Marginal cost)

Also, at X*,

- Benefit to supplier : LKFE*D
- Congestion externality : KFE*
- Net social benefit : LKE*D

Therefore, net gain in social benefit from moving from X_E to X* is E*JE

Several interesting conclusions can be derived from this analysis.

- Firstly, except when the demand curve intersects the private cost curve in its flat part (O-Xc), the natural equilibrium quantity of road usage is always greater than the optimal quantity of road usage: X_E is greater than X*. That is, roads are nearly always congested; they are only more or less congested. In this regard, the concept of an optimal quantity of road usage implies the concept of an optimal level of congestion. Since there is always some congestion, the objective of policies should not be to eliminate congestion completely at least in the short run but to make sure that the optimal level of congestion prevails. It can be inferred that an objective to eliminate congestion does not make much sense.

- Secondly, the optimal quantity of road usage X*, which is associated with optimal level of congestion, is a function of the demand for road usage. if the demand increases, the curve D(X) moves rightward, and so does the optimal quantity; similarly, If the slope of the demand curve decreases, that is if the demand relative to price becomes more price elastic, the optimal quantity of road usage decreases. This points to the main difference between the engineer's approach and the economist's approach: while the engineer defines the optimal road usage and congestion as a function of road characteristics only, the economist approach defines it as a function of both road characteristics and road demand (Prud'homme and Bocarejo, 2005).

- Thirdly, the optimal charge is the congestion externality, which is the difference between the social cost and the individual cost at the optimum, not at the 'natural' equilibrium. It is E*F and not JE. A congestion charge equal to JE would overshoot, and reduce road usage to a point much to the left of X*, that would be suboptimal.

- Fourthly, congestion costs should be defined as what is lost by society for not being at the optimum, for being at E rather than at E*, for having X_E rather than X* vehicle km. Congestion costs are, therefore, equal to E*JE. They are also equal to the increase in welfare associated with the move from E to E*, that is to GDE*F (consumer and government surplus, after) minus IDE (the consumer's surplus, before[2]). They are the benefits of introducing a congestion charge. In addition, under the charge, total consumer's surplus plus government revenue is GFE*D, which is greater than IBED, provided GFBI is greater than E*BE. In this case, GFBI minus E*BE is equal to E*EJ

- Finally, the amount of the congestion charge paid, HE*FG, is larger, often much larger, than the economic benefits brought by the congestion charge. To an economist, this is not a problem, because the charge is a transfer, not an economic cost. However, drivers or policy makers may certainly have a somewhat different viewpoint.

The above is a short run analysis in that infrastructure is fixed, however, infrastructure could be expanded in the long run. If government decides to enlarge road capacity in an attempt to reduce congestion, generalized travel costs fall to MSC_2, ASC_2, and expected outcome is a traffic volume X_L. Since, expanded infrastructure allows an expansion of demand (Romilly, 2004), so the demand curve shifts to $D_2(X)$. However, at the higher capacity level, road user on demand curve $D_2(X)$ still expect further capacity increases to reduce congestion. Therefore, Downs-Thomson paradox is able to be explained in terms of capacity increase corresponding to congestion occurrence.

For several decades, the fundamental point of the debate on taxation of the road use has been the theory of marginal cost pricing, starting from the welfare theories of Pigou (1920). In this theory, the social costs generated by the single user are to be 'internalized', levying on the use of each

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[2] Government surplus is zero (where there is no tax)

road a tax equal to the marginal social cost, that is, the incremental social cost induced by one additional user. Consequently, the toll imposed on the user would have to vary in accordance with the charging location, toll level, time, vehicle type, etc. The Commission of the European Communities (1998) recommended a rule of thumb for setting tariffs for the transport infrastructures in the White Paper ‘Fair and efficient pricing of the transport infrastructure’. However, the application of the theory of marginal cost pricing shows gross limitations for different reasons (Verhoef, 2002b);

- The charging structure would be excessively complicated and extremely difficult for users to understand
- The current technology, while greatly evolved in recent years, is not yet able to support so complex a charging structure
- It is almost never possible to impose road pricing on the entire network, and, at least in an initial phase, the pricing scheme should be introduced on a suitable part of the network
- The charging level of toll may not be politically acceptable.

Such obstacles have given rise to the identification of different second-best solutions which take account of the limits imposed by the practical necessities of implementation (Verhoef, 2002a, May and Milne, 2000), even if this means the process will become less efficient (Liu and McDonald, 1999). One of the most common second-best solutions is area based pricing, where access to a given portion of the road network is charged a toll. Most of the recent implementations of adopted area based pricing can be found in London, Singapore and Stockholm.

As a consequence of rapidly grown congestion problem and greater awareness of environmental problems, a lot of local city governments are considering it as an essential part of transport management in urban transportation. With the availability of the new pricing technology and increasing concern over external cost, it is likely that congestion charging will be politically justified over the next decades and be put to greater practical use.

1.5.3. Congestion charging experiences

Congestion charging experiences, once implemented, have shown impressive results leading to congestion relief in charged area, and hence it can be a successful tool to manage demand and decrease congestion and environmental costs. In the cases of London, Stockholm, Singapore and even in the Norwegian cities where the goal was not traffic management, this measure provided significant reductions in the congestion costs associated with the entrance to city centres, providing revenue to invest in public transportation or road projects.

Table **2-1** describes existing congestion charging schemes implemented in some countries. The existing schemes show that congestion charging schemes vary according to the policy objectives, pricing scheme, toll area, payment and enforcement. If the objectives were associated with economic efficiency and congestion relief, the amount of the charge and hours of operations would most likely vary throughout the day dependant upon the level of traffic (Whittles, 2003). However, if the objective were connected with merely raising revenue, then there would be less need to vary the charge. Furthermore, most of the existing schemes are area based charging; vehicles pay to cross the cordons or boundary. Likewise, the extents of the scheme, by size of restricted area and length of operating time diverge depend on objectives; if the objective was to reduce congestion the scheme might operate in only the city centre for the peak hours, where and when congestion is usually worst. However, if the objective was to raise revenue then the scheme might encompass the whole city and for longer hours, to increase the amount of revenue collected.

On the other hand, despite the benefits of congestion charging policies, they have been opposed to implement the policy by the public and government officials in many cases. Recently, the success of the London initiative as the first congestion charging program in a major European city is important for many other nations in demonstrating the political feasibility of pricing (Ison & Rye, 2005). Other metropolitan areas that have invested heavily in advanced capability in electronic tolling and associated administrative support systems in the supply chain are well placed to benefit. What we must ensure, however, is that any congestion charging system is not selected for the convenience of an appealing cordon such as the CBD, but for broader system wide efficiencies. Several experiences around the world provide lessons to be learned from successes and failures in the viewpoint of politics, public acceptance, impacts and such experiences could maximise the chances of future success.

	UK	**NORWAY**	**SINGAPORE**	**SWEDEN**	**KOREA**
City	London	Bergen, Oslo, Trondheim..	Singapore	Stockholm	Seoul
Inception	2003	1986	1998[ERP]*	2006	1996
Objective	- Primarily, to reduce Congestion - Secondly, to increase public transport use	Initially revenue generation Amendments to Road Acts now permit demand management to enhance environmental quality, safety	- Optimizing the usage of road infrastructure - Encouraging use of public transport or carpool and alternative route and time travel	Reduce congestion and improve the environment and fund increased public transport and Park & Ride.	Demand management: - Reduce congestion - Encourage use of public transport or carpool
Pricing scheme	Area licensing scheme. Paid daily Flat toll Monday to Friday 7:00-18:30	Cordon toll charging Inbound cordons. Per passage Variable tolls in Trondheim & Stavanger. Flat tolls else where	CBD cordon and linear Per passage - CBD : 07:30-19:00 - Expressway: 07:30-09:30	Cordon toll charging In & outbound trip; Variable charge Monday to Friday 6:30-18:30	Link Per passage. Flat toll Monday to Friday 07:00-21:00 Saturday 07:00-15:00
Tolled area	21 ㎢ charge area around city centre	Toll rings successively added in Bergen, Oslo, Trondheim and Stavanger.	CBD, expressways and arterial roads. Charged infrastructure progressively expanded.	30 ㎢ charge area around city centre	Nam Mt. 1,3 Tunnel
Means of payment	Post payment manually by various means	Pre payment via DSRC or manually at road side	Pre payment Cash card and DSRC	Electronic payment and various manual means	Manually payment at toll booth
Enforcement	Camera and ANPR	Camera and ANPR	Camera and ANPR	Camera and ANPR	Camera and ANPR
Differentiation by vehicle & user characteristics	Exempt : Various vehicle and individual categories. Discounts : 90% for residents, 12.5% for fleets	By vehicle type Discount for passes	Differentiated by 6 vehicle types. Exempt: Buses, Emergency vehicles	Exempt : various vehicle Bus, Emergency vehicles Taxi, Diplomatic car Military vehicles Motorcycles, etc	Exempt : Bus, emergency vehicles, diplomatic cars, taxi Discount : 50% for car with displacement under 800cc from 2003

* Supplementary Area Licensing carried out much earlier

Table 0-1 Characteristics of existing congestion charging scheme (Summarized CfIT, 2006b)

1.6. KEY ISSUES OF CONGESTION CHARGING

Researches in congestion charging have focused on the development of methodologies to determine the optimal toll and evaluation of efficiency impact. These kinds of studies provide evidence of the effectiveness of congestion charging to reduce traffic congestion and improve economic efficiency. However, according to advanced charging technology, the assessment of various charging strategies has been given a considerable attention in recent research. Furthermore equity and acceptability of the implementation of congestion charging have emerged recently as a new paradigm for the study of congestion charging in accordance with various advanced technologies and the successful implementation of congestion charging in several cities including London and Singapore. This section is allocated to review recent research trends and emerging issues of congestion charging policy.

1.6.1. Determination of optimal toll

The optimal toll can be defined as the toll that maximise the benefit, defined as social welfare improvement. Determination of the optimal toll levels has been a key issue of congestion charging research so far. Two broad categories of pricing can be defined in relation to determination of optimal charging known as first-best and second-best pricing.

ⅰ. First-best pricing

The well-known first-best pricing principle assumes that a toll equal to the user externality, or the difference between the marginal social cost and the marginal private cost, is charged on each link so that the optimal network traffic flow condition can be obtained. Based on the marginal cost pricing principle, Walters (1961) estimated an efficient system of taxation for a highway network using data on traffic flow and speed. The applications of the marginal pricing principle have been investigated by a number of authors (Beckman, 1965; Yang & Huang, 1997). Yang and Huang (1997) investigated the marginal cost pricing principle on networks in the presence of queue and delay. This is the method in that social cost incurring due to diseconomy perceived to be capable of being off set by charging the cost to road users. Congestion toll charges for all the roads that are causing congestion with a view to maximizing social welfare. However, it is not easy to satisfy such a condition from the practical standpoint (Button & Verhoef, 1998). The reason is that it is practically very difficult to measure the demand, marginal social cost and average social cost curves themselves that are reflective of the traffic condition of each given road section as well as setting up congestion sections. Consequently, the perfect first-best pricing policy is in a structure of little practical interest or application, because it is impractical to charge users on each network link, in view of the high operating cost and low public acceptance of such a method.

ⅱ. Second-best pricing

Researchers have lately devoted their efforts to the study of second-best alternatives and to the development of algorithms to find second-best optimal toll levels and locations (Verhoef, 2002a; May et al., 2002; Mun et al., 2005; Zhang and Yang, 2004). Second best pricing is the method of setting the toll levels by estimating the monetary value of the external diseconomies from traffic congestion as through computing time loss or additional costs incurred on account of traffic congestion. Though the target of the second-best pricing method is the same as that of the first-best pricing method in light of maximization of social welfare, it differs in the fact that this method can't reflect in a toll the which is the total cost of external diseconomies incurring from congestion.

Studies of second-best pricing mechanism were generally conducted with the respect to the determination of toll levels for given charge locations. Researches explored the impact of congestion charging that is different across toll location, and hence examined the performance based on the premise (Verhoef, 2002a; May et al., 2002; Yang and Zhang, 2002; Zhang and Yang, 2004; Ho et al., 2005). Verhoef (2002a) examined the selection of individual toll links and the determination of toll levels using some sensitivity indicators. May *et al.* (2002) examined the performance of various pre-specified toll cordons on a simple hypothetic network and succeed in developing a set of analytical procedures identifying the optimal locations for imposing charges and the optimal charges at those points.

Yang and Zhang (2002) considered selection of optimal toll locations and toll levels for achieving maximum social welfare using a bi-level programming approach with both discrete and continuous variables. They employed a system which the upper level program aimed to maximize the total social welfare and the lower level program was a multiclass network equilibrium model in terms of generalized travel cost. Zhang and Yang (2004) investigated the cordon-based second-best congestion-pricing problems on road networks, including optimal selection of both toll levels and toll locations. Ho et al (2005) proposed a continuum traffic equilibrium model to identify the cordon locations and charging levels of a cordon-based congestion pricing scheme for a monocentric city.

ⅲ. Comment

This kind of work has moved the theory forward but it has been applied to simplified networks and cannot be applied to actual complex networks yet. Furthermore, in spite of the fact that the charging scheme to first-best pricing method is the most appropriate one in terms of mitigating road traffic congestion, most cities (e.g. London, Stockholm, Singapore, etc.) are focusing on the second-best pricing method.

1.6.2. Charging schemes

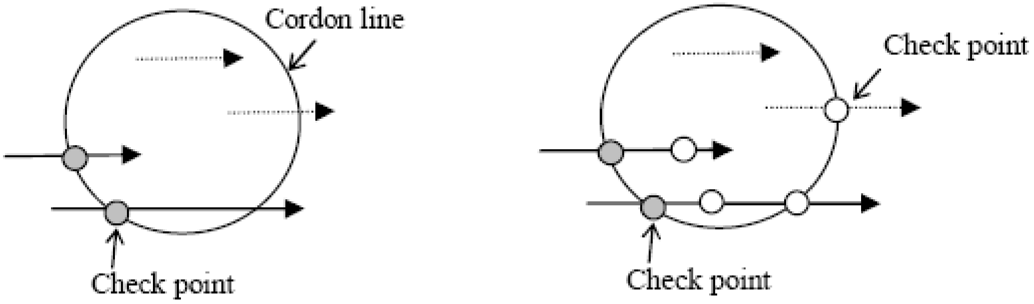
Since various strategies of congestion charging are made available with the advanced technologies, stakeholders are more interested in, besides area-based charging (e.g. cordon pricing, area licensing), the type of charging system in order to achieve the best performance result through collecting congestion charges or attain the most akin outcome of charging to that of the best available charging system. Research on various congestion charging mechanisms is being conducted, for example charging based on distance travelled, time spent travelling and time spent in congestion (May and Milne, 2000; Santos, 2001).

ⅰ. Cordon charging

Cordon pricing is equal to an entrance and exit fee into/out of a city. Vehicles entering the designated area are charged basically every time they enter the area. In a cordon pricing system, a cordon line defines around the designated area. Checkpoints are set up along the cordon line and when vehicles enter the area passing the checkpoints, vehicles are checked if they have already paid the charge (See **Fig. 2-5** A). In case of passing vehicles that have not yet paid the charge, the vehicle number is recorded. Vehicles travelling inside the area and driving out of the area are not charged nor checked**.** Cordon charging performs better as trip destinations become more concentrated around the centre. This fact suggests that cordon charging is effective in cities where the structure is close to monocentric (Mun et al, 2005). Cordon charging schemes are used in Oslo, Trondheim, and the electric road pricing (ERP) system in Singapore. Since cordon pricing is the most easily implemented charging scheme, it should be noted that the assessment employed a specific case and other patterns of cordons can be performed better. Studies have demonstrated that the performance of cordon scheme (e.g., Sumalee et al., 2005; Mun et al, 2003; May et al, 2002; Santos, 2004b) is critically dependent on cordon location.

ⅱ. Area license system

Area licence pricing also sets a designated zone but it differs from cordon pricing in that all vehicles running inside the designated area are charged by the day. Vehicles are checked but not charged not only at the entry points but also when driving inside the area and exiting the area. Since, it doesn't charge for every trip, the restraint effect is diluted. This was applied in the area licensing system in Singapore (1975-1998), and the London by charging £8 a day (initially £5). It is possible to charge according to the travel distance or the spent time within a specified area, but most cities adopt cordon pricing due to the problem of execution and for user convenience. Area pricing schemes seem simple theoretically but users' benefits can be changed sensitively according to charging time zone or charging direction (inbound, outbound or both), etc (May et al, 2002). In brief, the major difference between cordon pricing and area license pricing, the former charged every time the check point is passed and the latter charges for being in target area for a given time period.



(A) **(B)**

Figure 0-5 Area based charging system
Source : (Ohta, 2003)

ⅲ. Others

Traditional congestion charging consists of payment at a point or cordon for entry on to a particular facility (e.g. a road, bridge or tunnel). More flexible systems consist of payment for time by metering or electronic systems may charge by distance. Alternatively, some combination of point, time and distance charging may be used. Some of the recent interest in congestion charging is due to recent advances in charging technology. Armstrong-Wright (1986) proposed pricing strategies emphasizing implementation instruments, such as area licensing, parking restraints, user taxes and vehicle ownership restraints. O'Mahony et al (1999) discussed several charging scheme: cordon-toll scheme, distance pricing, time based charging and delay-based congestion charging. May and Milne (2000) compared performances of cordon-based, distance-based, time-based and delay-based charging schemes using a static assignment model and concluded that the delay-based charging scheme performed best in reducing the congestion level in the network whereas the cordon-based scheme was the least effective.

A motorist is charged a fixed amount to enter and/or leave the charged area at all or only some times of the day at the area based charging scheme. The charge does not depend on the time taken or distance travelled within the charged area nor on levels of prevailing congestion. However, in the distance-based pricing, a road user is charged according to the distance travelled, normally within a cordoned area. The charges paid by users are proportional to the distance travelled. In the time-based pricing, a road user is charged according to the time spent travelling within a specific area. Charges are related to the level of congestion, as trips in congested conditions will usually take longer than in free-flow or non-congested conditions. Finally, in the delay-based or congestion charging, a road user is charged according to its speed, which is taken as a proxy for the level of congestion on that road. The slower the speed, the higher will be the likely congestion, and the higher the resulting charge. This system requires the recording of time taken and distance travelled for each vehicle individually on a rolling basis by in-vehicle technology. In practice, the tolls can be imposed upon travellers per crossing of designated toll points or cordon line, per time or distance of travel, or per day as similar to area entry charge. Theoretically, it is still uncertain on the type of charging regime which performs best.

ⅳ. Comment

Locations of cordons are crucial, and research has lately focused on the issues (Mun et al, 2005; Verhoef, 2002a; May et al, 2002; Santos, 2004b). Generally, it is more effective to apply a shape of continuous loop or screen line around the target area rather than to apply a cordon independently (May et al, 2002). It takes an advantage that getting greater social benefits or toll revenue generation. Santos (2004b) argues that a second outer cordon implemented jointly with an inner cordon surrounding the city centre enhances the increase in social benefit in comparison to a single inner cordon. The cordon charging is more effective to reduce the traffic congestion, however, it may not be applicable in reality since the drivers could not easily realise the pricing scheme as operated and intended by the transport authorities. Accordingly, the scheme design is crucial and it appears that simple, easy-to-understand technology can boost the probability that the scheme will be a success (Ison & Rye, 2008).

1.6.3. Efficiency and equity of congestion charging

Efficiency refers to the extent to which the achievement of such a goal yields the highest possible net social benefits, defined as the difference between social benefits and social costs (Verhoef et al, 1996) whereas equity refers to the distribution of impact and whether they are considered fair and appropriate. If we consider the arguments put forward by economists in the discussions about congestion and congestion charging as a measure to fight it, the objective of efficiency always comes forward, in most cases associated with prices based on marginal social costs. Leaving aside deeper considerations on efficiency aspects (it will be deeply explored next), it may be agreed that a democratic society give priority to equity rather than efficiency and economic growth so the equity problem will be emphasised on this thesis.

There is a fairly large number of theoretical studies regarding equity issues of congestion charging (e.g. Arnott et al., 1994; Richardson and Bae, 1998; Small, 1983; Evans, 1992). From them, one can conclude that the equity effects will in general depend on the design of the charging system, when and where the charges are levied, and socioeconomic differences in travel pattern. For example, mode choice and destination choice will differ across income groups. The most studied question has been whether congestion charges will benefit the poor or the rich. Different studies have come to different conclusions. This is largely dependent on what assumptions are made about the preferences and travel behaviour of different groups, and what effects are taken into account in the study or the model.

Some literature argue that congestion charges will be regressive, since people with high income have a higher value of time, and hence more often feel that the time gain is worth the charge (Arnott et al., 1994, Small, 1983, Evans, 1992, Richardson, 1974). Furthermore, people with small economic margins will suffer more from congestion charges (Richardson, 1974). In addition, they generally have lower possibilities to decide their time for work, and thus cannot avoid charges levied during peak hours. They are more likely to live far from the city core, and their destination is more often located outside the inner city in areas where public transport is poor. What is more, if road investments are not financed by charges they have to be financed by income taxes, and since those with high incomes pay more tax they would suffer more from that alternative (Arnott et al., 1994).

On the other hand, some other literature argue that those with low incomes would gain the most from congestion pricing (Evans, 1992) and people with high incomes suffer more than those with low income (Foster, 1974; Thomson, 1998). When there is a choice between a fast and a slow mode, car vs. public transport, a toll that increases welfare is likely to be on the fast mode. Since those using the fast mode usually are the more affluent travellers, such tolls will be progressive. Moreover, since low-income groups more often use public transport, not only will they be less affected by the charges, but they will also profit more from the revenues if they are spent on improving public transport (Evans, 1992). Moreover, those with high income drive more frequently, and more often have their destination in the inner city where congestion is highest (Foster, 1974). They are also more likely to live within or close to the inner city and therefore cannot avoid the charges or choose alternative routes (Thomson, 1998).

These disparate views indicate that it is difficult to come to clear-cut conclusions about the distributional effects of congestion pricing. Rather we have to carry out equity analyses for specific congestion pricing schemes and specific cities. Such quantitative studies have been carried out for some cities, e.g., Stockholm (Eliasson and Mattsson, 2006), Paris (de Palma and Lindsey, 2006), and Cambridge, Northampton and Bedford (Santos and Rojey, 2004). These studies indicate that those with high incomes are affected the most since they more often drive a car, and in addition are more likely to live in areas with poor access to public transport. The net effect if all were to equally share the revenues would then be that those with low incomes would gain the most.

Common for all studies is that the differences in the direct benefits and costs between income groups are fairly small. It may therefore be more important for the issue of equity how different groups benefit from the use of the revenues (Eliasson and Mattsson, 2006). In many theoretical studies treating the case when revenues are channelled back in some way, it is often assumed that all trips are subject to congestion charging. This stands in contrast to most real cases, where charges are only implemented in the city centre, and where a large share of the trips is by public transport, especially in the city centre. This is for example the case in London, where only car trips in the city centre are charged, and a large majority of the trips are already made by public transport.

Further, these studies often assume that the revenues are refunded through lump-sum redistribution. It is then not unlikely that congestion pricing will be regressive. But most often, a more realistic assumption would be that the revenues would be used to increase public spending, perhaps in the form of road investments or improved public transport, to decrease taxes, or both. Clearly, different use of revenues will imply different net effects, and consequently will determine whether the charging system, viewed as a whole, will be progressive or regressive (Small, 1992). This study will come back to some of them later on in this thesis.

1.6.4. Enhancing acceptability

Congestion charging policy contribute to solving congestion and environmental problem but also financial resources for transport infrastructure. However, the policy has been conceived as a representative policy that is separated theory from reality, since it is rarely implemented in major urban cities (Santos et al, 2001). Some scholars argued with a negative perspective that the policy can not be implemented in a democratic society (Wilson, 1988). That is because of the strong objection of citizens and politicians for the policy that consumers must pay money for using a road which was previously free. Some research has been devoted to making the user know about the real benefit of charging and to reduce the repugnance against the charging policy (Goodwin, 1989; Small, 1992; Morrison, 1986; Litman, 2005; Langmyhr, 1997). They mainly discussed about how to distribute the charging revenue in order to improving equity and acceptability. Goodwin (1989) and Small (1992) have illustrated a way in which the revenue could be distributed in order to obtain the public acceptability by what he calls the 'rule of three'. The notion is that the revenue could be arbitrarily divided such that (Ison, 1996):

- A third could be used for development and maintenance of new road infrastructure, where the investment would be both acceptable and cost effective.
- A third could be allocated to improving the effectiveness of public transport.
- A third could be used to reduce the general tax burden or to increase social spending in line with the priorities of the authority.

Although arbitrary, this allocation in thirds would aim at compensating losers and promoting improvements in the transport sector. Morrison (1986) considers that political issues are primarily responsible for blocking the implementation of congestion pricing. He argues that although congestion charging may appear to be regressive, that is not necessarily always the case. His main argument is that if there is a net benefit, the government can redistribute revenues so that all groups gain. Although all income classes may be left better off after the introduction of congestion pricing, it may not be the case for individual users, some of whom may be left worse off. Also, Litman (2005) indicates that political acceptability can be secured if congestion charges are invested not only into traffic improvement but also into reducing variable tax or providing financial discount, making more peoples live more convenient.

Langmyhr (1997) state that concerns about various equity aspects seem to be a main barrier to public acceptance. He point out that the location of toll gates in a city will give rise to equity discussions and better public transport service is the most often recommended solution to counteract negative equity effects.

Empirical evidence has shown that public support for congestion charging is increased with detailed fund allocation information to public (Chung et al., 2006; Harrington et al., 2001; Ison, 2000a). Ison (2000a) conducted a survey in which, amongst other things, he compared public support for congestion pricing before and after the question relating to the use of revenues had been asked. He found that the acceptability increased from 11.3% to 54.6% after it was explained that revenues would be allocated to specific, clearly established objectives. Harrington et al (2001) found between 7% and 17% increase in support to congestion charging when use of revenues was specified in a survey they conducted between residents in Southern California. Likewise, a recent study by Chung et al (2006) found that the positive opinion to congestion charging is increased 30% from 54% to 84%, if the revenue is reinvested to improving public transport such as bus, metro, bike road, etc. in the survey between residents in Seoul, Korea.

To summarize, the way in which revenues are used seems to strongly influence political acceptability. It may not be enough for a scheme to be progressive in its own right, car users may still demand that revenues are returned to the transport sector.

1.7. SUMMARY AND DISCUSSION

There has been a vast accumulation of the literature that deals with the theoretical and empirical aspects and policy experiences issued by congestion charging. Theoretical literatures have focused on such themes: why road pricing should be introduced to cope with the road congestion (Armstrong-Wright, 1986; Vickrey, 1969), what the pricing policy should be like in order to reduce the external congestion cost imposed by an additional vehicle trip on the road network (Walters, 1961; Small, 1983; Yang & Huang, 1997; De Palma & Lindsey, 2006). The discussions of empirical aspects and policy experiences have mainly addressed what the policy objectives and pricing schemes are in various cities in terms of their traffic circumstances (Eliasson and Mattsson, 2006). Most of the practical systems have to be simplified with the applications of the theory in order to be operationally feasible.

In spite of a fairly large amount of efficiency benefit, there are considerable obstacles to the actual implementation of congestion charging policy: equity refer to fairness, and public acceptability in public opinion comes up first. Moreover, the acceptability is related to the trade-off between total welfare gains and equity aspects. Leaving aside deeper considerations of these aspects (it will be deeply explored next), it is relatively easy to note how the theme of equity and efficiency is brought up mainly by the introduction of pricing policies. Implementing the congestion charging policy can be thwarted by equity concerns, and otherwise justified policies frustrated by debates about their equity impacts. Most policy makers sincerely want to address equity concerns and are happy to incorporate equity into their analysis of efficiency improvement (Litman, 2002), but few resources exist to provide guidance on how to do this in an objective, comprehensive and effective way.

Additionally, assessment of congestion charging impact has been given a considerable attention in recent studies as a type of determination of optimal toll. However, they focused on efficiency such as economic benefit and transport improvement. Moreover, in spite of implementation of congestion charging in several cities, only a few studies tackled the issue of equity and acceptability at the implementation of congestion charging in reality. There are still remained many problems about detailed application methodology that could not reach an accord on how to enforce the congestion charging, and hence it is being an obstacle of implementation of congestion charging to policy makers. Particularly, the trade-off between equity and efficiency is crucial to overcome the obstacles. In this regard, this research is motivated in stimulating the debate on how to deliver improved efficiency and equity outcomes in delivery of improved accessibility for all and not just the few.

The subsequent chapter is devoted to exploring the efficiency and equity of congestion charging, which are concerned with not only identifying the trade-off between equity and efficiency of congestion charging but also potential impact and assessment indicators.

EFFICIENCY OF CONGESTION CHARGING

1.8. INTRODUCTION

The concept of tolling and congestion pricing is based on charging for access and use of road network. It places responsibility for travel choices squarely in the hands of the individual traveller, where it can best be decided and managed. This is mainly because that the car is often the most convenient means of transportation. However, with a little encouragement, people may find it attractive to change their travel habits, whether through consolidation of trips, car-sharing, by using public transportation, or simply travelling at less-congested times. Basically the aim of congestion pricing is, therefore, to alleviate traffic congestion by altering travel behaviour.

This chapter focuses on the efficiency issues associated with congestion pricing, namely, the effectiveness of congestion pricing in maximizing social welfare. The economic principle of congestion pricing, known as ‘marginal cost pricing’, involves imposing higher charges on travellers who travel at times and places where a road system is congested, based on the rationale that travel in congested periods or places imposes high costs on other travellers. A congestion toll can thus be viewed as a user charge that is based on the difference between the marginal social cost and the average cost perceived by the traveller.

The aim of this chapter is to review previous researches on the evaluation of congestion charging in terms of efficiency, as well as the measurement of efficiency impacts on social welfare and the relief of traffic congestion. Sometimes it has been argued that the efficiency of congestion charging is not always guaranteed since the performance of the road network system may become more poor even after introducing the charging scheme due to the diversion of traffic congestion.

This chapter is organized as follows. Section 3.2 briefly reviews the theoretical background of evaluation of efficiency impact, and Section 3.3 explores the evaluation criteria of congestion charging for traffic efficiency based on congestion relief and economic efficiency based on social welfare change. Section 3.4 explores the measurement of efficiency in congestion charging with mode choice and traffic assignment model which are played significant role in measuring the impact. The summary and discussion is given in Section 3.5.

1.9. THEORETICAL BACKGROUND

The initial case of congestion pricing was an economic one related to the efficiency with which congested roads are used (Ministry of Transport, 1964). Congestion pricing, by charging the difference between the marginal social cost and the marginal private cost of a journey, was designed to ensure that the only drivers who travelled were those whose benefits from travelling exceeded the cost that they imposed both on themselves and on others. As a result, traffic flows would be lower, and the speed and reliability of journey times would be higher.

Making traffic flow more efficient by reducing travel demand is a matter of how net benefit is maximized. Thus, the evaluation of the congestion charging effects needs to take account of all sources of transport costs, and all of the important direct and indirect behavioural responses of individuals and user groups to changes in these costs, both in the short and the long run. This is necessary in order to make an accurate assessment of the effects; however, these conditions are not usually fulfilled in practice as simplified assumptions are used that leave out some important responses. This research, therefore, adopts conventional economic appraisal methods, with a special focus on social welfare change, which is reviewed briefly below.

1.9.1. Computation of Welfare

The traditional economic objective of optimal congestion pricing design is to maximise the ‘net benefit’, which is the social welfare benefits minus the costs of the congestion pricing system (i.e. implementation and operation costs). The optimal toll is defined as the toll that would yield the highest increase in social welfare improvement, as defined by the difference in total benefits minus the difference in total costs before and after the implementation of the congestion pricing.

ⅰ. Sumalee’s Approach

Sumalee et al. (2005) present a method of assessing the efficiency as a social welfare benefit, by employing a social surplus measure. In order to measure the social surplus, they considered two components – consumer benefits and operator benefits. The gross total benefit is expressed mathematically as follows:

$$W = \sum_{i} \int_{0}^{Ti} D_i(x)dx - \sum_{j} v_i c_j - \sum_{j} \varepsilon_j s_j \, , \tag{0.1}$$

where $i\,j$: the index of O-D pair i and j,

T_i : the travel demand,

v_j : link flow,

c_j : travel time,

s_j : cost of implementing a toll point,

ε_j : 1 if link j is tolled, and 0 otherwise, and

D_i : the inverse demand function.

The first and second terms are the consumer surplus and consumer cost, respectively. The third term is the cost of the congestion pricing scheme. The net benefits are calculated by deducting the capital and operating cost per toll point from the gross welfare benefits.

ii. Santos's Method

Santos (2004b) computed social surplus as the sum of the total utility of all trips minus the sum of the total costs of all trips, utilizing SATURN and SATTAX in order to discuss the optimal toll of eight English towns. The optimal toll was defined as the toll that maximises benefits, which was defined as the increase in social surplus. The disutility of paying a higher charge and the disutility of not making the trip or making it at some other time are captured in the area under the demand function, which decreases after the toll scheme has been introduced. The gross surplus of trips from each origin to each destination was measured by the area under the demand schedule for such trips up to the actual level of traffic. The difference between drivers' gross surplus before and after the introduction of the toll was computed for each origin-destination pair and then summed over all such pairs to give the overall change in gross surplus. The change in total costs was obtained directly from the new cost matrix produced by SATTAX. The change in social surplus was thus computed as the change in gross surplus minus the change in costs:

$$\Delta SS = \sum_{1}^{p} \left(\int_{q_1}^{q_0} c_{ij}(q_{ij}) dq_{ij} \right) - \sum_{1}^{n} \left(SC_{ij}^{0} - SC_{ij}^{1} \right) \tag{0.2}$$

$$SC_{ij} = VOT \times time_{ij} + VOC \times dist_{ij}, \tag{0.3}$$

where ΔSS is the change of social surplus; p is the number of O-D pairs; c_{ij} is the average cost to go from origin zone i to destination zone j, measured in pence per PCU; q_{ij} is the number of PCUs demanding a trip from origin zone i to destination zone j, C_0 is the original cost; q^0_{ij} is the original demand; n is the total number of PCUs (assumed identical to the number of trips); *0* indicates the original situation of no toll, and *1* indicates the final situation in which one or two cordon tolls are introduced; and *SC* is social cost. The social costs computed as a generalized cost by SATURN are described in Eq. (**3.3**).

iii. Palma and Lindsey's method

De Palma and Lindsey (2006) measured social welfare using social surplus by the dynamic simulator METROPOLIS in order to describe the impact of congestion pricing in Ile-de-France. The change in social surplus induced by a given regime is as follows:

$$\Delta W = \Delta CS + (1 + MCPF) \cdot \Delta R - \Delta C_{EXT}\,, \tag{0.4}$$

where ΔW : change of social surplus
ΔCS : change of consumers' surplus
MCPF : marginal cost of public fund
R : revenues from tolls and any other user charges
CEXT : external cost for noise, accidents and emission

The first component of social welfare is consumers' surplus, which is computed by the logsum formula in a nested logit model and accounts for the congestion externality via travel time and schedule delay costs. The second component is formed by revenue from tolls and any other user charges. Revenues are multiplied by a factor (1+MCPF), where MCPF is the marginal cost of public funds[1]. The final component of social surplus is the monetary costs of externalities other than congestion. The externalities that are accounted for are noise, accidents and the emissions of four pollutants – carbon monoxide, volatile organic compounds, nitrous oxides and carbon dioxide.

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[1] The marginal cost of public funds (MCPF) is the direct tax burden plus the marginal welfare cost produced in acquiring the tax revenue. De Palma and Lindsey (2006) set this value to 0.14, which means that government expenditures are at least 14% more productive than private expenditures in producing a net welfare gain.

ⅳ. Kalmanje and Kockelman's Method

Social welfare improvement is estimated by the daily travel-related benefits after a congestion pricing implementation as consumer surplus (CS), at the destination choice level for the average person residing in each zone (Kalmanje and Kockelman, 2004). In this case, CS is the difference in the maximum expected utility of one's destination choice opportunities before and after a change in the travel environment, as shown in Eq. **(3.5):**

$$\Delta CS_{ip} = \frac{1}{\alpha_p}\left(E(Max(V_{ip}))^n - E(Max(V_{ip}))^o\right) \tag{0.5}$$

where a_p is the marginal utility of money (specific to each trip purpose) and is the product of the estimated coefficients on cost in the mode-departure time model and generalized cost in the destination choice model, *n* and *o* denote the new and old scenarios (e.g., pricing vs. no-pricing); and $E(Max(V_{ip})) = \ln(\sum_{j \in C} e^{V_{ip}}) \cdot V_{ijp}$ denotes the utility of person at origin *i* choosing destination *j* for trip purpose *p*, with *c* denoting the full choice set of all possible destinations. However, this measure of CS is not applicable for home-based work trips since the destination choice is fixed.

ⅴ. Gupta et al

Gupta et al. (2006) compute consumer surplus for home-based work trips. It is the difference in expected maximum utility levels after policy implementation derived across all modes and departure time choices available to a particular destination, and is multiplied by the probability of choosing that destination (P(j)):

$$\Delta CS_{ip} = \sum_{j \in C} \frac{P(j)}{\beta_c}\left(Logsum_{ijp}^{n} - Logsum_{ijp}^{o}\right) \tag{0.6}$$

where, $Logsum_{ijp}^{n}$ is the generalized cost between an origin-destination pair*(i,j)* and is defined as the negative of the maximum expected utility derived across all mode and time-of-day combinations for a trip purpose *p:*

$$Logsum_{ijp} = -\ln\left(\sum_{m,t} e^{\beta_{t,p}Time_{i,j}+\beta_{c,p}Cost_{i,j}+\beta_{m,t,p}}\right), \qquad (0.7)$$

where, β_t, β_c and $\beta_{m,t}$ are the coefficients for time, cost and the alternative-specific constants in the joint mode-departure time choice model. Average daily CS is calculated for an individual residing in zone *i* by aggregating CS for home-based trips using the average daily number of trips per individual.

1.9.2. Compensating Variation vs. Consumers' Surplus

The social welfare change in accordance with congestion charging can be measured by compensating variation (CV) and social surplus as well. The social surplus is derived from the ordinary or Marshallian demand curve in the discrete choice process. On the other hand, CV is derived from the compensated or Hicksian demand curve. The best option for the assessment of social welfare change is compensating variation, which excludes income effect; however, since the Hicksian demand curve cannot be observed in reality, an approximate value of CV can be derived from the social surplus, which revises the welfare change by adding an income effect. However, because the portion of transport expenditure in income is very small, it can be inferred that the income effect is small according to the implementation of transportation policy. Thus, it can be regarded that the social surplus derived from Marshallian demand curve is an approximate compensating variation from the Hicksian curve.

The compensating variation was defined by Hicks (1942) as the amount one would have to deduct from a person's income to make him just as well off after the change in prices and income as he was initially. Since the compensating variation endows a uniquely defined numerical indicator of welfare improvement, it provides an implicit ranking of alternative prospective situations not only relative to the initial situation, but also relative to each other.

Figure 0-1 shows how Hicksian demand curve relates to a Marshallian system. On the upper part of the diagram, the axes are delineated in terms of good X and ($Y-P_xX$), which is the amount of monetary income available for all other purposes after deducting expenditure on good X. The slope of the budget line in this case is equal to - P_x. The initial budget line LQ is drawn assuming a monetary income of OL and a price of P_{x1}. When the price of X falls from

P_{x1} to $P_{x2,}$ the budget line pivots to the position LR, and the demand (along the conventional demand curve) rises from X_1 to X_2. However, if we reduce monetary income until the consumer is only able to reach the original indifference curve, then the budget line corresponding to P_{x2} will shift to the parallel position tangential to indifference curve 1 (NS), and demand will fall back to X_3. This is the demand resulting from a price of P_{x2} on the compensated demand curve corresponding to indifference curve 1. The conventional (AD) and compensated (AB) demand curves for X are shown on the bottom part of the diagram, on the assumption of linearity. Relating distances on the upper part of the diagram to areas in the bottom is as follows;

- LM = expenditure on X at the original levels of price (P_{x1}) and monetary income (OL)
  = area O P_{x1} A X_1
- NK = expenditure on X at the new levels of price (P_{x2}) and monetary income (ON)
  = area O P_{x2}B X_3
- MK = sum of money which is equivalent in terms of utility to an increase in X from X_3 on the original indifference curve = area X_1ABX_3
- LN = compensating variation for a fall in price from P_{x1} to P_{x2} when the consumer is held at indifference level 1. Since this equals LM+NK-MK, it must correspond to the area $P_{x1}ABP_{x2}$ on the bottom part of the diagram.

The concept of compensating variation (CV) is derived from the compensated or Hicksian demand curve, and hence can be obtained by consumers' surplus less the income effect. Since it indicates that the amount needed to revert the utility of travellers to its level before the congestion charging was implemented, this becomes the amount of welfare change of travellers that is due to the levying of the congestion toll. In this case, CV is set by the demand relationship, only using replacement to remove income effect due to a change of price. Although CV is a useful concept for accurately measuring welfare change, it requires knowledge of the individual's indifference map. Since that is difficult to obtain, an alternative, more practical but less accurate measure of changes in consumers' surplus is useful. The most commonly used method of measuring welfare change is ordinary consumers' surplus. Marshall suggested that the consumers' marginal valuation could be measured by the amount they would have to be compensated for not consuming the marginal unit. Consumer surplus is the difference between what a consumer is willing to pay (WTP) for a good and what he/she has to pay.

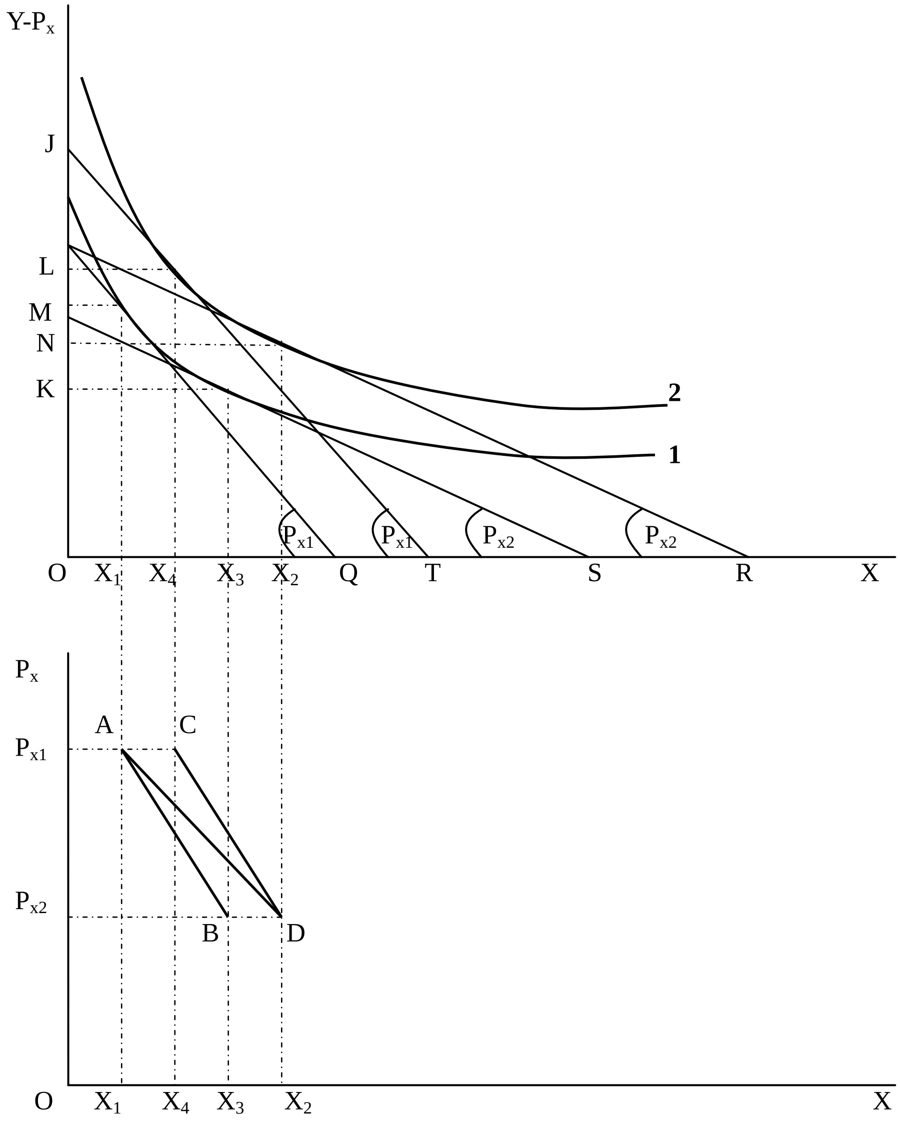

Figure 0-1 Compensating Variation
(Source : Pearce & Nash, 1981)

1.9.3. Efficiency and Congestion Relief

Congestion charging can be introduced to make the cost incurred by the driver include the cost of the congestion to which he or she is contributing. In an economic sense, it would be more efficient, and in practical terms, there would be less congestion as some people would decide not to travel or to use a different mode of transportation. However, although traffic may be restrained in the charged area, some of this traffic may divert to another destination or route.

This can either be an advantage, as traffic is diverted to more suitable roads, or a disadvantage, liable to cause congestion and inefficiency elsewhere.

Evaluation of traffic efficiency on congestion charging is related to congestion measurement, which is focused on system performance and measures of people's experiences. Primary definitions of congestion include mention of travel time, speed, volume, level of service (LOS) and traffic signal cycle failure, i.e., one has to wait through more than one cycle to clear the queue. Typical LOS measures include volume/capacity, density, delay, and number of stops, among others. Particularly, there is a 'time' component (e.g., travel time, speed, cycle failure and LOS) – all of which are related to the fact that users experience additional travel time due to congestion (Institute of Transportation Engineers, 1982).

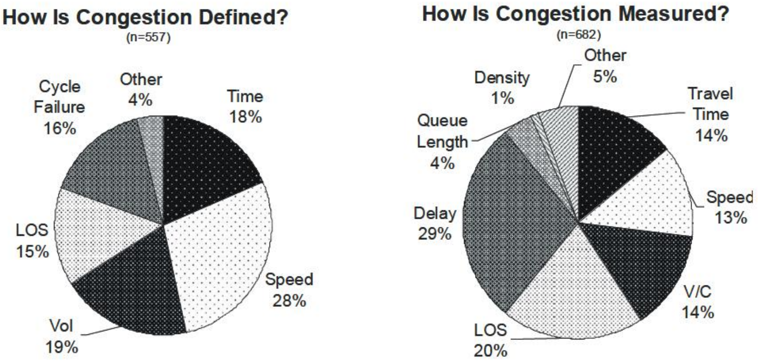

Figure 0-2 Congestion survey results
Source : Bertini, 2006

Fig. 3-2 shows the survey results about the definition and measurement for congestion by Bertini (2006). Normally, as shown at the Fig.3-2, measurement of congestion is related to time: delay, speed, travel time and LOS, all of which include the notion that actual travel time can be a primary measure of congestion. Other measures included volume/capacity as well as queue length and density. A great deal of the literature includes a wide array of possible congestion measures including volume/capacity, VKT, VKT/lane km, speed, occupancy, travel time, delay, LOS and reliability (Bertini, 2006).

In the U.K. survey, several helpful measures of congestion were identified: delay, risk of delay, average speed, and amount of time stationary or less than 10 mph is 20%, 18%, 51% and 11% of responses, respectively (Department of Transport, 2001).

1.9.4. Summary and Discussion

Economic theory assumes that individual road users are rational and base their trip decisions upon a comparison of the benefits and costs that they will receive from using the road. The costs that they consider do not typically include the congestion cost that their travelling imposes on other road users or the negative environmental effects that their driving imposes on smaller or larger fractions of the population. Since these cost components are seldom considered, some trips will add more costs than benefits to the society and, as a result, the road system will be overly or inefficiently used.

The disregard of these “negative external effects”, and the resulting inefficiency, constitute the basic theoretical rationale for road pricing. By introducing a charging mechanism directly related to the use of a road, it is possible, in principle, to force all travellers to also consider the external costs. If such a charging system is implemented, there will be both winners and losers. According to the fundamental economic welfare criteria, i.e. the Kaldor-Hicks criteria, such a change will increase the overall social welfare if the winners are able to compensate the losers and still be on the winning side. If each traveller has to pay a charge that equals the gap between the social and private cost of the trip, then it will be possible for the winners to do that.

Congestion charging also has another type of impact. Except for the short-term influence on transportation flows, other markets will be affected. In particular, the introduction of congestion charging may induce households to change their location patterns, their workplaces, and their travel decisions as regards retail services, recreation, etc. Location adjustments will affect the markets for labour, land and retail services in addition to travel behaviour (Harsman, 2001). Economic companies will also be similarly affected. In general, interaction costs will be higher. This means that the congestion charging system will make the location of some companies non-optimal, which may ultimately force some to relocate. In any case, the impact will include both that companies will have to pay a toll and that their locations may no longer be optimal**.**

1.10. EVALUATION CRITERIA

The objectives of congestion charging policy may be expected to influence the relative importance of various factors in the evaluation. If the motivation for congestion charging is to provide transportation-related revenue, then one has to be careful about how much weight is placed on other factors, such as reducing congestion, environmental improvement and road safety. The valuation of specific factors and potential impacts from congestion pricing must be logically connected to the goals of the project (Lo & Hickman, 1997). This section provides evaluation criteria for congestion charging which is focused on efficiency. Particular emphasis is placed on exploring congestion measurement as it impacts traffic and changes social welfare, as this measurement can help us to choose a potential assessment indicator and suggest criteria for the evaluation of congestion charging policy from the standpoint of efficiency.

1.10.1. Evaluation of Efficiency

The main objectives of congestion charging may be categorized as follows: to reduce traffic congestion and externalities, to enhance environmental quality, to encourage the use of public transportation, to raise revenue to fund transportation improvement, etc. The potential impact should be noted by the objectives of congestion pricing, which may vary according to policy considerations. Thus, the impacts of congestion charging on efficiency should be analyzed, including one or more of the following;

(1) How much traffic congestion can be relieved?
(2) How does a particular user group change its travel behaviour, in terms of departure time choice, mode choice, route choice, destination choice, and decision to travel?
(3) How much has economic efficiency improved?
(4) How will air quality, noise levels and accident rates change?
(5) How will costs and revenues of the pricing program affect the financial status of traffic authorities?

Literatures have focused on two types of efficiency that are impacted – traffic and economic. The first and second impacts are usually relation to impacts on traffic efficiency, whereas impacts three, four and five may be connected to economic efficiency.

1.10.2. Traffic Efficiency

Traffic efficiency, namely the impact on transportation, is a demand-supply interaction effect that is related to the following questions. How does a particular user group change its travel behaviour in terms of departure time, mode, route, destination and decision to travel? What are the demand shifts? Improvement of the efficiency of transportation is the most substantial effect of congestion pricing, and it is most evident in the mitigation of road congestion through a decrease in or a shift from the mode of private transport. Thus, it can be assessed by the degree of improvement in terms of how much traffic volume has decreased or how much high-operation-efficiency traffic has increased, and the influence of such effects upon the whole road network (i.e., how much traveller's time has been saved or how much travel speed has improved). Many studies employ some of the following effect indicators in order to estimate the change in operating efficiency on transport.

- Level of service (LOS)
- Efficiency of a single line of vehicles (the number of travellers per lane per time)
- Change in average number of boarding each vehicle
- Change of high-occupancy vehicle share
- Change of travel time (VHT), travel speed
- Change of travel length per trip (VKT, VMT)
- Change of traffic volume in applied road or area (V/C ratio)
- Punctuality,
- Etc.

Typically, traffic-related impacts, such as fuel consumption, vehicular emissions, congestion levels and noise production, can be quantified using the aggregate level of vehicle travel measures – vehicle kilometres travelled (VKT) and vehicle hours travelled (VHT). The addition of new tolled corridors is expected to reduce congestion on parallel corridors and improve the overall level of service, while the total system VKT may increase due to latent demand. Since they improve overall accessibility, toll roads are expected to be welfare enhancing (Gupta et al., 2006). In contrast, congestion pricing on existing facilities will discourage trip making, thereby reducing VKT. Litman (2007) suggests an evaluation criteria of traffic efficiency in terms of mobility as physical travel and accessibility, i.e., people's ability to reach desired activities and destinations. Mobility is easier to measure than accessibility, so conventional transport performance indicators, such as traffic speed and roadway level-of-service, tend to measure motor vehicle mobility, while other forms of access tend to be undercounted and undervalued.

Recently, London's congestion charging scheme has been estimated to have initially reduced zone travel delays by one third while significantly shifting mode choice. According to TfL (2005, 2008), after one year of operation, traffic circulating within the charging zone had reduced by 15 percent during charging hours (vehicle-kilometres driven by vehicles with four or more wheels) and the traffic entering the charging zone during charging hours had reduced by 18% (vehicles with four or more wheels). Annualised results for 2007 compared with pre charging conditions in 2002 reveal reductions of 16 percent in total vehicles, 21 percent in vehicles with four or more wheels and 29 percent in potentially-chargeable vehicles, as shown in **Table 3-1**. The traffic reductions achieved in 2003 in the months after the introduction of charging in the original central zone have therefore been maintained (TfL, 2008).

(Unit:%)

Vehicle type	2003 vs. 2002	2004 vs. 2003	2005 vs. 2004	2006 vs. 2005	2007 vs. 2006	2007 vs. 2002
• All vehicles	-14	0	-2	0	0	-16
• Four or more wheels	-18	-1	-2	-1	0	-21
• Potentially chargeable	-27	-1	3	0	1	-29
- Cars	-33	-1	-3	-1	0	-36
- Vans	-11	-1	-4	+2	1	-13
- Lorries and other	-10	-5	-4	+6	9	-5
• Non chargeable	+17	+1	-1	-1	-1	+15
- Licensed taxis	+17	-1	+1	-3	-5	+7
- Buses and coaches	+23	+8	-4	-3	+5	+31
- Powered two-wheels	+13	-2	-9	0	-3	-3
- Pedals cycles	+20	+8	+7	+7	+12	+66

Table 0-1 Key changes in traffic entering the Central London charging zone
source : TfL, 2008

In addition, traffic outside the Inner Ring Road did not change significantly. Speed surveys conducted in 2004 show that the main radial routes approaching the zone were only slightly less congested than before the charging was introduced (Santos & Fraser, 2006).

The charging effects in Stockholm[2] appeared immediately causing traffic across the charging cordon to be reduced by around 30% during the first week, before settling down at a surprising stable decrease of around 22% less traffic than in corresponding periods of 2005. Also, the number of vehicle kilometres driven in the inner city decreased by around 16%. Outside the inner city, on the outlying approach roads and streets, traffic volumes fell by just over 5%

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[2] The charging system consists of a cordon around the inner city of Stockholm with time-differentiated charges. The area inside the cordon is around 30 km^2. The cost for crossing the cordon is SEK 10, 15 or 20 (£1 is a little less than 10 SEK) depending on the time of day with a maximum amount per vehicle and day of SEK 60. The cost is the same in both directions and no charge is levied during nights or holidays. The charging technology adopted is Electronic Toll Collection (ETC) using microwave technology supported by ANPR cameras. Therefore, there are no barriers or cash payment points by the side of the road, which allows the unimpeded flow of traffic (CFIT, 2006b)

(Soderholm, 2006). The potential implementation of a permanent scheme in Stockholm was to be decided in a referendum in September 2006 on the completion of the trial, and it was reintroduced via political argument in August 2007. During the trial, public opinion gradually changed from a large majority opposed to the charges to a small majority in favor of them. When charges were removed August 1, 2006, the traffic immediately jumped back to its old level nearly. However, charges were reintroduced the next year, traffic once again decreased around 20% compared to 2005 levels, i.e. to about the same traffic levels as during the trial (Eliasson, 2008).

In Singapore, the first road pricing scheme, the area licensing scheme (ALS), was introduced in the restricted zone (RZ) in 1975. The scheme subsequently extended to the major expressways and arterial road beyond the RZ. In 1998, the electronic road pricing system introduced and charges were levied on a 'per pass' basis and rates are based on traffic congestion levels at the pricing points. The ERP scheme reduced traffic in the area by around 13% and increased average speeds by up to 20% (CfIT, 2006b).

In the case of Seoul, the charging policy had a great impact on transport (i.e., traffic volume) by reducing it 24% in the first month after the toll charge had been implemented in 1996. This, in turn, led to an increase in travel speed from 21.6 to 33.6 km/h. Although the longer-term impact on traffic volume subsequently lessened to a decrease of just over 14% after 2 years, it remained at almost 14% after that point (Hwang et al., 1999). However, according to the increasing ratio of exemption vehicles and the expansion of the congestion area beyond the central business district, claims have often been made that it needs to improve or at least make up for these weak points. Currently, further expansion of the affected area is being considered by the local government of Seoul.

1.10.3. Economic efficiency

Congestion charging, by pricing the difference between the marginal social cost and the marginal private cost of a journey, was designed to ensure that the only drivers who travelled were those whose benefits from travelling exceeded the cost which they imposed both on themselves and others. As a result, traffic flows would be lower and the speeds and reliability of journey times would be higher. That is, economic efficiency is concerned with the use of society's resources to achieve the maximum net benefit (Arnott et al., 1994), which is equal to the social welfare benefits minus the costs of the congestion charging system.

The welfare gain from congestion charging generally arises as a sum or difference between various components. It may be fruitful to distinguish between three main institutional categories: consumer, operators and authorities, and overall public welfare concern (Fridstrom et al., 2000);

- *Consumer*; one considers travellers as well as non-travellers
- *Operators and authorities;* in addition to the public revenue service, all operators of public transport services, whether or not they are publicly owned or not, as well as those operators who are charged with enforcing parking regulations, cordon toll schemes, etc, and
- *Overall public welfare concerns;* environmental and safety effect as well as general allocative efficiency, which may or may not be affected by congestion charging or by other alternative forms of taxation.

The consumer welfare effect for private consumers results in a balance between monetary costs and time benefits. Most congestion charging schemes entail a considerable increase in out-of-pocket expenditure for motorists who maintain their demand in the face of a higher unit cost. Other motorists may choose to reduce their demand; these individuals suffer consumer surplus conditioned by the difference between their willingness to pay in the initial situation and the initial generalized unit cost of travel. On the other hand, certain time gains accrue for travellers who remain on the road or public transport carriers aboard, as delay is reduced due to diminished demand.

Impact	Central London		Inner London	
Change in traffic levels	Base veh. Km	Change	Base veh. Km	Change
am peak (07.00–10.00)	0.8m	– 10%	5.9m	– 3%
14-hour (06.00–20.00)	3.6m	–12%	25.5m	– 3%
Change in average traffic speeds	Including junction delays		Including junction delays	
am peak (07.00–10.00)	from 15 to 18 km/h		from 21 to 22 km/h	
14-hour (06.00–20.00)	from 16 to 18 km/h		from 22 to 23 km/h	
Economic benefits per year	£125m to £210m			
Area license annual operating cost	£30m to £50m			
Overall annual benefit	£95m to £160m			

Table 0-2 Estimated traffic impacts and economic benefits of a £5 area licence for London (Source : ROCOL, 2000)

The Review of Charging Options for London (Road Charging Options for London Working Group, 2000) estimates the economic benefits to be gained from the charging scenarios, using conventional consumer surplus measures. The modelling was concentrated largely on a £5-per-day area license for Central London, which would apply between 07.00 and 19.00 on weekdays, but not on weekends. The consultant estimates that the charging scheme would produce net economic benefits of £95m-160m per year. The benefits included in the calculation include travel time and reliability benefits to cars and commercial vehicles, time savings to bus passengers, and road accident savings. Disadvantages include additional rail and underground overcrowding and the impact on those who shift from personal to public transport. There are also vehicle operating cost savings and the ongoing costs of the charging scheme. Time and reliability benefits of cars and commercial vehicles are the largest component of the benefits. A summary of some of the main results is displayed in **Table 3-2.** On the other hand, Prud'home and Bocarejo (2005) argued that the London congestion charge, which is a great technical and political success, seems to be an economic failure. They found, though the findings are preliminary, the economic costs associated with the charging system are larger than the economic gains it generates. That is, the economic benefits represent less than 60 percent of the economic costs. But the results caused by the assumption of excessive implementation cost, which is more three times than ROCOL's analysis.

1.10.4. Summary and Discussion

A number of works of literature have tackled the social welfare change for the assessment of congestion charging. Small and Rosen (1981) presented a CV model that made estimates from a Logit model and evaluated the user welfare change, but they did not consider the social welfare of the whole system from an efficiency perspective. Sumalee et al. (2005) examined the impact of congestion charging through social surplus measure, but they did not consider the user welfare from an equity perspective. They adopted the Gini coefficient to be defined separately as a measurable index. Santos (2004b) adopted the social surplus concept with a computation of the social cost utilizing generalized cost by SATURN and discusses the optimal toll of eight English towns. Although the researchers considered the distribution impact using a transport impact outline, namely the percentage of people crossing the cordon and their income, the model failed to provide a measurable index of equity. Palma and Lindsey (2006) measured social welfare using social surplus, but welfare distribution impact is not measured concurrently.

In addition, most studies considered social welfare change in order to assess the impact of congestion charging, they did not explore the impact on equity and efficiency simultaneously. In this regard, using CV across income groups and expanding it to social welfare change in a whole system is a substantial advance in measurement method of equity impact within an efficiency outline.

Congestion relief is accepted by researchers as a representative impact of congestion charging. This impact can be measured by mode shift from private car to public transport and variation of traffic volume and speed. In order to analyze such impacts on transport, this research builds O/D data and mode choice model by income level and then conducts traffic assignments. The mode shift is analyzed in the mode choice model, and variation of traffic volume and speed is evaluated using the result of a traffic assignment. More investigations should be concerned to quantify how much congestion pricing scheme can contribute to reduce the traffic congestion. The subsequent section is followed by measurement of efficiency impact with an extensive investigation about mode choice and traffic assignment model.

1.11. MEASUREMENT OF EFFICIENCY IMPACT

This section deals with the measurement of efficiency in congestion charging. A number of measurement approaches may be applied to quantify the efficiency, depending on the definition to the efficiency. Since the efficiency is defined as the relief the traffic congestion and the modal shift to public modes from private car usage, the methods of mode choice and traffic assignment are essential techniques to evaluate the efficiency of congestion charging scheme. In this section, more general approach is firstly reviewed for the evaluation of efficiency impact and then two core methods adopted in this thesis, mode choice and traffic assignment method are reviewed later.

1.11.1. General approach methods

ｉ. Simulation based vs. survey based approach

It is well known that there are strong interactions between transport problems, decision-making mechanisms and modelling approaches. In order to consider such interactions, transport modelling techniques are usually applied not only to predict and describe future situation but also to evaluate a substantive rationality of transport policies such as congestion charging scheme.

To assess the efficiency resulted from congestion charging schemes, two approaches can be considered: simulation based and survey based approach. The simulation based approach is basically a modelling approach that puts together some explanatory variables identified from a theoretical framework adopted, and then assesses the impacts by simulating and varying the variables. The survey based approach aims to evaluate how much the impact will be based on the responses derived from surveyors. The simulation-based and Survey-based approach are basically supplementary in that the result of simulation can be used to validate the result of survey, and vice versa.

With regard to the approach method for the efficiency impact assessment, the simulation based approach is more appropriate in a sense that the simulation approach can identify which variables are more sensitive to the efficiency change, and can quantify how much efficiency impact will be by varying the variables incorporated into the simulation model, while the survey based approach has a limitation to evaluate the efficiency impact in fact that the responses obtained from interviewees may not be consistent due to experimental survey design and sampling techniques.

ⅱ. Aggregate approach vs. disaggregate approach

The simulation based modelling approach can be divided into two: the aggregate approach is basically a macro one in that it represents the behaviour of an entire population or market segment, while the disaggregate approach is a micro one in that it is based on individual behaviours. Basically both approaches can be applied to evaluate the efficiency impacts by examining the sensitivity with respect to changes in the values of key variables under the control of the analyst.

In general, it is well known that the aggregation over unobservable factors, such as attributes or personal characteristics, results in a probabilistic decision model and the aggregation over the distribution of observables results in the conventional aggregate or macro relations (Ortuzar and Willumsen, 2001). Cast in these terms, the difficulty of the aggregation problem depends on how the components of the model system are described within the frame of reference employed by the modeller. In the case of a disaggregate micro approach, the problem is how to obtain from data at the level of the individual, disaggregate measures such as responses to congestion charging.

Related to the disaggregate approach to assessment of efficiency impact, two kinds of survey can be considered: the first one is the revealed-preference (RP) survey that obtain surveys response data about actual or observed choices made by individuals after implementing congestion charging. The second one is the stated-preference (SP) survey that obtains response data before implementing congestion charging. The difference between RP and SP surveys is that in the latter case individuals are asked about what they would choose to do in one or more hypothetical situation or scenarios for congestion charging. The degree of artificiality of these situations may vary, according to the needs and rigour of the implementation of congestion charging.

ⅲ. Comment

The efficiency impacts resulted from the implementation of congestion charging scheme can be evaluated with a range of approach methods mentioned above. The choice of appropriate approach method for assessing the efficiency impacts depends on time and cost available for the impact evaluation. Considering the data availability for the application of the Seoul case, this thesis makes use of a conventional simulation model that consists of mode choice and traffic assignment model to evaluate how sensitive to the level of congestion pricing road use will be. It is also taken into account that it is not very hard to collect survey data of responses to the congestion charging due to time and cost, and especially the quality of SP data depends on how much faith we can put on individuals actually doing what they stated they would do when the congestion charging arises. Mode choice and traffic assignment models play an important role in measuring the impacts from congestion charging. Consequently, subsequent section works towards exploring mode choice and traffic assignment model that can help traffic demand forecasts for which could be used for the evaluation of congestion charging schemes.

1.11.2. Review of mode choice model

The mode choice is a process of allocating the traffic demand to a transport mode. The mode choice model is one of the most important classic models in transport planning because of its key role in policy making by providing an index of traffic congestion. Since this research considers the mode shift from private car to public transport as an indicator of impact by congestion charging, the mode choice model plays a key role in the assessment process.

ⅰ. Classification of mode choice model

Using aggregation level, the models can be categorized as aggregate and disaggregate demand models; the former are either based on the observation of groups of travellers, or on average relations at travel zone level, and it produces overall results whereas the latter is related to individual travellers, and it produce more detailed results but it needs more detailed input data (See, **Table 0-3**). In this regard, the use of disaggregate models may lead to more realistic results.

Classification	Features	Models
Aggregate Models	· Related to large groups of travellers (or whole zones) · Overall result, based limited data	Diversion Curves, Elasticity Analysis
Disaggregate Models	· Related to individual travellers (or small group) · More detailed results, but need more detailed input	Discrete Choice Models

Table 0-3 Mode choice modelling

The aggregate models continued to be used in the majority of transport modelling until the early 1980s, however, only then the disaggregate models started to be considered as a serious modelling option (Ortuzar and Willumsen, 2001). As a most commonly used methodology on analyzing travel decision, discrete choice models are briefly reviewed hereafter.

ii. Discrete choice model

The travellers' mode choice can be explained with the use of the random utility theory (Domencich & McFadden, 1975; Williams, 1977). The theory is based on the assumption that the total utility is maximized via the selected alternative under the given options. Namely, in the case of expressing the utility as a function of attributes of alternative, the select a mode that maximizes their own utilities when they select the transport mode. The random utility theory is the most common theoretical framework that generates discrete choice models. The basic assumptions are as follows:

1)) Individuals belong to a given homogeneous population, act rationally, and possess perfect information; i.e., they always select an option that maximizes their net personal utility subject to legal, social, or budgetary constraints both in terms of time and money.

2) There is a certain set **A**={A_1,.....A_j,....A_n} of available alternatives and a set **X** of measured attributes of the individuals and their alternatives. A given individual q is endowed with a set of attributes $x \in$ **X** and in general will face a choice set **A**(*q*) $\in$**A**.

3) Each options $A_j \in$ **A** has associated a net utility U_{iq} for individual *q*. A modeller does not possess complete information about all the elements considered by the individual making a choice, thus, the modeller assumes that U_{iq} can be represented by two components:

   - A measurable, systematic or representative part V_{iq}, which is a function of the measured attributes x;
   - A random part ε_{iq} which reflects the particular taste of each individual, together with any measurement or observational errors made by the modeller.

If it is assumed that these two components of utility are independent, the total utility (U_{iq}) by individual (*q*) to specific alternative (*i*) can be expressed follow **Eq.(3.8);**

$$U_{iq} = V_{iq} + \varepsilon_{iq} \qquad (0.8)$$

$\boldsymbol{V_{iq}}$ is an index of all the observed attributes associated with alternative *i* which influence the choice. However, it is a function of the attributes **x** and this may vary across alternatives *i* and individual *q*, we have to decide on how these attributes might be represented. The simplest assumption is to define them in a linear function with the taste weights and additive in the attributes as shown in eq.(3.9), where the parameters β are assumed to be constant for all individuals but may vary across alternatives.

$$V_{iq} = \sum_k \beta_{ikq} x_{ikq} \tag{0.9}$$

The key assumption is that is that the individual *q* selects the maximum-utility alternative, that is, the individual choose alternative *i* if and only if (hereafter, "iff") the following is true:

$$\boldsymbol{U_{iq}} \geq \boldsymbol{U_{jq}} \qquad j \neq i \in A \tag{0.10}$$

From Eq. (3.10) alternative *i* is chosen iff,

$$\boldsymbol{(V_{iq} + \varepsilon_{iq}) \geq (V_{jq} + \varepsilon_{jq})} \tag{0.11}$$

Rearrange Eq. (**3.11**) to observables and unobservable together to give eq. (4.4)

$$\boldsymbol{(V_{iq} - V_{jq}) \geq (\varepsilon_{jq} - \varepsilon_{iq})} \tag{0.12}$$

As the analyst does not observe $(\varepsilon_{iq}-\varepsilon_{iq})$, hence cannot determine exactly if $(V_{iq} - V_{jq}) \geq (\varepsilon_{jq} - \varepsilon_{iq})$. One can only make statements on the choice outcomes up to the probability of its occurrence. Thus the analyst has to calculate the probability that $(\varepsilon_{iq} - \varepsilon_{iq})$ will be less than $(V_{iq} - V_{jq})$. This leads to the following equation Eq.(**3.13**).

$$\boldsymbol{P_{iq}} = \text{Prob}\{ \varepsilon_{iq} \leq \varepsilon_{jq} - (V_{jq} - V_{iq}), \forall \text{A}i \in \text{A(q)}\} \tag{0.13}$$

In this process, the random part of the utility functions usually refers to the latent or unobservable factors in discrete choice models. Depending on the distribution of the unknown residuals **ε**, different model forms may be generated. Due to its high complexity, very few model forms have been developed and hence, the logit model, including the Multinomial Logit model, the Nested Logit model, and the Probit model have been very popular for their tractability (Ben-Akiva and Bierlaire, 1999). However, more recently flexible model forms such as mixed logit[3](Bhat, 2000), which is a generalization of the Multinomial Logit model, are utilized.

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[3] Terminology for this model referred to in various literatures as 'random-coefficients logit', 'error-component logit', mixed logit', 'probit with a logit with kernel', kernel logit and hybrid logit, etc.

iii. Comment

Most transport analysis heavily relies on comparing the relative cost, which is based on the generalized cost (travel cost, travel time) instead of comparing the benefit of the traveller. The logit family of models is recognised as the essential toolkit for studying discrete choices. Starting with the simple binary logit model, they have been progressed to the multinomial logit model (MNL) and the hierarchical or nested logit (HL) model, the latter becoming the main modelling tool for sophisticated practitioners (Hensher and Greene, 2003).

Although more advanced-choice models, including multinomial probit (MNP) models, existed in conceptual and analytical form in the late 1970s, parameter estimation was seen as a practical barrier to their empirical usefulness. During the 1980s, several researchers devoted MNL and HL models to a primary focus on refinements as well as a greater understanding of their behavioural and empirical strengths and limitations. Software including Limdep/Nlogit (Koh, 1999) and Alogit offered a relatively user-friendly capability to estimate MNL and HL models (Hensher and Greene, 2003). The breakthrough in the ability to estimate more advanced choice models came with the development of simulation methods (e.g., simulated maximum likelihood estimation), which enabled enhancing modelling techniques such as MNP and mixed logit to be estimated with relative ease.

This study adopts the MNL model under the assumption that the random utility is independent and identically distributed residuals (Ben-Akiva and Lerman, 1985). However, the logit model, which is a simple and very popular practical discrete choice model, has weakness in alternative specification and flexibility compared to other relevant models (Bell and Iida, 1997), it has advantages in the simplicity of modelling and straightforward interpretation of results. Thus, the MNL model is adopted and revised in order to apply to evaluation of congestion charging in Seoul in this research.

1.11.3. Review of the traffic assignment model

The traffic assignment is a decision-making process that distributes the link volume under the assumption that road travellers choose the optimal path from origin to destination. Therefore, the aim of traffic assignment is to determine the route flows of the network by simulating travellers' route choice behaviour. Since the traffic facilities are limited, some traffic problems such as congestion occur when the demand and supply do not meet at equilibrium. Thus, the basic premise of network analysis starts from the assumption of demand and supply equilibrium. The model has an important role in the analysis of impact of congestion charging. Namely, the impact of congestion charging can be analyzed by comparing the traffic assignment results such as traffic volume, travel time, travel length, etc., before and after the charging. In this regard, it is crucial to select an adequate assignment methodology, which enables incorporation of appropriate congestion charges into the analysis of urban traffic network.

ⅰ. Classification of traffic assignment

The traffic assignment is made up of two parts; search of the minimized trip route and allocation of the traffic load on the road network. The former is operated through the Bellman’s optimality principle[4](Bellman, 1957), and the latter can be carried out by various traffic assignment methods. Here, the traffic assignment methods can be classified into various types depending on criteria.

Ortuzar and Willumsen (2001) classified the traffic assignment methods into four groups, depending on whether or not both capacity restraint effects and stochastic effects are included, as shown in **Table 3-4.** This results in the all-or-nothing, pure stochastic, Wardrop’s equilibrium, and stochastic user equilibrium methods, respectively. The all-or-nothing and pure stochastic assignment methods do not commonly consider the capacity restraint effect, but pure stochastic assignment methods do consider the stochastic effect in route choice. Wardrop’s equilibrium assignment represents the driver’s route choice under capacity-restrained conditions, while stochastic user equilibrium methods are concerned with different drivers’ perception of route travel cost under the existence of a congestion effect.

		Stochastic effects included?	
		No	Yes
Is capacity restraint included ?	No	All-or-nothing	Pure stochastic Dial’s, Burrell’s
	Yes	Wardrop’s equilibrium	Stochastic user equilibrium

Table 0-4 Classification scheme for traffic assignment
Source : Ortuzar and Willumsen (2001)

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[4] The principle of optimality was developed by Richard Bellman (1957) : that an optimal path has the property whatever the initial conditions and control choices over some initial period, the decision variables chosen over the remaining period must be optimal for the remaining problem, with the state resulting from the early decisions taken to be the initial condition.

Among these assignment methods, the method that does not consider the capacity restraint effect including all-or-nothing and pure stochastic assignment are classified as the proportional assignments (Chung, 2001). The proportional assignment methods satisfy the following conditions:

- The total assigned flow on a link is the summation of all the flows assigned if each O/D pair is assigned separately,

- If all the elements of the trip matrix are changed by a certain fraction, then all the assigned flows on each link are also changed by the same fraction. For example, if all the entries of the trip matrix are doubled, the assigned flow will double the flow assigned with the original trip matrix.

According to the behavioural assumption governing route choice, Prashker and Bekhor (2000) classified traffic assignment models into three groups: deterministic user equilibrium, stochastic user equilibrium and system optimum. If drivers have perfect knowledge about travel costs on a network and choose the best route according to Wardrop’s first principle, this behavioural assumption leads to deterministic user equilibrium. Stochastic methods consider both the travel perception errors as well as the stochastic of network travel times, which describes the variations in the travel times experienced by the travellers. The system optimum (Wardrop’s second principle) is achieved by assuming a non-realistic behavioural assumption, in which drivers cooperate with one another.

ii. Equilibrium traffic assignment

Trials to take into account of traffic congestions in modelling for traffic demand forecasting have continued since the 1950s. Wardrop (1952) proposed two equilibrium principles- the principle of user equilibrium and the principle of system optimality. The former is one in which traffic users select routes independently in such a way that the travel cost is minimized, and the latter describes when traffic users decide routes and choose them in a way in which the total cost of the road network becomes minimal.

The traffic assigned to the optimum within the system will indicate the status of social equilibrium since one’s own travel time includes the travel time caused by others in addition to that taken by the traffic itself as assigned. The two principles of the equilibrium traffic assignment of Wardrop are summarized as below **Table 3-5**.

	Concept
User Equilibrium Principle	Under equilibrium conditions, traffic arranges itself in congested networks such that all used routes between an O-D pair have equal and minimum costs while all unused routes have greater or equal costs.
System Optimality Principle	Under social equilibrium conditions, traffic should be arranged in congested networks in such a way that the average (or total) travel cost minimised.

Table 0-5 Wardrop's equilibrium theory

In particular, the user equilibrium principle involves several substantial assumptions in the two Wardrop's equilibrium principles. Sheffi (1985) pointed out the assumptions, including the following:

- All traffic demands between zones are fixed regardless of time of day.
- Cost function is a non-decreasing function and is separable from the other link traffic. That is, cost function increases as the link traffic increases and is influenced only by concerned link traffic.
- All travellers have a perfect knowledge about network, such as travel time, trip cost, etc.
- All road users recognize the trip cost equally.

Despite the assumptions of crucial factors in constructing Wardrop's user equilibrium principle, they are unrealistic. That is, the traffic demand is not fixed between zones, and it varies by time, such as peak or non-peak hours and weekdays or weekends. Also, the cost function is influenced by the traffic of matched links as well as other related links. Furthermore, most users do not have perfect knowledge of the network, and the perceived trip costs vary in reality. This is because that in reality drivers may not only have different weights on the components in the generalised travel cost, but also perceived them in different ways. For instance, some drivers choose the shortest routes, some the fastest.

A number of studies have been devoted to developing an assignment method that is more compatible with the reality in order to preclude unrealistic assumptions. Some assignment techniques are being used as representative techniques, such as a variable demand assignment that considered flexible trip demand between zones, excluding the first assumption (Yildrim &

Hearn, 2005); stochastic user equilibrium assignment that introduces a stochastic concept on route choice excluding the fact that all users jointly have a perfect knowledge (Lam et al., 1999; Bell, 1995); or a multi-class assignment that assigns traffic considering the difference of perceived knowledge (Ran et al., 2002), excluding assumptions that individual users equally perceived the trip cost.

iii. Comment

When a traveller uses a road network between cities, they commonly cannot have a perfect knowledge about travel time and organize an alternative network from origin to destination. However, when using roads in an urban area, they can access more complete information about travel time and the composition of networks than when using inter-city roads because they are familiar with the route, which is often used to go to work or for business. Thus, when assigning the traffic on an inter-city road network, the stochastic user equilibrium assignment can be considered in accordance with route choice probability, whereas in a city, it is more feasible to use the deterministic user equilibrium assignment, which is based on the perfect knowledge of the network conditions. Wherever inter-city or urban area are, the intelligent transport system provide more information of congestion situation and driving route, and increase the level of knowledge on a network

In summary, since the target area being analyzed in the network for implementing the congestion charging policy is the inner urban road network, it is deemed reasonable to use the deterministic user equilibrium assignment in order to investigate the efficiency of the congestion charging policy, assuming that the road user has a perfect knowledge of the travel cost and composition of the network.

1.12. SUMMARY AND DISCUSSION

From the relevant literature review of the efficiency issues in congestion charging, the following summary can be made: the evaluation of congestion charging from theory to practice naturally raises the question of what information can be obtained from a charging scheme. This exploration may only prove the feasibility of implementation of congestion charging. However, more fundamentally, there are many unsolved questions about congestion charging that could be asked empirically. This should begin with an examination of evaluation criteria based on its objectives and impacted groups. Several broad evaluation criteria of congestion charging have been mentioned in the literature (Hau, 1992; Lo & Hickman, 1997; Litman, 2005) that provide the most persuasive argument of congestion charging including the division of user group by income, society or system, etc. The UK Department of Transport has identified eight major areas for assessment of congestion charging (Richards, 1992), such as travel choice impact, transportation impact, urban economy impact, social and equity impact, environmental and safety impact, technology, and social and public acceptability. Also, one would expect policy objectives to be met if a form of charging scheme was introduced. The assessment indicators have been defined in the literature according to the study objectives; however, most of the assessment of congestion charging has been concentrated on congestion relief or economic efficiency improvement (Santos, 2004b, Santos et al., 2001, May and Milne, 2000).

It is appropriate, as mentioned earlier, to use assessment indicators as often as possible in order to estimate the impact of congestion pricing more accurately. However, in reality it is difficult to adopt all indicators at once, considering the restricted availability of proper data sets, and hence research has mainly discussed improvement of efficiency in transport, such as travel time, mode sharing of public transport, or reduction of economic externalities in the past. However, the assessment of congestion charging should be considered not only for the improvement of efficiency on transport, but also as an additional indicator such as equity impact and public acceptability.

Congestion charging induces cost to travellers, particularly private car users; furthermore, it affects the weak in a society more readily. In this regard, it is not suitable to assess the policy only according to efficiency in transport, since the stress or burden of the traveller is different. Consequently, in order to improve the compatibility of the analysis, this research divides the data to emphasise two major impact items: equity, and efficiency.

With regard to the measurement of efficiency impact, general approach methods are firstly reviewed by the comparison between simulation and survey based approached, and aggregate and disaggregate approach. Also advantage and disadvantage for those approaches are suggested in term of data availability, and time and cost for the impact evaluation. By considering the data availability, the application of aggregate and simulation based model is taken into account for assessing the impact of efficiency resulted from the implementation of various congestion charging schemes. The aggregate and simulation based mode consists of mode choice and traffic assignment procedure that respectively reflects individual’s choice under various monetary level of congestion pricing.

EQUITY OF CONGESTION CHARGING

1.13. INTRODUCTION

The equity problem in transport policy has been one of key issues, since the equity, referred to the distribution of impacts such as benefits and costs resulted from policy implementation, has an essential role in the acceptance of transport policies. Transport policy decisions, including introduction of congestion pricing scheme, have significant and diverse equity impacts in that the quality of transportation available affects people's opportunities and quality of life. It is, therefore, necessary to place more emphasis on the equity issues, in line with the efficiency ones described in chapter 3.

Nowadays it is natural to recognise that implementation of the congestion charging policy can be foiled by equity concerns, and otherwise justified policies thwarted by debates about their equity impacts. Most policy makers sincerely want to address equity concerns and are happy to incorporate equity into their analysis (Litman, 2002). However few resources exist to provide guidance on how to do this in an objective, comprehensive and effective way, since the equity problem in congestion charging can nor be easily treated and analysed due to the difficulties due to the problem of identification to equity impacts and beneficiary group and the problem of measurement to quantify the equity impacts by social groups.

The aim of this chapter is to review such previous research work on the identification of equity issues raised from congestion charging, as well as on the way of setting up the evaluation criteria and the methods of measuring the equity impacts. Also, to achieve such goals, this chapter provides an overview of transport equity issues, defines various types of transportation equity, discusses methods of evaluating equity impacts, and describes ways to incorporate equity analysis into a congestion charging policy..

This chapter is organised as follows. Section 4.2 reviews theoretical backgrounds related with the equity problems and then section 4.3 is devoted to reviewing the evaluation criteria, in particular focusing on how assessment criteria indicators can be set up related with congestion charging. Section 4.4 discusses the measurement methods and section 4.5 describes the trade-off relationship between equity and efficiency. The summary and discussions of the literature review on equity issues are given in section 4.6.

1.14. THEORETICAL REVIEWS

As already mentioned in the introduction, the equity analysis can be difficult, because there are several types of equity, various ways to categorize people for equity analysis, numerous impacts to consider, and various ways of measuring these impacts. A particular decision may seem equitable when evaluated one way but inequitable when evaluated another. As a result, equity impacts tend to be evaluated inconsistently or simply dismissed as “intangibles,” with the implication that they are immeasurable and can be ignored. However, equity analysis is often important and unavoidable, especially in terms of acceptance of congestion pricing policy. This section briefly reviews several issues of equity, including the type of equity, impacted user group, and beneficiary groups.

1.14.1. Types of Equity

Besides efficiency, equity is normally taken as a basic objective in the definition of congestion pricing impact as a transport policy (Viegas, 2001). On the topic of equity, one can discuss whether this is really a case of equity or of distribution of some kind of benefit. In addition to the fact that there is a significant body of literature that defines the equity issue of congestion charging (Langmyhr, 1997; Jones, 2002; Litman 2002, 2005; Viegas, 2001; Yang and Zhang, 2002).

Two broad categories of equity in relation to road user charging identifies: (1) spatial equity, relating to the geographical location of the individual or organisation affected; (2) Social equity, relating to the personal, economic, or social characteristics of an individual, organisation, etc. In practice, the two may become inter-related in that the people living in the areas that are spatially disadvantaged in some way may also be socially disadvantaged. This is quite a common phenomenon in relation to road traffic, as poorer people tend to live on busy main roads and therefore experience higher noise and air pollution levels, but road user charging may serve to either accentuate or mitigate such effects (Jones, 2002).

Another dimension must be considered in dealing with a system that is facing a deterioration of resources available for each consumer. Longitudinal equity, associated comparison of conditions between the present and the past, conditions for each citizen individually, and those of social groups (balance of gains and losses). For the discussion of urban road pricing, Viegas (2001) claims that the two most pressing dimension of equity are longitudinal equity (having to pay for what previously was freely available and taken by many as a basic right) and vertical equity (risk of exclusion from access to a wide range of urban functions for those with little revenue available for the extra cost of driving into the city).

Likewise, several researchers define equity with two main dimensions: vertical and horizontal equity impact (Langmyhr, 1997; Sumalee et al., 2005; Litman, 2002). The vertical equity impact is concerned with the unequal impact of road pricing on different groups of the population (e.g., classified by income level, gender, or access to car). The horizontal equity impact is also referred to as the spatial equity impact. The spatial equity impact can be defined as the distribution of the benefits and costs of the scheme across the population from different areas in the network (Sumalee et al., 2005). Litman (2002) describes the equity issue on congestion charging with horizontal equity and vertical equity. Horizontal equity is concerned with the distribution of impacts between individuals and groups considered equal in ability and need. According to this definition, equal individuals and groups should receive equal shares of resources, bear equal costs, and in other ways be treated similarly. This means that public policies should avoid favouring one individual or group over others and that consumers should get what they pay for and pay for what they get from fees and taxes unless a subsidy is specifically justified. Vertical equity is concerned with the distribution of impacts between individuals and groups that differ in abilities and needs; in this case, by income or social class. By this definition, congestion charging policy is equitable if they favour economically and socially disadvantaged groups, therefore compensating for overall inequities. Policies favouring disadvantaged groups are called progressive, while those that excessively burden disadvantaged people are called regressive. This definition is used to support affordable modes, discounts, and special services for economically and socially disadvantaged groups and efforts to ensure that disadvantaged groups do not bear an excessive share of external costs (pollution, accident risk, financial costs, etc).

Congestion charging is usually considered vertically inequitable because fixed charges impose a larger burden on the poor. For example, a £2 per day toll might be horizontally equitable, since everybody pays the same amount, but vertically inequitable because it represents a larger portion of income for a low-income driver than for a high-income driver. This impact is tempered by the fact that lower income people drive less on average than those with higher incomes. Lower income people drive less than average on suburban highways that are candidates for road pricing, so as a class they would pay relatively little in tolls, although there may be significant individual exceptions.

These different types of equity often overlap and conflict each other. For example, horizontal equity requires that users bear the costs of their transport facilities and services, but vertical equity often requires subsidies for disadvantaged people. Therefore, transport planning often involves tradeoffs between different equity objectives.

1.14.2. Beneficiary Groups

The final goal of the evaluation process of congestion charging could be to assess whether the scheme is efficient for the system as a whole and for specific user groups. However, despite the assessment that system efficiency is critical since it is the motivation for implementing congestion charging in the first place, assessment of allocation of cost and benefit by the impacted group come back with questions regarding the distributional effects of achieving such system efficiency. The equity impact as a fair distribution of congestion pricing has been a topic of steady argument in the literature (Evans, 1992; Arnott et al., 1994; Santos, 2004a; Eliasson and Mattsson, 2006). As identified in the literature, objections based on inequitable distribution of benefit and costs of congestion charging are the most difficult barriers to overcome (Lo and Hickman, 1997). Therefore, it is crucial to identify the winners and losers and the extent to which they are affected.

Studies have discussed the winners and losers of congestion pricing (Giuliano, 1992a; Gomez-Ibanez, 1992; Hau, 1992; Langmyhr, 1997). Due to its impact on trip making, congestion pricing can generate a set of perceived winners and losers. Charging for the use of roads affects the traveller as a consumer of mobility. The costs involve the actual toll imposed, inconvenience resulting from change travel behaviour, and possibly increased congestion due to rerouting of traffic to untolled roads and thereby time saved. Langmyhr (1997) discusses the main groups of winners and losers when congestion pricing is implemented on an existing road system. Gomez-Ibanez (1992) identifies eight groups affected by congestion pricing, three direct winners and five direct losers. He claims that travellers changing from private to public transport may end up as winners if the public transport time savings are substantial. Giuliano (1992a) offers a more precise breakdown of the pricing's winners and losers, outlining that congestion pricing will benefit the following three groups:

- Drivers whose time saved is more valuable than the tolls they pay
- People who already use transit or carpools and will not pay the toll
- People who receive the toll revenue

Congestion pricing will disadvantage the following three groups:

- Drivers whose time saved is less valuable than the toll they pay
- People who switch to a less convenient route to avoid the toll
- People on non-tolled routes whose traffic increases when drivers from Group 5 switch to their roads.

Giuliano argues that, in areas where auto-dependency is high, congestion pricing creates a problem because the initial number of travellers disadvantaged by pricing will be high. Particularly, when the demand for driving is highly inelastic, most people confronted with congestion pricing will end up paying the toll or seeking a less convenient route instead of switching to another mode or travel time (Giuliano, 1992a).

The most commonly adopted view of equity is the distributional effect according to income class. Thereby, one typical way to classify travellers is by income level. This is a convenient classification, particularly for an evaluation of the impacts on the low-income traveller. Litman (2005) discussed how the equity implications of revenue distribution depends on whether the class incurring costs is considered to include only those who pay the toll or also those who change their travel patterns and whether compensation for externalities is required, and if so, what scope of costs are to be compensated. He classifies users into four classes: non-driver, low-income driver, middle-income driver, and high-income driver. ROCOL(2000) provides a framework for identifying the broad categories of winners and losers from a road user charging scenario, the £5 area license in London. It identifies the impacts of charging on transport system users, on residents and businesses in different parts of London, and on relevant social groups including transport system users, impacts on households by income category, impacts on residents of the charging area, impacts on residents of adjacent areas, impacts on businesses in the charging area, impact on businesses outside the charging area, and impacts on women.

The benefit and cost distribution can be made clear by differentiating user groups. Hau (1992) discussed the opposition to congestion pricing, because those who are tolled would face a higher price relative to no tax situation on average; those who are priced off the road in order to circumvent paying the toll (the “tolled off”) are clearly worse off as a result of the forced switch onto a different mode or time of day, and the other road users who are not tolled (the “tolled on”) are not better off and, indeed, may even be worse off if congestion is encountered. In Hau’s discussion, the exceptional case that all groups can benefit on average is the hyper-congestion case, which occurs when vehicles keep entering the road over the maximum flow or capacity of links. Otherwise, the only group that gains the most is the government (and the untolled – the rest of society). The other groups that are likely to be better off are those with very high values of time. The rest of the groups (the tolled, tolled off, and tolled on) would not endorse congestion pricing unless toll revenues are channelled back through reduced transportation related taxes, user charges, or improved public services.

Economic theory assumes that individual road users are rational and base their trip decisions on a comparison of the benefits and costs that they will receive from using the road. The costs they consider normally do not include the congestion cost that their travelling imposes on other road users or the negative environmental effects that their driving imposes on smaller or larger fractions of the population. Since these cost components are not considered, some trips will add more costs than benefits to society and, as a result, the road system will be overly or inefficiently used. According to the fundamental economic welfare criteria, such a change will increase the overall social welfare if the winners are able to compensate the losers and still be on the winning side. If each traveller has to pay a charge that equals the gap between the social and private cost of the trip, it will be possible for the winners to do so.

Richardson and Bae (1998) argued that everyone loses under congestion pricing without redistribution of tolls and relaxation of the assumption of homogeneous users. Those remaining on the tolled road have to pay additional costs, and those who shift to non-tolled roads or other facilities will suffer longer travel times and/or costs. However, with traveller heterogeneity via varying values of time, many researchers assert that winners are the toll-collecting entity, and people with higher values of time and – usually – higher incomes who enjoy the benefits of reduced travel times on tolled roads (Richardson and Bae, 1998). In general, high income group placing high values on the time constitute the most likely winners. Consequently, an evaluation of who is a winner and who is a loser and how much is warranted as part of the assessment process.

To summarize, many researchers assert that winners are the charging authority and have higher values of time and usually higher incomes who enjoy the benefits of reduced travel times on tolled roads (e.g., Hau, 1992; Richardson and Bae, 1998). On the other hand, some researchers have concluded that congestion charging can benefit all groups of people if toll revenue is carefully distributed (e.g., Small, 1983; Litman, 2005). However, redistribution is filled with complexities. Furthermore, concern about equity and fair distribution for implementation of congestion charging has not surfaced as a serious issue in the research of congestion charging field.

1.14.3. Regressivity of congestion charging

The possibility of a regressive impact on income has been argued by researchers who emphasized equity (Morrison, 1986, Richardson and Bae, 1998, Small, 1983), since people with high income have higher value of time, and hence more often feel that the time gain is worth the charge. This situation has been a main obstacle to the implementation of congestion charging policy. Low-income travellers generally have inferior flexibility to decide their time for work and thus cannot avoid charges levied during peak hours (Arnott et al., 1994). Richardson's (1974) argument that congestion charging has a progressive effect is most unlikely; according to any plausible assumptions concerning the relationship between values of time and income, road pricing must be regressive between motorists.

However, recent research shows that not only can the problem of equity impact be mitigated by the charging system, but also the regressive effect of charging system can vary depending on the characteristics of city (Santos and Rojey, 2004). Small (1983) analyzes the distributional impacts of a peak expressway toll in San Francisco Bay area and concludes that, if attention is paid to revenue allocation, congestion tolls may be beneficial to many income groups, including lower income groups. He argues that the incidence of tolls should be analyzed only in concurrence with revenue uses. He admits that the low-income driver will be harmed by the imposition of a toll mainly because his time savings will not compensate what he pays. However, the poor as a group can benefit when revenue allocation is carefully planned. An increase in public services or reduction of regressive local taxes are possible approaches that would have this effect.

Santos and Rojey (2004) show that equity impacts depend on the design of a scheme and the geo-economic characteristics of the town in question; where do people live, where do they work, and how do they get to work? Therefore, the equity impacts of congestion pricing have to be assessed on a city- and scheme-specific basis, taking into account where different population groups live and work, what mode of transport they use for their travelling, and how revenues are allocated back to them.

Litman (2005) presents the concept of horizontal and vertical equity, which emphasizes the importance of distributing revenue in an equitable and fair way. From a horizontal equity perspective, all individuals are equal and pay equal tolls, and therefore, all congestion toll revenue should be distributed equally. From a vertical equity perspective, on the other hand, revenue should be distributed differently according to the need and ability of travellers. Therefore, he claims that it is not against vertical equity to distribute more earning to low-income groups or to socially weak people who have a greater need of public transport. The impacts of revenue distribution to enhance acceptability leads to considerable attention in literature regarding congestion charging.

1.14.4. Summary and Discussions

From the relevant literature review on the equity problem, the following summary can be made: As for the definition of the equity, most studies deals with the types of equity, beneficiary groups and regressivity of congestion charging. For the types of equity, spatial and social equity are identified in relation to road user charging, while some studies define equity with two dimension: vertical and horizontal impact concerned with unequal impact on different groups of population and distribution of benefits and costs of the charging scheme across the population from different areas in the road network respectively.

In the case of beneficiary groups, it is found that from literature reviews, there are three groups of winners and losers resulted from the implementation of congestion charging, and the most commonly adopted view of equity is the distributional effect according to income class. Also it is found that everyone loses under congestion pricing without redistribution of tolls and the assumption of homogeneous users.

Finally for the regressivity of congestion charging, it is found that the regressivity has been a main obstacle to the implementation of congestion charging since people with high income habe higher value of time and hence more often feel that the time gain is worth the charge. This may mean that the congestion charging is the policy for richer people.

1.15. EVALUATION CRITERIA

There is no single way to evaluate transportation equity. Equity evaluation depends on the type of equity, how people are categorized, the impacts that are considered, and how they are measured. Therefore a number of evaluation criteria can be set up, depending on the decision of which aspects are more essential to measure the equity impacts in terms of acceptance of congestion road pricing. Following subsection deals with the assessment criteria, and equity indicators and measurement techniques.

1.15.1. Assessment indicators

Indicators are measurable variables selected to reflect progress toward planning objectives. It is useful to identify a practical set of indicators for transport equity analysis. Indicators should be selected to reflect various equity issues and perspectives, to meet reasonable data and analysis requirements, and to be transferable between various situations. Several equity objectives and possible indicators for each are described below (Litman, 2007):

Firstly, the assessment treats everybody equally, unless special treatment is justified for specific reasons, such as the following:

- Policies and regulations are understood by the public and applied without bias.
- Per capita public expenditures and cost burdens are equal for different groups.
- Service quality is comparable for different groups and locations.
- Different modes receive public support approximately in proportion to their level of use.
- All groups have opportunities to participate in transportation decision making.

Second, individuals bear the costs they impose:

- Transport user fees reflect the full costs imposed by each person or trip, unless a subsidy is justified on equity grounds.
- Subsidies provided for equity or economic objectives are efficiently targeted.

Third, variables are progressive with respect to income:

- Lower-income households pay a smaller share of their income or gain a larger share of benefits than higher income households.
- Affordable modes (walking, cycling, ridesharing, transit, car sharing, etc.) receive adequate support and are well planned to create an integrated system.

- Special discounts are provided for transport services based on income and economic need.
- Transport investments and service improvements favour lower-income areas and groups.

Lastly, the assessment benefits transportation-disadvantaged people (non-drivers, the disabled, children, etc.).

- Investments and policies help create a more diverse, less automobile-dependent transport system that effectively serves non-drivers.
- Land use policies improve non-motorized accessibility.
- Transportation services and facilities (transit, car sharing, pedestrian facilities) reflect universal design (they accommodate people with disabilities and other special needs, such as using strollers and handcarts).
- Special mobility services are provided for people with special mobility needs.

These factors significantly affect equity evaluation. Analysis conclusions may change depending on how people are categorized, which impacts are considered, and how they are measured. There is no single correct way to evaluate transportation equity. It is generally best to consider various perspectives, impacts, and analysis methods. Transportation affects and is affected by other physical, economic, and social factors related to equity.

Moreover, transportation equity analysis is affected by the perspective and scope used in analysis. For example, short-term equity goals to make automobile travel more affordable to lower-income residents often conflicts with the long-term goal of increasing accessibility options for non-drivers by creating more multi-modal transportation systems and more accessible land use patterns.

1.15.2. Equity indicators and Measurement

Transportation activities and impacts can be measured in various ways that give different conclusions about what is equitable. Analysis often uses reference units to compare impacts, such as per-capita, per-trip, per-passenger-mile, or per-pound impacts. Cost values can include capital, operating, or total expenditures; expenditures for a single year or several years; and expenditures by a particular agency, a particular level of government, or by society overall (for example, including parking subsidies by businesses). Geographic areas and demographic groups can be defined in various ways. These factors can be selected and manipulated to support a particular conclusion. Litman (2007) suggests that the comprehensive transport equity indicators and categories which describe the following lists relating to various types of equity, categories of people, and measurement units. Major categories are bold, and many have subcategories. These can be selected to reflect the issues considered most important in a particular transportation equity evaluation.

Types of Equity

- Horizontal (or spatial) equity – Equal treatment, equal use of public facilities, equal allocation of funds and other resources, and cost recovery.
- Vertical (social) equity – Transport affordability, housing affordability, discounts for low-income travellers, impacts on low-income communities, employment opportunities, and quality of services for lower-income travellers.

Categories of people

- Demographics – Age, gender , race, ethnic group, family status, and lifecycle stage.
- Income class – Quintiles, below poverty line or lower-income community residents.
- Geographic location – Jurisdictions, residents of impacted neighbourhoods/streets, and urban/suburban/rural areas.
- Ability – People with disabilities or licensed drivers.
- Mode – Walkers, cyclists, motorists, and public transit users.
- Vehicle Type – Cars/SUVs/motorcycles, trucks (light and heavy), bus, and rail.
- Industry – Freight (trucks, rail, etc.), personal transport.
- Trip Type and Value – Emergency, commute, commercial/freight, and recreational/tourist.

Measurement

- Per capita – Per adult, per commuter, per student, per disabled person, and per low-income household.
- Per vehicle-mile or kilometre
- Per passenger-mile or kilometre
- Per trip – Per commute trip, per “basic mobility” trip, and per peak-period trip.
- Per pound – Per pound of user fees paid, per pound of total taxes paid, and per pound of subsidy.

Further comprehensive equity analysis allows policy makers to better anticipate problems, incorporate equity objectives in transport policy (for example, it can help identify congestion reduction strategies that also improve mobility for non-drivers and help lower-income people), and optimize planning decisions to maximize equity objectives. Improved equity analysis in introducing congestion pricing policy can reduce conflicts and delays and better reflect a community’s needs and values.

Equity analysis often involves comparing per capita expenditures by geographic region or by mode. However, it may be wrong to assume that expenditures in an area only benefit residents or that expenditures on a particular mode only benefit its users. Residents may benefit little from a highway project through their neighbourhood; it may primarily benefit through its travellers and provide them a disadvantage due to traffic impacts. Public transit improvements may benefit motorists as well as transit riders by reducing roadway congestion and their need to chauffeur non-driving family members and friends.

In summary, reference units are useful for equity analysis, but it is important to understand their assumptions and perspectives. Horizontal equity analysis should usually be based on per capita rather than per-mile comparison, with adjustments to reflect differences in user need and ability for vertical equity objectives. For example, when comparing two geographic areas or demographic groups with comparable incomes and abilities, it would be most fair for them each to receive equal annual per capita allocations of public resources, but if one area or group is economically, socially, or physically disadvantaged, it should receive a greater allocation. Similarly, if one group or travel activity imposes greater costs, it should be charged higher user fees or taxes until per capita subsidies are about equal, unless one group deserves extra subsidy on vertical equity grounds.

1.15.3. Summary and Discussion

Transportation activities and impacts can be measured in various ways that give different conclusions. Equity refers to the distribution of impacts and whether they are considered fair and appropriate. Transport planning decisions often have significant equity impacts, but these can be difficult to evaluate since there are various types of equity, categories people, impacts, and ways to measure impacts, as a particular decision may seem equitable evaluated one way but inequitable evaluated another (Litman, 2007). These factors must be carefully defined. Many people fall into multiple categories and change status over time. Some impacts must be explained to help stakeholders understand their transportation equity impacts. New equity issues emerge over time, reflecting changing needs, values, and understanding of impacts. The large number of categories may be intimidating. It is not generally possible to evaluate all possible permutations of perspectives, impacts, and groups. However, it is useful to recognize the full universe of possible issues and select those most important in a particular situation.

New analysis tools and information resources are available to better evaluate equity and incorporate equity objectives into transport planning. There is no single correct methodology. It is generally best to consider a variety of issues and perspectives. A planning process should reflect each community’s equity concerns and priorities. Public involvement is therefore important for transport equity planning.

1.16. MEASUREMENT OF EQUITY IMPACT

The equity impacts resulted from the implementation of congestion charging can be measured by traditional welfare economics, such as Gini coefficient which represents how much inequality there is. Another approach, to be applied in this thesis, is compensating variation analysis, derived from a logit model in discrete choice.

1.16.1. Compensating variation by Small and Rosen

Small and Rosen (1981) present a measurement method of compensating variation which was derived from a logit model in the discrete choice. The compensating variation (Δe^{od}_{n}) defined by Small and Rosen (1981) is mathematically expressed as follows;

$$\Delta e_{n}^{od} = -\frac{1}{\lambda_{n}^{od}}\left[\ln\sum_{k=1}^{4}\exp(V_{nk}^{od})\right]_{V^{odb}}^{V^{odp}}, \tag{0.1}$$

$$\lambda_{n}^{od} = -\frac{\beta_{1}}{INC_{h}^{od}}$$

where, Δe^{od}_{n} : Compensating variation

λ^{od}_{n} : Marginal utility of income (price) of traveller n between OD pair

V^{od}_{nk} : Indirect utility when traveller *n* travels between OD pair by mode *k*

k : Mode (1; car, 2; bus, 3; taxi, 4; metro/rail)

b, p : Before (b) and after (p) imposing the toll

INC^{od}_{h} : Average income of traveller by income level *h*

β_1 : Coefficient of cost in a logit model

By employing this model, if the compensating variation is estimated by income group, the equity impact of congestion charging can be measured. The total travellers' compensating variation (CV) is the amount of money required to compensate the travellers for keeping the level of travellers' utility before charging. Namely, the total CV ($\sum\Delta e^{od}_{n}$) is an amount of compensation for travellers as users so that they will have the same utility before and after the implementation of congestion charging. The result of the CV analysis can be interpreted as follows: if a positive CV result is derived after charging, the utility is decreased and the user welfare (travellers' benefit) is worse off; if a negative result is derived, the user welfare is better off. The equity effect can be estimated with the use of CV by income level such as low, middle, and high. More detailed process will be provided later.

1.16.2. Gini coefficient

Several scholars employ the Gini coefficient for analysing equity (Ramjerdi, 2006; Sumalee et al., 2005; Fridstrom et al., 2000). The Gini coefficient is commonly used with income inequality measure to analyse the distributional effect. It is defined as the ratio of the areas on the Lorenz curve diagram. As shown **Fig 4-1**, the Lorenz curve, due to Lorenz (1905), relates the cumulative proportion of income units (*x*-axis) to the cumulative proportion of income received (*y*-axis), when units are arranged in ascending order of their income. It takes the form of a straight line through the origin with slope 1 (45-degree angle) if and only if all units in the population receive the same income. The Gini coefficient is bounded between zero and one, with the increasing as the coefficient reduces from one to zero. This means that, the lower the Lorenz curve, the more income is concentrated in the upper income levels and the less equitable the distribution is.

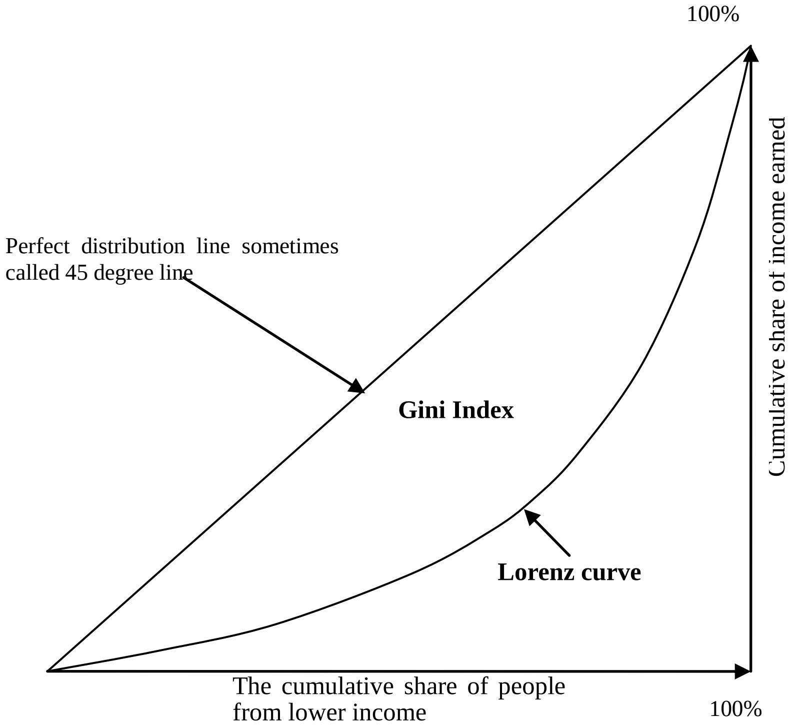

Figure 0-1 Gini coefficient

Ramjerdi (2006) evaluates the vertical equity impacts of various mobility management transport policies in Oslo, Norway, including road pricing, parking pricing, and public transit service improvements. The analysis employs a range of equity measures reflecting different assumptions and perspectives, including the Gini coefficient and the Lorenz curve, which are measures of inequity.

Sumalee et al. (2005) adopted the Gini coefficient to consider the geographical distribution of benefits from the imposition of a charging scheme and applied it to the spatial distribution of welfare changes brought about by the scheme. Fridström et al. (2000) used the same measure to analyse the distribution effect of various transport policies. The change in social welfare for each origin-destination pair is used as the measure for the distribution impact. For this, Sumalee et al. (2005) suggest a useful formulation of the Gini coefficient as follows:

$$G = \frac{1}{2T^2\overline{W}} \sum_{i=1}^{I} \sum_{r=1}^{I} T_i T_r \left| \hat{W}_i - \hat{W}_r \right|, \tag{0.2}$$

where $\hat{W}$ denotes the social welfare improvement compared to the do-nothing scenario, T is the total demand in do-nothing scenario; i and r are the OD indices, I is the number of OD pairs; $\overline{W}$ is the average value of $\hat{W}$. The resulting coefficient ranges from 0 indicating total equality to 1 indicating total inequality between travelers from different parts of the network. More recently, Fridström et al. (2010) compute costs, benefits, and demand effects and show how equity impacts can be described in terms of differential *Lorenz curves* and *Gini* coefficients. Particularly, they focused on the general framework for equity impact assessment.

1.16.3. Summary and Discussion

Two types of measurement on equity impacts are reviewed: compensating variation derived from a logit-based model and Gini-coefficient commonly used with income inequality in welfare economics. It is recognised that the compensating variation, defined by Hicks (1942) as the amount one would have to deduct from a person's income to make him just as well off after the change in prices and income as he was initially. Since the compensating variation endows a uniquely defined numerical indicator of welfare improvement, it provides an implicit ranking of alternative prospective situations not only relative to the initial situation, but also relative to each other. Also, Gini coefficient indicates and evaluates the vertical impacts of various mobility management transport policies.

1.17. TRADE-OFF BETWEEN EQUITY AND EFFICIENCY

It is well known that transport policy offers a glaring example of a field with a large discrepancy between theory and practice. One of the main instances of such gap is the fact that efficient pricing instruments for optimal regulation of road transport externalities apparently provoke so much social and political resistance that they are not likely to be widely introduce and accepted. Congestion road pricing, recognised as a regulation, has also a large gap between equity and efficiency, while trying to reduce the externalities such as congestion, air pollution etc.

1.17.1. Variation of Benefits

As shown by Rietveld and Verhoef (1998) the net benefits of travellers affected by a pricing scheme closing the gap between private and social costs can be assessed by dividing them into three groups. Those who stay and pay will on average become losers. They lose more than they gain because their toll payment exceeds the value of time they save. The second group includes those who change their travelling pattern –to another mode, route or time of day. They are obviously made worse off since they would not otherwise have changed their behaviour.

Those who use public transport and continue to do so risk facing a more crowded environment. This reduction in quality implies that they become worse off provided that faster or more frequent public transport (made possible by less congestion) does not outweigh the crowding effect. It no doubt seems strange that all three groups will become worse off if congestion tolls are introduced. The explanation is that the toll collector is the main gainer of the pricing scheme. If all effects are added up the net benefit will be positive as expected.

A politician believing in the idea of road pricing and also interested in being re-elected would immediately realise that the allocation of toll revenues to different uses is a strategic issue. It seems evident that everyone would gain if the revenues were in some way channelled back to the three groups of travellers. As long as we assume that all travellers are identical as regards their appreciation of a given reduction in travel time this means that it should be relatively easy to “sell” congestion pricing to the public. However, public acceptability will be more difficult to obtain as soon as we relax this simplifying assumption and instead assume that people differ in their valuation of travel time reductions. Eliasson (1998) has shown that this kind of heterogeneity makes it is very difficult to design a congestion pricing scheme that fulfils the two following requirements: (1) more than half of those affected should be better off with than without the pricing system ; (2) aggregate welfare should increase for those involved

Designing and implementing a congestion pricing scheme, which is optimal for the average individual and returning the revenues to the losers is not enough to fulfil the two requirements. A majority of the users may still be worse off. This is further explained by the more general problem indicated by **Fig.4-2**. The figure indicates that a skewed distribution of the benefits resulting from a certain policy measure can cause a large variation in net benefits if all of them are charged the same amount. The curve in the figure shows the distribution of benefits ordered from the highest to the lowest benefit and the charge is indicated by the line A. The fraction of losers is larger than the fraction of winners in spite of the fact that the total gain is positive.

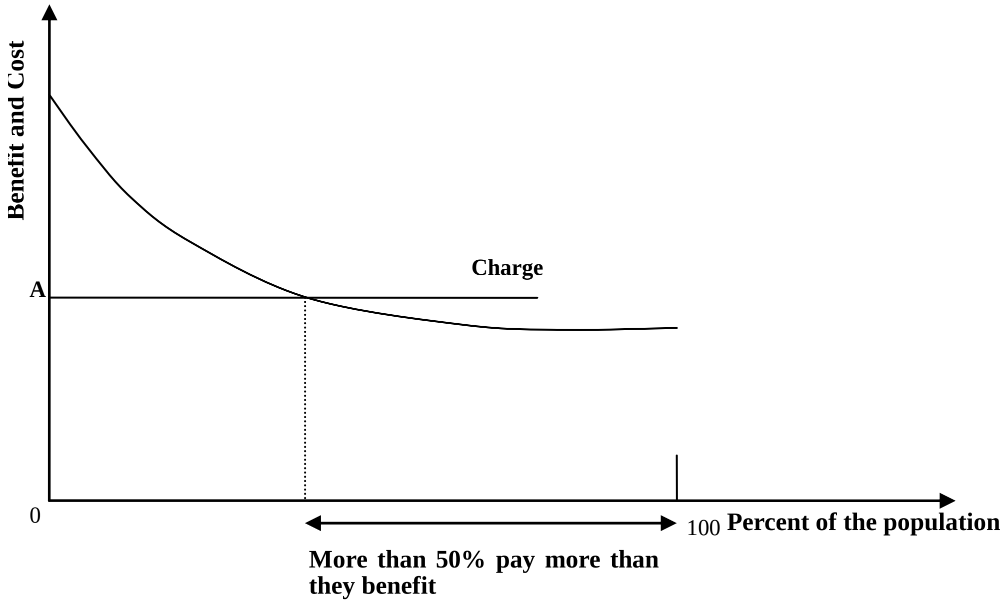

Figure 0-2 Distribution benefits versus charge
(Source: Harsman, 2001)

As a consequence we can expect that politicians who think that people may have rather different values will find it more difficult to argue for congestion pricing. It will be even more troublesome for those who care about equity and who believe that the value of time tends to be higher the higher the income level.

1.17.2. Trade-off between efficiency and equity in terms of change of toll level

It is well known that in general the excessive pursuit of efficiency may bring about an equity problem, such as violating the rights of the low-income citizens. This means that there is a strong trade-off relationship between efficiency and equity. Such a trade-off is, in practice, affected by various factors, such as the charging zone, time, and toll level so that it is worthwhile to examine the trade-off in accordance with the factors. In particular, the impact of the toll level influences the travellers' behaviour significantly.

The equity impact of congestion charging was investigated through the mode shift by income and the compensating variation by income as user benefits. Moreover, the efficiency of congestion charging was evaluated in terms of its transport efficiency related to congestion relief and its economic efficiency based on the social-welfare improvement brought about by the implementation of the policy. For example, as a different mode shift ratio from private car to public transport (PT) appeared between the high- and low-income groups, it can be inferred that a higher mode shift ratio gap between the two user groups leads to a more inequitable situation. In particular, according to the toll increment, the low-income group cannot help shifting to PT because the burden of the toll on them is higher than on the high-income group. Likewise, to determine the individual user benefit of congestion charging in this study, CV per person (CVPP), whose values were different by income group, was employed. Thus, it can be inferred that the bigger the gap between the CVPP values of the two user groups is, the more inequitable the situation becomes. In this sense, the degree of equity from the toll increment can be justified by the evaluation value gap between the high- and low-income groups. That is, as the gap becomes bigger, the unfairness between the low- and high-income groups becomes higher.

On the other hand, the improvement of the traffic speed, the reduction of the traffic volume per capacity (V/C), and the improvement of the social welfare are the representative effects from the efficiency standpoint. It is worthwhile to investigate the change in the efficiency impact by comparing it with the equity impact. Consequently, the trade-off between equity and efficiency was investigated by comparing them in accordance with the toll increments.

1.18. SUMMARY AND DISCUSSION

From the relevant literature review of the equity issues in congestion charging, the following summary can be made: As for the definition of the equity, most studies deal with the types of equity, beneficiary groups and regressivity of congestion charging. For the types of equity impact, spatial and social equity impact or vertical and horizontal impact are concerned with the unequal impact on different groups of population and distribution of benefits and costs of the charging scheme across the population from different areas in the road network, respectively.

For the beneficiary groups, there are three groups of winners and losers resulting from the implementation of congestion charging, and the most commonly adopted view of equity is the distributional effect according to income class. Also it is found that everyone loses under congestion pricing without redistribution of tolls and the assumption of homogeneous users. For the regressivity of congestion charging, it is found that the regressivity has been a main obstacle to the implementation of congestion charging since people with high income have higher value of time and hence more often feel that the time gain is worth the charge.

With regard to the evaluation criteria for congestion charging, it is found that some impacts must be explained to help stakeholders understand their transportation equity impacts, since new equity issues emerge over time, reflecting changing needs, values, and understanding of impacts. The large number of categories may be intimidating. It is not generally possible to evaluate all possible permutations of perspectives, impacts, and groups. However, it is useful to recognize the full universe of possible issues and select those most important in a particular situation.

This skews planning and investment decisions to favour motor vehicle travel at the expense of other modes, and so tends to favour people who drive more than average at the expense of those who drive less than average. For example, prioritizing transport projects based on their ability to improve roadway level-of-service, and therefore their ability to increase vehicle traffic volumes and speeds, tends to create roadway environments less suitable for walking, cycling and public transit access. Only by measuring transport based on accessibility can such trade-offs, and their equity impacts. Furthermore, due to its impact on trip making, congestion pricing can generate a set of perceived winners and losers. However, the welfare impacts of congestion pricing depend on the design of pricing strategies, user heterogeneity and the way revenue is used to compensate disadvantaged user groups.

F MODEL APPLICATION FOR CONGESTION CHARGING EVALUATION

1.19. INTRODUCTION

The impact of congestion charging (CC) was defined in this study to analyze the transport policy that maximizes economic efficiency and that improves equity. Two different types of impact, efficiency and equity, were considered, and the assessment indicators and measurement methods were reviewed. For each type of impact analysis, two types of transport modelling techniques were considered either to produce a simulation result or to improve the performance: mode choice and traffic assignment. With a description of the detailed data for modelling, the adequacy of the model that will represent the system being simulated was verified. In addition, an assessment logic was provided for the model, including the application model's components, as part of the assessment process involved in the modelling that was conducted in the case study.

The main objective of this chapter is to validate the proposed model on a Seoul network for application in the study, and to provide the logic of the impact analysis model. Another important objective is to review the transport system in Seoul. As it is expected that the impact of CC will be found to depend on the CC scheme, including the area, time, and toll level, considering the transport system in Seoul, a CC scheme was designed for the case study.

This chapter is organized as follows. Section 5.2 presents the data for transport modelling, such as the mode choice and traffic assignment models. Section 5.3 defines the impact analysis models for the evaluation of CC from the efficiency and equity standpoint, respectively. Section 5.4 investigates the transport in Seoul for the setting up of the CC scenarios. Finally, section 5.5 gives a summary of this chapter.

1.20. DATA DESCRIPTION

In this study, the transport modelling technique was used to evaluate CC. This section provides a data description of the applied mode choice and traffic assignment models and presents the results of the verification that was made of the adequacy of the model for representing the system being simulated.

1.20.1. Data for the mode choice model

Applied in this research was a function consisting of the following variables related to the observable utility item ($\boldsymbol{V}_{iq}$) of an income level (h) that uses a traffic mode (i). The relation between the considered explanatory variables and the denominators was linear in the parameters and followed the assumption of the Logit model.

$$V_{iq} = \alpha_i + \beta_1 \frac{TCOST_i}{INC_h} + \beta_2 IVTT_i + \beta_3 OVTT_i \, , \tag{0.1}$$

where α_i : alternative specific constant of mode i;

$TCOST_i$: total travel cost of mode i;

INC_h : household income of level h;

$IVTT_i$: in-vehicle travel time of mode i; and

$OVTT_i$: out-of-vehicle travel time of mode i.

Among the generic variables, travel cost and travel time play a key role in modelling traffic demands; hence, the two variables were set as the main generic variables in this study. Particularly, the travel cost divided by the income was selected for the analysis of the impact of the CC level in accordance with the examination of the mode shift by income level. This process is needed to calculate a compensating variation (CV) measure, which is required for the analysis as well of the equity effect.

Table 0-1. Explanatory variables applied in the model

	Explanatory Variable	Remark
Generic variables	• Travel cost/income • Travel time (IVTT, OVTT)	Car, bus, taxi, and metro/rail
Mode-specific constant	• Car-specific constant • Taxi-specific constant • Metro/rail-specific constant	Mode dummy variables (categorized by bus)

On the other hand, travel time was applied for the in-vehicle travel time (IVTT) and out-of-vehicle travel time (OVTT). In the process of model estimation, the mode-specific constant explains the difference in relative utility. Four mode choice alternatives were considered: car, bus, metro/rail, and taxi. Bus was selected as a basis, and the remaining modes were analyzed in terms of the difference in their utility, which is included in the mode-specific constant.

When CC is implemented in a certain area, the estimation of a new mode choice model is required, using individual data that better reflect the specific situation. As this, however, is not easy to do and is beyond the scope of this study, a multinomial Logit model was adopted and was partly revised to estimate the modal split. The model of Koh (1999), which adequately involves the independent variables, was selected, and it was proven in the previous studies that the independent variables have an effect on the mode choice; that is, they cover three generic variables: the travel cost divided by the travellers' income, IVTT, and OVTT.

Table 0-2. Mode choice model

Variables		Parameter	Standard Error	t-value
Travel cost/income		-0.15702	0.0092	-17.114
IVTT		-0.15724	0.0124	-12.694
OVTT		-0.29644	0.0181	-16.419
Mode-specific constant	Car	-1.34860	0.2402	-5.615
	Metro/rail	-0.99056	0.1953	-5.073
	Taxi	-2.87000	0.2823	-10.167
Goodness of fit of the statistics		$L^*(\hat{\beta})$ = -627.657 $L^*(0)$ = -1648.304 $\overline{\rho^2}$= 0.619 ρ^2 = 0.616 No. of samples = 1,189		

Source: Koh, 1999

Generally, the value of the likelihood ratio (ρ^2) is used as an indicator of model fit, and the value between 0.2 and 0.4 is considered an extremely good model fit (Hensher and Brewer, 2001). The adjusted likelihood ratio, which indicates the appropriateness of the model, was estimated to be 0.616. It demonstrates that the model is extremely well fitted statistically. In addition, a negative sign associated with time and cost is expected as an individual's relative utility will increase when the time or cost decreases. Also, the signs of mode-specific constant, compared to bus, are negative and taxi shows the greatest absolute value in mode-specific constant, as shown in **Table 5-2**. This implies that if the travel time/income, IVTT and OVTT are identical, the probability of mode choice diversion to taxi from bus is the lowest, compared to car and metro/rail.

A dataset of the travel time, travel cost, and mode choice ratio by income level must be built for the revision of the mode choice model and for the analysis of the equity impact. The travel time and travel cost by mode were evaluated utilizing the travel time and travel length derived from an EMME/2 model. On the other hand, the mode choice ratio by income was utilized for the 3,763 effective samples processed by the Korea Research Institute of Human Settlements (Chung et al., 2006). This dataset was originally collected from the results of a Seoul household travel survey (SDI, 2003). After segmenting the sample into three income groups, the mode choice ratio of the samples was compared with the estimated results. The variables in the applied model consisted of the travel time, travel cost, and income of the traveller. They are briefly described below.

ⅰ. Travel time by mode

The total travel time by mode consists of the IVTT and OVTT. The travel times were estimated based on the results of the traffic assignment under the user equilibrium in the EMME/2 model. **Table 5-3** shows the travel time by mode with its empirical basis (KOTI, 2005). The detailed evaluation process that was used is as follows.

Car

The travel time of a car adopts the time of the shortest route of zone to zone in a road network. The IVTT was evaluated based on the result of the traffic assignment by the EMME/2 model, and the OVTT was assumed to be zero.

Bus

Buses have their own routes and jointly use the road network with cars, and their operation schedule has the characteristics of transit (i.e., route, headway, bus stop, etc.). As road congestion situations, however, deeply affect one another, it is not advisable to put the bus under network analysis as this will create ambiguity. It was assumed in this study that buses use the shortest path from their origin to their destination. Therefore, the travel time of a bus was calculated using the car travel time, but considering the bus stops. The IVTT of a bus was empirically determined to be between 1.2 and 1.35 times the car travel time, according to the travel route (KOTI, 2005). In addition, the OVTT of a bus was determined to be between 7 and 30 minutes based on the travel route and distance (see **Table 5-3**).

Metro/rail

The IVTT uses the travel time of the shortest route of zone to zone in the transit network. On the other hand, the OVTT of the metro/rail, which consists of the access time and waiting time, was categorized by travel length (see **Table 5-3**).

Taxi

For the travel time of a taxi, the travel time of a car was adopted, but for its OVTT, 5 minutes were added for the waiting time.

Table 0-3. Travel time by mode

	IVTT		OVTT		
Car	Travel time of the shortest route of zone to zone in the road network		None		
Bus				Under 10 km	Over 10 km
	Inner big city	1.2 × car		7 min	15 min
	City to adjacent city	1.3 × car		15 min	22 min
	Small city to city	1.35 × car		20 min	30 min
Metro/rail[1]	Travel time of the shortest route of zone to zone in the metro/rail network		~0.75 km	Distance/speed (3 km/h)	
			0.75~3 km	Distance/speed (20 km/h) + waiting time (5 min)	
			3~5 km	Distance/speed (25 km/h) + waiting time (10 min)	
			5 km~	130 min	
Taxi	Same as a car		5 min		

Source: KOTI, 2005

ⅱ. Travel cost by mode

A few assumptions must be made to be able to evaluate the travel cost by mode. In the case of a car, the travel cost is out-of-pocket money, which is directly influenced by the travel decision and for which the fuel and parking cost must be considered. In addition, car users who travel to a charging area have to pay extra money as CC toll. The fuel cost of a car adopts “the price in April 2006.”

- Fuel cost = travel distance × fuel efficiency × unit fuel cost
- Fuel efficiency = 1/11.8 litre/km (SDI, 1996)

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[1] The OVTT of Metro/rail by each access distance from the departure point is calculated simply by dividing the distance with access speed (3Km/h of walking for under 0.75Km, 20Km/h of small bus for 0.75-3Km and 25Km/h of general bus for 3-5Km distance) and added up waiting time. However, for the distance over 5Km, 130minutes is uniformly allocated without such calculation mentioned earlier since such travel is quite rare in reality (KOTI, 2005).

- Unit fuel cost = 1,800 won/litre

On the other hand, the parking fee was assumed to be ₩3,016, which was the average daily parking fee in Seoul in 2006 (SMG, 2007b). The bus and metro/rail fare that was applied was ₩900 (initial fare in 2006-2007, cash basis). The taxi fare was evaluated as follows:

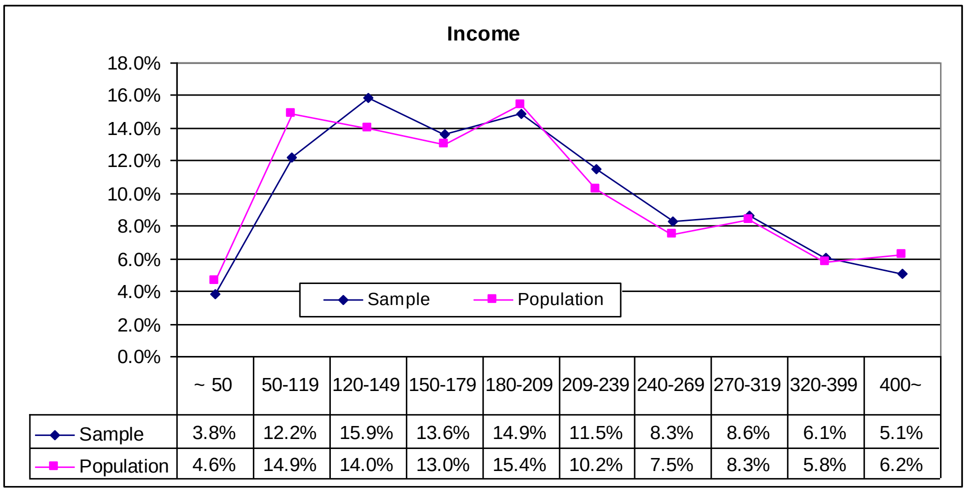
- Taxi fare (₩) = initial fare + (in-vehicle distance – 2 km) × ₩100/0.168
- Initial fare = ₩1,600 up to 2 km

ⅲ. Income by traveller

The travellers' income was surveyed in the 10 categories of the monthly average income of a household (SDI, 2003). The hourly income was evaluated based on the average income divided by the number of legal working hours, which was converted into the central value in the category and was used for model validation.

$$\text{Hourly income (won/hr)} = \frac{\text{Monthly average income (won/month)}}{\text{Monthly legal working hours (hr/month)}}$$

On the other hand, the travellers were classified into three income levels (low-, middle-, and high-income levels) for convenience of analysis. As this study aimed to analyze the impact of the implementation of CC on efficiency and equity, the income data of travellers accounted for a significant difference in the research results. Thus, the feasibility of the sample data must be validated. That is, the following question must be answered: To what extent do the income distributions of the samples match those of the population, or can the research go forward under the assumption that it will make use of choice-based samples? By comparing the income distributions of the samples and the population, it was confirmed that there are similar patterns of distribution, as shown in **Fig. 5-1**.



	~ 50	50-119	120-149	150-179	180-209	209-239	240-269	270-319	320-399	400~
Sample	3.8%	12.2%	15.9%	13.6%	14.9%	11.5%	8.3%	8.6%	6.1%	5.1%
Population	4.6%	14.9%	14.0%	13.0%	15.4%	10.2%	7.5%	8.3%	5.8%	6.2%

Figure 0-1. Income distribution of the samples and population.

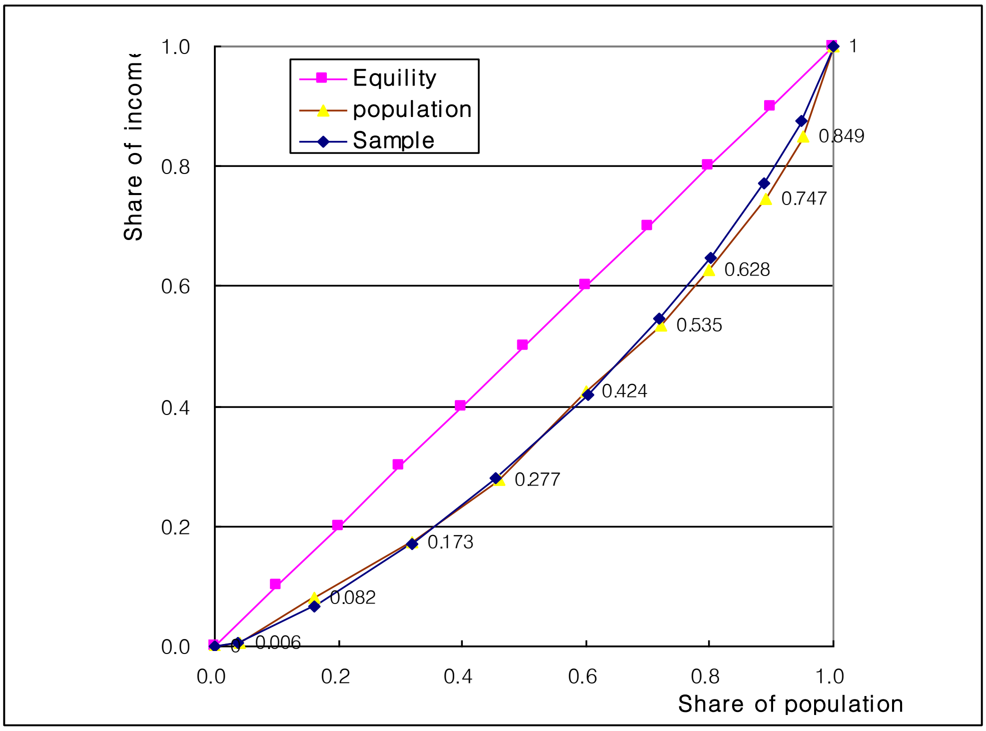


Figure 0-2 Lorenz curve and the Gini-coefficient

Fig.5-2 shows the Lorenz curve which is converted from the **Fig.5-1**. Income levels are grouped into 10 brackets, generally ₩0.5mn per month wide. The lowest bracket runs from zero to ₩0.5mn (about £250), while the uppermost bracket includes income from ₩4mn(£2,000) upwards. As shown by the Lorenz curve, the lowest 40 per cent of the population earn about

25% of the total income. Note, however, that this picture is conditioned by the fact that this study use household income. An analysis based on household income would most probable provide a less disturbing picture of income inequality (Fridstrom et al., 2000). One way to summarise the information contained in the Lorenz curve is by way of the Gini coefficient, as the area between the 45-degree strait line and the Lorenz curve. The higher the Gini-coefficient, the larger the gap between the actual and the maximally equitable, and the less equitable is –in a sense- the distribution at hand. Also the computed Gini coefficient is 0.1333 and it can be inferred that the income distribution is fairly equitable.

The mode choice ratios of the samples were 37.6% for cars, 36.9% for buses, 18.2% for the metro/rail, and 7.2% for taxis, and it was shown that the mode share decreased in the order of car, bus, metro/rail, and taxi. On the other hand, the mode shares by income level were as follows: The higher the income, the higher the mode share for private cars and the lower the mode share for the public-transport (PT) modes, such as buses and the metro/rail, as shown in **Table 5-4**.

Table 0-4. Mode choice ratios of the samples

Income / Mode	High-Income	Middle-Income	Low-Income	Average
Car	41.3%	38.9%	34.3%	37.6%
Metro/rail	17.3%	18.1%	18.8%	18.2%
Bus	33.2%	35.9%	40.1%	36.9%
Taxi	8.2%	7.1%	6.8%	7.2%

1.20.2. Data for the traffic assignment model

In this research, the EMME/2 program package was used, and the volume-delay function (VDF) was adopted as SDI (2005). For traffic assignment, the equilibrium assignment technique was used, and the change values were reiterated by combining the mode choice models until they reached a state of equilibrium, to reflect the value onto each model repeatedly. A traffic volume was assigned to the existing network based on Wardrop's principles. The new mode choice ratio was calculated through this process, after which the new traffic assignment was again processed. This iteration continued until a state of equilibrium was reached.

ⅰ. Algorithm of traffic assignment in EMME/2

The traffic assignment technique that was implemented in EMME/2 was *deterministic user equilibrium assignment*. This method is based on the following assumption: "*Each traveller chooses the route that he/she perceives as the best; if there is a path shorter than the one being used, the traveller will choose it. At the state of equilibrium, no one can improve his/her travel time by changing paths*" (INRO, 2002). Thus, the traffic volumes resulting from the equilibrium assignment are such that all the paths used between an origin-destination pair involves equal time.

In an equilibrium assignment, the travel time is usually taken as the cost measure on which travellers base their route choice. There are situations, however, in which other factors, such as the distance or road toll, are also considered in the route choice process. Such situations can be modelled by using a generalized cost assignment. The *generalized cost equilibrium in auto assignment* implemented in EMME/2 is based on the combination of the travel time and an arbitrary fixed-link cost based on the distance, or on a link user data or extra attribute. The travel time is given by the VDF, as for a time-based assignment. The generalized cost of a link is expressed as

Generalized cost = travel time + attribute × *weight.*

Auto traffic assignment in EMME/2 obtains an equilibrium solution to minimize the VDF through the linear approximation method, which is based on the Frank-Wolf[2] (1956) algorithm (INRO, 2002). The linear approximation method has the advantage of being able to easily estimate the difference between the actual traffic flow and the equilibrium flow by decreasing the total area under the volume-delay curve at each iteration. In this study, the auto traffic assignment used the fixed-demand auto assignment mode, and Beckmann's (1965) mathematical programming method was utilized to obtain the objective function (Eq. **5.2**), which was made up of the user equilibrium and turn penalties function. The auto assignment model implemented in EMME/2 computed the equilibrium flows and travel times by solving the fixed-demand problem.

$$\begin{aligned} \min\ f(v) = {} & \sum\nolimits_{a\in A}\int_0^{v_a} s_a(v+x_a)\,dv + \\ & \sum\nolimits_{i\in \bar{I}}\sum\nolimits_{a_1\in A_i^-}\sum\nolimits_{a_2\in A_i^+}\int_0^{v_{a_1}v_{a_2}} p_{a_1a_2}(v+x_{a_1a_2})\,dv\,, \end{aligned} \tag{0.2}$$

subject to:

---

[2] Frank and Wolfe (1956) suggested the convex algorithm as a process of solving quadratic programming problems on linear constraints. It is called "Frank-Wolfe algorithm." This algorithm has been evaluated as being useful in deciding the equilibrium flow on a road network (Sheffi, 1985).

$$v_a = \sum_{k \in K} \delta_{ak} h_k \qquad a \in A,$$

$$v_{a_1 a_2} = \sum_{k \in K} \delta_{a_1 k} \delta_{a_2 k} h_k \qquad a_1 \in A_i^-,\ \ a_2 \in A_i^+,\ \ i \in I,$$

$$\sum_{k \in K_{pq}} h_k = (g_{pq} / \eta_{pq}) + \gamma_{pq} \qquad p \in P,\ \ q \in Q,$$

$$h_k \geq 0 \qquad k \in K_{pq},\ \ p \in P,\ \ q \in Q.$$

The notations used above are described below.

Indices and sets:

$p \in P$	Origin zones
$q \in Q$	Destination zones
$i \in I$	Nodes of the auto network
$a \in A$	Links of the auto network
$a_1 \in A_i^-$	Links “ending” at node *i*
$a_2 \in A_i^+$	Links “starting” at node *i*
$k \in K_{pq}$	Directed paths linking p and *q*
$k \in K_{pq}$	All the directed paths
$i \in I$	Nodes corresponding to the intersections with turn penalties

Constants:

δ_{ak}	1 if link *a* belongs to path *k*; otherwise, 0
g_{pq}	Auto demand from *p* to *q* (persons)
η_{pq}	Car occupancy for O/D pair *p, q* (persons/car)
γ_{pq}	Additional demand (vehicles)
x_a	Additional volume on link *a* (vehicles)
$x_{a_1 a_2}$	Additional volume on turn (a_1 a_2)

Functions:

$s_a(v_a)$	Volume-delay or cost function on link *a*
$p_{a_1 a_2}(v_{a_1 a_2})$	Penalty function on turn (a_1 a_2)

Variables:

v_a	Auto volume on link *a*
$v_{a_1 a_2}$	Auto volume on turn (a_1 a_2)
h_k	Flow on path *k*

ⅱ. Volume-delay function (VDF)

In most traffic assignment methods, the effect of the road capacity or the congestion effect on the travel time is specified by means of VDFs, which are used to express the travel time (or cost) on a road link as a function of the traffic volume. Usually, these functions are expressed as the product of the free flow time multiplied by the normalized congestion function. The travel cost is the basis of traffic assignment, and it increases or decreases according to the ratio of volume per capacity. This simple proportional function between the traffic volume and the travel time is expressed by the VDF. As this is the most significant factor influencing traffic assignment, the appropriate choice of the travel cost function is important.

Despite the fact that many different cost functions have been proposed and used, there has been no clear consensus on the type of cost function that is necessary for any particular link. The link cost function requires convenience of integration and function differentiation for practical considerations because the procedure of traffic assignment requires their implementation. Furthermore, theoretically, it should be a non-decreasing function in accordance with the increase in link flow, to make sense of the implication of the function as well as to find an equilibrium solution for the optimization problem of traffic assignment.

By far the most widely used link cost function is the BPR function (Bureau of Public Road, 1964), which is defined in **Eq.(5.3).**

$$T = T_0[1 + \alpha(V/C)^{\beta}], \tag{0.3}$$

where T : travel time;

T_0 : travel time on free flow;

α, β : parameter; and

V/C : traffic volume per capacity.

Although the BPR function has no theoretical support, the values of 0.5 for α and 4 for β are often used in practice (Chung, 2001). On the other hand, the BPR function becomes unstable when the V/C ratio becomes higher, and it takes a long time to calculate the function when it uses a high β value. Spiess (1990) developed the conical function to speed up the convergence at the traffic assignment stage.

$$t = t_0 \times [t_c / t_0 + \sqrt{a^2 \times (1-x)^2 + b^2} - a \times (1-x) - b], \qquad (0.4)$$

where t : travel time;

t_0: travel time on free flow;

t_c: travel time under full-capacity conditions (Spiess uses $t_c/t_0=0.2$);

a: calibration factor (larger than 1);

b: $(2a-1)/(2a-2)$; and

x: traffic volume per capacity.

In this research, 11 VDFs revised by SDI (2005b) according to the Seoul traffic conditions were adopted. The VDFs were established by utilizing the BPR and conical functions according to the road conditions to calculate the traffic volume, based on which the roads were classified as those with an interrupted traffic flow and an uninterrupted flow (SDI, 2005). These are summarized in **Table 5-5**.

Table 0-5. Volume-delay function

Classification	Volume-delay function
Expressway	60×(length/90+1/180)×(1+0.5× $(V/C)^2$)
City expressway	60×(length/80+1/180)×(1+0.5× $(V/C)^2$)
Inner-ring road	60×(length/80+1/180)×(1+0.5× $(V/C)^2$)
Arterial road	60×(length/60+1/180)×(2+ $\sqrt{1.1^2 \times (1-V/C)^2 + 6^2}$ -1.1×(1-V/C)-6)
Subarterial road	60×(length/50+1/180)×(2+ $\sqrt{1.25^2 \times (1-V/C)^2 + 3^2}$ -1.25×(1- V/C)-3)
General road	60×(length/50+1/180)×(2+ $\sqrt{1.3^2 \times (1-V/C)^2 + 2.67^2}$ -1.3×(1-V/C)-2.67)
National highway	60×(length/70+1/180)×(2+ $\sqrt{1.05^2 \times (1-V/C)^2 + 11^2}$ -1.05×(1-V/C)-11)
Provincial road	60×(length/50+1/180)×(2+ $\sqrt{1.3^2 \times (1-V/C)^2 + 2.67^2}$ -1.3×(1-V/C)-2.67)
County/district road	60×(length/50+1/180)×(2+ $\sqrt{1.3^2 \times (1-V/C)^2 + 2.67^2}$ -1.3×(1-V/C)-2.67)
Ramp	60×(length/40+1/180)×(1+0.5× $(V/C)^2$)
Centroid connector	60×(length/10)

Source: The Traffic Demand Forecast of Seoul and Policy Strategies (SDI, 2005b)

The capacity in the VDF means the hourly capacity. When the traffic assignment is conducted by daily O/D, the capacity is required to adjust to the daily level. In this research, the peak hour factor of the hourly O/D data in the “2002 Household Traffic Survey in Seoul” was adopted.

1.20.3. Validation of the transport model

The model application for analyzing the impact of CC required a validation process for verifying the adequacy of the model for representing the system being simulated. The simulation model was validated in two stages. The first step involved determining whether the mode choice model was internally appropriate for assessing CC, and the second stage concerned the traffic assignment model in the Seoul network. These two stages will be discussed later.

ⅰ. Mode choice model

Normally, as the observed mode choice ratio may be different from the value estimated by the model through the process of applying the mode choice model, a process of model calibration and validation is required. In this research, such process was conducted by using the calibration dummy factors suggested by KOTI (2005). The utility function was revised by including therein the dummy factor, which reflects the difference in mode choice ratio between the estimations made by the model and via observation. The method of evaluating the dummy factors is summarized in **Table 5-6**. First of all, the correction dummy factors that are suitable for estimation by the model and the observed O/D are evaluated. Then the mode choice ratio is estimated under the dummy factor included in the individual utility function.

Table 0-6. Calibration and validation of the mode choice model

Car	Before	$\hat{P}_{ij}^{A} = \frac{e^{\hat{U}_{ji}^{A}}}{e^{\hat{U}_{ji}^{A}} + e^{\hat{U}_{ji}^{B}} + e^{\hat{U}_{ji}^{S}} + e^{\hat{U}_{ji}^{T}}} \neq P_{ij}^{A}$
	After	$\Longrightarrow \frac{e^{\hat{U}_{ji}^{A}}}{e^{\hat{U}_{ji}^{A}} + e^{\hat{U}_{ji}^{B}+\hat{D}_{ji}^{B}} + e^{\hat{U}_{ji}^{S}+\hat{D}_{ji}^{S}} + e^{\hat{U}_{ji}^{T}+\hat{D}_{ji}^{T}}} = P_{ij}^{A}$
Bus	Before	$\hat{P}_{ij}^{B} = \frac{e^{\hat{U}_{ji}^{B}}}{e^{\hat{U}_{ji}^{A}} + e^{\hat{U}_{ji}^{B}} + e^{\hat{U}_{ji}^{S}} + e^{\hat{U}_{ji}^{T}}} \neq P_{ij}^{B}$
	After	$\Longrightarrow \frac{e^{\hat{U}_{ji}^{B}+D_{ji}^{B}}}{e^{\hat{U}_{ji}^{A}} + e^{\hat{U}_{ji}^{B}+\hat{D}_{ji}^{B}} + e^{\hat{U}_{ji}^{S}+\hat{D}_{ji}^{S}} + e^{\hat{U}_{ji}^{T}+\hat{D}_{ji}^{T}}} = P_{ij}^{B}$
Metro / Rail	Before	$\hat{P}_{ij}^{S} = \frac{e^{\hat{U}_{ji}^{S}}}{e^{\hat{U}_{ji}^{A}} + e^{\hat{U}_{ji}^{B}} + e^{\hat{U}_{ji}^{S}} + e^{\hat{U}_{ji}^{T}}} \neq P_{ij}^{S}$
	After	$\Longrightarrow \frac{e^{\hat{U}_{ji}^{A}+D_{ji}^{S}}}{e^{\hat{U}_{ji}^{A}} + e^{\hat{U}_{ji}^{B}+\hat{D}_{ji}^{B}} + e^{\hat{U}_{ji}^{S}+\hat{D}_{ji}^{S}} + e^{\hat{U}_{ji}^{T}+\hat{D}_{ji}^{T}}} = P_{ij}^{S}$

<table>
<tr><td rowspan="2">Taxi</td><td>Before</td><td>$\hat{P}_{ij}^{T} = \dfrac{e^{\hat{U}_{ji}^{T}}}{e^{\hat{U}_{ji}^{A}} + e^{\hat{U}_{ji}^{B}} + e^{\hat{U}_{ji}^{S}} + e^{\hat{U}_{ji}^{T}}} \neq P_{ij}^{T}$</td></tr>
<tr><td>After</td><td>$\Longrightarrow \dfrac{e^{\hat{U}_{ji}^{A}+D_{ji}^{T}}}{e^{\hat{U}_{ji}^{A}} + e^{\hat{U}_{ji}^{B}+\hat{D}_{ji}^{B}} + e^{\hat{U}_{ji}^{S}+\hat{D}_{ji}^{S}} + e^{\hat{U}_{ji}^{T}+\hat{D}_{ji}^{T}}} = P_{ij}^{T}$</td></tr>
<tr><td></td><td></td><td>$\hat{P}_{ij}^{S}$: mode (s) choice ratio of O/D pair i, j (estimation)
P_{ij}^{S} : mode (s) choice ratio of O/D pair i, j (observation)
D_{ji}^{S} : calibration dummy for the s mode of O/D pair i, j
A, B, S, T: car, bus, metro/rail, taxi</td></tr>
<tr><td colspan="3">According to the above equations, the correction dummy factor of the bus that estimated the values in accordance with the observed values is evaluated as follows:
$$\frac{P_{ij}^{B}}{P_{ij}^{A}} = \frac{e^{U_{ji}^{B}+D_{ji}^{B}}}{e^{U_{ji}^{A}}} \Longrightarrow \frac{P_{ij}^{B}}{P_{ij}^{A}} = e^{U_{ji}^{B}+D_{ji}^{B}-U_{ji}^{A}}$$
$$\Longrightarrow D_{ji}^{B} = U_{ji}^{A} - U_{ji}^{B} + \ln\frac{P_{ij}^{B}}{P_{ij}^{A}} .$$
As in the above process, the evaluation equation of the dummy factors of the metro/rail and taxi are as follows, and the factor of the car is zero because it was used as a base case:
$$D_{ji}^{S} = U_{ji}^{A} - U_{ji}^{S} + \ln\frac{P_{ij}^{B}}{P_{ij}^{A}}$$
$$D_{ji}^{T} = U_{ji}^{A} - U_{ji}^{T} + \ln\frac{P_{ij}^{T}}{P_{ij}^{A}}$$
$$D_{ji}^{A} = 0 .$$</td></tr>
</table>

Source: KOTI, 2005

Additionally, the mode-specific constants (MSC) of the model suggested in **Table 5.2** must be revised to analyze the effect of CC on a specific area. Although the MSCs have an effect on the mode choices of travellers, they may differ by period or area in a city because they exhibit the possibility of omitting the explanation variables in the model. Therefore, contrary to the parameters related to policy, such as the travel cost and time, there is no theoretical basis that can be transferable to other times or areas. Thus, it can be inferred that it is appropriate to use the revised estimated value of MSC (Oh et al., 2001).

On the other hand, the mode choice model was segmented by income level to analyze its effect on equity, and it was applied individually. As the relative utilities of the four modes differed by income level, the MSC was revised by income level to better reflect the mode choice ratio by income level.

Value of time

The compatibility of the selected model can be determined by investigating the value of time (VOT). VOT is a monetary value converted from the travel time. It is not meaningful as the absolute time, however, but it is significant when compared to the time for other activities. That is, it points to an opportunity cost for time when used as the time for other valuable activities or based on the willingness to pay to reduce the travel time. It plays a significant role in a traveller's mode choice in a traffic demand model. VOT can be evaluated by estimating the marginal rate of substitution of the travel time and travel cost in the Logit model. On this point, it is based on the premise that the marginal reduction of the travel time is indifferent to the supplementary travel cost (marginal travel cost).

The applied utility function, which was investigated above, followed Eq.**(0.5)**, and the VOT was calculated using Eq.**(0.6). Table 5-7** shows the VOT by income model, which was evaluated using Eq.**(0.6)**.

$$V_{iq} = \alpha_i + \beta_1 \frac{TCOST_i}{INC_h} + \beta_2 IVTT_i + \beta_3 OVTT_i \qquad (0.5)$$

$$\text{VOT} = \frac{\beta_2}{\beta_1} \times INC_h , \qquad (0.6)$$

where β_2 / β_1: the ratio of the in-vehicle time to the cost.

As a result of the estimation of the VOT, the ratio (β_2 / β_1) of the marginal substitution of the travel cost was 1.0014. This means that the one-hour reduction of the travel time produced a benefit of 1.0014 times the hourly income. Therefore, the travellers' one-hour trip was substituted by the average of ₩10,786, with₩6,458 for the low-income group, ₩10,895 for the middle-income group, and ₩18,227 for the high-income group.

Table 0-7. Value of time by income level

Unit: won/hour

Income Level	β_2/β_1	Hourly Income	VOT	Avg. VOT
High	1.0014	6,449 (£3.22)	6,458 (£3.23)	10,786 (£5.39)
Middle	1.0014	10,880 (£5.44)	10,895 (£5.45)	
Low	1.0014	18,202 (£9.10)	18,227 (£9.11)	

VOT, as shown in **Table 5-7**, appears similar to the hourly income on each income level, and the average VOT of the samples was about ₩10,786. Mohring (1976) suggested that the value of the in-vehicle time of commuters is 25~50% of their income while Wilson (1989) suggested that it is about 41%. The estimated values in **Table 5-7** are thus much higher than the empirical values. Wardman (1998) reviewed the large number of empirical studies in the UK that provide VOT estimates. He suggested that the estimated VOT tends to be lower for the gains in journey time than for the losses, and to be higher for larger changes in journey time. In addition, it tends to be underestimated in cases where the research objective is to estimate the VOT rather than simple forecasting. Thus although studies elsewhere suggest that the values in **Table 5-7** may be overestimates they represent the best available local evidence.

Elasticity

The elasticity of the traffic demand model is used as a measure of the responsiveness of the demand to the individual attribute that influences the demand. Direct and cross-elasticities can be used for this purpose. In this study, direct elasticities were employed. Direct elasticities are the percentage change in the probability of choosing an alternative in a choice set with respect to the given percentage change in the attributes of such alternatives. Cross-elasticities, on the other hand, are the percentage changes in the probability of choosing particular alternatives in a choice set with respect to the given percentage changes in the attributes of the competing alternatives. In the case of the MNL model, the direct elasticities are given by

$$E^{P_{iq}}_{X_{ikq}} = \frac{\partial P_{iq}}{\partial X_{ikq}} \cdot \frac{X_{ikq}}{P_{iq}} \tag{0.7}$$

which can be interpreted as the elasticity of the probability of choosing alternative *i* for individual *q* with respect to a marginal change in the *k*-th variable, which describes the utility of the *i*-th alternative for individual *q*. The direct elasticity of the model is shown in **Table 5-8**. The direct elasticity of the IVTT is shown to be commonly higher than the other variables, except for the taxi. This indicates that travellers reflect more on the travel time than on the travel cost.

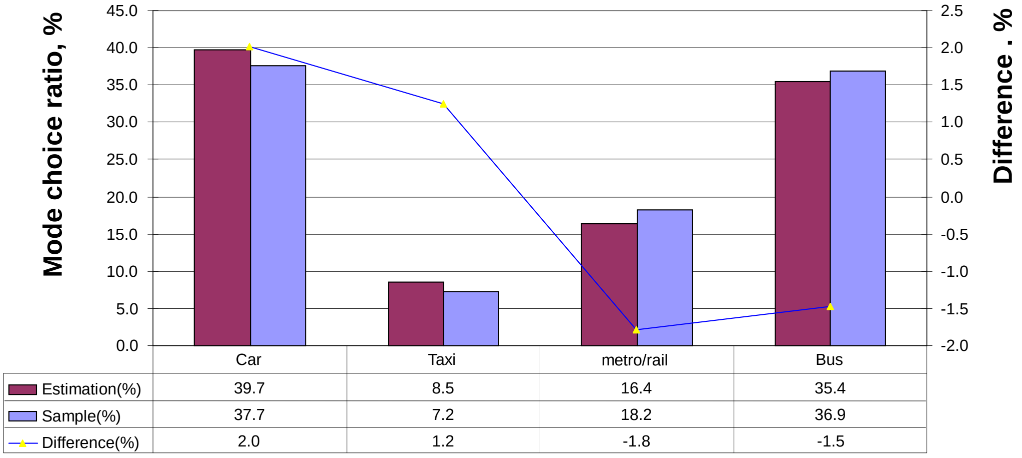
Table 0-8. Elasticities of the model

	Car	Bus	Metro/Rail	Taxi
Cost/income	-0.3689	-0.2262	-0.2988	-4.0333
IVTT	-1.3768	-1.2830	-0.8241	-2.6319

On the other hand, traffic modes, except for the metro/rail, are elastic to the travel time. It is shown that the absolute value of elasticity is bigger than 1. As the punctuality of the metro/rail is the highest compared to those of the other modes, it can be inferred that the metro/rail users reflect the travel time less on their mode choice. In addition, the elasticity of the travel cost is highest for the taxi, followed by the car, metro/rail, and bus, in the travel cost/income variable, because the travel cost of the taxi is highest among the four modes. Oum et al. (1992) surveyed the elasticities of the transport demand of passengers in empirical studies, and the elasticities were shown to be -1.10~-0.10 for the cars, -1.30~-0.10 for buses, and -1.18~-0.30 for the metro/rail. Considering the empirical range of the elasticities, it can be inferred that the application model in this study is feasible.

Mode choice ratio

The average mode shares of the samples were 37.6, 36.9, 18.2, and 7.23%, and the estimated values were 39.7, 35.4, 16.4, and 8.5% for cars, buses, the metro/rail, and taxis, respectively. The differences between the samples and the estimated values were 2.1, -1.5, -1.8, and 1.2%, respectively (see **Fig. 5-3**). The results indicate that the mode choice ratios of the car and taxi were overestimated, and that those of the bus and metro/rail were underestimated overall. As the differences are not very high, however, it can be concluded that the model well reflects the mode choice ratio of the samples.



	Car	Taxi	metro/rail	Bus
▨ Estimation(%)	39.7	8.5	16.4	35.4
▨ Sample(%)	37.7	7.2	18.2	36.9
—▲— Difference(%)	2.0	1.2	-1.8	-1.5

Figure 0-3. Mode choice ratio of the samples and model.

On the other hand, considering the income level, the differences between the samples and the estimated values were 2.4, -1.0, -1.7, and 0.5% in the high-income group; 0.8, -0.5, -1.7, and 1.4% in the middle-income group; and 0.4, -0.2, -1.5, and 1.4% in the low-income group for the car, bus, metro/rail, and taxi, respectively. As the differences are smaller than 2%, the model well reflects the mode choice by income. Consequently, it can be inferred that the revised model validates the applicability and compatibility in this research. **Table 5-9** shows the mode choice ratios of the samples and the estimated results.

Table 0-9. Mode choice ratios of the samples and the estimated results

(Unit: %)

Income Level \ Mode		Car	Bus	Metro/Rail	Taxi
High	Sample	41.3	33.2	17.3	8.2
	Estimation	43.7	32.2	15.43	8.6
	Difference	2.4	-1.0	-1.68	0.4
Middle	Sample	38.9	35.9	18.1	7.1
	Estimation	39.7	35.4	16.4	8.5
	Difference	0.8	-0.5	-1.7	1.4
Low	Sample	34.3	40.1	18.8	6.8
	Estimation	34.7	39.9	17.3	8.2
	Difference	0.4	-0.2	-1.5	1.4
Average	Sample	37.6	36.9	18.2	7.2
	Estimation	39.7	35.4	16.4	8.5
	Difference	2.1	-1.5	-1.8	1.3

ii. Network

Validation of a network was conducted using the traffic volume. The data in the *2005 Annual Report on the Road Traffic Volume* (MOCT, 2006) and the traffic data provided by the Seoul metropolitan police agency's comprehensive traffic information centre were used as the monitoring data for model validation. The 2005 O/D trip matrix was assigned for the Seoul network and was validated by comparing the real and assigned traffic volumes.

The O/D matrix and network data for traffic assignment adopted those from *Traffic Demand Forecast of Seoul, and Policy Strategies* (SDI, 2005). The mode trip O/D on the road network was converted into vehicle O/D by applying vehicle occupancy, which is 1.27 persons for cars, 1.54 persons for taxis, and 14.57 persons for buses, per vehicle. The passenger car equivalent (PCE) of a bus is 2.0 PCU per vehicle, according to *Household Travel Survey and Analysis in Seoul* (SDI, 2003).

An applied transport network consists of a road network and a transit network built separately. The road network dates back to 2005 and consists of 1,142 centroids and 16,856 regular nodes connected by 43,987 links. The transit network, on the other hand, consists of 1,142 centroids and 1,553 regular nodes connected by 3,443 links. It is described in **Table 5-10**. In addition, the traffic zone was made to consist of 1,142 small zones and 58 large zones by the administrative district system. The small zones consist of 522 in Seoul, 118 in Incheon, 480 in Gyunggi province, and 13 external zones. As the large zones are formed when small zones are put together, individual districts (gu) in Seoul become large zones, and several districts (gu, si, and gun) are joined together geographically. Similar peculiarities occur in Incheon and Gyunggi province.

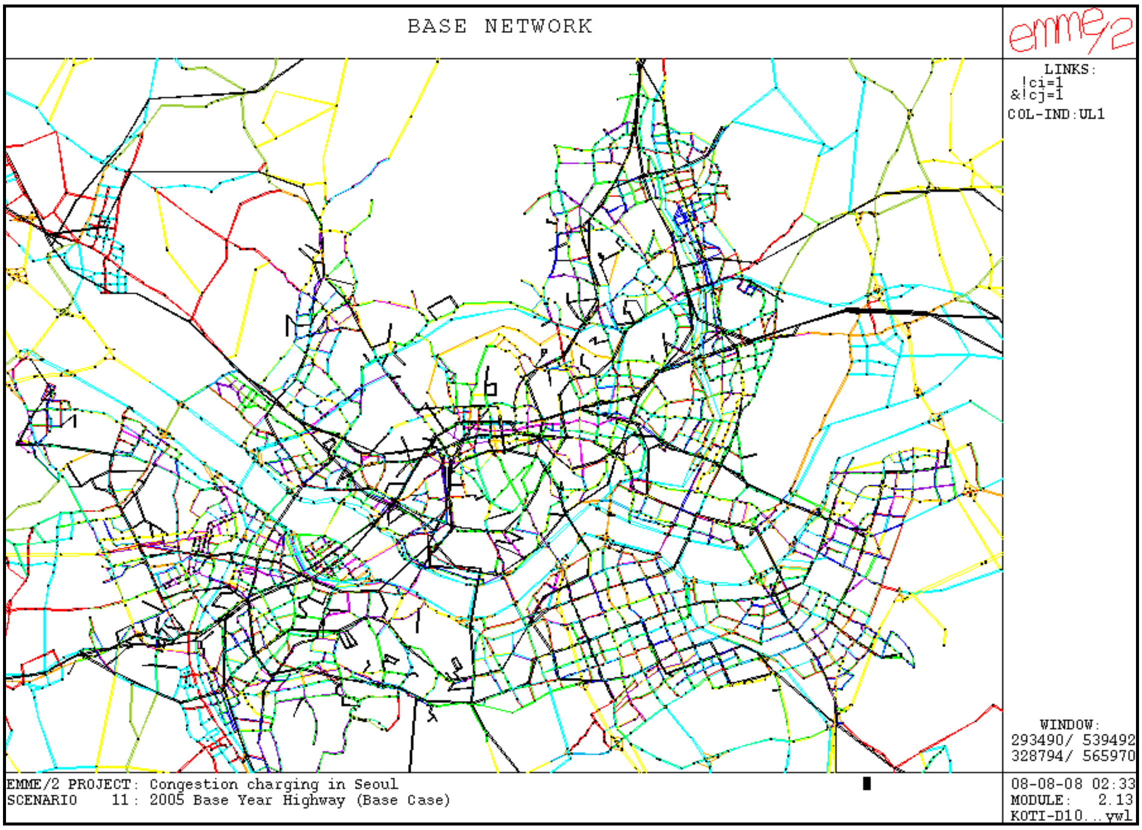


Figure 0-4. Base network in EMME/2.

Table 0-10. Seoul network in EMME/2

	No. of Centroids	No. of Nodes	Links	
			Total No.	Length (km)
Road	1,142	16,856	43,987	44,113
Transit	1,142	1,553	3,443	18,252

An applied network covers over 12-meter-wide roads and metro/rail lines. An 11-VDF (see **Table 4-8**) is implied according to the road capacity, considering the road classifications provided by SDI (2005). **Fig. 5-4** shows the base network of the Seoul metropolitan area in EMME/2.

Statistical analysis methods of the root mean square error (RMSE) and percent root mean square error (PRMSE) were applied. The lower the values of RMSE and PRMSE were, the better the trace of the real traffic volume, which is the volume assigned by model. The difference in the errors between the real traffic volume and the assigned volume was calculated using the following equations:

$$RMSE = \sqrt{\frac{\sum_i (t_i - T_i)^2}{N}}, \tag{0.8}$$

$$PRMSE = (\frac{RMSE}{T_e}) \times 100, \tag{0.9}$$

where t_i : assigned traffic volume on link *i*;

T_i : real observed traffic volume on link *i*;

N : no. of links; and

T_e : average real observed traffic volume.

Validation of the traffic volume in the network was conducted on 27 main links. The results are shown in **Table 5-11**.

Table 0-11. Network validation (summary)

Unit: vehicle/day

	No. of Observations	∑ Real Traffic Volume (A)	∑ Assigned Traffic Volume (B)	Difference (B/A-1)	PRMSE
CBD	7	552,991	543,744	-1.7%	
2^{nd} CBD	5	528,368	536,343	1.5%	
Bridge	7	701,175	655,098	-6.6%	
City boundary	8	669,981	675,083	0.8%	
Total	27	2,452,515	2,410,268	-1.7%	9.9%

The difference between the real traffic volume and the assigned volume was estimated to be 1.7% overall. The absolute values of the difference were 1.7 and 1.5% in the CBD and secondary CBD, respectively. Particularly, the difference between the values of eight observation links on the city boundaries was estimated to be small (below 1%). Moreover, as the

PRMSE was 9.9%, the model traces the real network well. Consequently, the model is appropriate for application to the Seoul network. The results of the comparison of the observed and assigned traffic volumes are shown in **Table 5-12**.

Table 0-12. Validation of the traffic volume

Unit: vehicle/day

Classification		Real Traffic Volume (A)	Assigned Traffic Volume (B)	Difference (B/A-1)	PRMSE
CBD	Changgyungungro	61,189	59,245	-3.2%	9.9%
	Angukyuk	82,928	82,166	-0.9%	
	Jongro3ga	86,521	83,419	-3.6%	
	Seoul Station	103,871	101,840	-2.0%	
	Geumhwa Tunnel	77,498	70,668	-8.8%	
	Seosomunro	67,077	76,512	14.1%	
	Wangsimrigil	73,907	69,894	-5.4%	
2nd CBD	Gangnamdaero	85,512	73,303	-14.3%	
	Teheranro	104,195	96,723	-7.2%	
	Maebong Tunnel	90,673	97,913	8.0%	
	Dongjakdaero	127,472	134,719	5.7%	
	Nambusunhwanro	120,516	133,685	10.9%	
Bridge	Gayang Br.	73,691	78,160	6.1%	
	Seongsan Br.	194,253	171,900	-11.5%	
	Yanghwa Br.	126,543	119,298	-5.7%	
	Seogang Br.	63,856	56,148	-12.1%	
	Dongjak Br.	74,611	72,184	-3.3%	
	Jamsil Br.	79,955	68,970	-13.7%	
	Olimpic Br.	88,266	88,438	0.2%	
City boundary	Gaehwaro	82,205	80,040	-2.6%	
	Tongilro	66,435	62,804	-5.5%	
	Susaero	71,799	67,023	-6.7%	
	Songpadaero	80,484	73,157	-9.1%	
	Dongjakdaero	96,349	113,482	17.8%	
	Dongilro	110,510	99,396	-10.1%	
	Hwarangro	42,847	43,384	1.3%	
	Siheungdaero	119,352	135,797	13.8%	
Total		2,452,515	2,410,268	-1.7%	

1.21. EVALUATION OF CONGESTION CHARGING

This section presents the applied evaluation methodology from the standpoint of equity and efficiency. The efficiency was evaluated based on the economic improvement, as determined through cost-benefit analysis. Equity pertains to how to distribute the welfare change by user group and was evaluated by compensating for the variation by income level. A detailed description follows.

1.21.1. Efficiency impact analysis

The effects of transportation and user benefit change are significant indices of CC in a social system, but they do not include all the actual benefits and costs that occurred in the system when CC was applied. For example, the out-of-pocket money of a car user (e.g., for fuel cost, toll, etc.) does not properly reflect both the variable expense for the maintenance and repairs of roads and the total external cost, which is a burden to the system, as the results of traffic congestion, traffic accidents, or air pollution. Therefore, the car users neither recognize the social cost of their road use nor actually pay for it. Furthermore, the bus, metro/rail, or taxi fare that they pay may not match the social cost, which is related to the production of PT services. In this regard, it is not reasonable to decide on the feasibility of the implementation of the CC policy based only on its benefits to the travellers. Therefore, an advanced cost-benefit analysis method, which estimates all the effects and costs of the implementation of the policy, should be applied to justify the feasibility of the implementation of the policy. Accordingly, the efficiency impact of the CC policy was analyzed in this work by evaluating the social-welfare effects.

The social-welfare effects can be estimated by deducting the costs from the benefits. The items to be considered in cost-benefit analysis are as follows:

- Benefits: total welfare change of the traveller (change in willingness to pay)
- Costs: operating or private cost, toll collection cost, external cost, etc.

The amount of user welfare change, which is considered a benefit, can be evaluated based on the CV, which is estimated by the Logit model. On the other hand, the amounts of the operating or private cost change in the cost items include the operating cost of private cars and PT. Further, the management of the existing roads, parking facilities, metro/rail, etc. are excluded from the evaluation of the private-cost change based on the assumption that they are not changed in the short term. The external-cost change includes the costs caused by traffic congestion, traffic accidents, and air pollution from car emissions. The amount of social-welfare change (ΔSW) can be evaluated using **Eq.(5.10)**.

$$\Delta SW = \Delta U - \Delta C_{O/P} - \Delta C_{EXT} + \Delta R, \tag{0.10}$$

where ΔSW : change in social welfare;
ΔU : change in user benefit;
$\Delta C_{O/P}$: change in operating or private cost;
ΔC_{EXT} : change in external cost; and
ΔR : change in revenue.

The user benefit, recognized as a monetary value, is appropriate for estimating the welfare change of the traveller. It was evaluated in the previous section as a CV. The changes in private cost ($\Delta C_{private}$) and external cost (ΔC_{EXT}) are related to the production of transport services. The change in revenue (ΔR) relates to the toll and taxes for the government and the income of the PT suppliers. The detailed items in Eq.**(5.10)** and the evaluation process are shown below.

ⅰ. Operating or private cost ($\Delta C_{O/P}$)

The private cost is the cost confined to the owner who operates the vehicle and can be distinguished from the social cost, which induces other cost changes. Thus, the change in private cost when CC is applied is the cost change for the operation of private cars by the car owners and PT suppliers. As it has been evaluated in the previous CV, the change in private cost by the car user is no longer calculated herein. Additionally, in the case of the bus and metro/rail, since the amount or headway is assumed to be unchanged by the charge, variation of the private cost change does not occur. Moreover, the cost of operating the charging scheme for toll collection is included in the operating or private cost. Therefore, the change in private cost by the congestion charge, which is given in **Eq.(5.11),** can be estimated based on the parking cost change, which is supported by the employer, or on the cost change caused by the operation distance change of the taxi company and the toll collection cost.

$$\Delta C_{O/P} = \Delta PCE + \Delta TOC + TCC \,, \qquad (0.11)$$

where ΔPCE : change in the parking cost of the employer;

ΔTOC : change in the operating cost of the PT suppliers; and

TCC : toll collection cost (charging scheme operating cost).

Parking cost of the employer (ΔPCE)

The monetary cost perceived by a car user does not include the parking cost, which is paid by the employer when the commuters choose cars as a travel mode. That is, although most car commuters recognize parking as free, the employers in fact pay the cost of such. In this regard, the change in the private cost of a car user was evaluated based on the change in the parking cost, which is given in Eq.(5.12).

$$\Delta PCE = \sum_i \sum_j (A_1 \times PR) \times (NV_1^{ija} - NV_1^{ijb}) \,, \qquad (0.12)$$

where ΔPCE : parking cost of the employer;

A_1 : portion of the commuter trips for which the parking fee is paid by the employer;

PR : average parking fee; and

NV_1^{ija} : no. of cars using the charging zone (1:car).

a : after charging, b : before charging

Operating cost of the PT suppliers (TOC)

The total travel length of a taxi changes in accordance with the mode shift upon the implementation of CC. Typically, the travel costs of modes, which are used in the process of the mode choice model's estimation, do not always match the costs of the suppliers. Accordingly, the change in the private cost of the PT suppliers was estimated using the unit operation cost and the change in travel length, as in Eq **(5.13)**.

$$\Delta TOC = \sum_i \sum_j (OC) \times \Delta VKT^{ij} \,, \qquad (0.13)$$

where OC : unit operating cost of taxi service by the supplier (won/km); and

VKT : vehicle kilometre travelled.

Toll collection cost (scheme operation cost, TCC)

The toll collection cost was evaluated in accordance with the charging scheme under the assumption that the cost is proportionate to the charging point. The unit cost of the charging point was adopted by the existing CC schemes (e.g., the London and Stockholm schemes).

ii. Change in the external cost (ΔC_{EXT})

A road user imposes costs on others and on the overall social system. When charging is put into operation, the travel time and cost will change due to the mode or route change. Additionally, a change in external cost occurs as a result of traffic accidents, air pollution, and traffic noise. The car users and PT suppliers do not bear these costs, but these have to be considered in the social system. Therefore, the would-be external cost encompasses the traffic accident cost (ΔTAC) and environmental cost (ΔTEC) for air pollution and noise in this work. The amount of change in the external cost was evaluated using Eq **(5.14).**

$$\Delta C_{EXT} = \Delta TAC + \Delta TEC \,, \tag{0.14}$$

where ΔTAC: traffic accident cost; and ΔTEC : environmental cost.

Traffic accident cost (ΔTAC)

According to the CC of cars, the travel cost changes relatively by mode and affects the mode choice, traffic speed, and travel length. Moreover, traffic accidents take place in proportion to the traffic circumstances (Lee and Shim, 1997). As the amount or headway of buses and the metro/rail is assumed not to be changed by the charge, they will not change the travel length. Therefore, the change in the traffic accident cost was analyzed in relation to cars and taxis, in accordance with the change in travel length in this research. As the traffic accident cost of taxis, however, was reflected in the operation cost (OC) in the estimation of the private cost of a taxi supplier, it was excluded from the evaluation. The traffic accident cost of cars was calculated using Eq **(5.15),** under the assumption that a car is expected to incur an accident cost per kilometre (EAC).

$$\Delta TAC = EAC \cdot \sum_i \sum_j \Delta VKT^{ij} \cdot POA \,, \tag{0.15}$$

where EAC : expected accident cost (won/km);

POA : probability of accidents; and

VKT^{ij} : vehicle kilometer travelled.

Environmental cost (ΔTEC)

The environmental cost is considered based on the air pollution and noise and is calculated using Eq (5.16).

$$\Delta TEC = EEC \cdot \sum_{i}\sum_{j} \Delta VKT^{ij} \, , \tag{0.16}$$

where EEC : unit cost of the expected environmental impact (won/v-km); and

VKT^{ij} : vehicle kilometre travelled.

iii. Change in revenue (ΔR)

The revenue change consists of the toll fees collected and taxes imposed by the government as well as the fare income of the PT suppliers. It was estimated using Eq **(5.17)**.

$$\Delta R = \Delta RTO + \Delta RTX + \Delta IFR \, , \tag{0.17}$$

where ΔRTO : revenue by toll;

ΔRTX : revenue by tax; and

ΔIFR : income of a PT supplier.

Revenue by toll (ΔRTO)

The generating revenue was estimated by toll, particularly by multiplying the number of charged cars, using Eq **(5.18)**

.

$$\Delta RTO = \sum_{i}\sum_{j} CC \cdot NV_1^{ij} \, , \tag{0.18}$$

where CC : congestion charging toll; and

NV^{ij} : no. of charged cars.

Revenue by tax (ΔRTX)

Car users and PT suppliers are made to pay taxes at the stages of vehicle acquisition, ownership, and operation. Regardless of the PT mode shift by CC, the car ownership and the amount or headway of buses and of the metro/rail are assumed to be unchanged. Therefore, the change in revenue considers only the operation stage of cars and taxis. It is related to the fuel cost in accordance with the travel length and can be calculated using Eq **(5.19)**

.

$$\Delta RTX \quad = t_m^F \cdot FP_m \cdot FE \cdot \sum_i \sum_j \Delta VKT^{ij} \ , \qquad (0.19)$$

where $t^F{}_m$: portion of tax in the fuel price (LPG and petrol);

FP_m : retail price of fuel (LPG and petrol);

FE : fuel efficiency (liter/km); and

VKT^{ij} : vehicle kilometer travelled.

Income of the PT suppliers (ΔIFR)

The PT fare paid by the users does not always match the private costs of the PT suppliers. It was assumed that the private costs of the suppliers of bus and metro/rail services were not changed by CC in this study, as previously stated. In addition, the cost of the taxi service suppliers was calculated using Eq.(5.13). Therefore, the changed income of the PT suppliers was calculated using Eq.(5.20). The result of the calculation had to be deducted from the change in the private cost of the PT suppliers so as not to duplicate the estimation of the social-welfare change.

$$\Delta IFR \quad = \sum_i \sum_j FARE^{ij} \cdot (N^{ija} - N^{ijb}) \ , \qquad (0.20)$$

where $FARE^{ij}$: PT fare (won/trip); and

N^{ij} : no. of PT users.

1.21.2. Equity impact analysis

The equity impact that may be expected from the CC system is a complicated matter. It depends on how the charges are designed, how the revenue is used, and which groups and areas are affected by the charges. An analysis of the incidence of cost and benefit can identify the winners and losers. The calculation of the effects by socioeconomic group and geographic area, however, is very complicated. Even among experts, there are divergent opinions regarding the distributive effects that can be expected and to what extent they can be calculated. The assessment of who gains and who loses, and by how much, is warranted as a part of the evaluation process.

When CC is implemented, the stress or burden felt by the travellers can differ depending on their income level or travel purpose. In economics, this equity impact can be measured by analyzing the consumers' surplus, the CV, etc., across income levels. In this application, the users are classified by characteristic (i.e., high-, middle-, or low-income level, etc.), and then the change in the users' social welfare is analyzed by income group.

For this assessment, the social-welfare change by income level is evaluated after deriving the CV from a Logit model, such as that of Small and Rosen (1981). If the CV is evaluated by income level, the equity or distribution impact can be assessed. The amount of CV pertains to the price of returning to the travellers' utility before CC, and its size is the same as that of the travellers' welfare change. To estimate the CV by income, the parameter of utility function, which is estimated in the mode choice model, must be utilized. The detailed evaluation processes are as follows.

First of all, to assess the social-welfare change after CC under the assumption that the income effects are small enough to ignore, the equation of utility function (see Eq **5.21**) was differentiated by the cost variable built in the mode choice model. It was then deducted, after which the marginal utility of cost/price was derived (Eq **5.22**).

$$U_{hijk} = \alpha_{hk} + \beta_1 \frac{TCOST_{ijk}}{INC_h} + \beta_2 IVTT_{ijk} + \beta_3 OVTT_{ijk}\,, \qquad (0.21)$$

where U_{hijk} : utility of the traveller;

$TCOST_{ijk}$: travel cost;

INC_h : average income;

$IVTT_{ijk}$: in-vehicle travel time;

$OVTT_{ijk}$: out-of-vehicle travel time;

a : mode-specific constant;

h : income level (high, middle, low);

i : origin zone (i=1, 2, ..., m);

j : destination zone (j=1, 2, ..., n) ; and

k : mode (k=1, 2, ..., q).

$$\lambda_h = \frac{\partial U_{hijk}}{\partial TCOST_{ijk}} = -\frac{\beta_1}{INC_h} \quad \text{(h=1, 2, ...,p),} \qquad (0.22)$$

where λ_h = marginal utility of the price for income group h (assuming that $\beta_1<0$).

At the second stage, the travel cost and travel time by zone and mode is estimated by the model combined with the traffic assignment and mode choice to estimate the variation of utility when CC is implemented.

At the third stage, the CV is evaluated by zone and income level using the variation of the marginal utility of income, travel time, and travel cost, which were evaluated at the previous stages, and the variation of the utility of each mode is summarized using Eq. **5.23**. The items in the square brackets in Eq. **5.23** pertain to the expectation that one can gain the maximum utility. They can thus be made monetary values of the social-welfare change by multiplying these variations of the expectation of maximum utility by the marginal utility of the income.

$$\Delta e_{ijh} = -(\frac{1}{\lambda_h}) \times [\ln \sum_{k=1}^{q} \exp(U_{ijhk}^{a}) - \ln \sum_{k=1}^{q} \exp(U_{ijhk}^{b})] , \qquad (0.23)$$

where a : after the implementation of CC; and

b : before the implementation of CC.

At the fourth stage, the travellers' CV by income level is produced by the CV by each zone and income level (Δe_{ijh}), which is a product of the third stage. This is multiplied by the number of travellers and then added up. The sum of the travellers' CV then becomes the total travellers' CV. This total travellers' CV is the amount of money required to compensate the travellers for keeping the level of travellers' utility before charging.

$$\Delta E_h = \sum_{i=1}^{m} \sum_{j=1}^{n} (\Delta e_{ijh} \times N_{ijh}) , \qquad (0.24)$$

where ΔE_h : total traveller's CV by income level; and

N_{ijh} : number of travellers by income between O/D pair i-j.

$$\Delta E = \sum_{h=1}^{p} \Delta E_h , \qquad (0.25)$$

where ΔE : total CV.

Consequently, the total CV (ΔE) is an amount of compensation for travellers as users so that they will have the same utility before and after the implementation of CC. The result of the CV analysis can be interpreted as follows: If a positive CV result is derived after CC, the utility is decreased and the user welfare (travellers' benefit) is worse off; if a negative result is derived, the user welfare is better off.

At the last stage, the equity effect is estimated with the use of CV by income level, which is produced through the previous processes. In this study, the income level was divided into three categories: low, middle, and high. The average CV by income level was evaluated with the use of the CV by income level, which was calculated at the fourth stage, divided by the number of travellers. Such analysis allows the comparison of the average CVs of the three income groups and assesses the equity effect of CC.

$$\Delta\overline{e_h} = \frac{\Delta E_h}{N_h}, \tag{0.26}$$

where $\Delta\overline{e_h}$ = average CV by income level; and

N_h (number of total travellers by income) = $\sum_{i=1}^{m}\sum_{j=1}^{n} N_{ij}$.

In order to the analysis of the equity effects, an absolute value of the ratio(π_h, see **Eq.5.27**), which is the ratio of CV per person (CVPP) in the average income, can be used to judge the degree of real gain or loss. In this regard, it can be concluded that if the ratio(π_h) is positive and high income gets higher value rather than low income, the policy is progressive. On the contrary, it can be concluded that the policy is regressive if the ratio is negative and high income gets higher value rather than low income.

$$\pi_h = \frac{\Delta\overline{e_h}}{INC_h}, \tag{0.27}$$

where π_h = the portion of CVPP in the average income.

If the ratios of π_h,(h =1,2,3; 1=high income, 2=meddle income, and 3=low income), is defined as follows;

$$\pi_{12} = \frac{\Delta E_1}{\Delta E_2}, \qquad \pi_{23} = \frac{\Delta E_2}{\Delta E_3}, \qquad \pi_{13} = \frac{\Delta E_1}{\Delta E_3} \tag{0.28}$$

Where ΔE is negative, then the welfare change is positive whereas ΔE is positive then the welfare change is negative as these ratios get smaller (more negative) this is regressive. As they get larger, they are progressive. Note this is dependent on the definition of the numerator and denumerator. Also, if, $\pi_1 > \pi_2 > \pi_3$, this would be progressive, if $\pi_1 < \pi_2 < \pi_3$, this would be regressive.

1.22. TRANSPORT IN SEOUL

This section provides an overview of the transport in Seoul and its 10-year experience of CC. Then, the charging regimes for the case study are described following their selection based on the travel and socioeconomic data.

1.22.1. Overview of the transport in Seoul

Seoul, the capital of South Korea, is a city that rapidly progressed in terms of urbanization in the last decades. As of 2005, the Seoul metropolitan area covered a 12,446-km^2 area and had 22.8 million inhabitants, which comprised approximately half of the total population of South Korea then (Korea National Statistical Office, 2006). It includes the city of Seoul itself as well as the city of Incheon and Gyeonggi province. With a population of 10.3 million in 2005, the core city of Seoul is one of the world's largest cities, and with 16,221 inhabitants per km^2, it is also one of the world's most densely populated cities, 1.5 times more densely populated than London and twice as New York. In particular, its central area accounts for 1.4% (8.5 km^2) of the city and is 4 km long and 2 km wide. With about 45,000 inhabitants and a floating population of 2.5 million, over 1.4 million vehicles travel daily into and out of the city's CBD (SDI, 2003).

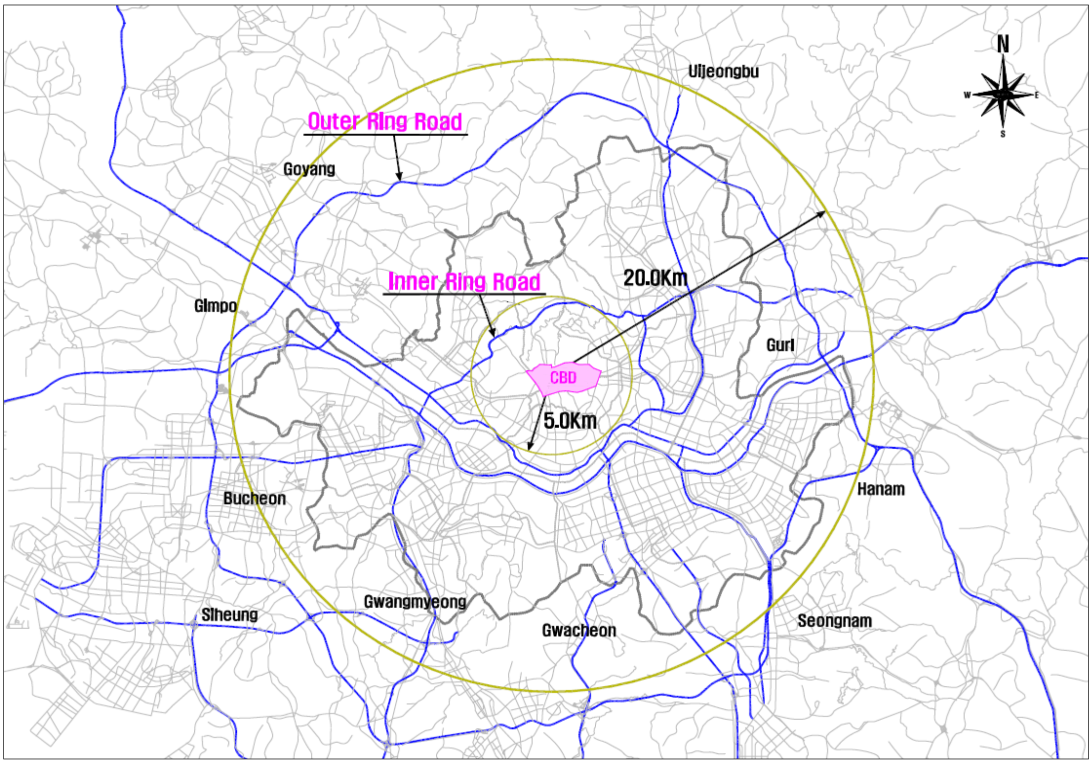


Figure 0-5. Seoul metropolitan area overview.

Seoul's rapid economic growth resulted in a large increase in the demand for both transport service and private car ownership. There are 2.8 million cars in the city, a fact that substantially leads to severe traffic congestion in Seoul. In 2005, the passenger car speed was very slow; the average daily travel speed was 22.9 km/h. In particular, the traffic speed of the cars in central Seoul was only 14 km/hr (SMG, 2007b). Moreover, the speed in central Seoul has been decreasing steadily for the last 10 years, as shown in **Table 5-13.**

Table 0-13. Travel speeds for passenger cars

		1996	1998	2000	2002	2004	2005
Passenger car speed[3] (km/h)	All	20.9	25.41	22.92	22.5	22.4	22.9
	CBD	16.44	17.72	18.84	16.3	13.6	14.0
	Other	21.23	25.9	23.21	23	23	23.5

Source: SMG, 2007c

The total number of daily trips in the Seoul metropolitan area in 2006 was 51.0 million. The traffic was 34.8% by metro/rail and 27.5 and 26.3%, respectively, by bus and car. This was influenced by the public-oriented transport policy, such as exclusive bus lanes, CC, parking, and the one-weekday-no-driving system.

Table 0-14. Traffic mode share in Seoul

	Car	Bus	Metro/Rail	Taxi	Etc.
Mode share (%)	26.3	27.5	34.8	6.5	4.9

Source: SMG, 2007b

Meanwhile, with regard to the trends of Seoul's annual road extension rate, the length of its roads increased from 7,689 km in 1996 to 8,067 km in 2006, which is a mere 0.5% annual average growth rate. The city's road area in the same period increased by merely 0.8% annually, and the road rate also increased by 0.8%. The number of registered vehicles, however, is steadily increasing, reaching 2.85 million in 2006. Comparing the road length with the number of registered vehicles, the road length decreased by about 20%, from 3.6 km per thousand vehicles in 1996 to 2.8 km per thousand vehicles in 2006. Moreover, the road area per thousand registered vehicles was reduced by 1/3, from 0.034 km^2 per thousand vehicles in 1996 to 0.029 km^2 per thousand vehicles in 2006. Compared to the explosive growth of vehicle registration in Seoul, the city's road length is nearly on the same level.

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[3] Note that the increased speed between 1998 and 2000 was due to the economic crisis in South Korea.

Table 0-15. Trend of road infrastructure and registered vehicles in Seoul

	1996	1998	2000	2002	2004	2006
Road length (㎞) (km per thousand vehicles)	7,689 3.55	7,801 3.55	7,888 3.23	7.943 2.95	8,011 2.88	8,067 2.82
Road area (㎢) (km^2 per thousand vehicles)	75.65 0.035	77.4 0.035	78.69 0.032	80.15 0.030	80.64 0.029	81.57 0.029
Road ratio (%)	20.2	20.66	21.01	21.37	21.53	21.78
Registered vehicles (1,000 vehicles)	2,168	2,199	2,441	2,691	2,780	2,857

* Road ratio: Road area ÷ settlement area (374.55 ㎢) x 100%, width over a 4m road
* Source : SMG, 2007b

ｉ. Characteristics of the traffic demand in Seoul

According to the Household Traffic Survey Data in Seoul (SDI, 2007), compared to the figure between 1996 and 2006, the total trips in Seoul decreased approximately by less than 1% from the average 20.1 million per day, to 20 million per day. The total number of inbound and outbound trips in Seoul, however, increased by 27%; the average daily traffic increased from 5.2 million in 1996 to 6.6 million in 2006. In this way, in spite of the reduction of the internal traffic in Seoul, the total traffic by purpose in the whole of Seoul increased by 25% during the same period. Seoul's inbound and outbound traffic has increased continuously due to the large number of new housing development projects in the city outskirts and these cities' lack of self-sufficiency (SDI, 2003, 2007). Looking into the traffic by purpose in Seoul, the long-distance commute traffic to Seoul for going to the office increased to a daily average of 0.3 million trips; meanwhile, the long-distance traffic for coming back home to the suburbs increased to an average of 0.5 million trips (SDI, 2007). On the other hand, according to the survey results on the total mode trips, the latter reached average daily trips of 31 million in 2006.

Whereas the inner-city traffic in Seoul declined by approximately 3.2%, like the objective trips, in the case of the long-distance traffic from Seoul to the suburbs and vice versa, they were boosted by 44.7 and 38.6%, respectively. In particular, looking into the inbound traffic for work, the ratio of inbound central-Seoul trips was 22.6%, which shows a decrease of 1.7% and is less than the 24.3% ratio in 1996. The total number of inbound Seoul trips for work, however, increased by 33.9% in 10 years, since 1996. Moreover, the total number of inbound Seoul trips increased by 47.9% in the last 10 years (SDI, 2003, 2007). It can be inferred from these data that demand management policies need to be implemented, including land use policies to enhance self-sufficiency, and CC to induce PT use and demand management at the city boundary.

The boarding number per vehicle is an important variable for determining the traffic. For example, even with a slight increase in passenger traffic using owner-driven cars, the average boarding number per vehicle could increase at the same time, and the traffic increase can be mitigated. In 2002, the percentages of cars boarded only by their drivers were 80.3 at the city boundary and 80.8 in the city. Accordingly, the number of people boarding each vehicle at the point of the Seoul City boundary decreased to 1.31 from 1.51 in 1996, and during the same period, it also decreased from 1.45 to 1.21 in the city itself..

Meanwhile, the rate of cars boarded only by their drivers during the peak time was 83.9%, which was higher than the daily average of 78.7% (see **Table 5-16**). This shows that the rate of cars boarded only by their drivers among the inbound trips at the city boundary during the peak time in the morning is the highest (87.5%). Accordingly, it is expected to dictate the need for a policy for reducing the rate of cars boarded only by their drivers during the peak time to relieve the traffic congestion during such time.

Table 0-16. Driver-only vehicle trips during the peak time

(Unit: %)

	Morning Peak (7:00~9:00 AM)			Daily (7:00 AM~5:00 PM)		
	Inbound	Outbound	Both	Inbound	Outbound	Both
CBD	83.3	83.5	83.0	78.6	78.3	78.4
City boundary	**87.5**	81.2	84.4	81.7	76.3	79.0
Inner Seoul	86.1	81.9	**83.9**	80.5	76.8	**78.7**

Source : SDI, 2007

ⅱ. Congestion cost

Due to the growing traffic congestion in Seoul, the traffic congestion costs in the city in terms of waste of time and fuel are noticeably increasing every year. Seoul’s traffic congestion costs went up to ₩6.7 tn in 2006, representing 27.3% of the whole country’s traffic congestion costs. In the Greater Seoul Area, it accounts for about ₩14.1 tn (57.3% of the whole country’s costs), which is good money being wasted due to traffic congestion. The annual average increase rate of the traffic congestion costs has been to 6.6% since 1996 (see **Table 5-17**).

Table 0-17. Trend of traffic congestion costs in Seoul

Unit: billion won

Year	1996	1998	2000	2002	2004	2006
Seoul	3,561	3,086	4,714	5,310	5,724	6,735

* Congestion cost is constant price

Seoul’s ₩6.7 tn traffic congestion cost represents nearly 3.5% of the city’s gross product of ₩194 tn (SMG 2007b). Converted into per capita, it can be inferred that the city incurs additional time and fuel costs (about ₩670,000 annually and ₩2.36 mn per person and per vehicle) due to traffic congestion (Cho and Lee, 2008).

Table 0-18. 2006 traffic congestion cost in Seoul

• Congestion costs (₩100 mn/year)	67,355
• Population (thousand people)	10,020
• Congestion cost per person (₩0.1 mn/person/year)	6.7
• Registered vehicles (thousand vehicles)	2854
• Congestion cost per vehicle (₩0.1 mn/vehicle/year)	23.6

ⅲ. Forecasting the traffic demand

According to the traffic forecast by SDI (2005), the average daily inbound Seoul traffic rate from the outskirts of Seoul, such as Incheon and Gyeonggi province, is expected to increase by as much as 38.2% until 2021, from 3.7 million trips in 2002 to 5.0 million trips in 2021. In the same period, it is also reported that the daily rate of the outbound vehicle traffic from Seoul is expected to decrease by 4.4%, from 2.2 million trips to 2.14 million.

Table 0-19. Traffic demand forecast in Seoul

		Seoul→Seoul	Seoul → Outer Seoul	Outer Seoul → Seoul	Outer Seoul → Outer Seoul
Estimated trips (mn trips/day)	2002	19.74	2.24	3.71	21.41
	2006	20.13	2.08.	3.96	24.20
	……	……	……	……	……
	2021	19.70	2.14	5.05	27.44
Incremental ratio (2002 vs. 2021)		-0.2%	-4.4%	36.2%	28.1%

The continuous conurbation of transport in the Seoul metropolitan area may be expected to intensify as most of the housing projects in the area, including new-city construction and land development, are situated in Gyeonggi province, which leads to population increase. Therefore, there is a continuously growing number of employers in Seoul in contrast to the city's decreasing population (SDI, 2005).

The number of registered vehicles in the Seoul metropolitan area may increase more than twofold, from 4.6 million (i.e., 0.59 vehicles per household) to 10.4 million (i.e., 1.07 vehicles per household). In particular, it may grow from about 2 million vehicles in 2002 to 3.8 million vehicles in 2021 in the city. On the other hand, although the population of Seoul decreased from 10.3 million people in 2002 to 9.8 million people in 2021, the total population of the metropolitan area during the same period is expected to continuously grow from 22.9 to 25.9 million people. Moreover, the number of employees in Seoul also increased from 3.8 to 4.1 million in 2021. Considering these changes in the traffic demand, it can be inferred that the implementation of comprehensive transportation measures for traffic reduction is inevitable.

1.22.2. 10-year experience of congestion charging in Mt. Nam Tunnel[4]

To mitigate the traffic congestion and to improve the economic efficiency of road use in the central city of Seoul, all private car users driving through Mt. Nam Tunnel began to be charged in November 1996. The results of the analysis of the effects of the 10-year implementation of CC on the traffic behaviours showed that the impact of the policy implementation has been reduced compared to that when it was initially introduced. The local government of Seoul recently announced that amendments to the policy are needed, including an increase in the toll rates and regional expansion of congestion tolls (SDI, 2008).

In the comparison of the travel behaviours before and after the implementation of CC (i.e., 1996 and 2006), it was determined that the private-car traffic decreased by 20.8%, from 66,787 to 52,944 cars per day, and that the travel speed became faster by 115.3%, from 21.6 to 46.5 km/hr.

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[4] The charging scheme aims to reduce congestion and to encourage PT use or carpooling. In 1996, the Seoul metropolitan government started a charging scheme for vehicles using the Namsan #1 and 3 tunnels, which connect the southern part of Han River to central Seoul. The congestion toll is ₩2,000 (nearly £1) for the vehicles passing the tunnels from Monday to Friday, between 7 a.m. and 9 p.m., and on Saturday, between 7 a.m. and 3 p.m. To encourage the use of compact vehicles, cars with a displacement of under 800 cc have been charged a 50% discounted toll rate since July 2003. Moreover, there are some cases where toll charging is exempted, such as vehicles with more than two people or with a disabled person inside, buses, taxis, and emergency vehicles.

In addition, the number of buses increased by 88.3%, and the total number of trips increased by 17.6%. In this regard, a mode shift impact from private cars to PT has occurred, along with other positive effects lending support to the economic activities due to the increase in the floating population. Consequently, it can be said that Mt. Nam Tunnel's CC scheme has attained its objectives in terms of boosting the efficiency of road use, such as reducing private-car use, improving the traffic speed, and increasing PT use. With the increasing total traffic and the increase in the number of exempted vehicles, however, as well as the reduction of the total number of diversion routes, the efficiency of the CC scheme has been reduced.

Table 0-20. Change in the traffic impact of the Mt. Nam Tunnel charging scheme

	1996 (Before Charging)	2006 (After Charging)
Total traffic in the tunnels (vehicles/day)	90,404	92,550
Exempt-vehicle rate (%)	31.5	57.1
Total traffic on diversion roads (vehicles/hr)	11,721	10,037

The total traffic of the tunnels was increased from 90,404 to 92,550 vehicles per day after the 10-year implementation of CC. The exempt-vehicle rate increased to 57.1% after 10 years, from 31.5%. Moreover, the total traffic on the diversion roads decreased to 10,037 vehicles/hr after 10 years, from 11,721 vehicles/hr (see **Table 5-20**). It can be inferred that although the tunnel users diverted to other routes at the initial stage of the implementation of the CC scheme on account of the burden that the scheme imposed on them, they switched back to the tunnel axis as their travel route with the improvement of the traffic speed in the tunnels and of their socioeconomic status, which reduced the burden that toll charging imposed on them.

Furthermore, due to the increase in the number of vehicles exempted from paying toll charges, the economic efficiency of charging has been reduced. Despite the fact that Mt. Nam Tunnel has become a main traffic axis as it is the fastest connection to central Seoul from the southern area, the traffic environment in the CBD is worsening due to the continuously increasing traffic therein. As such, the local government of Seoul is currently considering magnifying the CC scheme, including regional expansion.

1.22.3. Data analysis for setting the congestion charging area

As this study employs traffic data obtained by administrative area, charging areas are established by area. **Fig. 5-6** shows the 25 administrative districts (gu) of Seoul. The most severely congested area, which has the highest traffic volume and the lowest travel speed, was adopted as the charging area. These districts were analyzed using the data obtained from the Househould Travel Survey in Seoul (SDI, 2005) and other traffic data provided by Seoul Metropolitan Government, etc. In addition, generally, the congested area is the center of the economic and social activities in a city. The congested area is usually estimated by analyzing the number of business establishments and employees by district. Therefore, the CC scenarios were established based on the results of the investigation of the transport in Seoul. The detailed results of the data analysis are shown below.

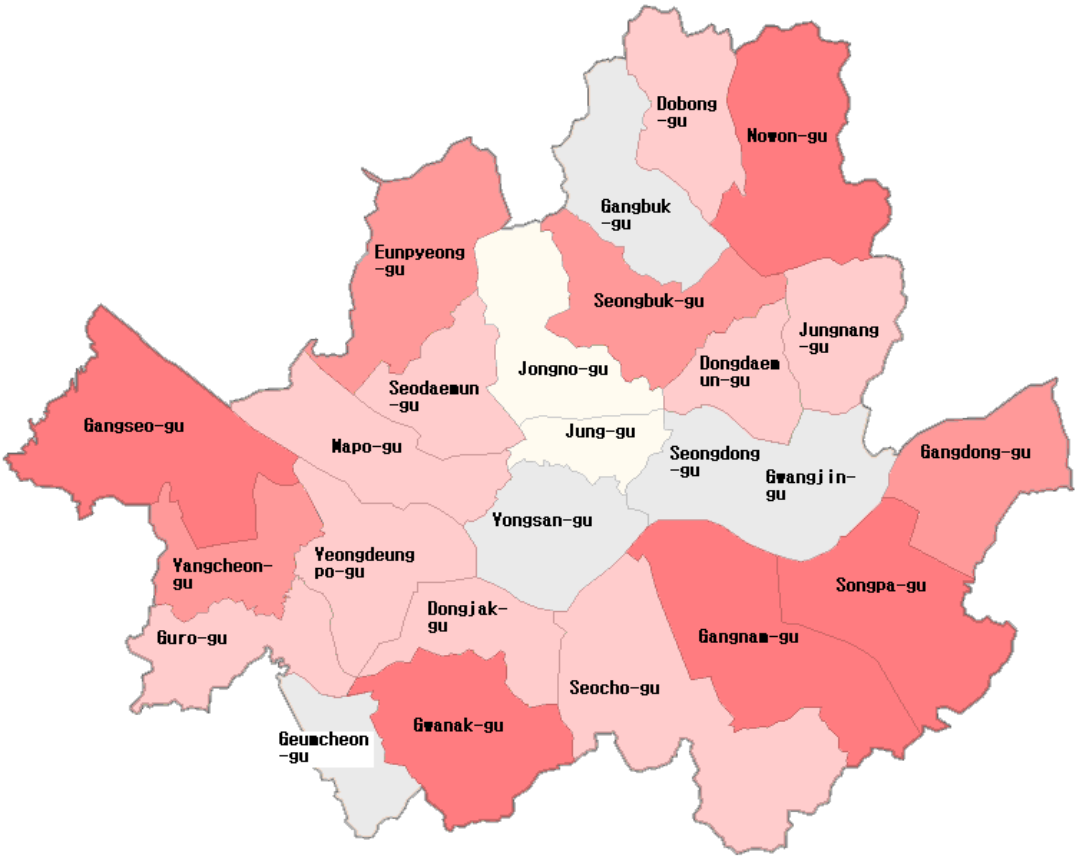

Figure 0-6. Administrative districts (gu) of Seoul.
(Source: www.seoul.go.kr)

1.22.3.1. Analysis of O/D trips

The origin and destination data of the 25 districts of Seoul were analyzed to investigate which areas induce the traffic volume, and the possibility of congestion. The analysis of the traffic volume to and from a district provides justification for the central business area. The results of the analysis of Seoul's to-and-from O/D trips by district are shown in **Fig. 5-7**. With regard to the inbound-trip volume, the area with the largest number of total inbound trips is Gangnam-gu, followed by Songpa-gu, Jung-gu, Seocho-gu, Yeongdeungpo-gu, Nowon-gu, Jongro-gu, and Gangseo-gu. On the other hand, the area with the largest number of total outbound trips is Gangnam-gu, followed by Songpa-gu, Seocho-gu, Nowon-gu, Yeongdeungpo-gu, Jung-gu, Gangseo-gu, and Jongro-gu. It is noteworthy that the more concentrated business is in an area, or the more the business establishments or employers therein, the greater the number of inbound trips, and the more concentrated housing is in an area, the greater the number of outbound trips therein. In this regard, the inbound trips exceed the outbound trips in Gangnam-gu, Seocho-gu, Jung-gu, and Yeongdeungpo-gu while the opposite is true in Nowon-gu, Gangseo-gu, and Songpa-gu. That is, Gangnam-gu, Seocho-gu, Jung-gu, and Yeongdeungpo-gu are traffic-congested areas throughout the daytime as they are central business areas.

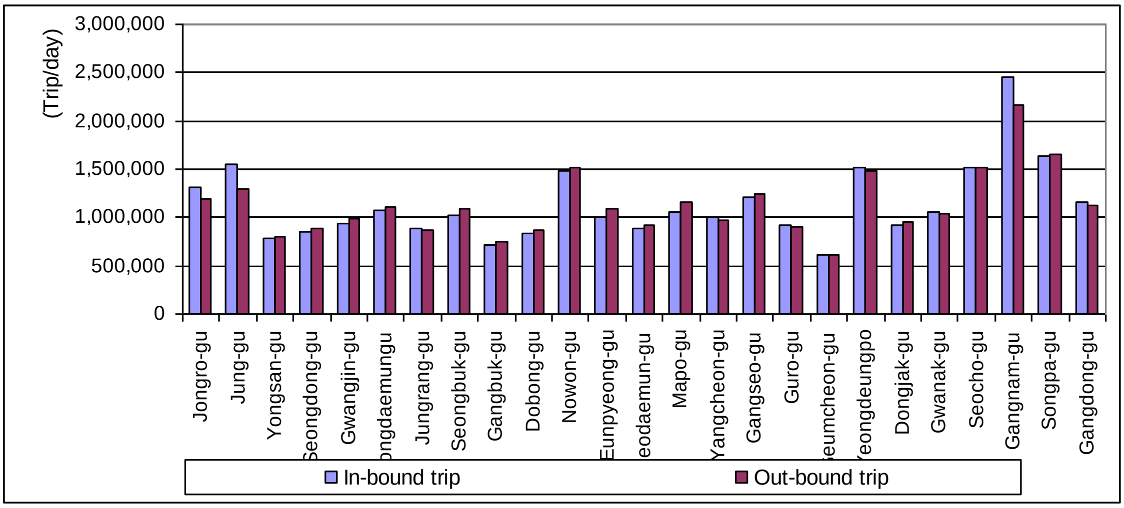

Figure 0-7. Inbound and outbound trips.

The results of the analysis of the mode O/D trips in the 25 districts of Seoul are shown in **Fig. 5-8 and 5-9**. As for the inbound trips, they occur in the order of Gangnam-gu, Songpa-gu, Seocho-gu, Yeongdeungpo-gu, Nowon-gu, etc. On the other hand, the outbound trips are in the order of Gangnam-gu, Seocho-gu, Songpa-gu, Yeongdeungpo-gu, Nowon-gu, etc. With regard to the mode choice ratios of the areas that have more outbound trips than inbound trips, such as

Gangnam-gu, Seocho-gu, Jung-gu, Jongro-gu, and Yeongdeungpo-gu, the mode choice ratios of the car in Gangnam-gu and Seocho-gu, respectively, are the highest among the modes (34.3 and 27.3%), followed by the metro/rail (23.9 and 26.1%). On the other hand, the bus and metro/rail ratios are higher than that of the car in Jung-gu, Jongro-gu, and Yeongdeungpo-gu. As such, it appears that the ratio of PT use is higher in Jung-gu, Jongro-gu, and Yeongdeungpo-gu than in Gangnam-gu and Seocho-gu.

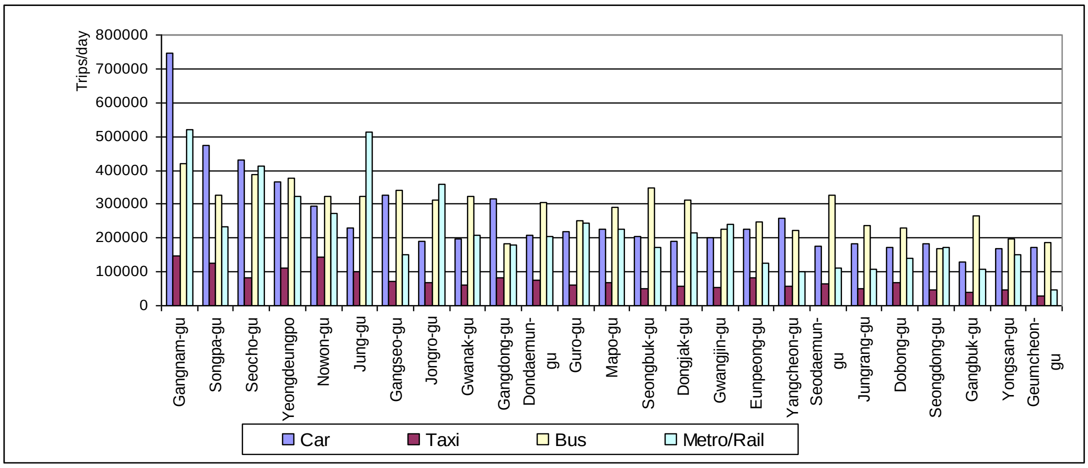

Figure 0-8. Mode O/D (inbound).

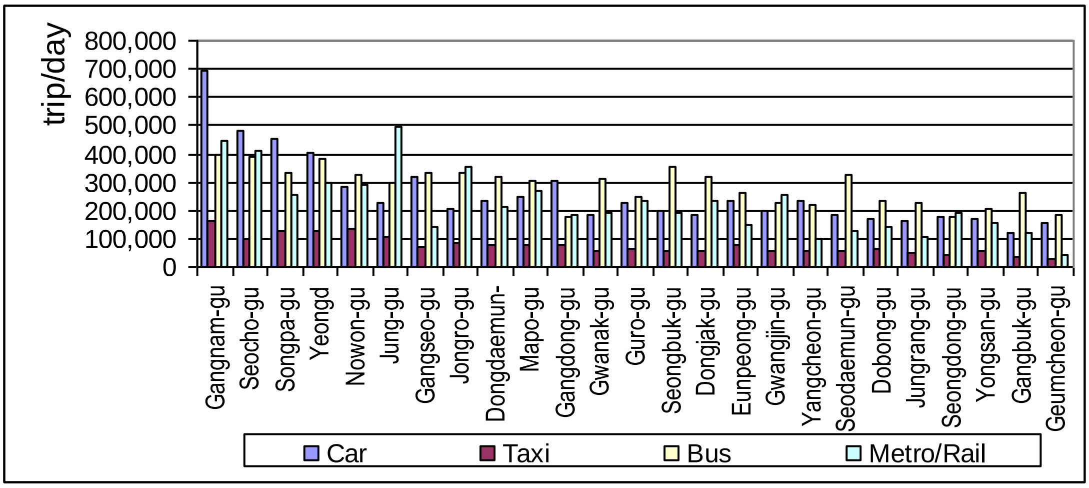

Figure 0-9. Mode O/D analysis (outbound trips).

1.22.3.2. Traffic speed

Seoul Metropolitan Government conducts a traffic speed survey annually. The traffic speeds in Seoul's 25 districts in 2005 were analyzed based on the 2005 report (SMG, 2007b) . It was shown in the report that the average traffic speed of Gangnam-gu, Jongro-gu, Jung-gu, Gangbuk-gu, and Dobong-gu in 2005 was under 20 km/hr. In addition, PT use in Jongro-gu and Jung-gu in 2005 was high, which was shown by the results of the mode trip analysis, but the average traffic speeds in such districts were very low (18.9 and 16.6 km/h, respectively). Despite the fact, however, that Seocho-gu and Yeongdeungpo-gu had high traffic volumes in 2005, their average traffic speed then was high (over 20 km/h). **Fig. 5-10** shows the traffic speed by district.

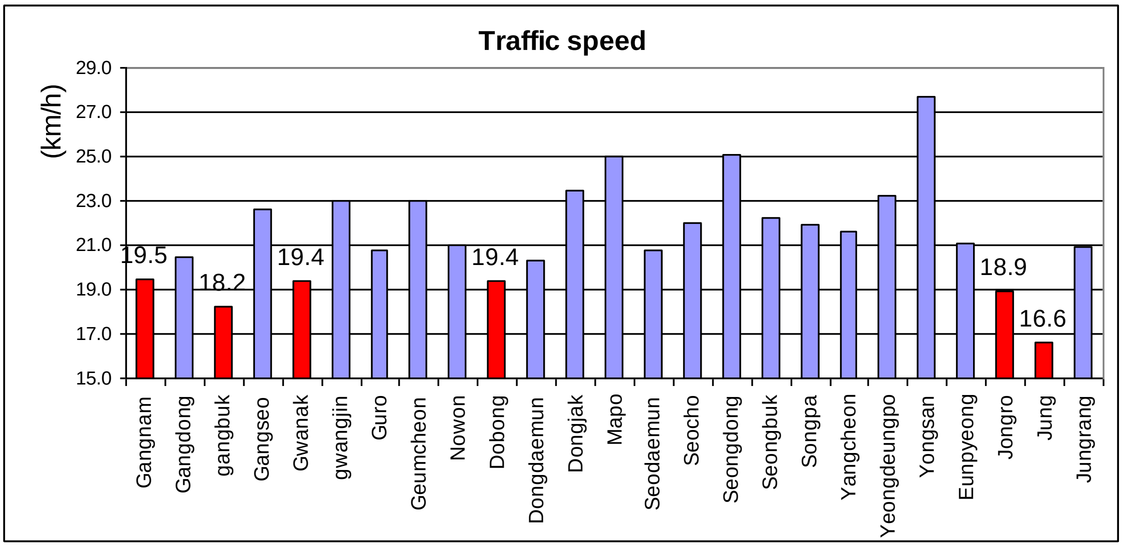

Figure 0-10. Traffic speed analysis.
(Source: (SMG, 2007b)

1.22.3.3. Business establishments and employees

Business establishments generate many commuters (employees), and business concentration is closely related to the traffic congestion that occurs during the traffic peak hours. The numbers of establishments and employees in the 25 districts of Seoul are shown in **Table 5-21** and **Fig. 5-11.** Among the 25 districts of Seoul, the establishments are densely aggregated in Jung-gu, Gangnam-gu, Yeongdeungpo-gu, and Jongro-gu. Gangnam-gu has the highest number of employees (over 540,000), followed by Jung-gu, Seocho-gu, Yeongdeungpo-gu, and Jongro-gu. These figures indicate that the numbers of establishments and employees are closely related to each other. Furthermore, on the index of employees over residents, Jongro-gu and Jung-gu have 1.2-2.6 times more employees than residents, and the numbers of employees working in Gangnam-gu and Seocho-gu are 0.7 times more than those working in the other districts. With regard to the numbers of establishments and employees and the index of employees over residents, the data indicate that many commuters go to Jongro-gu, Jung-gu, Seocho-gu, and Gangnam-gu (SMG, 2007a).

Table 0-21. Establishments and employees by district

	Establishments	Ratio (%)	Employees	Ratio (%)	Residents	Index
Jongro-gu	39,329	5.3	222,443	5.8	173,861	1.28
Jung-gu	67,681	9.1	352,436	9.2	134,420	2.62
Yongsan-gu	20,352	2.7	111,652	2.9	240,077	0.47
Seongdong-gu	25,000	3.4	114,087	3.0	342,691	0.33
Gwangjin-gu	24,028	3.2	96,456	2.5	380,480	0.25
Dongdaemun-gu	33,151	4.5	124,505	3.2	386,280	0.32
Jungrang-gu	26,044	3.5	78,865	2.1	429,922	0.18
Seongbuk-gu	24,135	3.3	85,261	2.2	467,308	0.18
Gangbuk-gu	19,788	2.7	62,613	1.6	355,334	0.18
Dobong-gu	17,388	2.3	59,508	1.5	383,448	0.16
Nowon-gu	25,546	3.4	98,207	2.6	624,855	0.16
Eunpyeong-gu	22,494	3.0	72,411	1.9	473,456	0.15
Seodaemun-gu	20,823	2.8	85,779	2.2	355,934	0.24
Mapo-gu	27,158	3.7	153,655	4.0	393,155	0.39
Yangcheon-gu	24,561	3.3	98,933	2.6	502,788	0.20
Gangseo-gu	29,146	3.9	137,258	3.6	557,373	0.25
Guro-gu	30,215	4.1	143,568	3.7	427,119	0.34
Geumcheon-gu	21,227	2.9	124,704	3.2	263,936	0.47
Yeongdeungpo-gu	38,856	5.2	261,492	6.8	421,327	0.62
Dongjak-gu	20,361	2.7	91,976	2.4	414,668	0.22
Gwanak-gu	26,480	3.6	95,624	2.5	537,235	0.18
Seocho-gu	36,347	4.9	312,911	8.1	406,875	0.77
Gangnam-gu	53,667	7.2	544,891	14.2	547,775	0.99
Songpa-gu	40,400	5.5	215,523	5.6	610,023	0.35
Gangdong-gu	27,052	3.6	98,252	2.6	466,664	0.21
Total	741,229	100.0	3,843,010	100.0	10,297,004	0.37

Source: (SMG, 2007a)

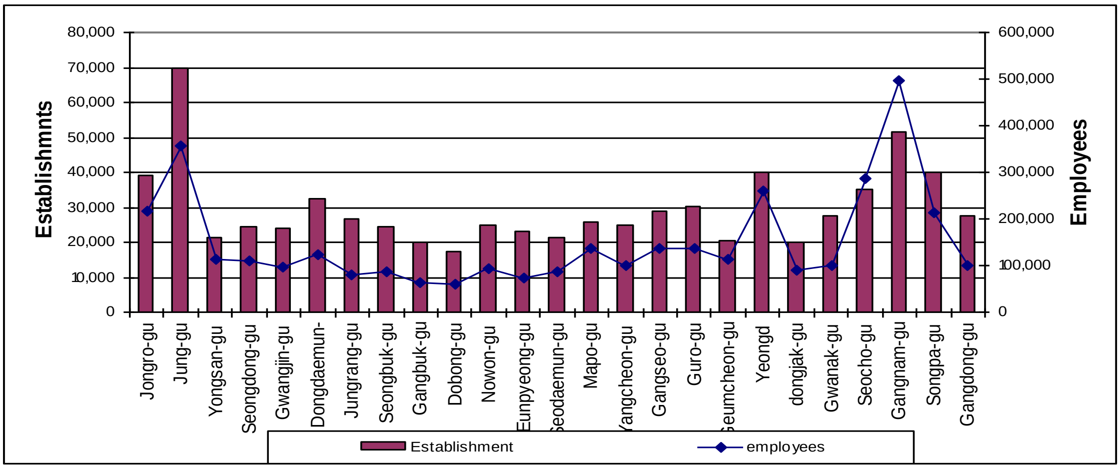

Figure 0-11. Number of establishments and employees in Seoul, 2005.

1.22.3.4. Recommendation for the congestion charging area

Generally, the congestion of the roads in Seoul is heavier than that in the other main cities in South Korea due to the higher traffic volume and lower travel speed therein. Setting the whole area or all the arterial roads as the target of CC, however, is problematic as it can cause a drop in the efficiency of road use by unduly reducing the traffic volume. Furthermore, in the congested area, the road congestion appears not only at a specific road section but over the whole area on and around the road proximate to the business facilities located in densely populated areas. When a congestion toll is charged at the main arterial roads with the application of corridor pricing, the overall mitigating effect of congestion may not be very high. As the congestion may decrease on the charged road, however, the congestion may transfer to the adjacent roads. In this regard, area pricing is more reasonable than corridor pricing. The CC scheme was thus set using area pricing in this study.

It can be inferred that central Seoul and Gangnam (south of Han River) are the most congested areas in Seoul, according to the results of the analysis. In particular, the CBD, represented by Jongro-gu and Jung-gu, has been recognized as a socioeconomic center and as the most congested area in the city. Therefore, the implementation of congestion pricing has an advantage in that the policy is expected to gain political acceptability more easily than other policies are expected to. It can be inferred that the CC of Mt. Nam Tunnel, which is connected to central Seoul, supports this reason as it was where CC was first implemented in Seoul, in 1996. After the 1990s, however, the traditional CBD was downgraded and spread out, and some areas south of Han River were turned into new economic centers. This area was called “2nd CBD” in this study.

To summarize the above results of the data analysis that was conducted in this study, the traffic volume was found to be the highest in Gangnam-gu, Jongro-gu, Jung-gu, Seocho-gu, and Yeongdeungpo-gu, and the lowest average speeds were found in Gangnam-gu, Jongro-gu, Jung-gu, Gangbuk-gu, Gwanak-gu, and Dobong-gu. First, Gangnam-gu, Jongro-gu, and Jung-gu, which have the highest traffic volumes and the lowest average speeds, were designated as congested areas. Second, Seocho-gu adjoins the congested areas because it has a high traffic volume and is located next to Gangnam-gu. It may be influenced depending on the change in the traffic pattern in Gangnam-gu due to CC. These four districts, however, are very wide as each of them has varying socioeconomic characteristics. Therefore, the detailed charging area in the CBD and 2nd CBD were justified by considering the number of business establishments, employees, and residents in the smaller administrative units (i.e., *dong*) within the districts. **Fig. 5-12, 5-13, 5-14,** and **5-15** show the number of employees and residents in the small administrative units of the selected districts. The index, which was calculated by dividing the number of employees by the number of residents, indicates that the area with a high index has a bigger floating population than number of residents. Therefore, it can be inferred that there is a possibility that the floating population can bring about more inbound trips, and therefore, traffic congestion. In addition, the connectivity of the charging area is an important factor because a cordon is set by small area units. Therefore, geographic connectivity is also taken into consideration when setting the charging area.

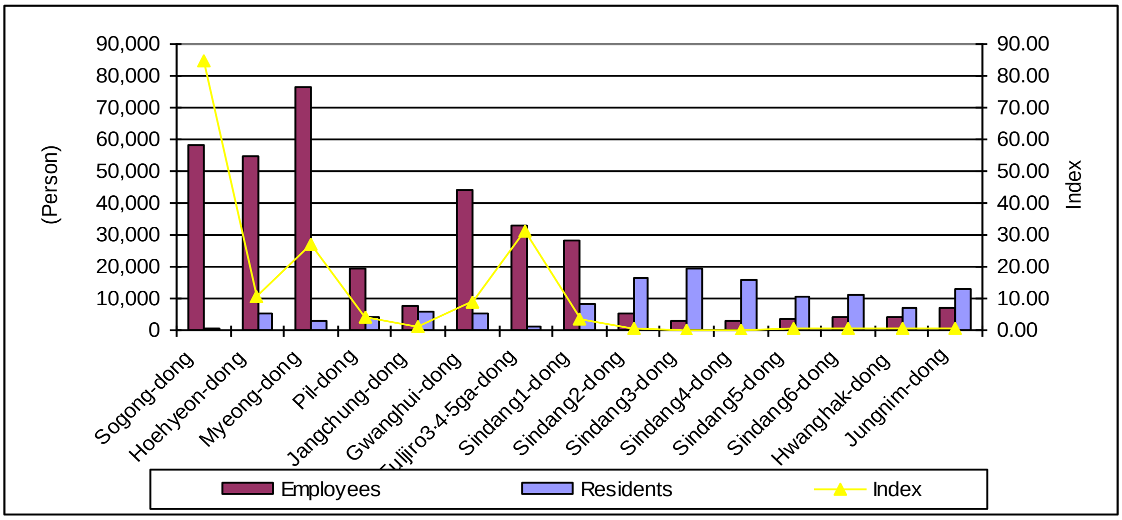

Figure 0-12. Employees and residents (Jung-gu).

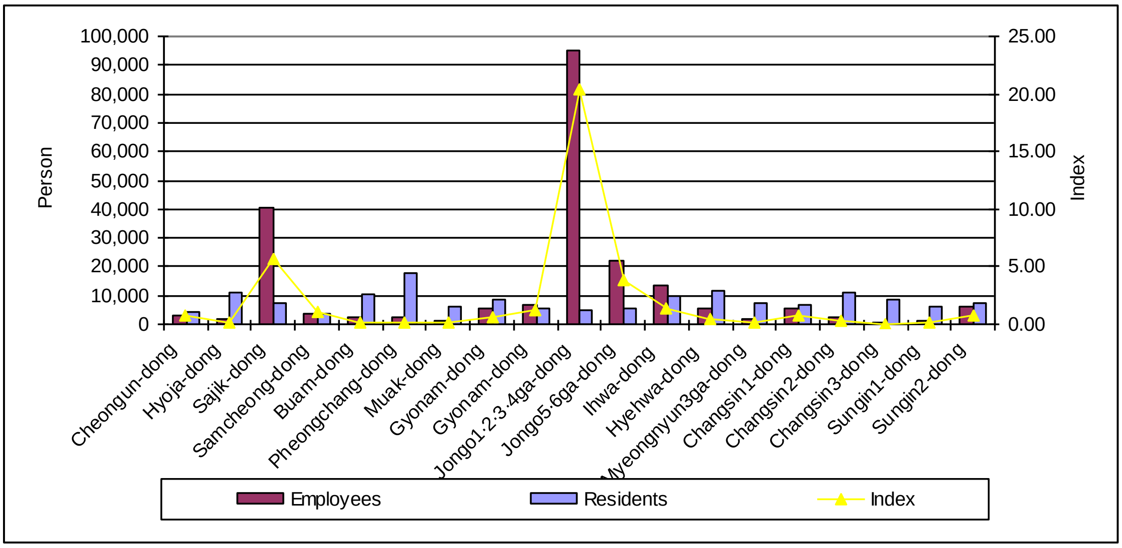

Figure 0-13. Employees and residents (Jongro-gu).

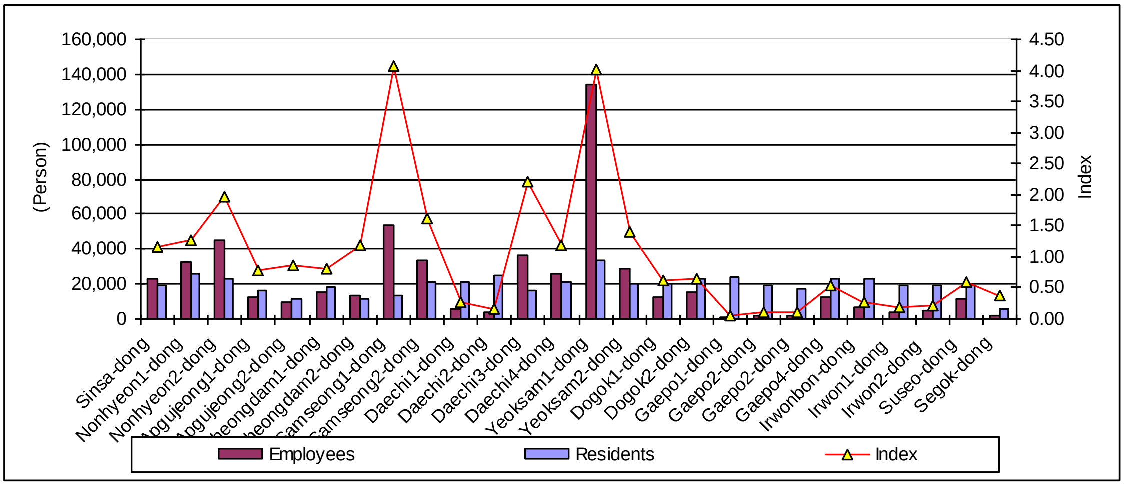

Figure 0-14. Employees and residents (Gangnam-gu).

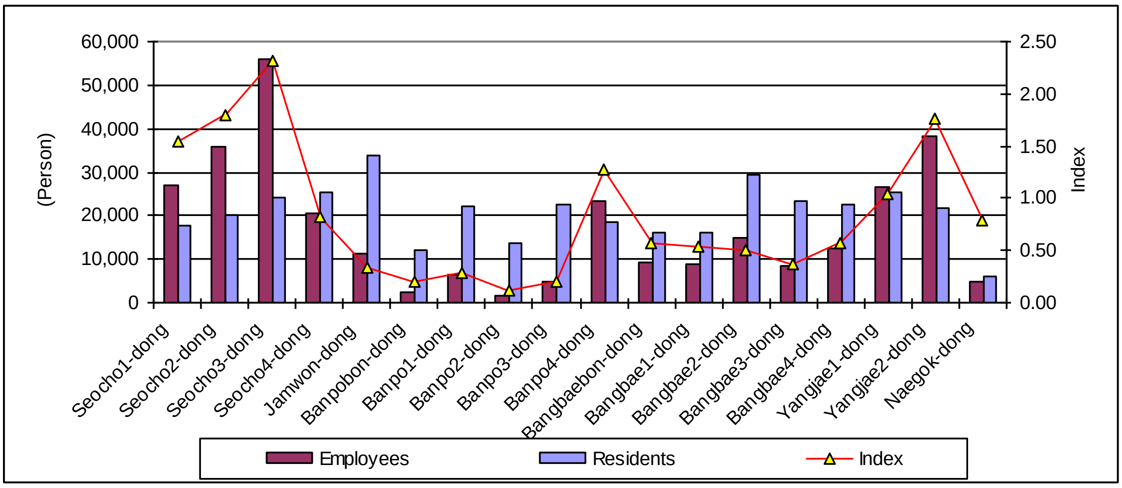

Figure 0-15. Employees and residents (Seocho-gu).

Based on the above data analysis results, the charging areas were set up. **Table 5-22** and **Fig. 5-16** show the selected areas for CC.

Table 0-22. Selected congestion charging areas

	Congestion Charging Areas
CBD (A)	· Jongro-gu : Sajik-dong, Jongro1-4ga-dong, Jongro5-6ga-dong · Jung-gu : Sogong-dong, Hoehyun-dong, Myung-dong, Pil-dong, Gwanghui-dong, Euljiro3-5ga-dong
2nd CBD (B)	· Gangnam-gu : Nonhyun1-2-dong, Samsung1-2-dong, Daechi-dong, Yeoksam1-2-dong, Dogok1-2-dong · Seocho-gu : Seocho1-4ga-dong, Banpo1-dong, Banpo4-dong

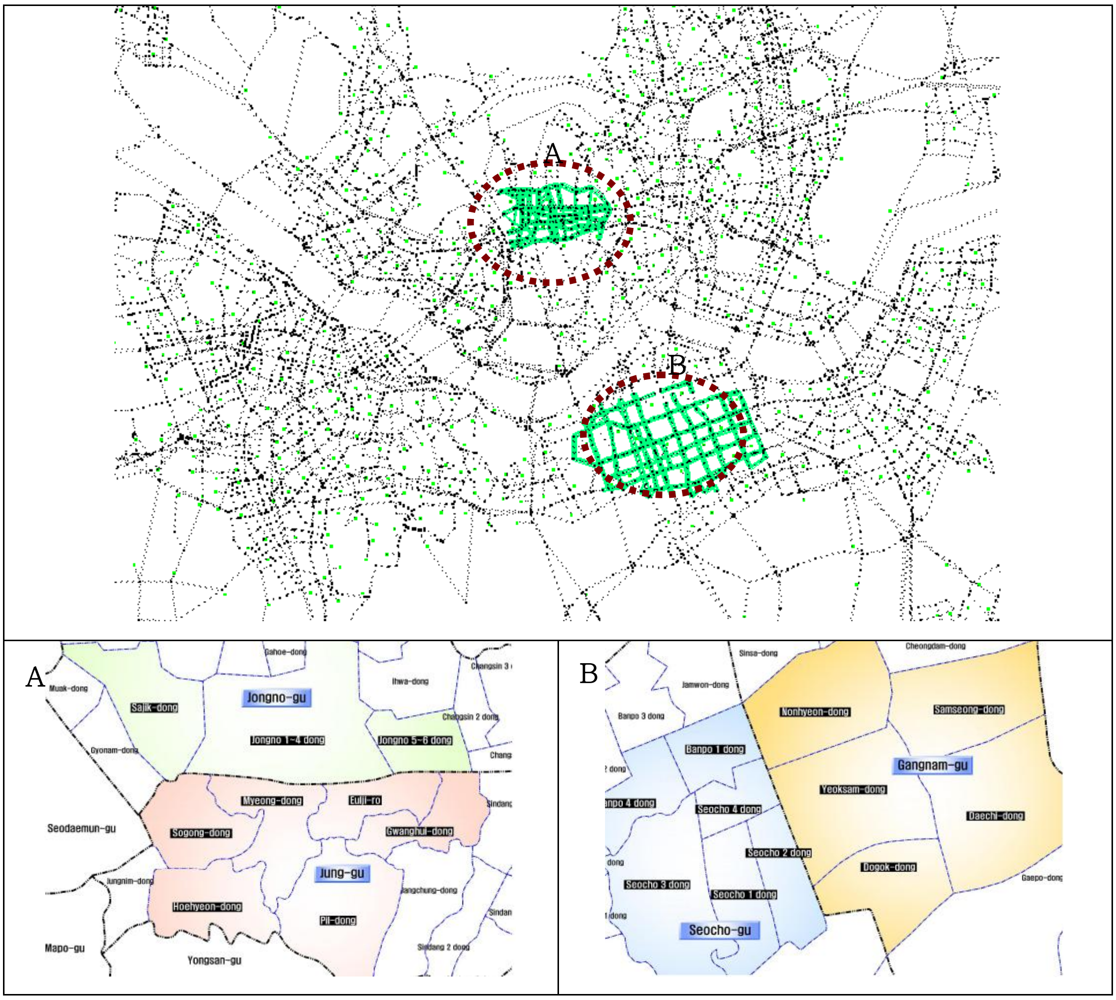

Figure 0-16. Congestion charging areas.

1.23. SUMMARY AND DISCUSSION

A description of the data for model application was provided. Two types of data were described for the validation of the applied model: the mode choice model and the network. To analyze the equity impact, the dataset of travel time, travel cost, and mode choice ratio by income level were built. The travel time and travel cost by mode were estimated based on the travel time and travel length derived from an EMME/2 model. The applied mode choice model was revised using the calibration dummy factors, and was validated with elasticity and by comparing the mode choice ratios of the samples. With the traffic assignment model in the Seoul network, the difference between the real traffic volume and the assigned volume was estimated to be 1.7% overall, and the RMSE was 9.9%. The model traces the real network well. Consequently, it can be said that the model is appropriate for application in the Seoul network.

The impact of CC can be evaluated in a variety of ways, by research purpose. This study considers the equity impact, which was synthetically analyzed within an efficiency impact outline. First, the efficiency can be evaluated based on the economic improvement as determined through cost-benefit analysis. Based on the results of the cost-benefit analysis, the social-welfare change, which plays a key role in the evaluation process in this study, can be derived. The social-welfare change consists of the change in user benefit, operating or private cost, external cost, and revenue. Second, equity pertains to how to distribute the welfare change by user group and can be evaluated by compensating the variation by income level.

Severe traffic congestion and the rapid growth of car registration call for traffic demand management, including congestion pricing. In particular, CC in Seoul has been floated as part of the city's transportation policy (SDI, 2008). The introduction of CC scheme in Seoul, even the experience of partial implementation of CC in the Mt. Nam Tunnel since 1996, is advocated in the fact that Seoul is one of the largest populations and the highest population density in the world and the traffic congestion is getting worse as the car ownership is still gradually increasing due to the increase of personal income. Also it is noticeable that Seoul has duo-centric urban structure, old and new central business district, and strong spatial interactions between both districts, so that the necessity of implementation of CC scheme is backed up to reduce the travel demand, especially of private cars, to facilitate the shift to public transit modes such as bus and metro/rail from the usage of private car. In this regard, to analyze the impact of congestion pricing, the transport environment of Seoul was reviewed, then the charging scenarios for the recommendation of a charging scheme, particularly of the charging areas, were set up based on the results of the analysis of the transport data of Seoul. Central Seoul and Gangnam (south of Han River) were found to be the most congested areas in Seoul.

The next chapter will therefore be devoted to the investigation of the impact of CC in Seoul, South Korea, through a case study. It is also interesting to investigate the trade-off between the efficiency and equity of CC. The identification of the impact of the charging policy will be very helpful in determining the optimal toll in the face of the objections to the implementation of CC. Taking into account the dataset (e.g., static model, fixed O/D matrix), the impact of CC will be analyzed based only on its short-term impact.

SE STUDY: CONGESTION CHARGING IN SEOUL'S CBD

1.24. INTRODUCTION

In general, a desirable evaluation of congestion charging has to satisfy both the efficiency and equity impact. *Efficiency* refers to the extent to which the achievement of such a goal yields the highest possible net social benefits, defined as the difference between the social benefits and the social costs (Verhoef et al., 1996), whereas *equity* refers to the distribution of the effects and whether they are considered fair and appropriate. The general effect of CC was to substantially reduce the number of car trips in some cases by as much as 30-40% (Fridstrom, et al., 2000). Most effects can be evaluated in relation to the reduction in the number of car trips.

The efficiency impact considers the traffic efficiency and economic efficiency. The former is analyzed based on the traffic conditions, including the mode shift, traffic speed, and traffic volume, while the latter is analyzed based on the social-welfare improvement, as determined through economic cost-benefit analysis, and justifies the feasibility of the CC policy. The equity effect is assessed based on the user benefit change and mode shift by income. At this point, the analysis considers not only the CV of the travellers but also the tax income change and revenue collection by the toll and external cost. Researchers have argued that the use of the collected revenue is directly influenced by the success of the implementation of the CC policy (Small, 1983, 1992; Litman, 2005; Eliasson and Mattson, 2006). An analysis of the revenue return effect was done to determine the equity and efficiency effects. This was done by utilizing the toll revenue, where the reduced PT fare was applied for the impact analysis.

This chapter provides an evaluation of CC as a case study of the CBD of the city of Seoul in South Korea. The main objective of the chapter is to examine the impact of CC on equity and efficiency through the case study. Another important objective is to justify the trade-off between the equity and efficiency of CC.

This chapter is organized as follows. Section 6.2 defines the impact analysis model by presenting its framework, scenario, and evaluation criteria; section 6.3 explores the base case as a do-nothing case; section 6.4 describes the assessment and analysis of the results of the case study on charging in Seoul's CBD; section 6.5 explores the case study in Seoul's 2nd CBD with focusing on equity and economic efficiency; and section 6.6 gives a summary and discussion of the analysis results.

1.25. DEFINITION OF THE IMPACT ANALYSIS MODEL

This research mainly aims to analyze the equity and efficiency effects of CC in accordance with the change in the travellers' mode and route choices. The application model presented in this research is a static model designed to estimate the short-term impact[1] of CC. The effects of CC were investigated in terms of the demand-supply equilibrium. In addition, a practical methodology can be developed considering both the efficiency and equity effects expected from the implementation of CC.

1.25.1. Framework of the impact analysis

The application model for analyzing the effects of CC incorporates three models: the mode choice, traffic assignment, and effect analysis models. The framework of the impact analysis model is shown in **Fig. 6-1**. The mode choice model adopts a Multinomial Logit model segmented by income level. The traffic assignment model is a network-forecasting model that considers the mode and route choices. To consider the mode shift concurrently with the route change, the mode choice and traffic assignment models were combined. In addition, this study utilized the EMME/2 programme package to calibrate and validate the demand-supply analysis model. Moreover, the effect analysis model assessed the social-welfare change in accordance with the variation in the individual utility.

An impact analysis of CC was conducted through the process of travel cost change among the independent variables of the utility function that affect the mode choice. A CC toll was imposed on the car users among the travellers bound to the charging area, then the mode split of the private cars was reduced due to the utility reduction. This reduction of private cars led to a decrease in the travel time of cars, thus causing its choice ratio to once again increase. Finally, this process was expected to repeat until it achieves a specific mode choice ratio and travel time. When the toll was added to the travel cost, as the cost divided by the income was applied to the utility function of the Logit model, the utility changes might differ by income level. Consequently, it allowed an analysis of the mode shift, which appeared to differ by income level under the CC toll. Moreover, the effect of CC can be analyzed by evaluating the traffic volume change in the network as well as the CV. In addition, it allows the determination of the most

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[1] The difference between long- and short-term demand analyses is related to the change in the total number of travelers when the toll is imposed. If the analysis period is long-term, the number of users is changeable; on the contrary, in the short term, the total number of trips is fixed, and only mode shift occurs. In this context, this study is based on the short-term aspect.

equitable toll level considering the utility change by income level on account of the imposition of various tolls.

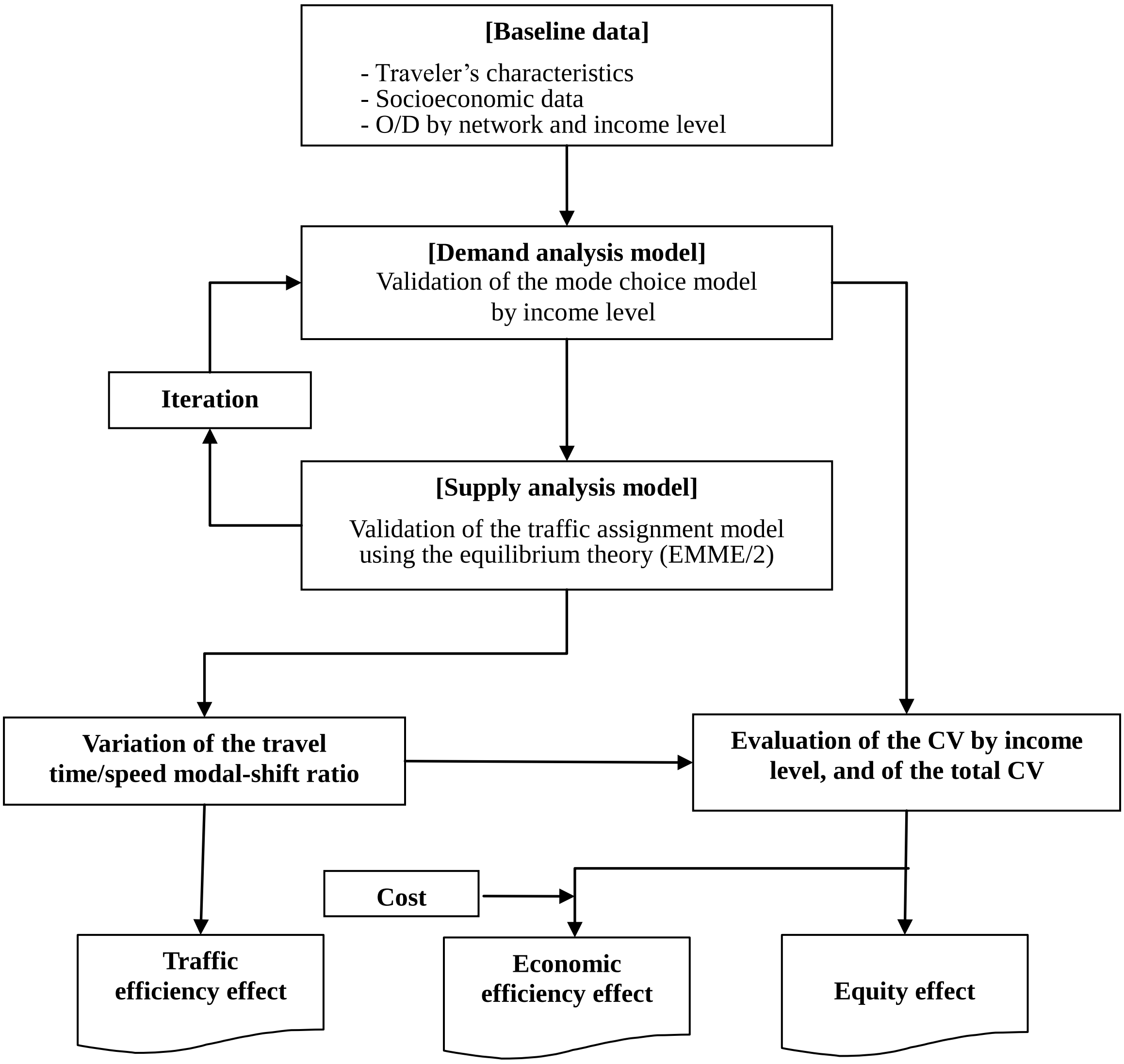


Figure 0-1. Framework of the impact analysis model.

Based on the framework of the impact analysis model, assessment and analysis was conducted for CC in Seoul, using the actual data regarding the network characteristics and trip matrices. The subsequent section is allocated to the setting of the charging scheme and to the impact analysis of the Seoul case.

1.25.2. Scenarios and Evaluation criteria

The scenarios for the examination of the impact of CC will be explained, and the evaluation criteria (i.e., how and what will be examined in this study) will be provided in this section.

1.25.2.1. Design of the scenarios

Considering that the main objectives of the evaluation of CC are to investigate (1) the extent to which traffic congestion can be relieved; (2) how a particular user group changes its travel behaviour in terms of mode choice, route choice, destination choice, and decision to travel; (3) how much the economic efficiency has improved; (4) how the air quality, noise levels, and accident rates will change; and (5) how the costs and revenues of the pricing program will affect the financial status of the traffic authorities, the following factors that will affect the evaluation results were first considered: charging area, charging time, payment and enforcement, and toll level.

The scenarios were established by concentrating on the area setting. The charging areas that were selected were the most congested regions with the lowest traffic speeds and the highest traffic volumes, as determined in the previous chapter. Moreover, the toll level and other options considered the existing schemes (i.e., the toll level and charging time) adopted by the existing Mt. Nam Tunnel CC scheme. The problems of technical complexity and traffic overflow, and the tradition of free access to the local streets, make the implementation of congestion pricing inherently difficult. With these technical and/or political constraints, it may not be possible to have an electronic toll-charging system to cover all the relevant roads and streets in a metropolitan area; hence, there will be portions of the urban road network that cannot be subjected to efficient tolls. In this regard, the London scheme was adopted for the payment and enforcement methods. For the sake of a CBD-focused policy, the expansion of the charging area was considered by the local government of Seoul, but as the main objective of this study is the investigation of the charging impact and of the trade-off between the efficiency and equity of CC, this study considers only CBD charging. Consequently, the evaluation scenarios are summarized as follows:

- charging area: CBD;
- charging time: 7:00 AM-21:00 PM;
- payment and enforcement: pre- or post-pay by various means, and camera-based ANPR; and
- toll level: ₩1,000 (£0.50), ₩2,000 (£1.00), ₩3,000 (£1.50), ₩4,000 (£2.00).

The basic toll level was set at ₩2,000 considering the existing Mt. Nam Tunnel CC toll, and a lower case (₩1,000) and higher cases (₩3,000, ₩4,000) of the tunnel toll will be analyzed through a sensitivity test by toll level.

1.25.2.2. Evaluation criteria

For each of the scenarios, the following evaluation criteria were used to assess how the implementation of CC impacted the users and the social system:

- Efficiency: Shows the extent to which the economic welfare improved and the traffic congestion was mitigated. It was assessed based on the transport impact and economic improvement. The former can be measured using the typical transport indices, such as the traffic speed, traffic volume, and VKT. The economic improvement was measured based on the social-welfare improvement, which is a conventional cost-benefit measure.
- Equity: Shows the impact by user group. The impact was differentiated by user group, and the evaluation was focused on the impact by income. For the equity with respect to the income level, the mode shift and CV by income were analyzed as the assessment indicators.
- Trade-off between efficiency and equity: Shows how the relation between the efficiency and equity of CC changed. This criterion was applied according to the congestion toll level.

The following performance measures were used to compare the results:

- total covered O/D flow;
- link travel time and travel cost by mode;
- number of links selected for the CC area; and
- mode choice (including by income level).

In addition, the compensating policy based on the revenue generated from CC affects the acceptability of the charging policy. Obviously, the chief beneficiary is the transport authority (Litman, 2007). Once the generated revenue is evaluated, it is worthwhile to analyze the revenue return effect with the efficiency and equity aspect.

The analyzed effects consisted of the transport effects and the equity and efficiency of the scheme. In particular, to assess the equity impact, the user groups were divided into three income levels: high, middle, and low. The transport effects considered the mode shift, travel length, travel time, traffic speed, traffic volume, etc. The feasibility of CC was assessed based on the social-welfare change, which considers the cost and benefit in the efficiency effect. In addition, the CV by user group was used as an assessment indicator to analyze the equity effects of CC.

Based on the above scenarios and evaluation criteria, the effects of CC in Seoul’s CBDs were analyzed in the subsequent section.

1.26. BASE CASE: DO NOTHING

When the congestion toll was imposed on the cars using the CBD, its impact was analyzed. The CBD, which is represented by Jongro-gu and Jung-gu, has been recognized as a socioeconomic centre and as the most congested area in central Seoul. The impact analysis was done by first exploring the base case (do nothing) and then assessing the impact by evaluation model.

1.26.1. Basic assumption

The impact of CC can be evaluated by comparing the results of transport modelling before and after the implementation of the scheme. The investigation of the base case aims to provide an evaluation basis for comparing it with other scenarios where charging is implemented. Therefore, in the investigation of the transport status before charging, various transport indices (e.g., mode choice, traffic volume, travel speed, and travel length) of the base case will be significant in the evaluation process.

For the examination of the base case, the following were assumed:

- the analysis model is static; the traveller can change only routes and modes and are not allowed to change their departure time;
- a fixed demand matrix was used; the overall travel demand was unchangeable;
- short-term impact analysis was done; trip generation or suppression was ignored and only the mode choice and traffic assignment were considered;
- four traffic modes (car, bus, taxi, metro/rail) were considered; other modes were excluded from the analysis;
- the frequencies of the bus and metro/rail were not changed; and,
- The capacity of public transport is sufficient to cover the number of passengers projected.

1.26.2. Results of the evaluation of the base case

ⅰ. Mode choice

The mode choice ratios for the CBD trips and other areas, respectively, in the do-nothing case were evaluated as 18.0 and 39.3% car, 7.8 and 8.4% taxi, 42.4 and 16.4% metro/rail, and 31.8 and 35.8% bus (see **Table 6-1**). The results shows that the car choice ratio in the CBD was only 18.0%, but that of PT, particularly the metro/rail and bus, was about 75%. Compared with the other areas, the ratio of private car use was relatively small, and the travellers preferred using PT than private cars.

Table 0-1. Mode choice ratio (do nothing: CBD)

Unit: %

Area		Car	Taxi	Metro/Rail	Bus
Charging area (CBD)	High	27.7	9.9	38.3	24.1
	Middle	18.1	7.7	43.4	30.8
	Low	8.2	5.6	45.6	40.5
	Average	18.0	7.8	42.4	31.8
Others	High	43.8	8.6	15.4	32.2
	Middle	39.7	8.5	16.4	35.4
	Low	34.7	8.2	17.3	39.9
	Average	39.3	8.4	16.4	35.8

The main reasons for the difference in mode choice by area are as follows: The CBD area is more inconvenient for private car use due to its traffic congestion, low traffic speed, lack of parking facilities, and better PT infrastructure. Therefore, PT use is much higher than the use of the other transport modes. On the contrary, the high ratio of private car use in the other areas can be attributed to their relatively lower traffic congestion and low PT infrastructure especially Metro/Rail.

ⅱ. Travel length, time, and speed

Total travel length and travel time employ the parameters of vehicle kilometre travelled (VKT) and vehicle hours travelled (VHT). It is noteworthy that the travel speed can be calculated based on the travel time and travel length. For the calculation of the travel speed, VKT is divided by VHT. Furthermore, the travel speed is adjusted based on the observed speed from the estimated speed (i.e., the travel speed in the do-nothing scenario is the same as the observed speed). Thus, the speed change after charging is calculated as the observed speed plus the speed increment in accordance with the proportion of the change. **Table 6-2** shows the VKT, VHT, and traffic speed of the base case.

Table 0-2. Travel length, time, and speed (do nothing: CBD)

	VKT (1,000 v-km)	VHT (1,000 v-hr)	Speed (km/hr)
Charging area (CBD)	1,579	179	14.0
Others	339,279	15,129	23.5

ⅲ. Traffic volume

The traffic volume is explored by inbound, destination, and crossing trips at the CBD cordon. The inbound trips are all the trips into the CBD. The destination trips are all the trips whose destinations are located within the CBD. The crossing trips just go through the CBD as their destinations are located beyond the CBD. In this sense, the crossing trips can be calculated by subtracting the destination trips from the inbound trips. **Table 6-3** shows the inner, inbound, destination, and crossing trips of the CBD. As it was assumed that the bus allocation does not change, the bus traffic volume was not considered in this research.

Table 0-3. Traffic volume (do nothing)

Unit: vehicle/day

	Inner	Inbound	Destination	Crossing
Car	20,294	387,996	185,530	202,466
Taxi	8,794	98,201	54,951	43,250
Total	29,088	486,197	240,481	245,716

Taking into account the assumption that the frequencies of buses and the metro/rail do not change, only private cars and taxis were considered for the traffic volumes. The results indicate that about 50% of the inbound trips cross the CBD. It can thus be inferred that the traffic congestion in the CBD can be mitigated practically only by reducing the number of crossing trips.

1.26.3. Comments

The impact of CC can be evaluated by comparing the results of transport modelling. The evaluation results of the base case provide the basis for evaluating the charging impact. In the charging area, the general effect of CC was to substantially reduce the traffic circulation within the charging area by mode shift or by diverting the charging area. As the diverted traffic, however, may end up in longer-distance trips as well, the impact analysis of congestion pricing must consider the whole system.

1.27. IMPACT ASSESSMENT AND ANALYSIS (Case1)

When the charging is implemented in the CBD, the impacts of CC are assessed by the efficiency and equity aspects. The efficiency impact was analyzed based on the travel demand effect and economic efficiency. The former is the evaluation of the typical transport impact, including mode shift, travel time, and travel volume. The latter, however, is the evaluation of welfare improvement as economic efficiency with the use of the transport modelling results. The detailed results of the impact analysis are shown below.

1.27.1. Efficiency of congestion charging

1.27.1.1. Efficiency of transport

ⅰ. Mode shift

When a toll is imposed on cars, the travel costs of cars increase, and the users will shift to other transport modes. The mode choice ratio of cars decreased by 2.3%, from 18.0 to 15.7%, after the implementation of CC. This means that 12.9% of the private car users gave up car use and shifted to PT. Therefore, the PT mode choice ratios were estimated to have increased to 8.0% for taxi, 43.6% for the metro/rail, and 32.8% for bus, compared to before the implementation of CC, registering increases of 2.6, 2.6, and 3.2%, respectively. **Table 6-4** shows the mode shift ratios after charging a ₩2,000 toll in the CBD.

Table 0-4. Mode shift after charging a ₩2,000 toll in Seoul’s CBD

	Before (%)	After (%)	Mode Shift (%)
Car	18.0	15.7	-12.9
Taxi	7.8	8.0	2.6
Metro/rail	42.4	43.6	2.6
Bus	31.8	32.8	3.2

ⅱ. Travel length, time, and speed

Table 6-5 shows the change in the traffic circulation, including the travel length, time, and speed. The general effect of CC was to substantially reduce the number of car trips in some cases by as much as 30-40%. Aside from the mode shift, the total travel length, time, and speed also change. The VKT and VHT decreased by 20.5 and 26.3%, respectively, in the CBD. The traffic speed in the CBD increased by 8.0%, from 14.0 to 15.1 km/h. It increased much, however, due to the car users who wanted to avoid the charging area by diverting to other roads. **Fig. 6-2** shows the traffic volume of the diversion roads. As can be seen in **Fig. 6-2**, the increased volume of traffic on diversion roads increased the travel length in the whole city. On the other hand, the travel time decreased overall, and the traffic speed improved due to the decreased private car use in the whole city. It seems that this was caused by the mode shift to PT.

Table 0-5. Traffic circulation after charging a ₩2,000 toll in Seoul’s CBD

		Before	After	Change
Charging area (CBD)	VKT (1000 v-km)	1,579	1,270	-20.5 %
	VHT (1000 v-hr)	179	132	-26.3 %
	Speed (km/hr)	14.0	15.1	8.0 %
Others	VKT (1000 v-km)	339,279	339,469	0.06 %
	VHT (1000 v-hr)	15,129	15,108	-0.14 %
	Speed (km/hr)	22.43	22.47	0.19 %

iii. Traffic volume

The change in traffic volume by using the roads of the charging area are shown in **Fig. 6-2** and **Table 6-6**. The traffic volumes were classified by inner, origin, destination, inbound, outbound, and go-through trips. The inner trips refer to the traffic within the charging area, the inbound and outbound trips refer to the traffic passing through the CBD cordon line, and the go-through trips refer to the traffic whose destination is located beyond the CBD.

- Inbound trip = Destination trip + go-through trip
- Outbound trip = Origin trip + go-through trip
- Go-through trip = Inbound trip – destination trip, or
  = Outbound trip – origin trip

Table 6-6 indicates that there will be a decrease of around 33% in the trips into the CBD. The inbound trips entering the charging area by cars will decrease by 47.3%, but the taxis will increase by 23.6% due to their toll exemption and the improvement of the traffic speed on the roads. The bus traffic was not considered because it was assumed in this research that the frequencies of buses will not change. When the inbound trips entering the charging area were divided into the destination and crossing trips, whose destinations are located beyond the CBD, the destination traffic was reduced by 15.2%, but 76.7% of the crossing traffic was reduced and diverted in the case of cars. In the case of taxis, however, the destination and crossing trips increased by 3.0 and 49.7%, respectively. Consequently, with regard to the car and taxi traffic combined, the destination and crossing traffic decreased by 11.0 and 54.5%, respectively.

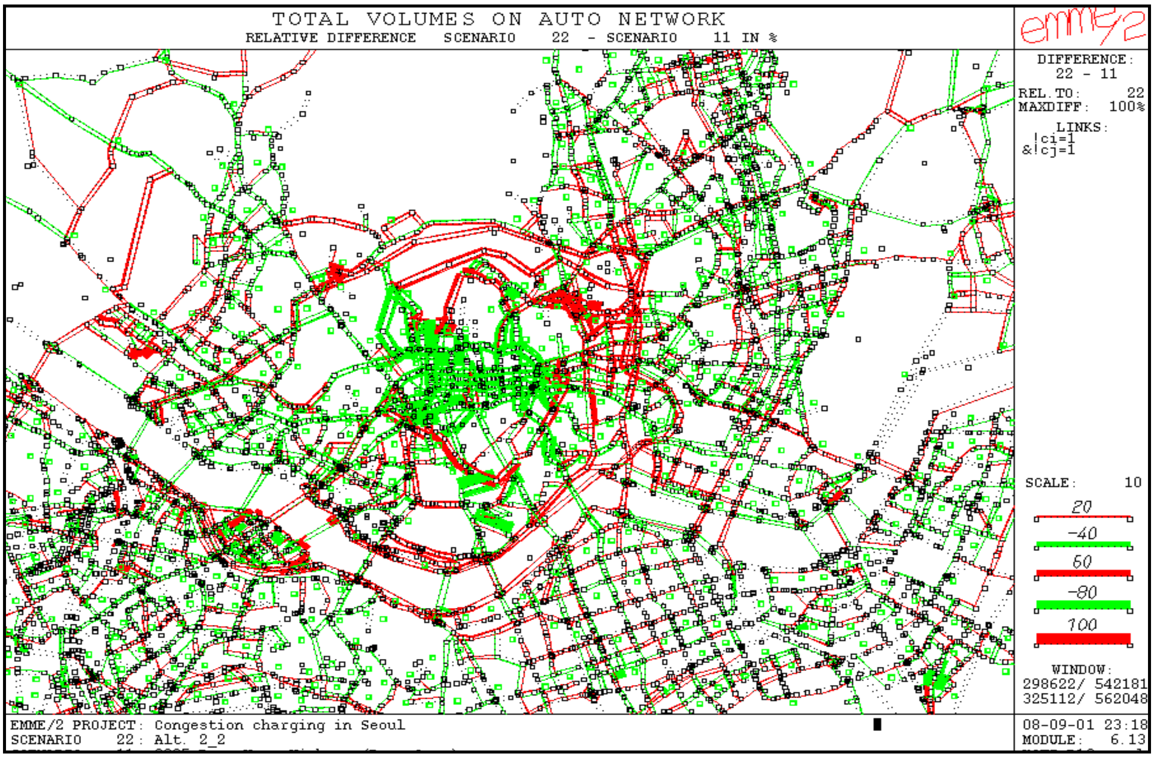


Figure 0-2. Traffic volume change.

Table 0-6. Traffic volume change

Unit: vehicle/day, %

		Before	After	Change
Inner	Car	20,294	15,662	-22.8
	Taxi	8,794	9,020	2.6
	Total	29,088	24,668	-15.2
Inbound	Car	387,996	204,416	-47.3
	Taxi	98,201	121,332	23.6
	Total	486,197	325,748	-33.0
Outbound	Car	387,996	204,416	-47.3
	Taxi	98,201	121,332	23.6
	Total	486,197	325,748	-33.0
Origin	Car	185,530	157,323	-15.2
	Taxi	54,951	56,585	3.0
	Total	240,481	213,908	-11.0
Destination	Car	185,530	157,323	-15.2
	Taxi	54,951	56,585	3.0
	Total	240,481	213,908	-11.0
Crossing	Car	202,466	47,093	-76.7
	Taxi	43,250	64,747	49.7
	Total	245,716	111,840	-54.5

ⅳ. Comments

The general effect of CC was to substantially reduce the number of car trips and VKT in the charging zone. In this sense, the results indicate that the VKT fell by about 20.5% and that the traffic volume significantly decreased within the charging area. Comparing these results to the London case, the VKT within the charging zone was projected to fall by 20-25% for the ￡5 area charging scenario (ROCOL, 2000), and the monitoring results showed a 15% reduction during the charging hours in 2004, after the implementation of CC (TfL, 2006). In addition, the changes in the inbound traffic entering the charging area fell by 33% in this study, and by 35% for the ￡5 area charging scenario in the London case (ROCOL, 2000). Part of this can be attributed to the fact that some drivers diverted around the charging area, in trips that would normally go through the central area. Consequently, it can be concluded that the transport modelling results can be reasonably used in the analysis of the impact of CC. In particular, as these results were utilized in the evaluation of the economic efficiency that followed, the reliability of the results is significant.

1.27.1.2. Economic efficiency

The criterion that was used to assess the economic benefit derived from CC was the improvement in social welfare. All the benefits and costs of the policy were estimated through the cost-benefit analysis method; hence, the feasibility of the policy implementation can be justified by the analysis results. The data for the evaluation of the social welfare and the evaluation process are presented hereafter.

ⅰ. Data for the evaluation of the social welfare

The amount of social-welfare change was evaluated using **equation (5.8)**. For the sake of the evaluation, the data for each item were outlined. First of all, the user benefits (ΔU) were calculated based on CV in the next section. Note that CV is the travellers' welfare change by charging. Second, the revenue collection of the toll was simply calculated based on the number of charged cars, which consisted of the crossing, origin, destination, and inner trips to the CBD, by multiplying the toll by the number of weekdays in a year (260 days). In addition, the parking fee was assumed to be ₩3,016/day (SMG, 2007b), which was the daily average parking cost of Seoul in 2005, and the fuel price and tax rate were applied to June 2005 (KPA, 2005). For the calculation of the revenue change, the fuel efficiency was made to adopt **Table 6-7**.

Table 0-7. Fuel price, tax, and efficiency

	Petrol	LPG
Fuel price (FP_m)	1,402 won/litre	725 won/litre
Tax ratio (t^F_m)	0.463%	0.308%
Fuel efficiency (FE_m)	0.085 km/litre	0.151 km/litre

Source: KOSIS (2005), KPA (2005), SDI (1996)

Third, the external cost consists of traffic accidents, air pollution, and noise costs that are not borne by the car users or PT suppliers but that have to be considered as a part of the social system. Shim and Ryu (2007) derived the unit cost of traffic accidents by analyzing the 2005 traffic accident data in South Korea. They estimated the social cost of traffic accidents in South Korea by using the “Gross Lost Output Approach,” which is considered the method that is most well suited to the economic environment of South Korea. The accident cost consists of the future income loss, medical costs, property damage costs, related administration costs, and PGS (pain, grief, and suffering) of the victims. The annual road accident cost of South Korea has been measured since 1995 by KOTI.

The probability of accident (POA) can be derived from the casualties per vehicle kilometre, and the unit cost was adopted by Shim and Ryu (2007) (see **Table 6-8**). As the external-cost unit for transport is rarely studied in South Korea, the research results in Europe (ECMT, 1998) on air pollution and noise were adopted in this study (see **Table 6-8**).

Table 0-8. Casualties and costs of traffic accidents, 2005

	Killed	Injured
Casualties per one million vehicle-km (person)	0.0193	0.65
Unit cost per casualty (₩1000/person)	389,877	4,228

Source: IRTAD (2005), Shim and Ryu (2007)

Table 0-9. Unit values for the external cost for transport

	Unit Cost
Air pollution	₩12,600 (£6.30)/1000 v-km
Noise	₩7,860 (£3.93)/1000 v-km

Source: ECMT, 1998

The operating costs of the charging scheme were roughly estimated using the London CC scheme; 404 monochrome and 254 colour cameras were installed at 203 locations, for enforcement. This typically amounts to £90 million per year (TfL, 2006). In particular, the cost per location, which was derived by dividing the operating cost by the number of camera locations, was taken into consideration to estimate the Seoul case (see **Table 6-10**).

Table 0-10. Operating cost of the congestion charging scheme

	London	Seoul
Charging area	22 km^2	9.4 km^2
No. of camera locations	203 places	26 places
Annual operating cost	₩180 bn (£90 mn)	₩23 bn (£11.5 mn)

Note: £1 = ₩2000; unit operating cost: ₩8,870 mn/year/location (£0.44 mn)

ii. Social-welfare change

Social-welfare change, which refers to the improvement of the economic efficiency to be gained from the charging scenario, was estimated using conventional consumer measures. **Table 6-11** summarizes the evaluation process of the social-welfare change for a ₩2,000 area charging scenario in central Seoul. It derived much social-welfare improvement as well as revenue generated via CC. The net social benefits or social-welfare improvement was estimated to be ₩731 mn daily and ₩190 bn annually.

Table 0-11. Social-welfare change

		Per Day (Mn Won)	Per Year(1) (Mn Won)
User benefit ($\Delta U=-\Delta E$)	High-income	14.8	3,848
	Middle-income	9.2	2,392
	Low-income	10.5	2,730
	Subtotal	34.5	8,970
Operating and private cost ($\Delta C_{O/P}$)	Employers' parking cost	-5.4	-1,394
	Service suppliers' operation cost	-44.4	-11,572
	Toll collection cost	88.7	23,054
	Subtotal	38.9	10,088
External cost (ΔC_{EXT})	Traffic accident cost	3.5	899
	Air pollution cost	3.6	940
	Noise cost	2.3	587
	Subtotal	9.3	2,426

Revenue (ΔR)	Toll (government)	650.6	169,165
	Fuel tax (government)	16.9	4,393
	Fare (service supplier)	77.6	20,170
	Subtotal	745.1	193,729
Social-welfare change = $\Delta U - \Delta C_{O/P} - \Delta C_{EXT} + \Delta R$		***731.5***	***190,186***

Note: (1) 1 year = 5 days x 52 weeks = 260 days

Based on the detailed items, the user benefits generated ₩34.5 mn per day, and the welfare increased in all the income groups. It seems that the increased user benefits were caused mainly by the travel time saving in accordance with the travel speed improvement. Normally, when charging is applied, a utility reduction occurs due to the monetary loss on account of the toll and the hassle caused by the mode shift to PT. As the effect of the travel time saving, however, was bigger than the utility reduction. This implies that the user benefits increased. This results is derived on the assumption that the marginal cost of extra passengers in public transport is neglected.

The operating and private cost consists of the parking cost of the employer and the operating cost of the service supplier as well as the toll collection cost by the government. It was estimated to be ₩38.9 mn daily. This was mainly caused by the operation cost of the charging scheme, which was ₩88.7 mn daily. On the contrary, the employers and service suppliers gain benefits according to the cost reduction; that is, as the number of employees who travel by car decreases due to CC, the business companies located in the CBD save on costs through the reduction of their parking cost, which they pay for their employees. In addition, some cost change occurs on the part of the taxi service supplier through the change in the operating distance.

The external cost, which consists of the traffic accident and environmental costs, was estimated to be ₩9.3 mn per day. This was mainly caused by the increase in the VKT, where the reduction of VKT through mode shift is much smaller than the growth of the diverted traffic. Similarly, it was estimated that the generated revenue of the PT suppliers increased to about ₩77.6 mn per day. This was because of the fact that many car users made a shift to PT, especially to buses and taxis, which highly affected the traffic speed on the roads. Consequently, it seems that the policy brings about fairly positive effects from the viewpoint of social welfare, as an efficiency effect.

iii. Comments

The analysis of the results from the model showed that the introduction of CC can improve social welfare significantly. The following comments are hereby presented based on the results of charging in the CBD:

- The improvement of social welfare is mainly caused by the generated revenue. As the welfare gains are similar to the toll revenue, a fair distribution of the revenue may resolve the key issue of CC policy acceptability.

- In spite of the improvement of economic efficiency, the external cost, including the air pollution, noise, and accident costs, are increased. It is noteworthy that the reduced traffic in the charging area causes a reduction in the external cost whereas the diverted traffic leads to an increase in the VKT; hence, it causes an increase in the external cost in the whole city.

Although it is difficult to say that the economic efficiency of CC guarantees the implementation of the policy, it seems that the improvement of social welfare improves the chances of implementing the CC policy.

1.27.2. Equity of congestion charging

According to the classification of the user groups, various assessment criteria can be derived, such as spatial equity and social equity or horizontal equity and vertical equity. Taking into account the fact that income is normally used in equity analysis, this study used income as a key factor for defining the user group, and the equity impact was analyzed based on the mode shift ratio and economic-welfare change by income level.

1.27.2.1. Mode shift by income

High-income households are more likely to own cars and to use them to go to their respective workplaces in central Seoul. They are therefore expected to be affected by the proposed charging measures. Among the transport indices related to the impact of charging, mode shift is the most clearly shown impact by income level. When the toll was imposed, 8.1% of the car users in the high-income group shifted to PT, but 15.9 and 22.4% of the car users in the middle- and low-income groups gave up their car use. **Table 6-12** shows the mode shift by income group.

Table 0-12. Mode shift by income group

	High	Middle	Low
Do nothing	27.7%	18.1 %	8.2 %
After charging	25.4%	15.2 %	6.4 %
Mode shift	-8.1%	-15.9 %	-22.4 %

Recall that disbenefits will be incurred by most of those driving in the charging area either because the charge exceeds the value of the time that they save or because they transfer to less favourable modes or destinations. Proportionally, there will be a greater reduction in the number of car trips into the central-Seoul charging area by those in the low- and medium-income groups than in the high-income group. It appears that the lower the income of the user, the more sensitively he/she reacts to CC. As the VOT of the high-income group is bigger than that of the low-income group, the benefit of time saving to the former is higher than that to the latter, in accordance with the equally imposed toll. Thus, although the travel cost increased due to CC, it seems that relatively less high-income users made a shift to PT.

1.27.2.2. CV by income

As a social-welfare change measure, CV is the amount of compensation of the travellers as users so they will have the same utility before and after the implementation of CC. The results of the CV analysis can be interpreted as follows: If a positive CV value is derived after CC, the utility decreased and the user welfare (travellers' benefit) is worse off, whereas if a negative CV value is obtained, the user welfare is better off. **Table 6-13** presents the CV by income under the toll of ₩2,000. Here, the CV was calculated using the macro function provided in EMME/2 (see Appendix A).

Table 0-13. CV by income

	High	Middle	Low
Total CV (mn won/day)	-14.8	-9.2	-10.5
CVPP (won/person)	-30.9	-10.9	-9.6
Portion of CVPP in income (%)	-0.17	-0.10	-0.15

The CVs by income were evaluated based on the utility change (see Eq **(5.21)**), according to the travel time savings and travel cost, including the toll, from the travellers' standpoint. Thus, the results indicate a change in the user welfare by income. The derived total CV, ₩34.5 mn, with a negative value, indicates that the user welfare improved, as previously stated**.** Different CVPP values were derived according to the users' incomes: -₩30.9 for the high-income group and -₩10.9 and -₩9.6 for the middle- and low-income groups, respectively. The high-income group gained about three times more benefits than the middle- and low-income groups. This indicates that the higher-income group obtained higher benefits. Furthermore, the portion of the CVPP in the income, which is an indicator of the equity effect, indicates that the high-income group gained the highest benefit as well.

1.27.2.3. Comments

As the CC toll is equally imposed regardless of the income level, a regressive effect is expected. The results show that CC had a regressive effect, which was backed up by the mode shift ratio of cars by income level. In addition, respectable differences were yielded in the CV by income level. These findings confirm that although the toll may be horizontally equitable because everybody pays the same amount, it may be vertically inequitable because it represents a larger portion of the income of a low-income driver compared to a high-income driver.

1.27.3. Revenue return effect

The way in which the government allocates revenues will determine both the equity and the political acceptability of a congestion pricing scheme. In this context, to assess any proposed, real-world CC scheme, it is important to investigate its distributional effects, to consider the impact of the different uses of revenues and to include this in the calculation of the distributional effects, and to compare the magnitude of the social-welfare change with the total distributional effect. In this section, how the equity and efficiency effects can be influenced by the CC revenue return is examined.

1.27.3.1. Applied scenarios for revenue return

The current conventional thinking is that revenues should be devoted to transportation improvement for them to be politically feasible, but some analyses indicate that alternative distributions that include tax reductions or financial rebates benefit the largest number of citizens and therefore may be more politically popular (Litman, 2002). Among the redistribution options of revenue, the reduced PT fare was selected in this study to analyze the effect of equity and efficiency. The effects were analyzed by estimating the CV by income and social-welfare change using the evaluation framework that was applied in the previous sections. In addition, it was assumed that the government provides the PT suppliers with a subsidy amounting to as much as the total amount of toll collection, to reduce the fare.

The revenues from the charging scheme were estimated to be ₩562 mn daily for the ₩2,000 charging scenario. Taking into account the total PT fare, the maximum reduced bus and metro/rail fare can be 5.2%. Thus, the impacts were analyzed in the scenarios with fare reduction rates of 3, 4, and 5%, respectively. The applied scenarios based on the total toll revenue and PT fare reduction rate were as follows:

- Total toll revenue : ₩562 mn per day;
- Total bus and metro/rail fare : ₩10,738 mn per day;
- Maximum ratio of reduced fare : 5.2%; and
- Applied scenarios : 3, 4, and 5%.

It can be supposed that an additional mode shift to PT due to reduced fare of PT. In this study, however, there would be sufficient capacity in the PT system to cover the number of passengers projected, as mentioned in section 6.3.1. The results of the analysis were subsequently divided into two sections: equity effect and efficiency effect. The equity effect was analyzed according to the CV by income, and the efficiency effect was analyzed according to the social-welfare effect.

1.27.3.2. Efficiency effect

Table 6-14 shows the variation in the social-welfare change by reduced PT fare in the case of charging in the CBD. The results indicate that the reduced PT fare did not produce an additional improvement of the net social welfare. The social welfare was estimated to be ₩732 mn daily under the no-fare-discount rate, whereas when the reduced rate was applied, the social-welfare values corresponding to the reduced rates of 3, 4, and 5%, respectively, were ₩313 mn, ₩331 mn, and ₩348.9 mn. That is, the net social-welfare improvement was smaller in the case of the discounted fare than in the no-discount case. This was mainly caused by the reduction of the service suppliers' fare income. Despite the fact that more car users made a shift to PT, the total income of the service suppliers decreased to ₩195 mn, ₩₩287 mn, and ₩379 mn daily from the reduced rates of 3, 4, and 5%, respectively. As it was assumed, however, that the reduced income from the fares can be compensated by the government subsidy, the service suppliers may not incur an income loss.

Table 0-14. Social-welfare change by reduced fare rate (CBD charging)

Unit: mn won/day

		Base Case	Reduced Rate		
		0%	3%	4%	5%
User benefit (ΔU=-ΔE)	High-income	14.8	40.0	40.3	40.6
	Middle-income	9.2	75.2	75.6	76.1
	Low-income	10.5	116.4	116.8	117.2
	Subtotal	34.5	231.6	232.7	233.9
Operating or private cost ($\Delta C_{O/P}$)	Employers' parking cost	-5.4	-5.6	-5.7	-5.8
	Service suppliers' operation cost	-44.5	-80.3	-92.7	-104.3
	Toll collection cost	88.7	88.7	88.7	88.7
	Subtotal	38.8	2.7	-9.7	-21.4
External cost (ΔC_{EXT})	Traffic accident cost	2.9	1.3	-0.1	-1.7
	Air pollution cost	3.6	1.6	-0.2	-2.0
	Noise cost	2.3	1.0	-0.1	-1.3
	Subtotal	8.8	4.0	-0.4	-4.9
Revenue (ΔR)	Toll (government)	650.6	638.7	636.8	634.8
	Fuel tax (government)	16.9	9.0	1.4	-6.4
	Fare (service supplier)	77.6	-195.1	-286.7	-378.6
	Subtotal	656.4	364.0	262.9	161.2
Social-welfare change = $\Delta U - \Delta C_{O/P} - \Delta C_{EXT} + \Delta R$		***732.0***	***677.6***	***594.4***	***510.1***

On the other hand, the results indicate that the user benefit improvement was fairly high, as presented in the previous section. It can be inferred from this that the decreased travel cost of the PT users brought about utility improvement and hence induced the improvement of the user benefit. In addition, as the reduced PT fare induced more mode shifts to PT, it generated a reduction of the operating or private cost ($\Delta C_{O/P}$) and external cost (ΔC_{EXT}). That is, the reduced number of car commuters made the employers cut the parking cost, and the reduction of VKT due to mode shift brought about an external-cost cut. Moreover, the external cost increased due to the diverted traffic under CC, and it increased less under the reduced fare rate than under the no-discount rate.

1.27.3.3. Equity effect

In the base case, which was under the no-reduced-fare rate, -₩14.5 mn, -₩9.2 mn, and -₩10.5 mn total CVs were generated in the high-, middle-, and low-income groups, respectively.

Moreover, the CVPPs were -₩30.9, -₩10.9, and -₩9.6 in the high-, middle-, and low-income groups, respectively. The CV was derived from the utility function of the Logit model. The reduced PT fare influenced the travel cost of the travellers and caused an increase in the utility of PT. It can be inferred that there was an additional mode shift as well as CV improvement. As the CV was estimated based on the utility function, the increased utility led to CV improvement. In particular, in the low-income group, the relatively high mode share of PT and the reduced fare led to a great increase in the utility by income group and consequently led to an increase in the CV of the low-income group.

Table 6-15 and **Figure 0-3** show the CV variation under the reduced PT fare. Under the 5% reduced fare rate, the total CVs of -₩40.6 mn, -₩76.1 mn, and -₩117.2 mn were generated in the high-, middle-, and low-income groups, respectively. Moreover, the high-, middle-, and low-income groups, respectively, had CVPPs of -₩84.8, -₩90.6, and -₩106.5.

Table 0-15. CV by income (CBD charging)

	Income	Base Case	Reduced Rate		
		0%	3%	4%	5%
Total CV (mn won)	High	-14.8	-40.0	-40.3	-40.6
	Middle	-9.2	-75.2	-75.6	-76.1
	Low	-10.5	-116.4	-116.8	-117.2
CVPP (won)	High	-30.9	-83.6	-84.2	-84.8
	Middle	-10.9	-89.6	-90.1	-90.6
	Low	-9.6	-105.8	-106.2	-106.5

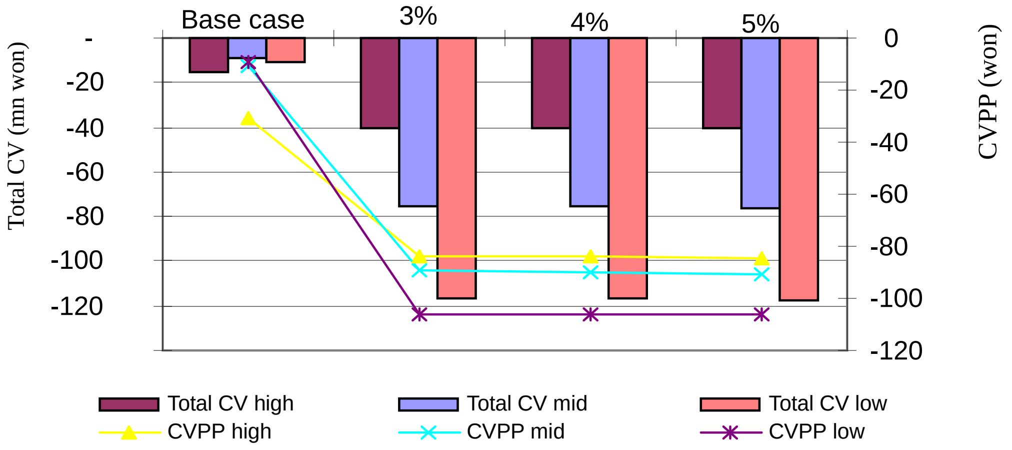


Figure 0-3. CV variation under the reduced PT fare (CBD).

When no fare discount was given, the results indicated that the high-income group obtained much more benefits than the low-income group did, but when the PT fare was reduced by using the toll revenue, the low-income group obtained a higher benefit than the high-income group did. This seems to be because the low-income group had a higher PT mode share than the high-income group. Thus, more welfare improvement was generated in the low-income group. It can thus be concluded that the regressive effect of CC can be mitigated by the reduced PT fare, using the toll revenue as a compensating policy.

On the other hand, the effect of equity improvement was explored by applying the incremental reduced fare rates 3, 4, and 5%. The 3% reduced rate is required to use about 50% of the toll revenue, and 5% to use much of the toll revenue. The results show an impact similar to the user benefit (CV) according to the variation of the reduced fare rate. Furthermore, the amount of CV variation was nearly parallel to the reduced rate. This indicates that there was no great difference in the equity effect in accordance with the variation of the reduced fare rate.

1.27.3.4. Comments

The revenue return effect of the reduced PT fare was examined from the standpoint of equity and efficiency. To summarize the results, the reduced PT fare improved the equity as a fair distribution whereas the economic efficiency did not improve.

From the viewpoint of the equity impact, even though the user benefit improved in all the income groups due to the reduced PT fare, the benefit was much bigger in the low-income group than in the high-income group. Thus, it can be inferred that the reduced PT fare mitigated the income-regressive impact. Moreover, considering the CVPP by case, the user benefit was three times higher in the high-income group and 10 times higher in the low-income group compared to the no-discount case. These results indicate that the low-income group obtained a much higher benefit from the redistribution of the toll revenue. Consequently, it can be concluded that the reduced PT fare mitigates the income-regressive impact even though the amount of the benefit varies according to the changing area or the reduced fare rate.

On the other hand, economic efficiency concerns the use of the society’s resources to achieve the maximum social welfare. The reduced PT fare did not produce an additional improvement of the net social welfare from the efficiency standpoint. That is, the net social-welfare improvement was smaller in the case of the discounted fare than in the no-discount case. This was mainly caused by the reduction of the service suppliers' fare income. From an economic standpoint, if the revenue, including the income of the service suppliers, is regarded as merely transferred to the government or service suppliers from the travellers, it can be inferred that the social-welfare improvement makes sense. In this case, the social-welfare improvement was mainly caused by the user welfare improvement. In addition, the private and external costs played a part in improving the efficiency. The reduced fare caused an additional mode shift to PT and hence produced an additional cutback of the external cost in accordance with the VKT decrease.

1.27.4. Trade-off between efficiency and equity

The transport policy is required to strike a balance between efficiency and equity. The excessive pursuit of efficiency may bring about an equity problem, such as violating the rights of the low-income citizens. *Efficiency* refers to the extent to which the achievement of such a goal yields the highest possible net social benefits, defined as the difference between the social benefits and the social costs (Verhoef et al., 1996) whereas *equity* refers to the distribution of the impacts and whether they are considered fair and appropriate. As these are affected by various factors, such as the charging zone, time, and toll level, it is worthwhile to examine the trade-off between efficiency and equity in accordance with the factors. In particular, the impact of the toll level influences the travellers' behaviour significantly. Thus, the trend of the impact of the toll level was examined in different scenarios (₩1,000, ₩2,000, ₩3,000, and ₩4,000 toll scenarios), after which the trade-off between the efficiency and equity of CC was investigated.

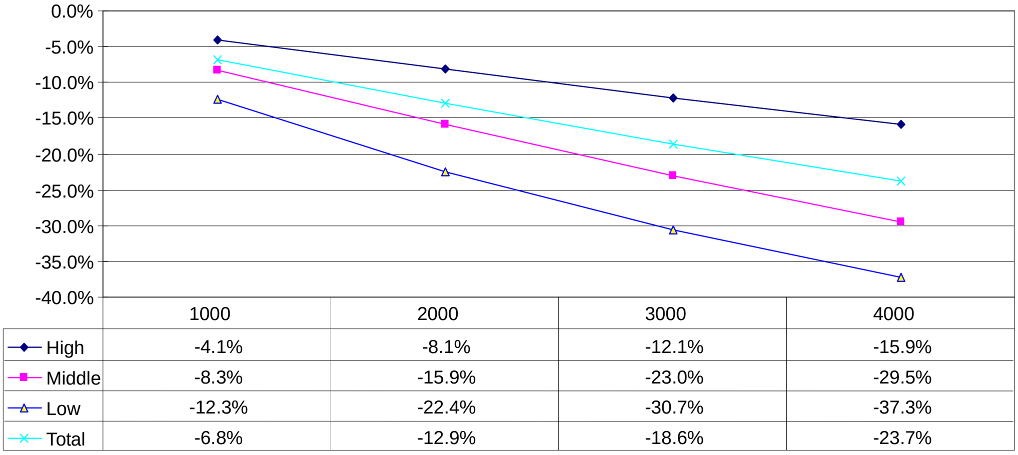
1.27.4.1. Impact analysis by toll increment

ⅰ. Traffic conditions

The mode shifts, traffic circulation (e.g., VKT and VHT), and traffic volumes were investigated for the analysis of the traffic conditions.

Mode shifts

As the toll increased, more private car users shifted to PT. **Fig. 6-4** shows the mode shift of the private car users. When the toll increased from ₩1,000 to ₩4,000, it was estimated that 6.9, 12.9, 18.6, and 23.7% of the private car users shifted to PT, respectively. Meanwhile, the mode shift of the private car users to PT slightly increased in the high-income group and sharply increased in the low-income group. As the toll went up, 4.1, 8.1, 12.1, and 15.9% of the private car users shifted to the PT mode in the high-income group, and 8.3, 15.9, 23.0, and 29.5% in the middle-income group, respectively. 12.3% of the low-income car users, however, gave up car use when a ₩1,000 toll was imposed, and 37.3% when a ₩4,000 toll was imposed. These results indicate that the low-income car users are more sensitive than the high-income car users. When the monetary loss due to the toll is bigger than the time saving benefit, the car users shift to the PT mode. It is usually recognized that CC is inequitable between car owners because the same charge is levied on car use regardless of the incomes of the motorists (Richardson, 1974; Litman, 2002). As the VOT, however, is higher in the high-income group than in the low-income group, it seems that the low-income group reflects greater sensitivity to the imposition of the toll.



	1000	2000	3000	4000
High	-4.1%	-8.1%	-12.1%	-15.9%
Middle	-8.3%	-15.9%	-23.0%	-29.5%
Low	-12.3%	-22.4%	-30.7%	-37.3%
Total	-6.8%	-12.9%	-18.6%	-23.7%

Figure 0-4. Trend of mode choice ratio by toll.

Consequently, a higher toll level will cause more car users to shift to PT and will thus improve the transport efficiency. As more low-income travellers, however, shift to PT compared to high-income travellers, it seems that the transport equity may be weakened by the implementation of the CC scheme.

Traffic circulation

The status of traffic circulation within the charging zone can be expressed by VKT and VHT. **Table 6-16** describes the VKT, VHT, and travel speed in accordance with the toll change. As the toll went up, the traffic speed steadily increased while cutting down the speed increments. The results, however, show different travel length (VKT) characteristics between the charging area and the whole city, the outer charging zone. That is, the VKT was continuously reduced in the charging area at all the toll levels (see **Fig. 6-5**) whereas it increased up to ₩3,000 and then decreased in the whole city. It can be inferred that the amount of reduced VKT traffic by mode shift was smaller than that of the increased VKT traffic by the diverted private cars to avoid the toll. When the toll of ₩4,000 was imposed, however, much more car users shifted to PT due to the reduction of the VKT (see **Fig. 6-6**).

Table 0-16. Travel length, time, and speed by toll

	Toll Level (₩)	Do Nothing	1,000	2,000	3,000	4,000
CBD	VKT (1000 v-km)	1,579	1,406	1,270	1,188	1,137
	VHT (1000 v-hr)	179	150	132	121	114
	Speed (km/hr)	14.0	14.7	15.1	15.4	15.7
All	VKT (1000 v-km)	339,279	339,467	339,469	339,391	339,256
	VHT (1000 v-hr)	15,129	15,114	15,108	15,010	15,080
	Speed (km/hr)	22.43	22.46	22.47	22.48	22.50

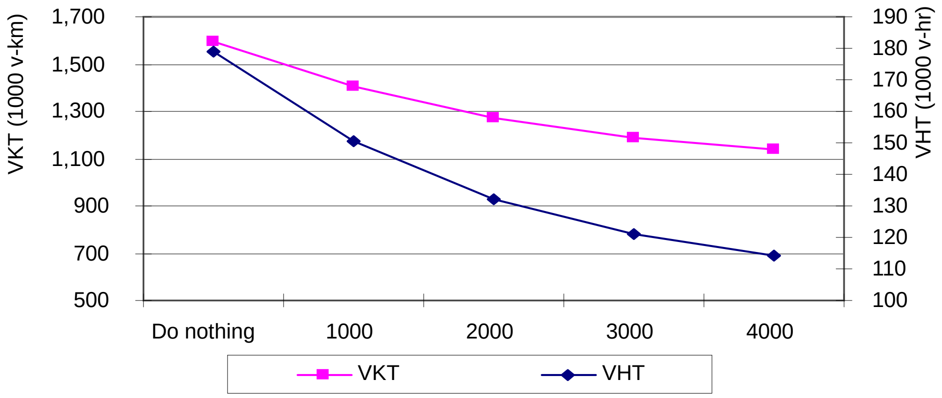


Figure 0-5. VKT, VHT (CBD).

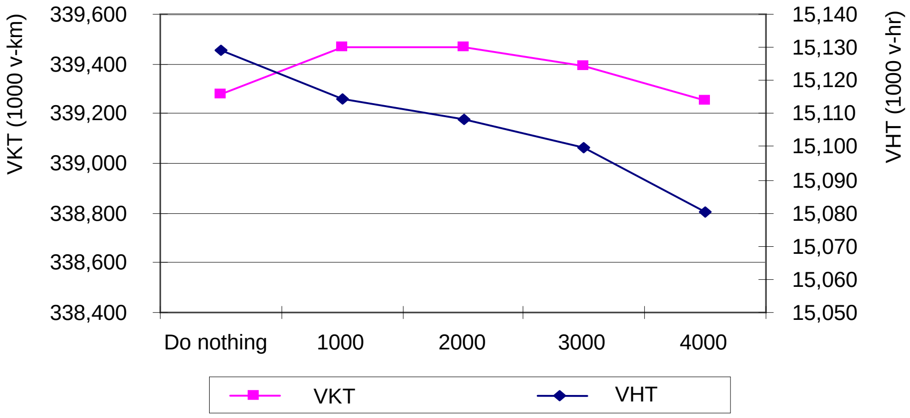


Figure 0-6. VKT, VHT (all).

Traffic volume

The change in the traffic volume is shown in **Table 6-17**. The table does not consider the bus traffic because the model assumed that the bus frequencies would not change. As the toll went up, the traffic volumes inbound to the CBD continuously decreased. In particular, the crossing traffic among them decreased by 35.9, 54.5, 63.6, and 66.8%, respectively.

Table 0-17. Traffic volume change (case 1)

Toll (Won)		1,000	2,000	3,000	4,000
Inbound trips	Car	-30.5%	-47.3%	-57.2%	-62.5%
	Taxi	16.5%	23.6%	27.6%	29.6%
	Total	-21.0%	-33.0%	-40.1%	-43.9%
Crossing trips	Car	-51.2%	-76.7%	-89.4%	-94.0%
	Taxi	35.5%	49.7%	57.3%	60.4%
	Total	-35.9%	-54.5%	-63.6%	-66.8%

When a ₩1,000 toll was imposed, more than half of the cars diverted, or their users shifted to PT to avoid the charge, whereas most of the car users did so when a ₩3000 toll was imposed. In this regard, it is expected that the traffic volume increased much on the diversion roads (e.g., ring roads). As taxis were exempted from paying the toll, however, the numbers of their inbound and crossing trips increased. **Fig. 6-7** shows this.

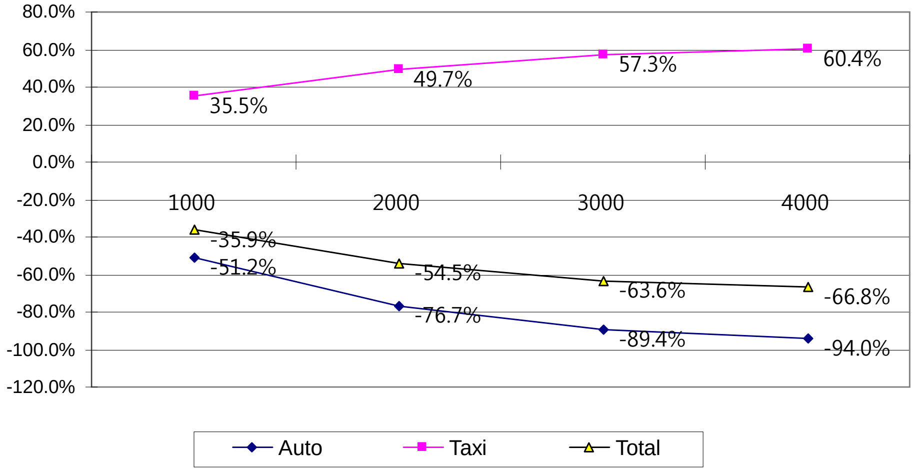


Figure 0-7. Change in the crossing traffic volume.

iii. Revenue

Fig. 6-8 shows the change in the toll revenue and in the number of charged cars in accordance with the toll level. It shows that the number of charged vehicles decreased but that the generated revenue increased. Of the options examined, when the toll was ₩4,000, the generated revenue was maximized, but as how much revenue can be generated is a key issue in the implementation of the CC policy, although maximizing the toll revenue is not always a priority among the policy's objectives, it is important to estimate the revenue-maximizing toll.

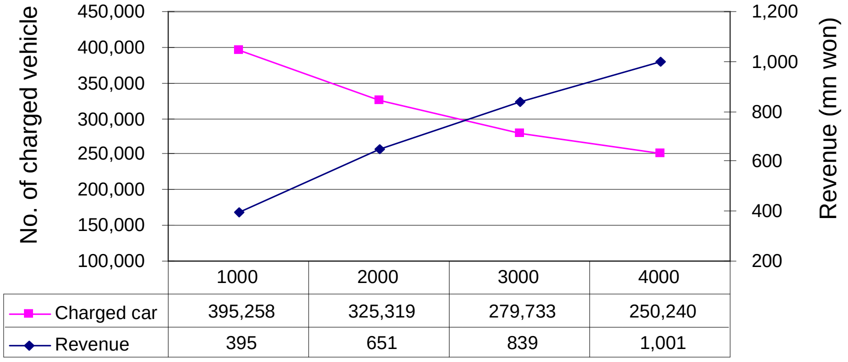


Figure 0-8. Generated toll revenue.

ⅳ. User benefit

Fig. 6-9 shows the total CV in accordance with the toll increment. When the toll was ₩1,000 and ₩2,000, it produced negative CV values; this means that the user welfare increased. It seems that the total utility increase due to VOT saving was higher than the monetary loss in spite of the payment of the toll, even though some users shifted to the PT mode. Beyond ₩2,000, however, the CV changed to positive values; this indicates that the user welfare was reduced.

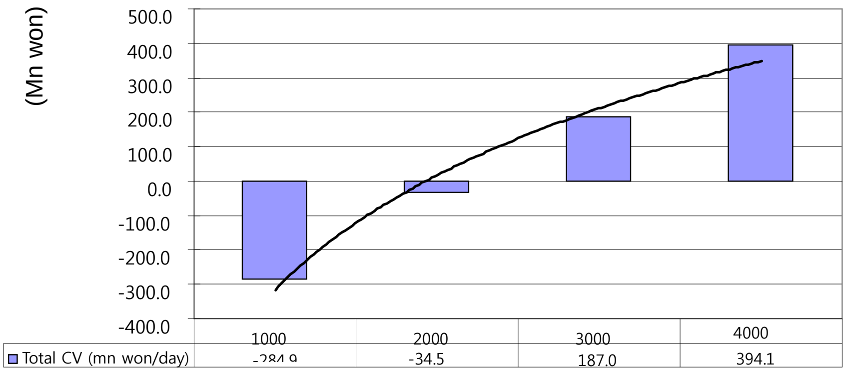


Figure 0-9. Total CV.

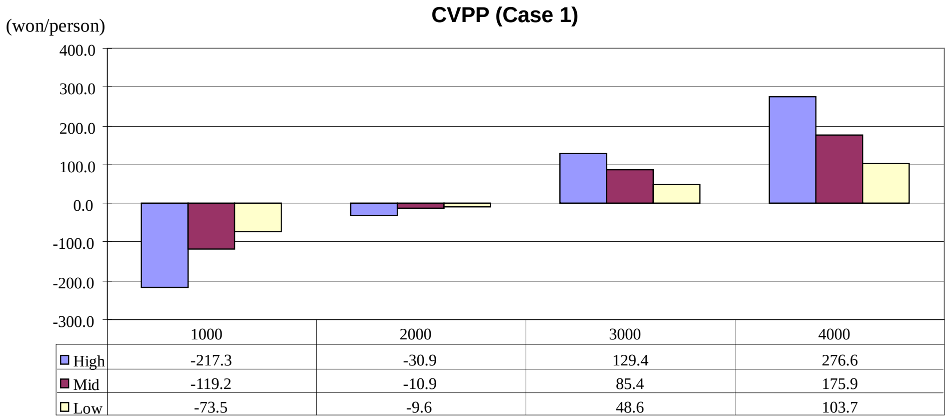
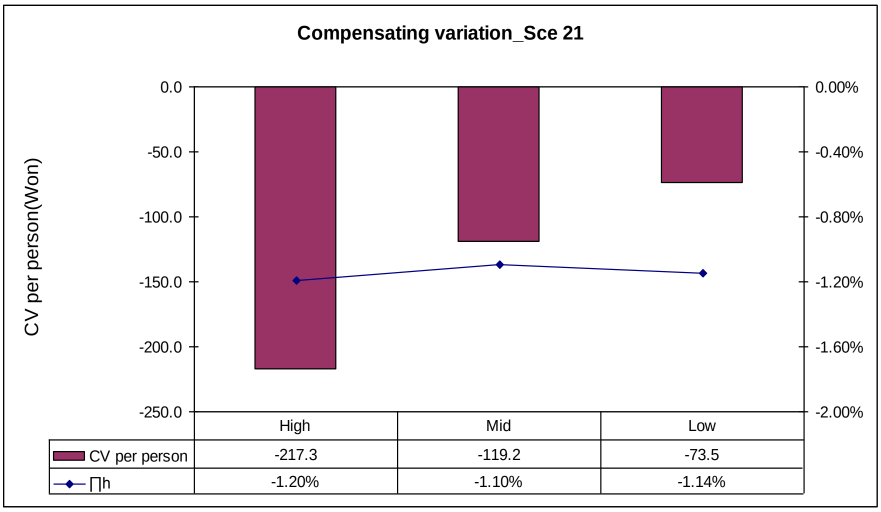


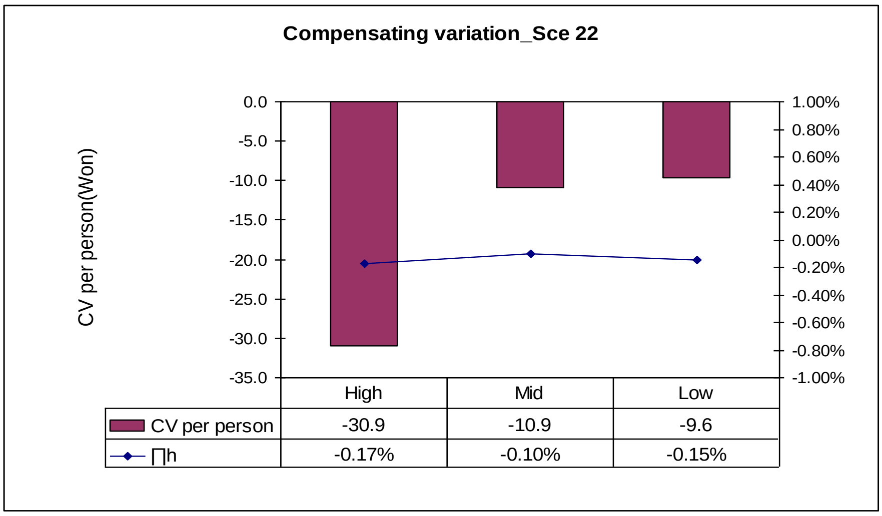
Figure 0-10. CVPP by income.

On the other hand, looking into the CV values by income group, the definite value was bigger in the high-income group than in the low-income group (see **Fig. 6-10**). This suggests that the high-income group obtained higher gains or losses, and that the low-income group obtained lower gains or losses in accordance with the toll increments. In this regard, it was demonstrated that the CV of the high-income group continuously increased sharply but that of the middle- and low-income groups increased only slightly. It seems that because there were more car users in the high-income group and that there were fewer among them who shifted to the PT mode, there was a greater welfare decrease in such a group. The relatively lower rate of car use in the low-income group, however, produced a lower welfare decrease. This suggests that the high-income group acquired a bigger benefit from the toll fees up to ₩2,000 and a bigger loss beyond the toll of ₩2,000.

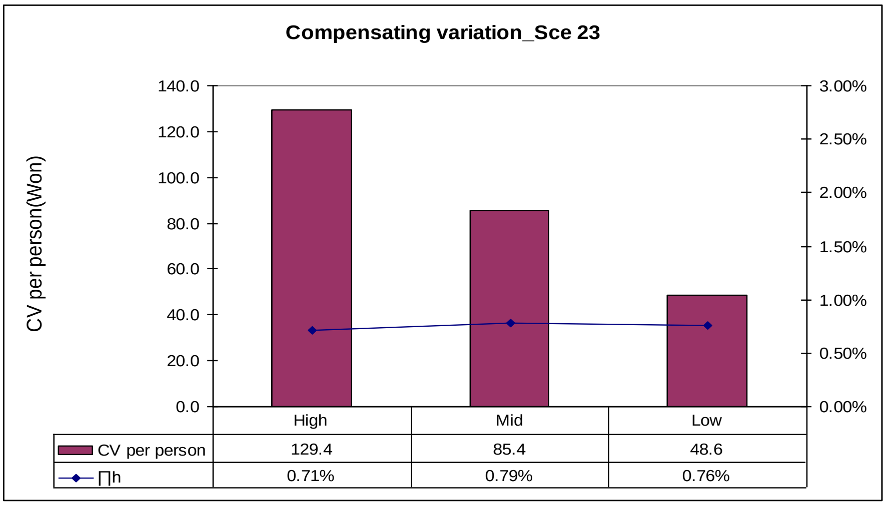
Fig. 6-11 shows the CVPP and the portion of CVPP in the income. The portion of CVPP in the income (π_h) has a significant meaning in the analysis of the equity effect. It indicates the actual benefit or loss of the user. The results indicate that the high- and low-income groups obtained similar values and that the middle-income group obtained a slightly higher value than did the two other income groups.



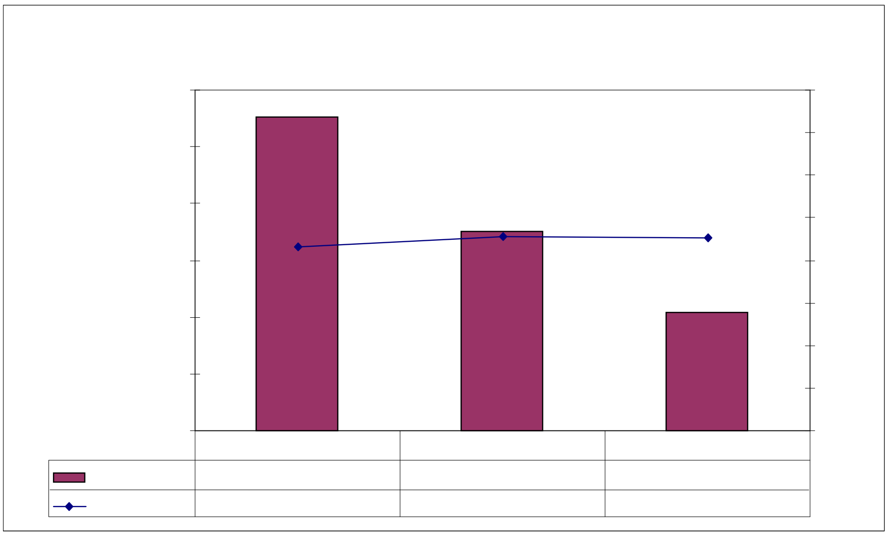
(A) At ₩1,000



(A) At ₩2,000



(A) At ₩3,000



(D) At ₩4,000

Figure 0-11. CV by income (case 1).

ⅵ. Social-welfare change

The result shows that the social welfare was enhanced and continuously increased up to the toll of ₩3,000 and then decreased: ₩670 mn, ₩731 mn, ₩734 mn, and ₩712 mn for the toll of ₩1,000, ₩2,000, ₩3,000, and ₩4,000, respectively. It can thus be concluded that from the efficiency standpoint, CC can be implemented. Moreover, it was maximized at the toll of ₩3,000. **Table 6-18** shows the change in the social welfare by toll.

Table 0-18. Social-welfare change by toll

Unit: mn won/day

Scenarios		₩1,000	₩2,000	₩3,000	₩4,000
User benefit $(\Delta U=-\Delta E)$	High-income	104.0	14.8	-62.0	-132.4
	Middle-income	100.0	9.2	-71.6	-147.6
	Low-income	80.9	10.5	-53.4	-114.1
	Subtotal	284.9	34.5	-187.0	-394.1
Operating or private cost $(\Delta C_{O/P})$	Employers' parking cost	-2.8	-5.4	-7.8	-10.0
	Service suppliers' operation cost	-27.2	-44.5	-43.6	-35.5
	Toll collection cost	88.7	88.7	88.7	88.7
	Subtotal	58.7	38.9	37.3	43.2
External cost (ΔC_{EXT})	Traffic accident cost	3.7	3.5	3.4	1.9
	Air pollution cost	4.1	3.6	3.5	1.8
	Noise cost	2.6	2.3	2.2	1.1
	Subtotal	10.3	9.3	9.1	4.8
Revenue (ΔR)	Toll (government)	395.3	650.6	839.2	1,001
	Fuel tax (government)	18.6	16.9	16.4	8.8
	Fare (service supplier)	40.1	77.6	112.3	144.4
	Subtotal	454.0	745.1	967.9	1154.2
Social-welfare change = $\Delta U - \Delta C_{O/P} - \Delta C_{EXT} + \Delta R$		***669.9***	***731.5***	***734.5***	***712.0***

Looking into the detailed items, as the toll went up, it was estimated that the generated revenue increased whereas the user benefit continuously decreased. It seems that the social welfare was enhanced mainly because of the generated revenue. In addition, as far as the user benefit was concerned, it can be inferred that the monetary loss of the toll was bigger than the time saving benefit caused by the traffic speed improvement according to the toll increment. Additionally, what the social-welfare-maximizing toll is may be a substantial issue for welfare impact analysis.

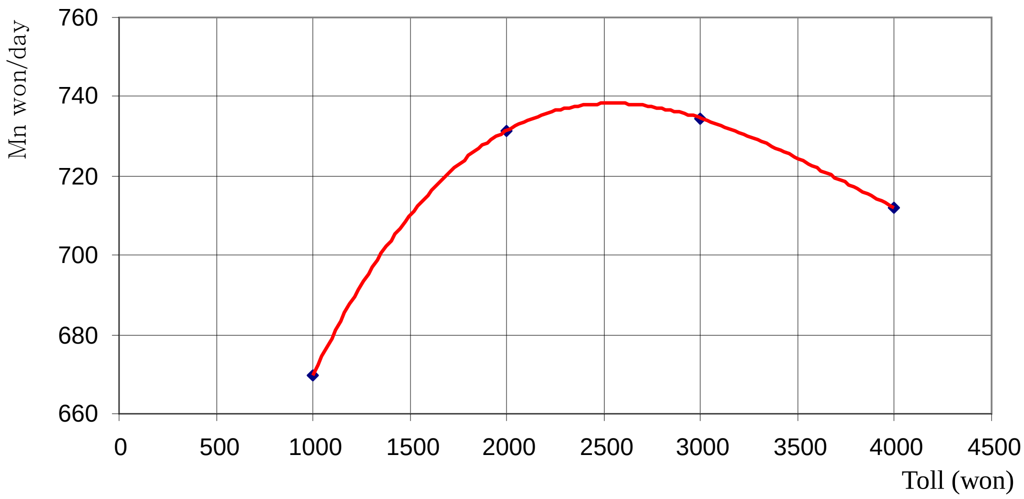


Figure 0-12. Trend of social-welfare change.

The optimal toll can be defined as the toll that maximizes the benefits, defined as the increase in social welfare. It should be noted that the optimal toll is not a toll that achieves a certain reduction in the number of trips but a toll that maximizes the increase in social welfare. The results indicate that the social-welfare-maximizing toll is ₩3,000. However, it can be inferred that based on the trend of the social-welfare change, the optimal toll is about ₩2,500, which maximizes the social-welfare improvement, although the fitting line of social welfare changes, shown in Fig 6-12, is made by ad-hoc method due to the lack of number of fitting data.

1.27.4.2. Trade-off between the efficiency and equity of congestion charging

The equity impact of CC was investigated through the mode shift by income and the CV by income as user benefits. Moreover, the efficiency of CC was evaluated in terms of its transport efficiency related to congestion relief and its economic efficiency based on the social-welfare improvement brought about by the implementation of the policy. The trade-off between efficiency and equity is sufficient to stimulate the researches. As equity refers to fair distribution, the difference in benefit (or loss) by income can be defined as a degree of equity. For example, as a different mode shift ratio from private car to PT appeared between the high- and low-income groups, it can be inferred that a higher mode shift ratio gap between the two user groups leads to a more inequitable situation. In particular, according to the toll increment, the low-income group cannot help shifting to PT because the burden of the toll on them is higher than on the high-income group. Likewise, to determine the individual user benefit of CC in this study, CVPP, whose values were different by income group, was employed. Thus, it can be inferred that the bigger the gap between the CVPP values of the two user groups is, the more inequitable the situation becomes. In this sense, the degree of equity from the toll increment can be justified by the evaluation value gap between the high- and low-income groups. That is, as the gap becomes bigger, the unfairness between the low- and high-income groups becomes higher.

On the other hand, the improvement of the traffic speed, the reduction of the traffic volume per capacity (V/C), and the improvement of the social welfare are the representative effects from the efficiency standpoint. It is worthwhile to investigate the change in the efficiency impact by comparing it with the equity impact. Consequently, the trade-off between equity and efficiency was investigated by comparing them in accordance with the toll increments.

Fig. 6-13 shows the trade-off between traffic speed and equity. According to the toll increase, the results indicate that the traffic speed improved but that the increment of speed became smaller. It can be inferred that many private car users who felt the burden of the toll imposition shifted to PT. This understanding is backed up by the mode shift ratio gap between the low- and high-income groups. That is, as the initial toll made most of the travellers shift to PT, it seems that the mode shift ratio was small although the toll increased. On the other hand, the results indicate that the difference in user benefit between the high- and low-income groups is not sensitive to the toll increments; that is, minimal equity changes occurred (0.02~0.10% difference in equity) although the toll increased.

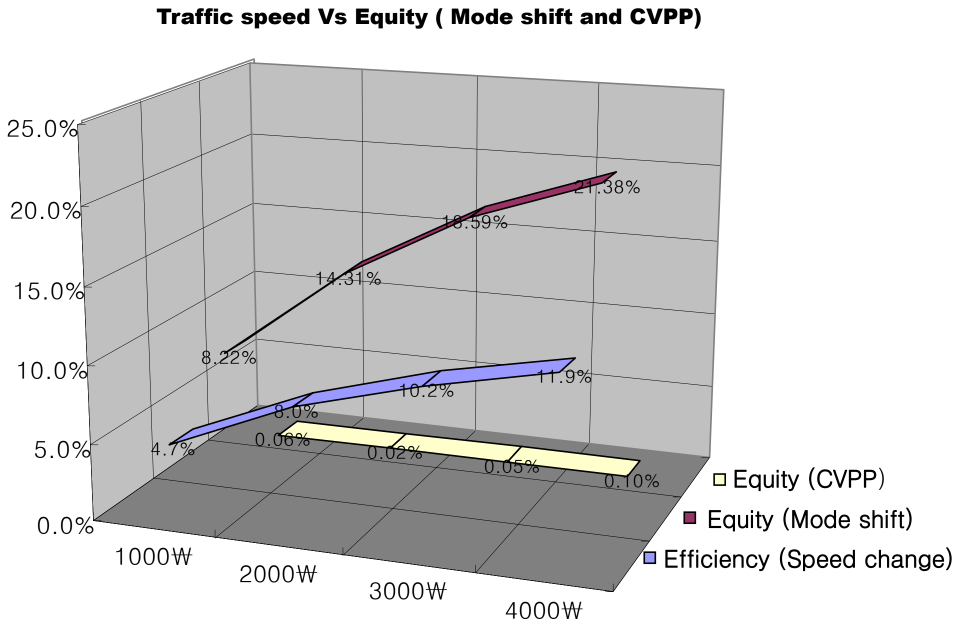


Figure 0-13. Trade-off between traffic speed and equity.

The change in the traffic volume within the charging zone has a significant meaning with regard to the congestion mitigation aspect. **Fig. 6-14** shows the trade-off between the traffic volume and equity. The traffic volume within the charging zone consisted of inner, origin, and destination trips and go through the charging zone. Likewise, with the traffic speed change, a large amount of total traffic volume decreased at the initial toll of ₩1,000 and then the decrements decreased. That is, it can be inferred that the effect of traffic volume reduction on efficiency decreased after a certain toll level, even when the toll level went up. According to the toll increments, the traffic volume in the charging zone decreased and improved the efficiency, but the increments of the efficiency decreased. From the equity standpoint, however, the change in the user benefit gap between the low- and high-income groups was very small.

As the change in traffic speed and volume as efficiency aspects are limited within the charging zone, the efficiency of CC must consider the social-welfare improvement in the whole city, including the charging zone. In this sense, the relation of social-welfare change to efficiency and equity is important in the investigation of the trade-off. The results indicate that when the toll increased linearly with the same increment, the social-welfare change improvement sharply increased under ₩2,000, then the increments decreased. **Fig. 6-15** shows the trade-off between social-welfare change and equity. The figure indicates that the efficiency (social-welfare change) showed the highest rate of increase at ₩2,000. Moreover, the difference in CVPP between the high- and low-income groups decreased and then increased, with the lowest value at ₩2,000. That is, when the equity was better off, the efficiency was also better off. Consequently, it can be concluded that the highest efficiency of CC can be produced at the highest equity point of the toll from the viewpoint of economy.

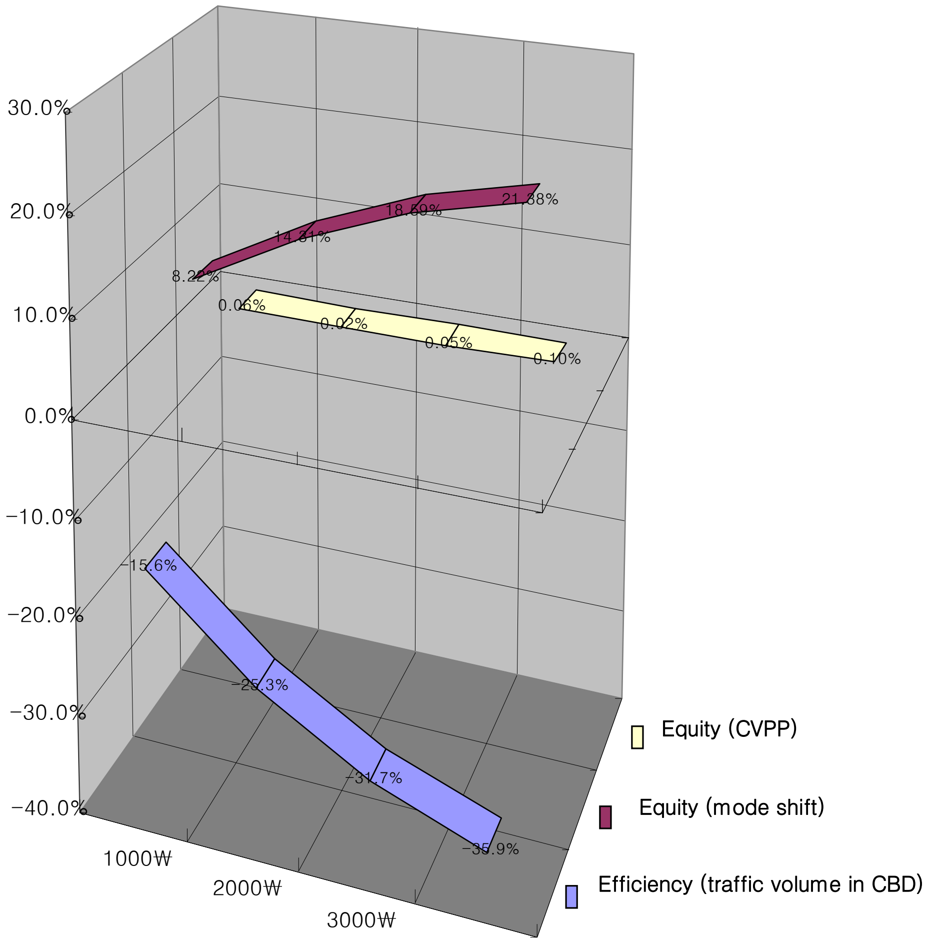


Figure 0-14. Trade-off between traffic volume and equity.

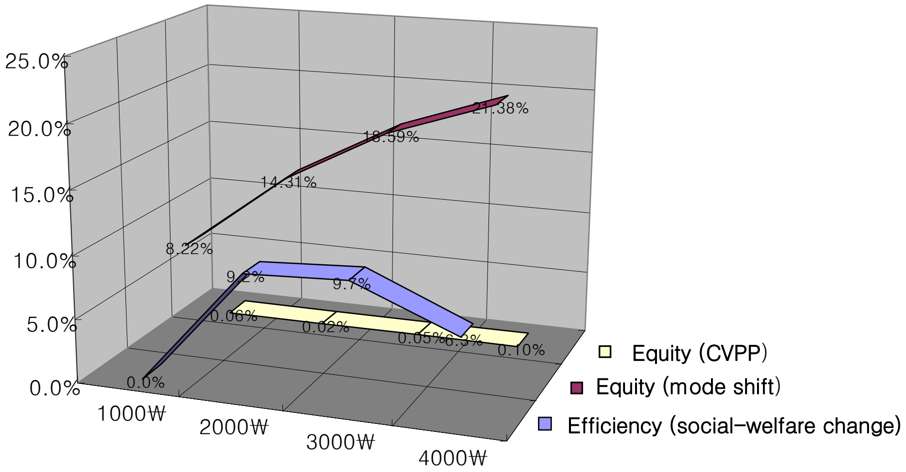


Figure 0-15. Trade-off between social-welfare change and equity.

1.28. CHARGING IN SEOUL'S SECOND CBD

The same evaluation methodology, which was conducted in previous section, is applied to analyze the impacts of charging in the 2nd CBD and both CBD and 2nd CBD in Seoul. The 2nd CBD, which is newly developed business aggregated area in Seoul, has higher mode share than CBD in private car due to good parking facilities, well planned road network, etc. The analysis of charging impact on 2nd CBD can provide for policy maker to the various implementation options such as subsequently or simultaneous apply the charging policy in the CBD and 2nd CBD. In this regards, the case 3 which is analyzed the impact of charging in both CBD and 2nd CBD, is crucial. In order to avoid the repetition of analysis with previous section, the results are provided with focusing on the economic efficiency and equity results.

1.28.1. Case 2 : charging in 2nd CBD

1.28.1.1. Equity effect

ⅰ. Mode shift by income

Under the toll of 2,000 won, 5.4% of private car users in the high-income level shift to PT whereas 11.3% and 16.3% of car user give up using car in the middle- and low-income level correspondingly. Table **6-19** shows the mode shift by the income level. It can be inferred that the lower the income, the more users sensitively react to congestion charging. Because the value of time of the high-income level is bigger than the low-income level, the benefit of time saving is bigger to the former than the latter in accordance with equally imposed toll. Likewise the case1, though the travel cost is increased due to congestion charging, it seems that relatively less high income users shift to public transport.

	High	Middle	Low
Do nothing	46.7%	35.2%	21.7%
After charging	44.1%	31.2%	18.1%
Mode shift	-5.4%	-11.3%	-16.3%

Table 0-19 Mode shift by income group on ₩2,000 (Case2)

ⅱ. Compensating variation (CV) by income

Table 0-20 shows the compensating variation by income level. In addition to the change of mode choice ratio, the CV by income level produced respectable differences. The derived total CV is ₩241 mn with negative, which means that the user welfare is increased similar to Case1. However, when it comes to the income level, the compensating variation per person (CVPP) is appeared differently, namely -159.5₩, -81.2₩ and -57.4₩ to high, middle and low income group, respectively. The CVPP addresses that the effect of travel time saving which is bigger than the utility reduction causes increased travel cost to all user group. Furthermore, and the high income group acquire much more benefits than the middle and the low income group. However, the portion of CVPP in income, which is a measurer of equity effect, are -0.88%, -0.75% and -0.89% to high, middle and low income respectively. Thus, it can be inferred that the charging in 2nd CBD cannot be concluded as regressive effect to income.

Table 0-20 Compensating variation by income on ₩2,000 (Case 2)

	High	Middle	Low
Total CV (Mn Won/day)	-88.5	-78.9	-73.2
CVPP (Won/person)	-159.5	-81.2	-57.4
Portion of CVPP in income (%)	-0.88	-0.75	-0.89

1.28.1.2. Economic Efficiency

ⅰ. Social welfare change

The efficiency impact of congestion charging is analyzed by social welfare effect. The amount of social net benefit or social welfare improvement is estimated ₩1.6 Bn daily and ₩426 Bn annually under the toll ₩2,000. Consequently, it can be inferred that the policy brings in fairly positive impacts in the viewpoint efficiency effect. Table **6-21** summarizes the evaluation process of social welfare change in accordance with charging in 2nd CBD under the toll of ₩2,000.

The user benefit is estimated ₩240 Mn per day and it is increased in all user groups as well. It seems that the welfare is increased mainly caused by increased utility in conjunction with travel time saving due to with travel speed improvement. Normally, when the charging is applied, utility reduction is occurred due to the monetary loss with the toll and the inconveniency caused by the mode shift to PT. Since the effect of the travel time saving is bigger than the utility reduction, and this implies that the user benefit is increased.

The operation and private cost is estimated ₩251.6 mn daily. It is comprised of the parking cost of the employer, the operating cost of the service supplier and scheme operation cost. Since the employees who commutes by car decrease due to the congestion charging, the business companies located in charging area save the cost by the reduction of parking cost paid for their employees. In other words, the employers gains benefit in accordance with parking cost cut for their employees.

The external cost, which is comprised of traffic accident cost and environmental cost, is estimated ₩-2.3 mn per day. It is mainly caused by the decreasing travel length. That is because the reduction of vehicle-kilometre travelled (VKT) by mode shift is bigger than the growth by diverted, but also the reduction of VKT by auto is bigger than the growth of taxi do. Similarly, it is estimated that income of public transport supplier increases ₩119 mn per day. Likewise the case1, it seems because lots of car users shifted to public transport.

Table 0-21 Social welfare change at ₩2000

		Per day (Mn Won)	Per year (Mn Won)
User benefit ($\Delta U=-\Delta E$)	High income	88.5	23,014
	Middle income	78.9	20,520
	Low income	73.2	19,034
	Sub total	240.7	62,569
Operation and private cost ($\Delta C_{O/P}$)	Employers’ parking cost	-7.3	-1,902
	Service suppliers’ operation cost	33.8	8,786
	Toll collection cost	225.1	58,522
	Sub total	251.6	65,405
External cost (ΔC_{EXT})	Traffic accident cost	-1.0	-263
	Air pollution cost	-0.8	-199
	Noise cost	-0.5	-124
	Sub total	-2.3	-586
Revenue (ΔR)	Toll (Government)	1,532.6	398,470
	Fuel tax (Government)	-4.2	-1,081
	Fare (Service supplier)	118.8	30,889
	Sub total	1,647.2	428,278
Social welfare change = $\Delta U - \Delta C_{O/P} - \Delta C_{EXT} + \Delta R$		***1,638.6***	***426,027***

ii. Optimal toll

Table 0-22 describes the variation of social welfare change in accordance with the toll increment. The social welfare changes are estimated that they are continuously increased ₩1.4bn, ₩1.6bn, ₩1.9bn and ₩2.0bn per day, respectively. It is mainly caused by the toll revenue as the toll gets higher. It seems because of the characteristics of charging area such as size of charging area, mode choice ratio, parking facilities, road network, etc. In this regard, relatively high mode share of private car generates more revenue and social welfare improvement. However, as seen it at **Table 0-22**, the estimated user benefit is steadily decreased. It seems because of the fact that the increment of utility reduction by the monetary loss of the toll is bigger than that of the time saving benefit caused by the traffic speed improvement.

In addition, the results indicate that the social welfare is maximized at the toll of ₩4,000 and, its variation trend is still increasing. It can be inferred that the congestion charging policy has a feasibility of implement and the optimal toll is over ₩ 4,000 on the efficiency standpoint. However, since user welfare is worse off over the toll of ₩2000, it can be suggested that an actual toll level for implementation of the charging needs to be determined under ₩2,000 in order to enhancing political acceptability.

(Unit : mn Won/day)

	Scenarios	1000	2000	3000	4000
User benefit ($\Delta U = -\Delta E$)	High income	255.8	88.5	-56.6	-185.2
	Middle income	252.4	78.9	-74.1	-212.0
	Low income	208.6	73.2	-48.1	-158.3
	Sub total	716.8	240.7	-178.7	-555.5
Operation and private cost ($\Delta C_{O/P}$)	Employers' parking cost	-3.7	-7.3	-10.7	-14.0
	Service suppliers' operation cost	9.9	33.8	56.4	85.3
	Toll collection cost	225.1	225.1	225.1	225.1
	Sub total	231.3	251.6	270.8	296.4
External cost (ΔC_{EXT})	Traffic accident cost	0.8	-1.0	-3.9	-7.6
	Air pollution cost	1.2	-0.8	-3.9	-8.2
	Noise cost	0.7	-0.5	-2.5	-5.1
	Sub total	2.7	-2.3	-10.3	-20.9
Revenue (ΔR)	Toll (Government)	899.3	1532.6	2130.4	2674.3
	Fuel tax (Government)	4.9	-4.2	-18.6	-37.8
	Fare (Service supplier)	61.3	118.8	177.7	232.2
	Sub total	965.5	1647.2	2289.4	2868.7
Social welfare change = $\Delta U - \Delta C_{O/P} - \Delta C_{EXT} + \Delta R$		***1448.3***	***1638.6***	***1850.2***	***2037.7***

Table 0-22 Social welfare change (Case 2)

1.28.2. Case 3 : charging in both CBD and 2nd CBD

1.28.2.1. Equity effect

ⅰ. Mode shift by income

Table 6-23 shows mode shift by the income level. It show a similar effect as the case 1 and case2, namely the lower the income, the more users sensitively react to congestion charging. Because the value of time is higher at the high-income than the low-income, the benefit of time saving is bigger to the former than the latter in accordance with equally imposed toll. It can be inferred that though the travel cost increased by the congestion charging, it seems that relatively less high-income users shift to public transport.

Unit:%

	High	Middle	Low
Do nothing	37.8	25.5	15.7
After charging	35.4	21.9	12.9
Mode shift	-6.4	-14.1	-17.9

Table 0-23 Mode shift by income level (case3)

ⅱ. Compensating variation (CV) by income

Table 0-24 describes the CV by income levels. The derived total CV is ₩235Mn with negative, which means that the user welfare is improved as stated previous. However, the CV per person (CVPP) by income level is derived differently, namely -89.6₩, -42.3₩ and -31.3₩ to high, middle and low income level respectively. The high income group acquire about three times more benefit than the low income group. That indicates that the high income group gets higher benefit than the low income group. However, the portion of CVPP in income, which is an indicator of equity effect, are -0.49%, -0.39% and 0.49% to high, middle and low income respectively. It point out that the low income group gets same portion as much as the high income. It can be inferred that though high income group acquire the higher benefit, it cannot be concluded that the charging policy generates regressive effect to income.

	High	Middle	Low
Total CV (Mn Won/day)	-89.3	-74.0	-71.7
CVPP (Won/person)	-89.6	-42.3	-31.3
Portion of CVPP in income (%)	-0.49	-0.39	-0.49

Table 0-24 Compensating variation by income (Case3)

1.28.2.2. Economic Efficiency

ⅰ. Social welfare change

Table 6-25 summarizes the evaluation process of social welfare change by charging of 2000₩. The amount of social net benefit or social welfare improvement is estimated ₩2.4Bn daily and ₩648Bn annually. As far as the improvement of social welfare are concerned, it can be inferred that the congestion charging policy has feasibility to implementation on the efficiency standpoint.

Table 0-25 Social welfare change at ₩2000

		Per day (million Won)	Per year (million Won)
User benefit *(ΔU=-ΔE)*	High income	89.3	23,225
	Middle income	74.0	19,228
	Low income	71.7	18,641
	Sub total	235.0	61,094
Operation and private cost ($\Delta C_{O/P}$)	Employers’ parking cost of	-12.7	-3,296
	Service suppliers’ operation cost	-14.1	-3,669
	Toll collection cost	313.8	81588
	Sub total	287.0	74623
External cost (ΔC_{EXT})	Traffic accident cost	3.4	886
	Air pollution cost	4.0	1,036
	Noise cost	2.5	646
	Sub total	9.9	2,568
Revenue (ΔR)	Toll (Government)	2,175.7	565,693
	Fuel tax (Government)	17.8	4,623
	Fare (Service supplier)	194.0	50,442
	Sub total	2,387.5	620,758
Social welfare change = $\Delta U - \Delta C_{O/P} - \Delta C_{EXT} + \Delta R$		***2,325.6***	***604,661***

Seen the result more detailed, firstly, the user benefit generates ₩235 Mn per day. It seems that the welfare increased is mainly caused by travel time saving in accordance with travel speed improvement. Normally, a utility cut is occurred when charging applied due to the monetary loss on the toll and uncomfortable cause by mode shift to public transport.

Secondly, the operation and private cost are estimated daily ₩287 Mn. It is comprised of parking cost of the employer, operating cost of service supplier and charging scheme operation cost. Since the employees who commute by car decrease due to congestion charging, the business companies located in charging area save the cost by the reduction of parking cost which is paid for their employees. Some cost change occurs to the taxi service supplier by the change of operating distance. Among the operation cost, the largest part is the toll collection cost. It is noted that the scheme operation cost varies by charging technique and this study adopts London's scheme.

Thirdly, the external cost, which is comprised of traffic accident cost and the environmental cost, is estimated ₩9.9Mn per day due to the increasing VKT. It seems because the increasing VKT by diverted traffic is bigger than the decreasing VKT by mode shift.

Finally, it is estimated that the income revenue of public transport supplier is increased about ₩194Mn per day. It seems because lots of car users shifted to public transport, particularly, bus and taxi which highly affects the traffic speed of road. In addition, the generated revenue by toll, which is a large part of social welfare change, is ₩2.4Bn and ₩621Bn per day and per year respectively.

ⅱ. *Optimal toll*

Table 6-26 describes the variation of social welfare change in accordance with the toll increment. Similar to the Case2. The social welfare changes are continuously increased: daily ₩2.1bn, ₩2.3bn, ₩2.5bn and ₩2.7bn, respectively. Likewise, it is mainly caused by the toll revenue as the toll gets higher and it seems that it is influenced from more the 2nd CBD rather than CBD. On the other hand, the estimated user benefit is steadily decreased. It seems because of the fact that the increment of utility reduction by the monetary loss of the toll is bigger than that of the time saving benefit caused by the traffic speed improvement.

In addition, the results indicate that the social welfare is maximized at the toll of ₩4,000 and, its variation trend is still increasing with the decreasing increment. It can be inferred that the congestion charging policy has a feasibility of implement and the optimal toll is over ₩ 4,000 on the efficiency standpoint. However, since user welfare is worse off over the toll of ₩2000, it can be suggested that an actual toll level for implementation of the charging needs to be determined under ₩2,000 in order to enhancing political acceptability.

Table 0-26 Social welfare change (Case3)

(Unit : Mn Won/day)

	Scenarios	1000	2000	3000	4000
User benefit (ΔU=-ΔE)	High income	346.2	89.3	-132.5	-330.1
	Middle income	339.7	74.0	-160.5	-373.1
	Low income	279.3	71.7	-114.4	-284.5
	Sub total	965.2	235.0	-407.5	-987.7
Operation and private cost ($\Delta C_{O/P}$)	Employers' parking cost of	-6.5	-12.7	-18.5	-24.0
	Service suppliers' operation cost	-21.0	-14.1	22.0	47.3
	Toll collection cost	313.8	313.8	313.8	313.8
	Sub total	286.3	287.0	317.3	337.1
External cost (ΔC_{EXT})	Traffic accident cost	4.2	3.4	0.2	-7.6
	Air pollution cost	4.8	4.0	0.5	-8.6
	Noise cost	3.0	2.5	0.3	-5.4
	Sub total	12.0	9.9	1.1	-21.6
Revenue (ΔR)	Toll (Government)	1293.6	2175.7	2965.7	3672.2
	Fuel tax (Government)	21.6	17.8	1.8	-39.0
	Fare (Service supplier)	99.2	194.0	284.0	368.9
	Sub total	1,414.4	2,387.5	3,251.5	4,002.1
Total (A) = $\Delta U - \Delta C_{private} - \Delta C_{external} + \Delta R$		***2081.3***	***2325.6***	***2525.6***	***2699.0***

1.29. SUMMARY AND DISCUSSION

1.29.1. Summary

1.29.1.1. Case1 : Charging in CBD

Central Seoul has been recognized as a socioeconomic centre and as the most congested area in Seoul. It has an advantage, however, in that the charging policy is able to gain political acceptability there more easily than in the other areas of Seoul. In this study, the equity impact of CC was investigated based on the mode shift by income and the CV by income as user benefit. Moreover, the efficiency of CC was evaluated in terms of transport efficiency related to congestion relief, and in terms of economic efficiency, which refers to the social-welfare improvement. **Table 6-27** summarizes the results of the impact analysis that was done at the toll of ₩2,000.

Table 0-27. Results summary at the toll ₩2,000 (Case1)

		Do nothing	Charging	Impacts	
Mode share (Auto, %)	High-income	27.7	25.4	-8.1%	Shift
	Middle-income	18.1	15.2	-15.9%	
	Low-income	8.2	6.4	-22.4%	
	Total	18.0	15.7	-12.9%	
Travel speed (km/hr)	CBD	14.0	15.1	8.0 %	Up
Traffic volume (vehicle)	Inbound trips	486,197	325,748	-33.0%	Down
	Crossing trips	245,716	111,840	-54.5%	Down
Toll revenue	Daily (mn won)	-	650.6	(£325,300)	
	Annual (bn won)		169	(£85 mn)	
CVPP (Won/person/day)	High-income	-	-30.9		
	Middle-income	-	-10.9		
	Low-income	-	-9.6		
Total CV	(Mn won/day)	-	-34.5	(£17,250)	
Social welfare	(Mn won/day)	-	731.5	(£365,750)	

* The exchange rate has been used ₤1=₩2000.

ⅰ. Efficiency of congestion charging

The efficiency of CC was investigated in terms of traffic and economic efficiency. The results indicate that both kinds of efficiency were improved by CC. From the point of view of traffic efficiency, about 13% of the private car users shifted to PT, and the traffic volume in the CBD significantly decreased. The number of inbound CBD vehicles was reduced by 33%, particularly the number of CBD-crossing vehicles, whose destinations were located beyond the CBD, which decreased by 54%. On the other hand, the economic efficiency was analyzed based on the social-welfare change. CC generated ₩34.5 mn as user benefits and ₩732 mn as daily welfare improvement in the social system. In spite of the social-welfare improvement, the estimated external cost, which consisted of the traffic accident cost and the environmental cost, registered a daily increase of ₩9.3 mn. This was mainly caused by the increase in VKT. As the CBD not only has a relatively low mode share of private cars but also has a very small charging area, it seems that the reduction of VKT by mode shift was much smaller than the growth of the diverted traffic.

ⅱ. Equity of congestion charging

The equity effects of CC were analyzed based on the mode shift ratio and user welfare change across the income levels, which is referred to as *social equity*. CC had an effect on the travellers' behaviour, especially on the low-income group. The results indicate that the mode shifts to PT for the trip charging area were 5.5, 15.9, and 22.4% in the high-, middle-, and low-income groups, respectively. That is, the lower the travellers' income is, the more mode shifts to PT are expected. It seems that the low-income group, which has a lower VOT, is more burdened by the increased travel cost than benefited by travel time saving. These results lead to the conclusion that CC has the biggest influence on the low-income group with regard to mode shift, and hence, political consideration is required for the low-income group.

At the same time, the users are expected to be worse off or better off across the income groups, depending on the toll level. This applies to all the cases. The estimated value of the CV across the income groups turns from negative to positive, with the high-income group obtaining higher positive values from ₩3,000. That is, the users in all the income groups are better off with the tolls of ₩1,000 and ₩2,000 and worse off with the tolls of ₩3,000 and ₩4,000. Normally, those who pay the toll gain travel time savings in spite of their monetary loss due to their payment of the toll. Those who are affected by the toll through mode shift gain travel time savings with the inconvenience of mode shift.

In this regard, it seems that if the toll is low, the utility improvement due to travel time saving is higher than the utility loss caused by the monetary loss due to the payment of tolls up to ₩2,000. As such, the user welfare is improved in all the income groups with the less than ₩2,000 tolls. On the contrary, beyond the toll of ₩3,000, the users in all the income groups are worse off. If the user welfare, however, is compared with the portion of the CVPP in the income, it is expected to be nearly parallel in all the income groups, although the middle-income group has a slightly higher or lower CVPP value in some cases. Consequently, it can be inferred that the charging policy induces a neither progressive nor regressive but neutral effect on income based on the user benefit measurement.

ⅲ. Trade-off between efficiency and equity

The trade-off between equity and efficiency was examined according to the toll increments of ₩1,000, ₩2,000, ₩3,000, and ₩4,000. Various impact changes were investigated, such as the traffic condition (e.g., mode shift, traffic speed, volume change), generated revenue, user benefit, and social-welfare change, to justify the trade-off. As the toll increased, more private car users made a shift to PT, with a slight increase in the high-income group and a sharp increase in the low-income group. Moreover, the results shows that the VKT, VHT, and travel speed in the CBD sharply decreased up to the toll of ₩2,000 and slightly decreased with the toll of ₩2,000. The VKT increased, however, up to ₩3,000 and then decreased in the whole city. Consequently, it can be inferred that the very small amount of mode shift and the fact that there were many diverting cars caused an increase in the total travel length, but at the toll of ₩4,000, much more car users shifted to PT, causing a reduction of VKT. In addition, the generated revenue increased, but the increment decreased. Furthermore, the CV turned from negative to positive at that point, and so the high-income group obtained a higher loss beyond the toll of ₩2,000. The social-welfare change was maximized at the toll between ₩2,000 and ₩3,000. Briefly, the highest efficiency of CC can be produced at the highest equity point of the toll, assuming no redistribution of toll revenue.

1.29.1.2. Case2 : Charging in the 2nd CBD

The second CBD, which covers 23.8 km^2 as a charging area, is about 2.5 times bigger than the case of central Seoul. As the road network is the lattice type and a number of parking facilities is located in the 2nd CBD. It encourages private car use relatively convenient compare to the CBD. **Table 0-28** summarize the results of impacts of charging with the toll of ₩2,000 in the second CBD.

		Do nothing	Charging	Impacts	
Mode share (Auto, %)	High income	46.7%	44.1%	-5.4%	shift
	Middle income	35.2%	31.2%	-11.3%	
	Low income	21.7%	18.1%	-16.3%	
	Total	34.5%	31.2%	-9.7%	
Travel speed	2nd CBD (km/hr)	19.1	19.6	2.9%	up
Traffic volume (vehicle)	Inbound trip	963,485	545,808	-43.4%	down
	Crossing trip	508,635	126,295	-75.2%	down
Toll revenue	Daily (mn Won)	-	1,532	(£766,000)	
	Annual(bn Won)		398	(£198mn)	
CVPP (Won/person/day)	High income	-	-159.5		
	Middle income	-	-81.2		
	Low income	-	-57.4		
Total CV	(mn Won/day)	-	-240.7	(£120,300)	
Social welfare	(mn Won/day)		1,638.6	(£819,300)	

Table 0-28 Results summary (Case 2)

ⅰ. Efficiency of congestion charging

According to the charging, about 10% of private car user shift to public transport and the traffic volume is significantly decreased in the charging area. The vehicle inbound to 2nd CBD reduced is 43%. Particularly, 75% vehicle of crossing the charging area is decreased. It can be inferred that the traffic affects the congestion to diverting roads of 2nd CBD. Also, congestion charging generates ₩241mn as the user benefit as well as ₩1,639mn as welfare daily in the social system. Therefore, it can be inferred that the policy brings in positive impacts in the view point of social welfare as the efficiency impact in the 2nd CBD charging.

ⅱ. Equity of congestion charging

Congestion charging has an effect on travellers' behaviour and it affects the low-income group utmost, similar to the CBD case. The mode shift ratio of private car to public transport back up the fact and the results is expected that 5.4%, 11.3% and 16.3% shifts the mode to high, middle and low income level respectively. On the other hand, in the viewpoint of economics, high-income traveller gains highest benefit based on the total CVPP: -₩159.5, -₩81.2 and -₩57.4 to high-, middle- and low-income level respectively. In other words, in spite of paying the toll, the high-income group, whose value of time is higher than others, gains higher benefit of time saving. However, when it comes to the portion of CV in income, the high-income group and low income group nearly parallel but the middle income group is expected to a little smaller negative value. Consequently, the result indicates that the policy is expected as neutral effect to the income.

ⅲ. Trade-off between efficiency and equity

As same as the case1, the trade-off between equity and efficiency was examined according to the toll increments of ₩1,000, ₩2,000, ₩3,000, and ₩4,000. As the toll increased, more private car users made a shift to PT with a slight increase in the high-income group and a sharp increase in the low-income group. Moreover, the results show that the traffic speed steadily increases but its increment decrease. However, the result of travel length (VKT) change shows different features between inner charging area and the whole city: the VKT continuously reduces in the charging area at all toll levels but it is increased at the toll of ₩1000 then changed to decreasing trend in the whole city. It can be inferred that the amount of the mode shift is too small and lots of diverted car cause to increasing the total travel length VKT, however, beyond the toll of ₩2000, much more car user shift to public transport cause to reducing travel length and time. In addition, generating revenue increased and the CV turn from negative to positive with higher income group getting higher positive beyond ₩2000. Also, the social welfare is maximized at ₩4,000 and its variation is increasing trend. It can be inferred that the congestion charging has a feasibility of implement at the efficiency standpoint.

1.29.1.3. Case3 : Charging in both CBD and 2nd CBD

Table 0-29 summarize the results of the impact of charging under the toll of 2000 Won(£1) simultaneously in both CBD and the 2nd CBD. As the congesting charging implemented, the results indicate that the congestion charging policy generate traffic congestion relief and social welfare improve as well, similar with case 1 and case 2.

		Do nothing	Charging	Impacts	
Mode share (Auto, %)	High income	37.8%	35.4%	-6.4%	Shift
	Middle income	25.5%	21.9%	-14.1%	
	Low income	15.7%	12.9%	-17.9%	
	Total	26.3%	23.4%	-11.2%	
Travel speed(km/hr)		17.0	17.7	1.0%	Up
Traffic volume (1000 vehicle)	Inbound trip	1,450	8,713	-39.9%	Down
	Crossing trip	754	238	-68.5%	Down
Toll revenue	Daily (Mn Won)	-	2,175	(£1.1Mn)	
	Annual(Bn Won)		565	(£287Mn)	
CVPP (Won/person/day)	High income	-	-89.6		
	Middle income	-	-42.3		
	Low income	-	-31.3		
Total CV	(Mn Won/day)	-	-235.0	(£117,500)	
Social welfare	(Mn Won/day)	-	2,325.6	(£1.2Mn)	

Table 0-29 Results summary (case 3)

ⅰ. Efficiency of congestion charging

By the charging, about 11% of private car user shift to public transport. The traffic speed improved from 17.0 km/hr to 17.7 km/hr and the traffic volume is significantly decreased in charging area. The inbound vehicle to the charging area are reduced by 40%, particularly, crossing vehicle that its destination is located beyond the charging area decreased about up to 69%. It seems that most of these traffic make a mode shift or divert, and hence it affects the traffic of the diverting roads of the charging area. It is expected large amount of the social welfare improving as well as revenue generating in accordance with the congestion charging. The amount of social net benefit or social welfare improvement is estimated ₩2,325mn (£1.2mn) daily and the generated revenue is ₩2.2bn (£1.1mn) and ₩565bn(£283mn) per day and per year respectively. Consequently, Thus, it can be concluded that the congestion charging is feasible to implement on the efficiency standpoint.

ⅱ. Equity of congestion charging

The mode shift of private car to public transport are expected to 6.4%, 14.1% and 17.9% to high, middle and low income level respectively. Since the user benefit is estimated by CV measure, the results of CV by income shows that high-income traveller gains highest benefit, namely the total CVPP is -89.6₩, -42.3₩ and -31.3₩ to high, middle and low income level respectively. In spite of paying the toll, the high-income group, whose value of time is higher than the others, gains higher benefit of time saving. However, when it comes to the portion of CV in income, the high-income and low income group are expected the parallel negative value. Thus, it can be inferred that although high income group gains the higher benefit, the policy generates neutral effect to income.

ⅲ. Trade-off between efficiency and equity

Likewise the case1 and case2, the trade-off between equity and efficiency was examined according to the toll increments of ₩1,000, ₩2,000, ₩3,000, and ₩4,000. As the toll increases, the results indicate that the mode shift from the private car to public transport steadily increased but the shift ratio is slightly changed in high income group but sharply in low income group similar to the case 1 and 2. The results shows that travel length, time steadily decreased in charging area but the VKT is increased up to ₩2,000 and then sharply decreased in the whole city. It can be inferred that the amount of the mode shift is too small and lots of diverted traffic cause to increasing the total travel length, however, beyond the toll of ₩2000, much more car user make a mode shift to public transport cause to reduction of travel length and time. Toll generating revenue steadily increased and the CV turn from negative to positive value beyond ₩2000 with higher income group getting higher positive. In addition, the social welfare change or net social welfare is continuously improved.

1.29.2. Discussion of the results of case studies

The impacts of congestion charging have been analyzed by the charging in the CBD (Case1), 2nd CBD (Case2) and both (Case3) in Seoul. **Table 6-30** summarizes the results of the case studyies. Several interesting finding can be derived from the analysis as follows.

		Case1	Case2	Case3
Mode shift (Auto, %)	High income	-8.1%	-5.4%	-6.4%
	Middle income	-15.9%	-11.3%	-14.1%
	Low income	-22.4%	-16.3%	-17.9%
	Total	-12.9%	-9.7%	-11.2%
Traffic speed change	Charging area	8.0 %	2.9%	1.0%
Traffic volume change (vehicle)	Inbound trip	-33.0%	-43.4%	-39.9%
	Go through trip	-54.5%	-75.2%	-68.5%
Toll revenue	Daily (Mn Won)	650 (£325,300)	1,532 (£766,000)	2,175 (£1.1 Mn)
	Annual(Bn Won)	169 (£85 Mn)	398 (£198 Mn)	565 (£287 Mn)
CVPP (Won/person)	High income	-30.9	-159.5	-89.6
	Middle income	-10.9	-81.2	-42.3
	Low income	-9.6	-57.4	-31.3
Total CV	(Mn Won/day)	-34.5 (£17,250)	-240.7 (£120,300)	-235.0 (£117,500Mn)
Social welfare	(Mn Won/day)	731.5 (£365,750)	1,638.6 (£819,300)	2,326 (£1.2 Mn)

Table 0-30 Comparing impact between CBD and 2nd CBD by toll of ₩2000

Firstly, congestion charging generates a substantial congestion relief effect in accordance with mode shift to public transport (PT) on the viewpoint of efficiency of transportation. As the toll charged, it is expected that the number of privates car user decreases whereas the mode share of PT increases. Particularly, due to the improvement of travel speed on the road, bus choice ratio is expected to increase more than metro. On the other hand, traffic volume, specifically inbound to charging area, is decreased by 33~43%. Particularly, most of private car users who have crossed the charging area make a mode shift or divert from the charging area in order to avoid the toll, namely, it decreases 67% in CBD charging, 79% in 2nd CBD charging and 69% in charging both of them. As a result, decrease of traffic speed and increase of traffic volume are expected at the boundary and crossing(or intersecting) roads of the charging area.

Secondly, the traffic pattern in/into/out of charging areas is a substantial factor in the determination of congestion charging scheme. Normally, when the congestion charging is implemented, the use of private car decreases and the mode share of public transport increases. Since the travel pattern of CBD or 2nd CBD is different in terms of the travel directions, i.e. inbound or outbound, an appropriate charging scheme should be considered along with the travel pattern. As severe traffic congestion is occurred in CBD and 2nd CBD, public transport has the majority part of mode share; 72% (32% for bus, 40% for metro) in CBD whereas only 58% (33% for metro and 25% for bus) in 2nd CBD. It seems that these figures are influenced by the road network, parking facilities and travellers' income, etc. In CBD of Case 1, it is difficult to use private cars due to poor road network and lack of accessible parking facilities. On the contrary, the 2nd CBD has lattice pattern road network and easily accessible parking facilities, it is relatively convenient to use the private car. Consequently, it can be confirmed that the traffic pattern in/into/out of charging area is a substantial factor in the determination of congestion charging scheme. In addition, the congestion charging policy is required to accompany an adequate supply of public transport service and facilities in order to induce convenient shift of private car user to public transport. Particularly, it is estimated that the traffic demand is increased in bus rather than metro due to the improved traffic speed on road, so it can be concluded that investment on bus service has priority to metro.

Comparing the results with the case 1 and case2, though the amount of change is a little different, the transport impacts are similar. However, the welfare improvement in the 2nd CBD is much bigger than in the CBD of Case 1. It seems because of the characteristics of charging area such as size of charging area, mode split, parking facilities, road network and public transport. Relatively high mode share of private car generates more revenue and social welfare improvement. It can be confirmed that the area with high mode share of private car is more effective to implementing congestion charging policy.

Thirdly, the congestion charging has the biggest influence to the low-income group on mode *shift and hence political consideration is required to low income users*. Equity impacts was analysed by mode shift ratio and user welfare change across the income level, which is defined as a social equity (or vertical equity). The results indicate that mode shift to PT for trip charging area is 6~9%, 11~15% and 16~22% to high, middle and low income respectively, depending on the cases. That is, the lower the travellers' income is, the more mode shift to public transport are expected. It can be confirmed that the low-income group, who has lower value of time, gets more burden by increased travel cost than the positive effect of travel time saving. This results lead to a conclusion that the congestion charging has the biggest influence to the low-income group on mode shift and hence political consideration is required to low income users.

Fourthly, the congestion charging in Seoul is neutral to income based on the user benefit measurement. The results indicate that users are expected to worse off or better off across the income groups in dependent upon the toll level and it is similar to the all cases. The estimated value of compensating variation across the income groups turn from negative to positive with higher income group getting higher positive from ₩3000. That is, the users better off under the toll of ₩1000 and ₩2,000 whereas the users worse off on the toll of ₩3,000 and ₩4000 to all income group. Normally, those who pay the toll gain travel time saving in spite of monetary loss of the toll, those who pay off the toll through the mode shift gains travel time saving with inconveniency of mode shift. In this regard, it seems that if the toll is low, utility improvement due to travel time saving is higher than the utility reduction caused by the monetary loss of the toll up to ₩2000. So user welfare are improved to all income groups with the toll less than ₩2,000. On the contrary, beyond the toll of ₩3,000, the users worse off in all income group. However, when the user welfare is compared to the portion of compensating variation per person (CVPP) in income, it is expected to be nearly parallel to all income group, although the middle-income group has a little bit higher or lower CVPP in some cases. Consequently, it can be inferred that the charging policy induces a neutral effect to income neither progressive nor regressive based on the user benefit measurement.

Fifthly, the congestion charging policy is expected to generate social welfare improvement on the economic efficiency standpoint. The social net benefit or social welfare improvement is evaluated by cost-benefit analysis considering user benefit, operation cost, toll revenue, external cost and so on. The results indicate that ₩2,000 toll as ₩731mn, ₩1,638mn and ₩2,325mn are generated daily for case1, case2 and case3, respectively. And hence, the results lead to a conclusion that congestion charging policy is feasible on the efficiency stand point. Looking into the estimated results across the detailed cost and benefit items, as the toll goes up, the generated revenue increases whereas the user benefit continuously reduces. Thus, it can be inferred that the enhanced social welfare is mainly caused by the generating revenue and the monetary loss of the toll is bigger than the benefit of time saving caused by the traffic speed improvement according to the toll increment. Moreover, despite the traffic congestion is mitigated in the charging area, the external cost such as traffic accident and environmental cost may be expected to be increased due to increased of the VKT by the diverted traffic from the charging area.

Sixthly, it is recommended that an actual toll level for implementation of the charging in Seoul needs to be determined under ₩2,000 in order to enhancing political acceptability. What is the social welfare maximizing toll may be a substantial issue for welfare impact analysis. The optimal toll can be defined as the toll that maximizes benefits in terms of social welfare increase. In the case 1, charging in CBD, the results indicate that the social welfare maximized at the toll of ₩3,000. However, looking into the trend line of the social welfare change, the social welfare improvement is maximized around ₩2,500. From that, it can be inferred that the optimal toll level is about ₩2,500. However, in the Case 2 and 3, the result of sensitivity of the toll indicate that the social welfare improvement is maximized on the toll of ₩4,000, but its variation is still increasing trend with decreased increment. In this regard, it can be inferred that the optimal toll level that maximizing social net welfare is higher than ₩4,000. However, the appropriate toll level has to be decided considering not only the social welfare improvement but also the user net benefit. In this regard, since user welfare is worse off over the toll of ₩2000, it can be suggested that an actual toll level for implementation of the charging needs to be determined under ₩2,000 in order to enhancing political acceptability. Consequently, it can be concluded that the objective of the charging, such as raising revenue or reducing congestion or both, is significant factor of the implementation.

To sum up, the results indicate that the CC policy induces not only traffic congestion reduction but also social-welfare improvement. In spite of the congestion relief in the charging area, however, the diversion roads (e.g., the ring road) of the charging area can become congested due to the car users who use them to avoid paying the toll. Such situation leads to an additional consideration in the analysis of the impact of CC. Furthermore, from the viewpoint of equity, CC produces a neutral effect on income; even the effect of travel time saving is higher than the utility reduction due to the increased travel cost on account of charging. Thus, CC must be implemented along with a compensating policy, such as one that will support the PT or that will reduce taxes through the use of the collected revenue, to improve the equity.

1.29.3. Comments

The effect of the implementation of a policy restraining car use by charging is explained by the Edgeworth paradox, which was pointed out by Mogridge (1995). It is well recognized that a disadvantage of private car use is that it generates a decrease in the equilibrium trip cost and causes a reduction of the social cost. That is, as CC brings about a reduction in private car use, the social welfare improves, and the traffic congestion reduction, which improves the access time, increases the mode share of PT and leads to environmental-cost reduction, among other effects. These results back up the Edgeworth paradox, but several remarkable issues came out in the Seoul case.

Normally, an important effect of pricing is that it *curbs the amount of externality* in the form of air pollution, noise, accidents, etc. (Fridstrom et al., 2000). At this point, however, the net effect is more questionable in Seoul's case as reduced congestion may allow for higher speeds and possibly a larger VKT due to the diverted traffic. As externality components, these costs are increased, although the cost is decreased in accordance with the toll increments. In this regard, this study considered VKT as a key variable in computing the cost, but it seems that more variables such as emissions of pollutants including carbon monoxide, volatile organic compounds, nitrous oxides and carbon dioxide are needed to investigate the effects.

The effect of tolled cordons is that of creating *boundary effects*. A small city centre cordon will hit those who reside within the cordon more than those who reside outside it as the cordon is small enough to allow routing around the charged area. The larger-toll-cordon-based system primarily affects those outside the cordon as the cordon is large enough to allow free movement within the area and to limit the opportunities for rerouting around the cordon.

It is usually recognized that CC is inequitable between car owners as the same charge is levied on car use regardless of the incomes of the motorists (Richardson, 1974; Litman, 2002). Furthermore, what ultimately determines the success or failure of the implementation of the policy is how the toll revenue is used. Clearly, different uses of the revenues will produce different net effects. Consequently, viewed as a whole, it will determine whether the charging system will be progressive or regressive (Small, 1992). The reduced PT fare due to the use of the toll revenue is expected to improve equity; in particular, the user benefit in the low-income group will be amplified much more than that in the high-income group. Consequently, it can be concluded that the negative view of the regressive impact of CC can be mitigated by the implementation of a revenue return policy. This leads to the conclusion that CC must be accompanied by a compensating policy, such as one that will support PT or that will reduce PT fares through the full use of the collected revenue. It is thus possible, in principle, to conceive of a CC scheme with revenue redistribution, which will enhance the economic efficiency and the equity.

The assessment results of the congestion charging in Seoul provide a feasibility of implementation of charging policy with the impact of congestion relief and social welfare improvement as usual. However, most of real congestion charging scheme has been started with gradual scheme implementation (e.g. Singapore, London, etc). It has an advantage to help raising the public acceptability as well as adjust to change of available charging technology and traffic condition (Sumalee, 2005). The initial design of the London congestion charging scheme, started in 2003, is implemented simply in the central London and recently the scheme extended to the west part of the central London. In this regard, a gradual scheme implementation is recommended in order to increase the performance of the existing scheme and gaining some public support from the initial scheme application.

An arising issue is the determination of optimal toll. The optimal toll is defined as the toll that would yield the highest net social welfare improvement, defined by the difference in total benefits minus the difference in total costs before and after the congestion charging. In the Case 2 and 3, the result of sensitive of the toll indicated that the net social welfare is maximized at the toll of ₩4,000 but its variation is still increasing trend with decreased increment. Thus, more analysis is needed in order to determine the optimal toll that maximizing social net welfare with higher toll application. However, the impact analysis on this study is concentrated on existing toll level, ₩2,000 on the Nam Mt. tunnel charging, it seems that an additional analysis remains for further study to determine exact optimal toll. In addition, in spite of the toll increments, the traffic condition did not change dramatically. It seems that this is because of the *limitation of the model* (i.e. the model makes use of fixed-demand O/D) in static and short-term analysis. It was also assumed that trip generation or suppression was not considered. In this sense, further study should be done to analyze a more dynamic model, employing a longer-term view, among others.

CONCLUSIONS AND FURTHER STUDY

In this final chapter, the main findings of this study will be summarized in section 7.1, the conclusions will be given in section 7.2, and suggestions for further study will be presented in section 7.3.

1.30. SUMMARY OF THE STUDY FINDINGS

With the increasing attention accorded to CC to solve the current urban traffic problems, such as traffic congestion and environmental issues, the assessment of CC has attracted much attention from researchers. Taking into account the fact that CC reduces externalities and improves efficiency, most of the evaluations of CC have focused on welfare evaluation. In spite of the advantage of social-welfare improvement on the efficiency, however, it was found from literature review that the implementation of CC has some difficulties in reality due to the equity problems with regard to the various user groups. The difficulties associated with the equity issues that were identified were (1) the fact that there are different user benefits by income level, and (2) political acceptability.

It was found from the literature review that was conducted that a number of methods have been developed and employed to evaluate the optimal toll for CC but also to more reliably estimate the impact of the implementation of CC under a general network. It was recognized, however, that little attention has been paid to how the trade-off between the efficiency and equity of CC is carried out to obtain more informative assessment results and to improve the policy’s acceptability in reality. This recognition led to the necessity of coming up with fitting evaluation criteria for the assessment of the CC policy in terms of efficiency and equity.

In this study, social-welfare measurement was employed in conjunction with cost-benefit analysis, which evaluates the whole cost and benefit for the efficiency impact. Here, *user benefit* can be defined as the travellers’ welfare change whereas *net social benefit* can be defined as the social-welfare change, including the user benefit. One of the remarkable assessment indicators for welfare measurement is CV. The amount of CV means the price of returning to travellers’ utility before the implementation of CC, and pertains to the amount of the travellers’ welfare change. By estimating the CV across the various income groups, the equity impact can be determined within an efficiency outline.

The evaluation criteria was divided into two issues in this study: the efficiency issue, where it is believed that traffic efficiency will mitigate traffic congestion and will boost the economic efficiency, which will in turn improve the social welfare in the system; and the equity issue, which pertains to the distribution of the effects of the implementation of the policy and whether they are appropriate to be considered. According to the toll increments and revenue returns, the contribution obtained by the effects of the efficiency and equity of CC will differ in the evaluation of the policy, and there appears to be a trade-off relationship between the efficiency and equity of CC.

The general aim of this study was to investigate and identify the impact of CC measures in terms of equity and efficiency. Towards this end, the South Korean city of Seoul was used for a case study. The main emphasis was placed on the impact analysis of CC in Seoul’s CBD. The main study findings are as follows:

- The CC policy induces not only traffic congestion reduction but also social-welfare improvement. In spite of the congestion relief in the charging area, however, the diversion roads (e.g., the ring road) of the charging area can become congested due to the car users who use them to avoid paying the toll. Such a situation leads to an additional consideration in the analysis of the impact of the implementation of CC.

- Moreover, from the viewpoint of equity, CC has the biggest influence to the low income group on mode shift and produces a regressive effect on income; even the effect of travel time saving is higher than the utility reduction due to the increased travel cost on account of CC. Thus, the CC policy must be implemented along with a compensating policy, such as one that will support the PT or that will reduce taxes through the use of the collected revenue, to improve the equity.

- Since the CBD and the 2nd CBD have different traffic characteristics, comparing the results with the case 1 and case2, the welfare improvement is much bigger in the 2nd CBD than in the CBD of Case1. In this regard, it was also found that the determination of CC scheme is heavily relied on not only the characteristics of charging area such as size of charging area, mode split, parking facilities, road network and public transport but also traffic pattern such as traffic volume of inner, inbound, outbound, and go through charging areas.

- The reduction of the PT fares as a compensating policy is expected to improve equity through fair distribution, whereas it is not expected to improve the economic efficiency by causing a social-welfare change. Compared to the no-discount case, the user benefit improved 1.3~3 times for the high-income group and 4~10 times for the low-income group. These results suggest that the user benefit improvement was much bigger in the low-income group than in the high-income group. It can thus be concluded that the revenue return policy mitigated the regressive impact of income. On the other hand, the reduced PT fares did not produce an additional improvement of the net social welfare, from the efficiency standpoint. That is, the social-welfare improvement was smaller in the case of the discounted fare than in the no-discount case, which was mainly due to the reduction of the service suppliers' fare income. To the economists, however, since the revenue including the income of the service suppliers is regarded as merely transferred to the government or the service suppliers from the travellers, it can be inferred that the social-welfare improvement makes sense.

- The sensitivity of the toll, as a trade-off between the equity and efficiency of CC, indicates that the social-welfare improvement was maximized at the toll of ₩3,000. More correctly speaking, according to the trend of social-welfare change, it can be inferred at ₩2,500. The *optimal toll* is defined as the toll that maximizes the benefits, defined as social-welfare improvement. Taking into account that it is most equitable at the toll between ₩2,000 and ₩3,000 in the equity aspect, it can be concluded that the optimal toll level is about ₩2,500 and that the highest efficiency of CC can be produced at the highest equity toll point.

1.31. CONCLUSIONS

As a means of reducing congestion externalities and raising revenue for transport improvement, CC has been floated as one of the most effective traffic management tools in transport policy. This study provided a comprehensive view of the effects of the implementation of CC measures on the equity and efficiency aspects, based on full-implementation scenarios in the city of Seoul, South Korea. After applying the impact analysis model, the impact of CC was measured in terms of equity and efficiency. The efficiency effect was analyzed based on the social-welfare change (net social benefit) that transpired, and it can be used to assess the feasibility of the implementation of CC. On the other hand, the equity effect was analyzed based on the user benefit across the income groups. The results of such analyses can provide an index of political acceptability. In this study, social-welfare measurement was adopted in conjunction with cost-benefit analysis, where all the costs and benefits were evaluated to determine the efficiency impact of the implementation of CC. Here, *user benefit* was defined as the travellers' welfare change whereas *net social benefit* was defined as the social-welfare change, including the user benefit. The conclusions that were arrived at based on the study results are as follows:

- One of the assessment indicators for welfare measurement is CV, which is the price of returning to the travellers' utility before the implementation of CC, and which is the amount of the travellers' welfare change. It is noteworthy that CV, an indicator that combines equity and efficiency and that is defined as user welfare change in the different income groups, is expected to be a suitable assessment indicator of the equity impact of the implementation of CC within the efficiency outline, and is an important factor in the feasibility of the policy. Most of the past related empirical studies considered social-welfare change to assess the economic-efficiency impact of the implementation of CC, but they did not simultaneously explore the impact on equity and efficiency. In this regard, estimating the CV by income group and expanding it to social-welfare change in a whole system in conjunction with cost-benefit analysis is a substantial advance in measuring the equity impact within the efficiency outline.

- Moreover, the revenue return policy mitigates the regressive impact of CC by improving the user benefit much more, particularly in the low-income group. It is noteworthy that the redistribution of the toll revenue through the reduced PT fare improved the equity whereas it did not cause an additional improvement in social-welfare. Studies have argued about the generated revenue for managing equity (e.g., Small, 1992; Litman, 2005; Morrison, 1986), and little attention has been paid to assessing the impact of revenue return as a compensating policy. In this regard, this study makes a contribution to the knowledge about CC, particularly regarding its impact on equity and efficiency depending on the reduced PT rate on account of the generated revenue.

- The results of the case study indicate that CC in Seoul produces traffic congestion relief and social-welfare improvement, but the user benefit varies by toll level. It was also found that private car users shift to PT, particularly in the low-income group. It was estimated, however, that with regard to the portion of CV in the income, which indicates the actual benefit or loss of the users, the high- and low-income groups obtain similar values and the middle-income group generates a slightly higher value than the other income groups do. These findings leads to the recommendation that although the CC policy impacts the low-income group the most, its impact on the middle-income group has to be considered as well.

- The new implementation of CC may easily start in the area that is well recognized as having severe traffic congestion despite the collection of the existing toll level. Central Seoul has been recognized as the socioeconomic centre of Seoul as well as the most congested area therein. It has an advantage, though: The CC policy is able to gain political acceptability more easily therein than in the other areas in the city. The optimal toll, however, which maximizes the net social welfare, is higher than the existing Mt. Nam Tunnel toll level. Thus, it can also be concluded that an applicable toll level has to be determined based on the policy objectives, one that maximizes either the social welfare or the toll revenue. In this regard, the recommendation of the results of this study may contribute to the successful implementation of CC in Seoul.

- In addition, the analysis results of CC on the two CBDs in a city is substantial contribution in that a gradual scheme implementation is able to recommend to increase the performance of the existing scheme and gaining some public support from the initial scheme application.

- The results of the analysis of the trade-off between efficiency and equity in accordance with the toll increments are also noteworthy. It was found that the highest efficiency of CC can be produced at the highest equity point of the toll. Although many researchers have devoted their efforts to analyzing the impact of the implementation of CC, very few studies have tackled the trade-off between equity and efficiency. As such, this study made an important contribution to portraying the impact of the implementation of CC.

In spite of this study’s contribution to the knowledge regarding the impact of the implementation of CC, however, the study has some weak points, such as the fact that the traffic condition does not change dramatically according to the toll increments. This is because of the limitation of the model that was used in the study: it makes use of fixed-demand O/D in static and short-term analysis. By considering this issue, further study can involve the analysis of a more dynamic model with variable demands and a longer-term view, and with more realistic assumptions.

1.32. SUGGESTIONS FOR FURTHER STUDY

During the conduct of this research, a number of areas for further research were identified. The most significant ones among these are outlined below.

First, the simulation model that was implemented in this study is a static model designed to estimate the short-term impact of the implementation of CC. The model was implemented under several assumptions; hence, it generated several issues for improving the model in the further study to be conducted.

- It was assumed that only the mode and route can be changed, and this study was conducted based on static analysis. When CC is applied, however, other changes in traffic behaviour occur, including departure time change, destination change, and suppression of trips. Thus, it is more desirable to apply dynamic traffic assignment when analyzing the realistic impact of the implementation of CC. In this regard, further study using dynamic assignment, based on a more realistic volume-delay link function, is required to overcome the limitation of static analysis.

- It was also assumed that the trip generation and distribution are fixed under the assumption that the total traffic demand does not change in the short term. Therefore, the model is able to analyze the effect of the transport policy, which can be implemented within one to five years. To analyze the long-term effects of the implementation of the transport policy, however, the forecasting data must be analyzed separately, and the results of such analysis must be inputted into the model and must be continually updated.

- As the model assumes that the socioeconomic change is fixed, it has difficulty suggesting the results solely of the model. Therefore, a continuous updating of the monitoring data and revalidation of the model are needed to overcome such limitation.

- In addition, the macro analytical approach that was employed has the limitation of analyzing the impact of the implementation of CC only on a specific road. That is, as the model focuses on the demand analysis of the whole Seoul network, it is not easy to reflect the change in the demand, which is influenced by the individual road levels.

Second, this study adopted the Hicksian approach, which estimates the social-welfare change by CV, which excludes the income effects. The social-welfare change can be measured using the

Hicksian or Marshallian approach in accordance with CC. Comparison of the result with the Marshallian measure, the social-surplus measure, is suggested for further study.

Third, this study focused on impact analysis based on the existing toll level (₩2,000) of the Namsan tunnel charging, which gave rise to the issue regarding the determination of the optimal toll, which is defined as the toll that maximizes the social-welfare improvement. This study roughly presents the region of the optimal toll through the analysis of the sensitivity of the toll. To determine the exact optimal toll, however, it seems that additional analysis must be done in the further study.

Finally, this study also focused on the conventional social-equity issue between the rich and poor car users, who pay the same toll charge. A spatial-equity issue among the users travelling between different locations can be raised, however, and it can be suggested that in the further study, the various equity effects be investigated.

APPENDICES

A. Macro in EMME/2 for calculating CV

```
~o|256
~?!i&32768              /if switch 15 (dialog echo mode) is off
~o=39                   /dialog echo mode off
~/ ---------------------------------------------------------------------------
~/ Computing Mode O/D
~/ ---------------------------------------------------------------------------
~t1=%1%
~t2=%2%
~t3=%3%
~/ Utility Caculation
~# AASC        TASC        RASC      IVTIME      OVTIME   COST/INC
~# HIGH   -1.6586    -3.8700    -0.65056
~# LOW -0.8486    -1.6000    -1.50056
~#r1=-1.3486
~#r2=-2.8700
~#r3=-0.99056


~r1=-1.6586
~r2=-3.8700
~r3=-0.65056
~r4=-0.15724
~r5=-0.29644
~r6=-0.15702
~r7=303.
~r8=-0.15702
~r6/%r7%
~# Computing MC Trips

~# Time & Cost Unit

~# Auto Utility
3.21                          / enter matrix calculator
1                             / matrix calculations
y                             / save results
'mf85'                        / result matrix
y                             / change header or initialize
'AutoA'                       / matrix name
'Auto Adjust Time'            / matrix description
~?q=1
y                             / initialize matrix
0                             / default matrix value
%t2%*0.81


n
2
q                             / return to main menu

~t2=mf85

~# Auto Utility
3.21                          / enter matrix calculator
1                             / matrix calculations
y                             / save results
'mf91'                        / result matrix
y                             / change header or initialize
'Auto'                        / matrix name
'Auto Utility Base Case'      / matrix description
~?q=1
y                             / initialize matrix
0                             / default matrix value
exp(%r1%+%r4%*mf35+%r6%*mf33)


n
2
q                             / return to main menu
```

```
~# Auto Utility
3.21                          / enter matrix calculator
1                             / matrix calculations
y                             / save results
'mf81'                        / result matrix
y                             / change header or initialize
'Auto'                        / matrix name
'Auto Utility'                / matrix description
~?q=1
y                             / initialize matrix
0                             / default matrix value
exp(%r1%+%r4%*%t2%+%r6%*%t1%)


n
2
q                             / return to main menu

~# BUS Utility
3.21                          / enter matrix calculator
1                             / matrix calculations
y                             / save results
'mf92'                        / result matrix
y                             / change header or initialize
'Bus'                         / matrix name
'Bus Utility Base Case'       / matrix description
~?q=1
y                             / initialize matrix
0                             / default matrix value
exp(%r4%*mf38+%r5%*mf37+%r6%*mf36)


n
2
q                             / return to main menu

3.21                          / enter matrix calculator
1                             / matrix calculations
y                             / save results
'mf82'                        / result matrix
y                             / change header or initialize
'Bus'                         / matrix name
'Bus Utility'                 / matrix description
~?q=1
y                             / initialize matrix
0                             / default matrix value
exp(%r4%*mf71*%t2%+%r5%*mf37+%r6%*mf36)


n
2
q                             / return to main menu


~# Taxi Utility
3.21                          / enter matrix calculator
1                             / matrix calculations
y                             / save results
'mf93'                        / result matrix
y                                   / change header or initialize
'TAXI'                        / matrix name
'Taxi Utility Base Case'      / matrix description
~?q=1
y                             / initialize matrix
0                             / default matrix value
exp(%r2%+%r4%*mf44+%r5%*mf43+%r6%*mf42)


n
2
q                             / return to main menu
```

```
~# Taxi Utility
3.21                            / enter matrix calculator
1                               / matrix calculations
y                               / save results
'mf83'                          / result matrix
y                               / change header or initialize
'TAXI'                          / matrix name
'Taxi Utility'                  / matrix description
~?q=1
y                               / initialize matrix
0                               / default matrix value
exp(%r2%+%r4%*%t2%+%r5%*mf43+%r6%*mf42)


n
2
q                               / return to main menu

~# Rail Utility
3.21                            / enter matrix calculator
1                               / matrix calculations
y                               / save results
'mf94'                          / result matrix
y                               / change header or initialize
'Rail'                          / matrix name
'Rail Utility Base Case'        / matrix description
~?q=1
y                               / initialize matrix
0                               / default matrix value
exp(%r3%+%r4%*mf41+%r5%*mf40+%r6%*mf39)


n
2
q                               / return to main menu

~# Rail Utility
3.21                            / enter matrix calculator
1                               / matrix calculations
y                               / save results
'mf84'                          / result matrix
y                                       / change header or initialize
'Rail'                          / matrix name
'Rail Utility'                  / matrix description
~?q=1
y                               / initialize matrix
0                               / default matrix value
exp(%r3%+%r4%*mf41+%r5%*mf40+%r6%*mf39)


n
2
q                               / return to main menu

~# Delta E
3.21                            / enter matrix calculator
1                               / matrix calculations
y                               / save results
'mf95'                          / result matrix
y                               / change header or initialize
'DELTAe'                        / matrix name
'Delta e'                       / matrix description
~?q=1
y                               / initialize matrix
0                               / default matrix value
%r7%/%r8%*(ln(mf81+mf82+mf83+mf84)-ln(mf91+mf92+mf93+mf94))


n
2
q                               / return to main menu
```

```
~#<matout mf95
~<calmat.mac mf95*mf19 mf96
~t4=%5%
3.21
1
y
%t3%
y
CVH%t4_2%
CV High Alt. %t4%
~?q=1
y                                          / initialize matrix
0
mf96

%4%
1,2,in
y
1,1129

1,1129



2
q
~:END
reports=

~o=6
~?m=000
~+|~?q=0|
```

B. Sub Macro for CV calculation : CVall.mac

```
~<CVH.mac mf21 mf59 ms11 mf56 21
~<CVH.mac mf22 mf60 ms12 mf56 22
~<CVH.mac mf23 mf61 ms13 mf56 23
~<CVH.mac mf24 mf62 ms14 mf56 24
~<CVH.mac mf25 mf63 ms15 mf57 31
~<CVH.mac mf26 mf64 ms16 mf57 32
~<CVH.mac mf27 mf65 ms17 mf57 33
~<CVH.mac mf28 mf66 ms18 mf57 34
~<CVH.mac mf29 mf67 ms19 mf58 41
~<CVH.mac mf30 mf68 ms20 mf58 42
~<CVH.mac mf31 mf69 ms21 mf58 43
~<CVH.mac mf32 mf70 ms22 mf58 44

~<CVL.mac mf21 mf59 ms23 mf56 21
~<CVL.mac mf22 mf60 ms24 mf56 22
~<CVL.mac mf23 mf61 ms25 mf56 23
~<CVL.mac mf24 mf62 ms26 mf56 24
~<CVL.mac mf25 mf63 ms27 mf57 31
~<CVL.mac mf26 mf64 ms28 mf57 32
~<CVL.mac mf27 mf65 ms29 mf57 33
~<CVL.mac mf28 mf66 ms30 mf57 34
~<CVL.mac mf29 mf67 ms31 mf58 41
~<CVL.mac mf30 mf68 ms32 mf58 42
~<CVL.mac mf31 mf69 ms33 mf58 43
~<CVL.mac mf32 mf70 ms34 mf58 44

~<CVM.mac mf21 mf59 ms35 mf56 21
~<CVM.mac mf22 mf60 ms36 mf56 22
~<CVM.mac mf23 mf61 ms37 mf56 23
~<CVM.mac mf24 mf62 ms38 mf56 24
~<CVM.mac mf25 mf63 ms39 mf57 31
~<CVM.mac mf26 mf64 ms40 mf57 32
~<CVM.mac mf27 mf65 ms41 mf57 33
~<CVM.mac mf28 mf66 ms42 mf57 34
~<CVM.mac mf29 mf67 ms43 mf58 41
~<CVM.mac mf30 mf68 ms44 mf58 42
~<CVM.mac mf31 mf69 ms45 mf58 43
~<CVM.mac mf32 mf70 ms46 mf58 44
```

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