wctr'04
4-8 july 2004 / istanbul-turkey

ANALYZING THE EFFECTS OF TRANSPORT DEMAND MANAGEMENT MEASURES USING COMPENSATING VARIATION VALUE

Jaehak Oh, Nakmoon Sung, Jeehyung Park
The Korea Transport Institute
emails: jhoh@koti.re.kr, sungnakm@koti.re.kr, jhpark@koti.re.kr

Abstract

To cope with traffic congestion in urban areas, transport demand management (TDM) measures which aim to reduce or redistribute transport demand have been proved to be effective. For successful implementation of TDM measures, it is important to evaluate the effects well before they are put into practice. It is often found that conflicts between different interest groups of travelers appear to be barrier to the successful implementation. The purpose of this study is to analyze various effects of TDM measures. Two effects, welfare effects(equity) and transport efficiency were estimated. Values of modal share and travel time were calculated as indicators of transport efficiency. Compensating variation(CV) value was calculated as indicator of equity effects. A logit based demand model combined with a network based model was built to estimate the change of modal share and travel time. CV value was estimated using a discrete choice logit model for three income levels (low, medium and high). A case study was carried out to validate the feasibility of the model developed in this study. The behaviors of travelers commuting to CBD area in Seoul were surveyed. The effects of TDM measures such as congestion pricing, fuel taxing, bus-exclusive lanes and vehicle use restriction were analyzed. It was found that apart from improvement of transport efficiency, traveler welfare decreases when implementing congestion pricing or fuel tax increase especially for travelers of low income group. Also, it was found that bus-exclusive lane scheme appears to be more equitable than other price regulation measures.

Keywords: TDM; Transport efficiency; Equity; Compensating variation value
Topic Area: E1 Assessment and Appraisal Method w.r.t. Transport Infrastructure Projects and Transport Activities

1. Introduction

Transport demand management (TDM) is often considered to be a cost effective method to reduce traffic congestion in urban areas. Various TDM strategies as a short-term resolution have been proposed to relieve traffic congestion caused from the unbalance between the rapidly increasing travel demand and the limited supply of transport infrastructure.

To maximize the operational efficiency of the strategies as well as minimizing the adverse effects to motorists, an appropriate level of a TDM measure should be decided based on the expected travel pattern changes before it is actually put into practice. Although several TDM measures have been implemented across the city of Seoul, few of them had such an evaluation process.

Two major objectives of TDM measures are 1) reducing traffic congestion and 2) improving transport efficiency. Since studies that aim to estimate the effects of TDM measures focus on the travel time reduction or modal shifts, they generally conclude that a TDM strategy should bring more economic benefits than the losses to transportation system users. But, it should be reminded that a TDM measure could accompany conflicts among groups of people having different interests, or impose economical losses on some groups.

In this study, a model to estimate the various effects of TDM strategies is developed. A distinguishing feature of this model is that it analyzes the effects of TDM measures comprehensively with consideration of transport equity as well as transport efficiency.

The main purpose of this study is to develop a model which can comprehensively measure the welfare changes after a TDM measure is implemented, which are estimated through modal and route shifts. For this, a methodology of estimating such effects is established, followed by a case study to validate the proposed model for the city of Seoul.

The model analyzes travel pattern changes through a process of estimating travel time/cost changes and route choice. The proposed model is expected to provide appropriate means of estimating the effects of regulatory or pricing strategies causing short-term travel time changes.

This research considers the following 4 TDM measures.

- Congestion pricing
- Fuel taxes
- Vehicle use restriction by vehicle registration number
- Bus-exclusive lanes

The Logit model and EMME/2 are used to analyze travel demand and supply. Parameters for the Logit model are calibrated using the data from the year 1996, which are categorized into the 3 income levels. To calculate the effects of implementing a TDM measure in terms of transport efficiency, an iterative process of estimating modal shares and traffic assignment is performed until the convergence criteria is met.

Based on the modal shares and travel times along with the indirect utility functions, the compensating variations (CV) of each income level are calculated to yield the total social welfare effects. The case study considers commuters traveling from Eunpyeong-Gu and Seodaemun-Gu toward Jongno-Gu and Jung-Gu taking Tong-Il-Ro, one of the major arterials of Seoul city.

2. Review of related literature and theory

Several TDM measures including congestion pricing, parking pricing, commuter financial incentives, vehicle restrictions, and fuel taxes have been widely implemented in Korea to reduce automobile travel since 1990s.

Most studies performed in Korea focus on determining the effects of the TDM measures in operation rather than estimating the effects before they are implemented. Lee et al. (1996) defines a model commuter representing travelers of an income group, and compares total commuting costs for each transportation mode before and after each TDM measure was implemented. They conclude that middle to low income single occupant motorists have good possibility of transferring to public transportation but not the high income group.

Oh et al. (1997) develops a disaggregated mode choice model to uncover the detailed effects of some TDM measures, such as parking and congestion pricing. They calibrate commuting and school trip models using the market segmentation method. Furthermore, modal and departure time shifts are modeled when a congestion toll is in place.

Hwang et al. (1998) presents a multinomial logit model to estimate the effects of TDM measures using the 1996 Household Travel Survey performed by Seoul city. Hwang et al. (1999) also develops a short-term congestion management system using the same data set to estimate the various effects of TDM measures. They estimate an increase of 0.3 US$ in fuel cost results in a 3.6% increase of travel speed, a 0.9% decrease of the automobile share, and a 4.8% decrease of the automobile travel.

Small and Rosen (1981) show how consumer welfare theories can be applied to discrete choice models, which provides a theoretical background to estimate the public welfare changes caused by a change of a transportation policy, using a discrete mode choice model. Small (1983) studies travel behavior of CBD commuters in San Francisco Bay Area in the early 1970s as the subject of congestion pricing. He analyzes the effects of congestion pricing for each group by calculating compensating variations classified by the mode and income level. He also compares HOV priority with congestion pricing with 213 commuters in the same area. He first establishes a detailed mode choice, traffic flow, and travel cost models as well as the highway traffic simulation model to build a demand-supply equilibrium model. A demand-supply equilibrium point is then found by applying an ad-hoc iterative algorithm. Comparison between the two TDM measures are followed by using equivalent variations for each income level group, calculated from the equilibrium point.

Hau (1986) attempts to integrate the equity effects into a discrete choice model. As a result, he shows that market segmentation needs to be introduced to calculate the equity effects. Hau (1987) applies the Hicksian approach to the cost-benefit analysis and calibrates the travel demand model using econometrical estimations and a simulation method.

Niemeier (1997) estimates the values of mode-destination accessibility for the morning-peak traffic through an econometrical expansion of the multinomial logit model. He shows that the value of accessibility can be used to determine the value of a transport policy as the compensating variations represent the amount of reward that each individual should receive before an important policy change occurs.

In a typical demand curve, a demand change caused by a price change is expressed as the sum of the substitution effects and the income effects. Contrast to this Marshallian demand curve, the compensated or Hicksian demand curve uses only the substitution effects by eliminating the income effects. Accordingly, to derive a compensated demand curve, it is needed to cancel the income effects by removing the actual income change resulted from the price change. In other words, if the price drops down, the income should decrease accordingly to keep the actual income at the same level before the price down and the other way around, which is called compensating variations of the income.

To measure the social welfare changes caused by a change of a policy, there exist three methods; compensating variations, equivalent variations, and consumer surplus. The consumer surplus method is based on a concept of the choice probability derived from the Marshallian demand curve, which can be observed during the discrete choice process. On the other hand, compensating variations and equivalent variations are from the Hicksian demand curve, which cannot be observed in the real world. The compensating variations or equivalent variations are superior in estimating the social welfare changes caused by a change of a policy, but they should be approximated from the consumer surplus as they are unobservable. Recently, the compensating variations method is widely applied to estimate the social welfare changes in many fields.

3. Conceptual framework of the model

The model of estimating the effects of TDM measures requires various functions which are able to provide transport equity and transport efficiency. The model in large consists of four sub-models, data manipulation sub-model, mode-choice sub-model, route choice and trip assignment sub-model, cost estimation sub-model.

In this study, the model was developed by combining mode choice sub-model and route choice sub-model so that mode share and route choice can be predicted. The combined model proved to be useful to simulate the effects of short-term TDM measures such as congestion pricing or fuel taxing. These schemes work by regulating price mechanism. The logit-based mode choice model is used to estimate the value of traveler welfare. In particular, the mode choice model is calibrated for each of income group and then the model is used to simulate the values of traveler welfare by income group. Finally, the implementation feasibility of TDM measures is tested by comparing welfare effects with implementation costs.

3.1 Data requirements and evaluation indicators

TDM measures aim to improve travel speed by discouraging the use of private cars. By considering this aspect, the change in travel time and mode choice was selected as the indicators for the evaluation of TDM measures. The implementation of TDM measures will affect the behavior of travelers and thus travel time and travel cost will be changed accordingly. Transport operational efficiency is possible to estimate by the simulation model which interacts between the network supply model and the logit-based demand model.

Table 1 Types of Evaluation Indicators

Type	Indicators
Efficiency	travel time, mode share
Equity	compensating variation by income
Implementation Feasibility	social welfare

In theory, the value of equity can be measured by analyzing consumer surplus, equivalent variation or compensating variation by income group. In this study, the total values of compensating variation by income group were estimated. First, travelers were segmented into three income groups, high, middle, and low. The value of welfares for each of income groups was calculated. For this purpose, a logit-based mode choice model needs to be calibrated for each of income groups. Travel cost, travel time and parameters in the logit based mode choice model need to be prepared for each of income groups.

3.2 Structure of the model

First, the mode choice sub-model is based on the standard discrete multi-nomial logit model. The model applied in this study is as follow:

$$V_{ik} = \alpha_i + \beta_1 \frac{COST_i}{INC_k} + \beta_2 IVTT_i + \beta_3 OVTT_i \quad (1)$$

here, V_{ik} : utility for mode I and income group k

α_i : alternative specific constant for mode i

$COST_i$: travel cost for mode i (won)

INC_k : income level of income group k (won/min)

$IVTT_i$: in-vehicle travel time of mode i (min)

$OVTT_i$: out-vehicle travel time of mode i (min)

The explanatory variables in the mode choice model are travel time and travel cost. In this study, the variable of travel cost divided by income was included in the model to represent the effect of income to mode choice. Furthermore, travel time is divided into in-vehicle travel time(IVTT) and out of-vehicle time(OVTT). The mode alternatives are auto, bus, subway and taxi. Bus mode was set to be the base mode. For other modes, mode specific constants were included in the model.

Second, the route choice sub-model is based on the equilibrium network assignment model using the Wardrop's principles. The model is iteratively processed until converged by testing tolerance level. The feedback process between mode choice and route choice is required. Also, O-D trip matrices classified by income group were prepared for the process of the trip assignment which produced travel volume for travelers of each income group.

Third, the value of compensating variation was estimated from the marginal utility of income. The marginal utility of income was calculated by taking the derivative of the utility function in the mode choice model with respect to cost variable and changing the sign of the derivative. At the same time, the zone to zone travel times and travel costs were obtained from the combined process of the trip assignment model and the mode choice model. The values of compensating variation by zone and by income were calculated from the values of the marginal utility, travel time and travel cost.

4. Calibration of the model

The base year for the analysis was set to be 1996 for the sake of data acquisition. The study area is one of typical transport corridors in Seoul City. The study corridor and area was selected by comparing two aspects: firstly, whether the corridor is served by a well-established public transport network, secondly whether a majority of trips are commuting into CBD at the morning peak time. Finally, the corridor that connects Eunpyeong-Gu and Seodaemun-Gu to the CBD area, Jongno-Gu and Jung-Gu was selected as the appropriate area for this study.

For practical convenience, this study made further assumptions to build the model. These assumptions are as follows:

- analysis is limited to commuting trips only traveling to CBD
- analysis period is the morning peak time, 07:30-08:30
- trip matrices are fixed and no change in travel time and trip destination
- through traffics are not affected by implementation of TDM measures
- public transport operation and service are fixed

The base data used in this study was obtained from the Seoul City Travel Census Data which was surveyed in 1997. The origins of the O-D trip matrices consist of 42 small zones and the destinations consist of 2 large zones. Travelers in the study area were segmented by three income groups, high, middle and low as shown in Table 2. Travel cost and travel time for trip assignment were also prepared for the modes of auto, bus, subway and taxi, respectively. The equilibrium trip assignment using the Wardrop's principle was applied along with the computer program suite, EMME2.

Table 2 Income Distribution of Travelers

Corridor	Low(%)	Middle(%)	High(%)
Eunpyeong-Jongno	37.10	38.71	24.19
Eunpyeong-Junggu	41.03	35.90	23.08
Seodaemun- Jongno	34.33	52.24	13.43
Seodaemun- Junggu	28.57	40.26	31.17
Average	35.92	40.85	23.24

Finally, Table 2 shows the values of parameters of the model calibrated by using the data explained above.

Table 3 Parameter Values of the Mode-choice Model

Variables		Parameter Values
β_1 (COST/INC)		- 0.15702
β_2 (IVTT)		- 0.15724
β_3 (OVTT)		- 0.29644
Mode-specific Constant	Auto	- 1.3486
	Subway	- 0.99056
	Taxi	- 2.8700

5. Effects of the TDM measures

5.1 Effects of congestion pricing

When the congestion charge of 2 US$ was imposed to cars entering CBD, the mode share of cars dropped from 26.6% to 14.7%. At the same time, the mode share of bus and taxi was expected to rise by 10% and the mode share of taxi was expected to rise from 2.9% to 5.1%. This change was attributed from the decrease of travel volume by car.

Table 5 Comparison of Mode Shares with Congestion Charge 2 US$

Mode	Mode Share(%)	
	Before	After
Auto	26.6	14.7
Bus	30.8	40.3
Subway	39.7	39.9
Taxi	2.9	5.1

In particular, car travelers whose travel distance is relatively short have changed their travel mode from car to public transport. It means that the congestion charge of 2 US$ had a strong influence to car travelers who commute from zones close to CBD.

The effects of congestion pricing scheme analyzed each for three income groups. First, for the low income traveler group the mode share of car dropped from 16.2% to 2.6%. In the other hand, for the high income traveler group the mode share of car dropped from 42.5% to 34%. The travelers of the low income group appear to be more sensitive than the travelers of the high income group. The total amount of compensating variation value was estimated to be about –160 US$. The congestion pricing scheme improved the total welfare. The welfare of the travelers of the high and medium income group increased. The welfare of the travelers of the low-income group rather decreased.

Table 6 Comparison of Compensating Variation Values with Congestion Charge 2 US$

Income Group	CV (US$/hr)	CV per person (US$/trip)	CV per person/Income
High	-184.066	-0.0336	-0.22%
Medium	-78.640	-0.0079	-0.08%
Low	102.748	0.0120	0.24%

For the sake of evaluating equity effects of the congestion pricing scheme, the proportion of the compensating variation value per person in the personal income was calculated for each income group. The proportion value for the three income group were –0.22% for the high-income group, -0.08% for the medium income group, -0.24% for the low income group respectively. The congestion pricing scheme can be the TDM measure which is reverse to income. For travelers of the high and medium income groups, the congestion pricing scheme produced the net increase in utility. However, for travelers of the low-income group, the congestion pricing scheme produced the net decrease in utility. Therefore, when the congestion pricing scheme is imposed, the subsidy for the improvement of public transport service or tax subsidy to travelers of the low income group need to be considered as a complementary measure.

5.2 Effects of fuel taxing

The mode share of car decreased from 26.6% to 22.9%. Especially, the mode share of car by travelers who commute longer distance dropped twice than by travelers who commute a shorter distance. The increase of fuel tax is shown to be very effective to reduce the total vehicle travel distance.

Table 7 Comparison of Mode Shares with Fuel Tax Changes

Mode	Mode Share(%)	
	Before	After
Auto	26.6	22.9
Bus	30.8	35.5
Subway	39.7	38.4
Taxi	2.9	3.2

The total amount of compensating variation value was estimated to be –1,018 US$. The fuel tax increase scheme produced the net increase of benefit for all the income groups. The scheme brought a higher increase of benefits to travelers of the high income group. This result occurred because the fuel tax is based on travel distance apart from the income level.

Table 8 Comparison of Compensating Variation Values with Fuel Tax Changes

Income Group	CV (US$/hr)	CV per person (US$/trip)	CV per person/Income
High	-423.946	-0.0773	-0.52%
Medium	-490.033	-0.0494	-0.49%
Low	-104.250	-0.0121	-0.24%

5.3 Effects of bus-exclusive lanes

The mode share of car was estimated to drop from 26.6% to 22.3% and the mode share of bus was estimated to rise from 30.8% to 38.5%. However, the mode share of subway dropped from 39.7% to 36.7%. In spite of the decrease of car travelers, the travel time by car appeared to be same.

Table 9 Comparison of Mode Shares with Bus-exclusive Lane Scheme

Mode	Mode Share(%)	
	Before	After
Auto	26.6	22.3
Bus	30.8	38.5
Subway	39.7	36.7
Taxi	2.9	2.5

Apart from congestion pricing scheme and fuel tax scheme, the mode share of car by income group appeared to be same. The total amount of traveler compensating variation value was estimated to be –1,944 US$. Travelers of all the income groups have the positive net benefits from the implementation of bus-exclusive lane scheme. Also, it is interesting to identify that the benefits of travelers of the low-income group are highest among three income groups. This result suggests that the bus-exclusive scheme is not reverse to the income level.

Table 10 Comparison of Compensating Variation Values with Bus-exclusive Lane Scheme

Income Group	CV (US$/hr)	CV per person (US$/trip)	CV per person/Income
High	-208.369	-0.03801	-0.25%
Medium	-1,161.078	-0.11695	-1.17%
Low	-574.703	-0.06684	-1.34%

5.4 Effects of vehicle use restriction by registration number

The effects of vehicle use restriction scheme were estimated by modeling zone to zone travel time by reducing the mode share of car by 10% for all the three income groups. The extra travel costs were 0.28 US$ for the high-income group, 0.15 US$ for the medium-income group and 0.07 US$ for the low-income group. The effect of the 10-day shift scheme is equivalent to one-minute reduction in travel time.

Table 11 Comparison of Travel Time with 10-day Shift Scheme

Mode	Mode Share(%)	
	Before	After
Auto	29.5	28.3
Bus	43.0	42.5
Taxi	34.5	33.3

The implementation of the 10-day shift scheme produced the total value of compensating variation and the value of compensating variation per person for each of three income groups, which are positive. This result means that the 10-day shift scheme is not reverse to income level. Among three income groups, the travelers of the high income group are affected most in terms of utility reduction.

Table 12 Comparison of Compensating Variation Values with 10-day Shift Scheme

Income Group	CV (US$/hr)	CV per person (US$/trip)	CV per person/Income
High	486.308	0.0887	0.59%
Medium	193.171	0.0195	0.19%
Low	24.706	0.0029	0.06%

6. Conclusions and suggestions for further study

This study proved that although the TDM measures are positive to improve operational efficiency, the effects would differ from the type of schemes, level of enforcement and income group. This suggests that the analysis of not only operational efficiency but also equity change is important to the successful implementation of TDM measures. It is necessary to identify various effects of TDM measures prior to implementation.

This study analyzed the equity effects of TDM measures by income group. In the future, it is interesting to analyze the effects of TDM measures by trip purpose or travel distance. In particular, fuel taxing is very sensitive to the amount of travel distance.

Also, it is necessary to evaluate the feasibility of TDM measures by comparing the benefits and the implementation costs. For the analysis of costs and benefits, the analysis on unit cost data for implementation of various TDM measures is required. Furthermore, in preparation of the implementation of multiple TDM measures at one time, the research for analyzing the effects of implementing a package of TDM measures is required.

References

Hau, T.D., 1986. Distributional cost-benefit analysis in discrete choice, Journal of Transport Economics and Policy 20 313-338.

Hau, T. D., 1987. Using a Hicksian approach to cost-benefit analysis in discrete choice: an empirical analysis of a transportation corridor simulation model, Transportation Research B, 21B 339-357.

Hwang, K., et al., 1998. Application of the multi-nomial logit model for the analysis of transport demand management measures, J. of the Korean Transportation Society 16(4) 53-63.

Hwang, K., Kim, I., Oum, J., 1999. A model for analyzing the short-term effects of transport demand management measures, J. of the Korean Transportation Society 17(1) 173-185.

Lee, B., Lee, E., 1996. Analysis of the effects of transport demand management measures by income group, Journal of the Korean Transportation Society 14(1) 7-28.

Niemeier, D.A., 1997. Accessibility: an evaluation using commuter welfare, Transportation 24 377-396.

Oh, J., Park, J., 1997. Analysis of Passenger Travel Behaviors in Seoul Metropolitan Area, The Korea Transport Institute.

Small, K.A., Rosen, H.S., 1981. Applied welfare economics with discrete choice models, Econometrica 49 105-130.

Small, K.A., 1983. Bus priority and congestion pricing on urban expressways, Research in Transportation Economics 1 27-74.

Small, K. A., 1983. The incidence of congestion tolls on urban highways, Journal of Urban Economics 13 90-111.