MODIFIED METHOD FOR OPTIMIZING TRANSPORT POLICY
PACKAGES BY USING STRATEGIC TRANSPORT MODELS

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Abstract: Strategic transport models have been developed since around 1990 in the U.K. in order to evaluate policy packages. However, with increasing number of policies, finding the optimal policy package by simulating the very large number of policy combinations becomes impractical. Fowkes et al. (1998) developed a short-cut method to find the optimal transport package based on a limited number of model runs together with a regression equation between the evaluation variable and policy variables. In this paper, this method is modified to improve its efficiency. The assumptions for applying the modified method and its applicability in case of discrete policy variables are discussed. Finally, the modified method is applied in Nagoya Metropolitan Area (Japan) to prove the applicability of the method.

Key Words: Strategic Transport Model, Integrated Transport Policy

1. INTRODUCTION

Many cities in developed countries are facing strict environmental and financial constraints. To cope with these constraints, transport planners are proposing new integrated transport strategies or policy packages combining Transport Demand Management (TDM), Transport System Management (TSM) and Transport Facility Improvement (TFI). Strategic transport models (May and Gardner, 1990; May et al., 1991; Oldfield 1993, etc.) have been developed, especially in the U.K., since around 1990 as tools to analyze and evaluate these policy packages at the strategic decision level. However, it is not possible to analyze all policy packages with the synergic and trade-off effects between policies especially when the number of policies is large. Using these strategic transport models, Fowkes et al. (1998) developed a short-cut method to find the optimal transport package without the need simulating all
packages based on a limited number of model runs together with a regression equation between the evaluation variable and policy variables. However, this method has the following two problems: (1) It does not utilize the information of model runs efficiently because a single-variable quadratic regression equation is used as the regression equation, which means that the regression function can not capture the synergetic effects among policies efficiently; and (2) The assumptions of the method and its applicability in the case of discrete policy variables are not discussed.

In this paper, the Fowkes method is improved to find optimal policy package efficiently by changing the single-variable quadratic regression equation to multi-variable equation. By considering the assumptions of the method and the cases of discrete policy variables, necessary conditions to apply the method are clarified.

In the following sections, firstly, the general features of strategic transport models are explained and a model is introduced in Section 2. In Section 3, the modified Fowkes method and its procedure are described, and the assumptions for the method and the case of discrete policy variables are discussed. In Section 4, a case study in Nagoya Metropolitan Area (Japan) is implemented including the parameter estimations of the modal split sub-model. As an example, a policy package combining road pricing and rail fare reduction are optimized. Finally the conclusions are summarized in Section 5.

2. STRATEGIC TRANSPORT MODELS

Strategic transport models are based on the standard four-step transport model (trip generation, trip distribution, modal split, and traffic assignment). However, these models focus less on the detailed network description and more on other factors including:

(1) Detail travel behavior, such as departure time, transport frequency, and trip pattern;
(2) Various transport modes including walking, bicycle, bus, LRT, Park and Bus/Rail Ride, in addition to rail and motor vehicle;
(3) Detailed transport time-cost function including congestion charge and parking fare, etc. in addition to usual time-cost function of line-haul and access/egress; and
(4) Keeping consistency among sub-models by including feedback loops and transport equilibrium mechanisms between demand and supply.

Strategic transport models do not aim to substitute the four-step transport model, but to complement it. These models are applied at the early strategic decision level considering many kinds of alternative transport policies. On the other hand, the four-step transport model is useful to evaluate more detailed network transport plans after the analyses using the strategic models. Thus, strategic transport models use coarse network description with rough zoning system.

As this paper aims to develop a method to optimize policy packages, a simple strategic transport model, including only modal split and traffic assignment, is applied. In this paper,
the modes in modal split are rail and motor vehicle. The modal split sub-model uses a logit model aggregated by trip purposes. In the traffic assignment sub-model, motor vehicles are assigned on coarse road network linking adjacent zones and having aggregate Q-V functions. The traffic is assigned by the incremental assignment method. Rail passengers are assigned on the network using the shortest path method. The rail network is not aggregated because the network of Nagoya is not so dense.

3. MODIFIED METHOD FOR OPTIMIZING TRANSPORT POLICY PACKAGE

3.1 Evaluation Function of the Strategic Transport Model

In order to optimize a transport policy package, we define the following evaluation function, considering case study in Section 4. The evaluation function can be used to evaluate policies, such as infrastructure improvement, road pricing, increase in gasoline tax, and decrease in public transport fare. As transport subsidy ($S$) and tax ($T$) are included in the total transport cost, the subsidy ($S$) is added and tax is subtracted in the right side of the function, because they indirectly contribute to the total cost as expenditure or gain of the society as a whole.

$$y = \sum_i \sum_j \sum_m \sum_k c_{ij}^{mk} q_{ij}^{mk} + E + S - T \rightarrow \min$$

where

$y$: Total transport cost (yen per day);

$c_{ij}^{mk}, q_{ij}^{mk}$: Generalized transport cost including subsidy and tax (yen per trip) and number of trips (per day), respectively, of mode $m$ and purpose $k$ between zones $i$ and $j$;

$E$: Expenditure for infrastructure improvement (yen per day); and

$S, T$: Total transport subsidy and tax, respectively (yen per day) (to offset those included in $c_{ij}^{mk}$)

The above expenditure for infrastructure ($E$) in the evaluation function can be calculated by the following equation:

$$E = \frac{C}{K} \left( \frac{1}{1 + r} \right)^L \frac{1 - \frac{1}{(1 + r)^L}}{1 - \frac{1}{1 + r}}$$

where

$C$: Total infrastructure cost including construction cost and maintenance/operation costs (yen);

$L$: Life time (year);

$r$: Discount rate; and

$K$: Number of days in a year, which is converted to equivalent number of weekdays considering the difference between traffic volumes of weekday and holiday.
The transport subsidy \((S)\) in the evaluation function can be calculated by the following equations, and the transport tax \((T)\) can be calculated similarly.

\[
S = \sum_i \sum_j \sum_k \delta_m C_{ij}^{mk} q_{ij}^{mk} \quad \text{or} \quad S = \sum_i \sum_j \sum_k \Delta S q_{ij}^{mk}
\]

where

\(C_{ij}^{mk}\) : Generalized transport cost excluding subsidy (yen / day);

\(\delta_m\) : Subsidy rate for a trip; and

\(\Delta S\) : Amount of subsidy for a trip

### 3.2 Modified Method

As stated in Section 1, Fowkes et al. (1998) developed a short-cut method to optimize transport package based on a limited number of model runs together with a regression equation between evaluation variable and policy variables, without simulating all of the policy packages, assuming that the evaluation function is convex in an area around an optimal set of policy and the area is enough wide for the calculation even when the convexity assumption is not satisfied strictly in total area of variables. However, this method does not use the information of model runs efficiently because it uses a single-variable quadratic regression equation that cannot capture synergic effects among policies efficiently. To capture these effects, we modified this method by introducing a multi-variable quadratic regression equation, which is more efficient than the original single-variable equation.

The procedure of modified method is illustrated in Figure 1 and summarized in Figure 2. Firstly, some policy packages are selected randomly from policy sets around the optimal policy set, referring to the sensitivity analysis of each policy (Step 1). Each selected package is simulated and the evaluation value is estimated using a strategic transport model (Step 2). Figure 1 illustrates the relationship between the evaluation value and policy variables. This relationship is determined by a multi-variable quadratic regression equation (Step 3). Using the regression equation, an approximate optimal policy can be calculated as illustrated in Figure 2 (Step 4). This approximate optimal policy is then evaluated using the strategic transport model (Step 5) and a convergence test is applied on the evaluation value (Step 6). The evaluation value can be improved by recursively iterating the above process around the approximate optimal policy package through narrowing the area of selected policy packages at the beginning of the iteration.
Figure 1. Multi-variable Quadratic Regression and Approximate Optimal Policy Package

Figure 2. Procedure of the Modified Method for Optimizing Transport Policy Package

3.3 Discussion of the Assumptions and Discrete Policy Variables

In this section, the following issues are discussed:
(1) The features of the policy variables that satisfy the assumption of the convexity of the evaluation function; and
(2) The applicability of the modified method in the case of policies with discrete variables.

As for the first issue, in order to satisfy the assumption of the convexity of the evaluation function, trade-off effects between policies should be avoided, because they may cause the evaluation function to become concave. In applying the method, only policies with either synergic effects or no inter-effects should be selected.

As for the second issue, the modified method can be applied to policies having discrete variables if the evaluation function is convex and roughly symmetric around the optimal policy package. In this case, the optimal policy package should be searched as if the discrete variables are continuous; then the policy package with discrete variables nearest to the variables of the optimal policy package should be selected. In order to allow this selection without ambiguity, the symmetry condition of evaluation function is required. If the symmetry condition cannot be assumed, the optimal policy package should be found among the neighborhood points by enumeration method. In addition, the number of items of each discrete variable should be three or more to allow for the estimation of the quadratic regression function.

4. CASE STUDY

4.1 Area, Zoning, and Data

The area for the case study is Nagoya Metropolitan Area (Japan), which includes 33 zones within 20 km radius from the city center as shown in Figure 3. Zones 1 to 16 correspond to Nagoya City area, and the other zones are located around the city. As for data, the 3rd Person Trip Survey in Nagoya Metropolitan Area (1991) is used. The road network for the simulation is based on aggregated road links between adjacent zones with aggregated Q-V functions. The road network aggregates major roads including expressways, national roads and principal

![Figure 3. Nagoya Metropolitan Area and Zoning](image)

*Figure 3. Nagoya Metropolitan Area and Zoning* 
local roads. The rail network for the simulation is based on the real rail network without aggregation because it is not so dense.

4.2 Estimation Results

(1) Modal Split Sub-model

The modal split sub-model uses the following equation

\[ P = \frac{1}{\exp(\lambda(t_s - t_r) + C)} \]

where

- \( P \): Modal share of rail (%)
- \( t_s, t_r \): Generalized costs of motor vehicle and rail, respectively (1,000 yen)
- \( \lambda, C \): Parameters

Table 1 shows the estimated parameters of the modal split sub-model for each trip purpose. The t-values are good, but the correlation coefficients are not good. The errors were adjusted in every OD pairs before simulating in Section 4.

Table 1. Estimated Parameters of Modal Split Sub-model

<table>
<thead>
<tr>
<th>Trip purpose</th>
<th>Generalized cost (1,000 yen) (( \lambda ))</th>
<th>Constant (C)</th>
<th>Correlation coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commuting</td>
<td>-1.586 (-16.1)</td>
<td>0.365</td>
<td>0.42</td>
</tr>
<tr>
<td>Business</td>
<td>-1.430 (-4.49)</td>
<td>1.493</td>
<td>0.39</td>
</tr>
<tr>
<td>School</td>
<td>-0.453 (-4.55)</td>
<td>-0.005</td>
<td>0.34</td>
</tr>
<tr>
<td>Private</td>
<td>-0.413 (-2.65)</td>
<td>0.862</td>
<td>0.48</td>
</tr>
<tr>
<td>Return home</td>
<td>-0.885 (-9.89)</td>
<td>0.584</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Note: Values in brackets are t-values

(2) Assignment Sub-model

The assignment sub-models use all-or-nothing shortest path assignment for the rail network and incremental assignment method for the aggregated road network. This sub-model for traffic assignment is validated based on Figure 4 that shows the relationship between the estimated and observed times of each O-D pair trip, where the observed times are calculated by using person trip survey data in Nagoya Metropolitan Area (1993). The correlation coefficient is 0.52 and the estimated times tend to be under-estimated. This can be because 1) the traffic assignment sub-model does not consider detouring rate, 2) the road network is aggregated, and 3) zone system is rough. However, the errors of each O-D pair are adjusted before the application in Section 4.

4.3 Optimization of Transport Policy Package

Although many transport policies should be analyzed using the strategic transport model, as an example, a package combining only road pricing and reduction of rail fare policies is optimized this case study. In the road pricing policy, motor vehicles entering the center zone (zone 6 in Figure 3) are charged. In the rail fare policy, the rail fares are reduced at the same rate in the whole study area.

Figure 5(a) shows the changes in the evaluation value in case of implementing road-pricing policy alone. The figure shows that the evaluation function is convex around the minimum point, which means that the assumption for applying the method is satisfied, and then the optimal charge is 300 yen/vehicle, which raises benefits of about 400 million yen/day (7.6 yen/trip saving) compared to do-nothing policy. Figure 5(b) shows the changes in the evaluation value in case of implementing rail fare reduction policy alone. The figure shows that the evaluation function is convex around the minimum point, which means that the assumption for applying the method is satisfied, and then the optimal reduction rate is about 7%, which brings about 250 million yen/day (4.7 yen/trip saving) compared to do-nothing policy.

Then, the policy package combining the above two policies was optimized using the modified method described in Section 3. The results are shown in Figures 5(c) and (d) and Table 2. Figure 5(c) shows that the evaluation value improved with the number of iterations, especially at the first iteration. Table 2 shows the multi-variable quadratic regression equation estimated in the first three iterations and the approximate optimal policy packages derived by the regression equation at each iteration. Figure 5(d) shows the changes in the approximate optimal policy package quickly converging at the third iteration. In this iteration, the approximate optimal policy package combines road-pricing charge of 249 yen/vehicle and
7.55% reduction in rail fare. This package raises benefits of about 900 million yen/day, which corresponds to a saving of 17 yen/trip. These benefits are larger than the sum of benefits gained by implementing two policies independently (about 650 million yen/day), which indicates that synergic effect arises between the two policies. This synergic effect can be explained by the modal shift from car vehicles to rail caused by the policy package, which resulted in additional decrease in congestion in the city center.

Figure 5. Optimal Policy Package Combining Road Pricing and Reduction of Rail Fare
Table 2. Estimated Quadratic Regression Equation and Approximate Optimal Policy Package

<table>
<thead>
<tr>
<th>Iteration number</th>
<th>Estimated quadratic regression equation</th>
<th>Approximate optimal policy package</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Reduction rate of rail fare</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$x_1$ (%)</td>
</tr>
<tr>
<td>1</td>
<td>$y = 4590x_1^2 + 0.193x_2^2 - 1.23x_1x_2 - 68400x_1 - 85.4x_2 + 530000$</td>
<td>7.48</td>
</tr>
<tr>
<td>2</td>
<td>$y = 4200x_1^2 + 0.182x_2^2 - 1.03x_1x_2 - 63000x_1 - 84.3x_2 + 530000$</td>
<td>7.53</td>
</tr>
<tr>
<td>3</td>
<td>$y = 4090x_1^2 + 0.180x_2^2 - 0.969x_1x_2 - 61500x_1 - 82.5x_2 + 521000$</td>
<td>7.55</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

In this paper, a modified method based on Fowkes et al (1998) was developed using as a tool to optimize transport policy packages in strategic transport models. The modified method uses multi-variable quadratic regression equation that can capture synergic effects among policies efficiently. Furthermore, the assumptions for applying this method and its applicability in cases including discrete policy variables were discussed. The modified method was applied in Nagoya Metropolitan Area (Japan) to prove its applicability. The following conclusions can be stated:

1. Only policies with either synergic effects or no inter-effects can be used in the modified method in order to insure the convexity of the evaluation function.

2. The modified method can be applied to cases including discrete variables as long as the evaluation function is convex and roughly symmetric around the optimal policy package. In addition, there should be three or more items in each discrete variable.

3. By applying the modified method in Nagoya Metropolitan Area, it was proved that it is capable to find an optimal policy package. This package combines road-pricing charge of 250 yen/vehicle and reduction of rail fare of 7.5%. Comparing with the do-nothing case, this policy raises benefits of about 900 million yen/day or 17 yen/trip.

4. The synergic effect benefit of implementing the optimal policy package is 250 million yen/day larger than the sum of benefits by implementing road pricing and rail fare reduction separately.

In the future, the modified method will be applied to cases including many policy variables by using more detailed strategic models. In addition, this method can be applied to optimize policy packages including land-use and transport policies in a strategic land-use and transport model.
REFERENCES

Journal papers


