Comparison of Transit-Oriented and Auto-Oriented Cities

Kazuhiro NOMURA*

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Abstract

Many researchers advocate transit oriented development or compact city concept. However, it is necessary to obtain a rational reason on urban policy by quantitatively grasping an effect of transportation mode on city growth. In this reason, we developed a simple simulation model that can compare the differences between automobile-oriented and transit-oriented cities, and clarify the difference among city forms by transportation mode. Following a theoretical model development, a series of simulation runs are tried. The model allocates people who commute to CBD from residential zones along a transportation corridor. As a result of many simulation runs, it is shown that automobile requires much more traffic space than transit.

In this paper, the improvement on the model is proposed using Linear Programming. It is an improvement for the purpose that the model can be applied to more general city forms. Through the trial, we confirm that the solution of LP model exists.

Keywords: transit oriented development, urban land use, optimization

1. INTRODUCTION

Recently, there are many discussions on the effect of induced traffic as the result of road construction and improvement, as is found in the SACTRA report (Ref. 1) and other studies. It is often observed that road improvement to reduce congestion makes traffic jam worse because of induced traffic. It is called Downs-Thomson Paradox (Refs. 2, 3). Sarker et al. (Ref. 4) have found that the transit utilization is high in the city where the road improvement level is low by using the gap index for 29 cities in Japan. Kenworthy et al. (Ref. 5) have shown that the population density of a city is closely related to whether the city is transit-oriented or automobile-oriented. Although their studies offered useful knowledge to those who try to promote transit system development, they cannot satisfactorily explain the reason why a city with high density and with a large gap index has higher level of transit utilization. It is necessary to clarify the theoretical aspect of why and how much these factors influence on urban forms, in order to use these indices for the practical and strategic urban planning tools.

2. BASIC MODEL

We consider that a rational reason on urban policy must be obtained by quantitatively grasping an effect of transportation mode on city growth. In this reason, an urban area which consists of CBD and suburb assumed to have one corridor. Then, simulation model which calculated the possible number of commuters to CBD was developed on the basis of the traffic capacity of transportation mode in the corridor. The transportation mode is either automobile or transit. In addition, maximum commuting time required by mode was fixed in order to express the size of the urban area (Ref. 7).

Although the model assumes a rather simple

*Department of Civil Engineering
structure, it reveals the following findings.

1) Automobile has lower transportation capacity than transit per traffic lane. Therefore, the transportation capacity can only be increased by increasing number of traffic lanes. In case of automobile, the maximum number of commuters increases with the increase in CBD floor area ratio and road rate. However, it will decrease eventually by the floor space constraint. So, it becomes that the maximum number of commuters is constant in case of transit. This is because it depends only on the transportation capacity constraint. Thus it became apparent that the situation with automobile is completely different from that of transit, because the former requires spaces for parking and travel, as Bruun et al. (Ref. 6) indicated.

2) Next, the efficiency of a corridor space is examined. We regard this index as the ratio of the maximum number of commuters to CBD for given corridor length. The corridor length for automobile is longer than that for transit because of higher speed and shorter access and egress time. Therefore, the transportation efficiency of transit is clearly higher than that of automobile. Of course, transportation efficiency increases as required maximum commuting time increases.

3) Finally, the traffic space area ratio of a corridor is examined. This index is the corridor area ratio of automobile and transit. Here, widths of a single lane for automobile and a track for transit are assumed to be the same. To accommodate the maximum number of CBD commuters, automobile mode requires CBD road rate of 30%. In case of maximum commuting time of 30 minutes, traffic space ratio becomes 8.7. It is apparent that automobile needs much larger traffic space than transit (Ref. 7).

3. PROPOSED MODEL

By limiting the relationship between CBD and suburb in one corridor, the previous model compared traffic space improvement quantity of automobile and transit in the corridor based on the floor space constraint of CBD. In the model, it is assumed that the traffic demand is limited by maximum commuting time from suburb to CBD. In the previous study (Ref. 7), it was proven that the city, which depends on the automobile, becomes the low-density dispersion than transit-oriented cities.

However, the model has the following problems:

1) Selection of housing location does not reflect market principle.
2) There are many cases in which houses are located far away from the corridor. It is greatly different from the assumption of the model.
3) Space for transit and space for automobile are mutually exclusive and does not coexist simultaneously.

Therefore, we examined a new model to solve the above-mentioned problems.

We want to prove that transit-oriented development is socially more desirable than automobile-oriented development that sprawls extensively into suburbs in low density.

This new model assumes that the service level of transit and automobile are clearly differentiated, and also it assumes selection of housing location will reflect the difference of their household types.

4. THE FORMULATION OF THE MODEL

4.1 The objective function

A hypothetical city is assumed as a mesh grid as is shown in Figure 1. In each mesh, commuting residents (the member of each household was made with 1 person for simplicity) of two types of attributes is the object area, and the optimum decision of the location quantity is carried out. Attribute-1 is those people who utilize automobile, whereas attribute-2 is those people who utilize public transport. The objective function was made to be the maximization of the product of resident number and per capita floor space, as is shown in (1). Therefore, it is equal to realize the location in proportion to the volumetric image of the region as an aim of this problem at the decision of the resident number.

\[ FL^1_i \cdot X^1_i + FL^2_i \cdot X^2_i = \left( \frac{\alpha \cdot IC^1_i - C^2_i}{LA^1_i} \right) \cdot X^1_i + \left( \frac{\beta \cdot IC^2_i - C^2_i}{LA^2_i} \right) \cdot X^2_i \rightarrow \max \cdots (1) \]

The decision variables \( X^k_i \), \( i = 1, \ldots, m \); \( k = 1, 2 \) are resident number of attribute-\( k \) of mesh-\( i \).

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4.2 Access guarantee between meshes by the public transport : Constraint-1

This constraint is based on the civil minimum principle that public transport network should be secured in the transfer between meshes, and is expressed that the location of attribute-2 does not occur at the mesh with the impossible access. Concretely, mesh cluster R in which the location is possible by making the cluster of possible transit station of the access by setting the access distance upper limit (the diagonal line length of the mesh) from the centroid to a station in every mesh, and the possibility of other access to the mesh according to the network data will be examined.

\[ TRA_{ij} = \begin{cases} 1 & i \in R, \ j \in R, \ i \neq j \rightarrow X^2_i \geq 0, \ i \in R \\ 0 & i \in R, \ j \in R, \ i \neq j \rightarrow X^2_i = 0, \ i \in R \end{cases} \]  \hspace{1cm} \text{(2)}

Where, \( TRA_{ij} = 1 \) can be moved here between mesh i and j by using public transport. And it is shown here that R is the mesh cluster with the availability of public transport.

4.3 The behavioral principle in location: Constraint-2

Cost which is related to the location selection is assumed as generalized cost + floor space \( \times \) unit floor space rental cost. This is equal to the result of making the transfer cost to be the zero in composite commodity. The formulation on attribute-1 will consist as following.

\[ C^1_i + FL^1_i \cdot LA_i \leq \alpha \cdot IC^1_i \]  \hspace{1cm} \text{(3)}

Where, \( C^1_i = \text{generalized cost at mesh-i} \), \( FL^1_i = \text{the floor space of attribute-1} \), \( LA_i = \text{Floor space unit price at mesh-i} \), \( IC^1_i = \text{Average monthly income of attribute-1} \), \( \alpha = \text{Location expenditure ratio at the average monthly income} \).

On the basis of (3), it is possible to obtain average floor space of resident of 1 unit of attribute-1 in which it was shown in (4).

\[ FL^1_i = \left\lfloor \frac{\alpha \cdot IC^1_i - C^1_i}{LA_i} \right\rfloor \]  \hspace{1cm} \text{(4)}

Similarly, average floor space of resident of 1 unit of attribute-2 can be also defined.

\[ FL^2_i = \left\lfloor \frac{\beta \cdot IC^2_i - C^2_i}{LA_i} \right\rfloor \]  \hspace{1cm} \text{(5)}

Generally, one mesh is regarded as a mixture of residents of attribute-1 and attribute-2. Therefore, floor space constraint shown in (6) every mesh can be introduced by using floor space upper limit of each the floor layer.

\[ \begin{align*}
FL^1_i \cdot X^1_i + FL^2_i \cdot X^2_i & \leq A_i \cdot (1 - \text{RoadRatio}) \cdot FLV_i \\
\cdot \left\lfloor \frac{\alpha \cdot IC^1_i - C^1_i}{LA_i} \right\rfloor 
& + \left\lfloor \frac{\beta \cdot IC^2_i - C^2_i}{LA_i} \right\rfloor \cdot X^2_i \\
& \leq A_i \cdot (1 - \text{RoadRatio}) \cdot FLV_i
\end{align*} \]  \hspace{1cm} \text{(6)}

Where, \( FLV_i = \text{the floor area ratio at mesh-i} \), \( \text{RoadRatio} = \text{the road rate} \).

Still, it is considered that a resident settles at the location, when it is under the value in which there is average floor space of resident of 1 unit of each floor layer. Therefore, the constraint of (7) was set.

\[ \begin{align*}
FL^1_i & < FL\text{min} \rightarrow X^1_i = 0, \\
FL^2_i & < FL\text{min} \rightarrow X^2_i = 0
\end{align*} \]  \hspace{1cm} \text{(7)}

4.4 The upper limit of resident number of each attribute : Constraint-3

Of the maximum constraint of resident number of each attribute at each mesh, it was introduced by (8).

\[ \begin{align*}
X^1_i & \leq S^1_i \quad i = 1, \ldots, m \\
X^2_i & < S^2_i \quad i = 1, \ldots, m
\end{align*} \]  \hspace{1cm} \text{(8)}

\( S^1_i, S^2_i \) are largest resident numbers according to the mesh of each attribute, and on the basis of (6), it is given as in (9) and (10).

\[ \begin{align*}
S^1_i &= \left\lfloor \frac{A_i \cdot (1 - \text{RoadRatio}) \cdot FLV_i}{\left\lfloor \frac{\alpha \cdot IC^1_i - C^1_i}{LA_i} \right\rfloor} \right\rfloor \quad \text{(9)} \\
S^2_i &= \left\lfloor \frac{A_i \cdot (1 - \text{RoadRatio}) \cdot FLV_i}{\left\lfloor \frac{\beta \cdot IC^2_i - C^2_i}{LA_i} \right\rfloor} \right\rfloor \quad \text{(10)}
\end{align*} \]

5. THE TRIAL

5.1 Object area and trial condition

We assumed a small district consists of square mesh in order to confirm the existence of the solution on the basis of the formulation in the previous section (Figure 1). The public transport network consisted of 6 lines, and line 1~3 were directly connected to CBD. In the meantime, the mesh in which the utilization is impossible by the equation of (2) may exist on the public transportation by the route network. The mesh of the right end is correspondent to this in Figure 1, and the location of attribute-2 becomes impossible. Still, it was assumed that for automobile users, the road network exists ubiquitously, and that transfer is possible between any meshes.
Generalized cost of every attribute and every mesh was calculated on the basis of the direct distance to CBD from centroid. Generalized cost of attribute-1 was made to be monthly sum charge only by fuel expenses from the assumption of the highway network using the distance between centroid and CBD. Attribute-2 was made to be 10 times of the automobile utilization. Originally, the shortest path according to public transport network should be used, and it was simplified so that the existence of the optimum solution can be confirmed.

Also, the rent per unit floor space of each mesh using the distance between centroid and CBD, by multiplying the reciprocal of the distance, the amount of money per monthly sum was calculated. The expenditure ratio was made to be $\alpha = \beta = 0.5$. And, the floor area ratio of each mesh in constraint (6) was set as is shown in Figure 2.

5.2 The test result

In order to confirm the effect of the public transportation route existence, trial computations were carried out on next two cases. Problem-1 is the case in which all routes of Figure 1 exist, and problems-2 is the case in which only route 1 through 3 exist. The generation conditions of location regulation in each problem are shown in Figure 3 and 4.

The solution of each problem is shown in Table 1 and Table 2. In addition, the following results are shown in Table 3. Number of residents is shown according to the attribute and objective function value of the solution.

It is shown that the difference has been drastically reduced in problem-2, while the ratio of attribute-2 of the resident number is overwhelming with about 88% in problem-1, although the numbers of residents are almost the same in both problems. It is shown that the difference of both solutions greatly depends on location propriety of attribute-2 by the equation (2), and number of residents of attribute-2 increases, as meshes in which access by public transport route is possible increases, and also the objective function value increases.

![Figure 1. Object area and public transportation network](image1)

![Figure 2. The floor area ratio](image2)

![Figure 3. Location regulation of each attribute in problem-1](image3)
Figure 4. Location regulation of each attribute in problem 2

Table 1. Number of residnets of each mesh in problem 1

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(upper stage = attribute 1; lower step = attribute 2)

Table 2. Number of residnets of each mesh in problem 2

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</table>

(upper stage = attribute 1; lower step = attribute 2)
### Table 3. Number of residents according to the attributes and objective function value in both problems

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<th>Residents</th>
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<th>Objective function</th>
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<td>attribute-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1) Problem-1</td>
<td>267.400</td>
<td>(0.12)</td>
<td>2050.816</td>
<td>(0.88)</td>
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<td>(2) Problem-2</td>
<td>1029.754</td>
<td>(0.44)</td>
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<td>(2)/(1)</td>
<td>3.851</td>
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<td>0.629</td>
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</table>

6. **CONCLUSIONS**

On the basis of transportation services, it was proven that the optimum decision of number of residents in each mesh according to the attribute was possible. However, we have to develop a more realistic generalized cost, in order to grasp the effect of public transport on the number of residents.

**REFERENCES**

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