OPTIMAL LOCATION OF ROUTE AND STOPS OF PUBLIC TRANSPORTATION

Abstract

This study is concerned with the optimal location of route and stops of LRT and the effects of LRT in central urban areas. In order to implement LRT, it is important to locate LRT lines and stations in appropriate places and to estimate the effects of LRT. In this study we accordingly address the optimal layout of LRT route network and estimation of the effects. First, for the estimation of the effects of introducing LRT, a new evaluation model based on space syntax theory is proposed. Two indexes which explain traffic flows and the character of location are introduced. One is the average travel cost from nodes to nodes, which corresponds to the depth index of space syntax. The other is the amount of through traffic on each link, which is the frequency that a certain link (a road, train or LRT link) is chosen as a part of route for traveling from nodes to nodes in the city. The former is named C_depth value, and the latter is named Flow value.

Second, the optimal location of LRT route and stops, which minimizes the mean cost in whole area, is considered. The case of the new LRT system in Maebashi city in Japan is examined. Optimal location and its effects are investigated by case study in Maebashi City. Two types of optimal location are studied and compared. In both cases, Flows on LRT and trains are still lower than the Flow by cars on main streets. Thus, one conclusion may be that in order to promote LRT and train usages, policies, such as road-pricing and discount of LRT fare, are needed.

Introduction

Along with the increase in private cars, the hollowing of central city areas and decline in shopping streets have become serious problems. In Japanese cities, the popularization of private cars increases urban mobility and accelerates suburbanization. Huge numbers of parking lots and chronic heavy traffic congestion are leading to a significant decline in traditional urban public spaces.

In European countries (France, Germany, Sweden, etc.), numerous successful examples of central town area revitalization and environment preservation through the development of urban public transportation have been reported. Also in Japan, various methods of
revitalization have been examined, and the redevelopment of new public transportation systems will be necessary in suburban cities.

Recently, arguments in favor of the introduction of LRT have been made in Japan, but it has not been realized to date. In this study, the methods and effects of introducing LRT in central urban areas is investigated. For estimating the effects, a method modified from space syntax theory is introduced. A model which considers road width, route and travel time is used, as it is difficult to assess the traffic of cars and transportations by using typical space syntax that is isovist based. Two indexes are defined, and by using these, traffic flows and the accessibility of the places can be visually and quantitatively analyzed.

In order to implement LRT, it is important to place LRT lines and stations in appropriate places and estimate the effects of LRT. In this study we accordingly examine how to find optimal locations of LRT route network and stations. The optimal location of route and stops that minimizes the average travel cost in the city is examined. The location problem and method of solution are likewise discussed. Their application to the specific case of Maebashi city is illustrated.

In regard to the optimal location solution, LRT lines are laid in Maebashi city so as to fit the existent road networks. Then the effects of introducing LRT are analyzed by the new evaluation model based on space syntax theory.

**Route Network Space Syntax**

**Model for Car Traffic and Public Transportation**

Space Syntax has mainly focused on the space for pedestrians. Global and Local Integration clarify the characteristics of pedestrians’ activities. However, it is not adaptable to the character of car traffic because the traffic flows are strongly influenced by road width. This will obviously be true for the traffic flow by railway and LRT as well. Accordingly, in this study, a new space syntax model is proposed. Traveling cost is the main concern in the model. We assume that all travelers choose the means and path of smallest “cost”.

The model considers the affinity of existent GIS data. Below, the data structure used is first explained, and then route network space syntax is described.

**Route Network data**

In this study, digital map data made by the Japanese Geographical Survey Institute (GSI) is used. The digital map data includes road nodes, road links with the attribute of width, station nodes, and railway links, etc.

Road node is defined as the point where more than 2 roads meet. Road links are the polylines which connect two road nodes. Station nodes are points of stations, and railway links are polylines which connect two railway stations. Road network and railway network data are on different layers and separated; we integrate the two layers and make new links so as to connect stations and road nodes. In this manner, the road and railway network data in which the people can travel on roads and railways in a city is formed. In this paper, the network is called Route Network Map. Links on the route networks map have the attribute of length, road width, and value of road or railway.

**Flow and C_depth Index**

The travel cost to go through each link is different, because people can go through faster on wide roads and go slower on narrow roads.
A railroad link takes much less time than a road, because trains run faster. On the other hand, a railway has additional fare cost at the station.

We assume that people choose the lowest-cost path on the route network map when traveling from a node to any other node. There are many paths connecting node to node; however, we focus solely on the path with the minimum cost to connect 2 nodes. Under this condition, the cost between a node and any node can be calculated and determined by Dijkstra method.

With the route network map, two indexes which explain accessibility of location and traffic flow, respectively, can be proposed. One is the average cost from nodes to nodes. Cost can be the time to reach, money cost, a mixture of both, etc. If the value is higher, it means that it costs more on average to travel to any other points. If the value is lower, it means that it costs less on average to travel to any other points. This is similar to the Depth index of space syntax. In space syntax, Depth is the index about visual connectivity by isovist, whereas in our model, it is defined as the index for each location’s accessibility or convenience in terms of travel cost. We called it C_depth in order to distinguish it clearly from depth index of space syntax. If C_depth is larger, travel cost to other nodes is larger and the node is locationally more inconvenient.

The other index has to do with the amount of through traffic on each link. Specifically, it refers to the frequency that a certain link (road or LRT link) is chosen as an element of path whereby people choose the minimum cost path.

The shortest paths which connect two nodes are calculated by the Dijkstra method. Thus if OD trip data in the target area is obtained, all traffic flows on all links can be calculated by summing up the through traffic (the frequency selected as an element of shortest path) which passes there.

In reality OD distribution of person-trips in a city can be obtained, for example, by public research data. Even if it cannot be obtained, OD trips can be estimated by spatial interaction models such as gravity or Huff model. If OD data is given, total characteristics in an entire city can be investigated under the assumption that people choose minimal cost route. This value is named Flow. If the Flow value of a link is large, it means that the link is chosen as the shortest route many times and consequently there is a high amount of through-traffic. If the Flow value is high, the link is used many times and vice versa. Using the two above-mentioned indexes, C_depth and Flow, we will analyze the effects of LRT development.

Figure 1:
Axial map vs route network map
Adaptability of the Flow Index

The region selected for this study is Maebashi city in Japan. Maebashi city, the capital city of Gunma prefecture, is a city with a population of 320,000 and is about 3 hours from Tokyo by a rapid-transit railway. It is 241 square kilometers in the area, and it has a private railway line (Jomo) and a JR (Japan Railway) line. Total number of stations is 13. The node number of route network map is 10836, and the link total number is 16404.

We calculated Flow and C_depth by setting costs as shown in Table 1. We assume that there is uniform OD distribution in the region. Generation and concentration values of OD distribution are assumed to be the same at all nodes.

Fig.3 shows the Route Network Map, including the road and railway network system. Travel time, train and LRT fares, gas cost, etc. are summed up, and all travel costs are converted to money value (yen) and calculated. The details are shown in Table 1. In Figure 3, road width is illustrated by line thickness. The thicker line shows the railroad line. Flow value is in a green to red color gradation. High value is in red and low value is in green.

Along the main streets, Flows are relatively high. With the distance from central area, Flow gradually decreases. In outlying areas and on narrower streets, Flow is low. Even in outlying areas it is still rather higher along main streets. The Flow value is related to road width. Furthermore, roads have a hierarchy system and the Flow value has strong relation the hierarchy and the distance from the center.

Here we examine the adaptability of the Flow index in comparison to the observed road traffic density which recorded by the city planning division of Maebashi city. Fig.2 is a scattering diagram showing the relation between Flow value and observed traffic density value. The correlation value is 0.7 and from this high correlation, we can see that the presented index faithfully explains traffic density at each road link.

In fig3, the result of C_depth is also shown. The areas where C_depth is particularly small are concentrated in the center. With the distance from the center, it gradually increases. It doesn’t have strong relation to the width of roads. Although the area along main roads has a relatively small value, it becomes larger value in the outlying areas. We can grasp the geographical accessibility of each area with this figure. Flow value indicates the traffic density, and C_DEPTH value indicates the geographical accessibility. From these two figures, the
route network map’s characteristics can be grasped visually for the entirety of Maebashi city.

Optimal Location of Route and Stops of LRT

In Maebashi city, the number of railroad users has decreased year by year while car traffic increases. In particular, users of the Jomo line have decreased year by year, and public transportation is going to fall out of use. Statistically, every household has more than 1.2 cars. However, local residents’ attitudes toward LRT are rather positive. About 80% of citizens have the opinion that they wish use LRT, if it existed and is convenient. Therefore LRT may be introduced for future operation.

Optimal Location Problem

To simplify the problem of optimal location, the cost is assumed to be proportional to travel time, and optimal location of LRT route and stops that minimizes the mean of the cost in the whole area is considered.

Here, a set of road nodes is denoted by $X=\{x_1,x_2,\ldots,x_n\}$, and a set of road links by $Y=\{y_1,y_2,\ldots,y_m\}$. The cost for pass link $y_i$ is denoted by $c(y_i)$. It is assumed that $c(y_i)$ is proportional to the time length for travel.
passage. If proportional coefficient is assumed to be $\alpha$, speed $v(y_i)$, and length of link $l(y_i)$, time length for passage can be described as $c(y_i) = \alpha l(y_i)/v(y_i)$. Speed $v(y_i)$ depends on road width or means of transportation on link $yi$.

$x_i$ are the origin nodes and $x_j$ are the destination nodes. A set of paths from node $x_i$ to $x_j$ is assumed to be $S_{ij}$; selected route $P_{ij}$ is the route which minimizes total cost and is denoted as follows.

$$P_{ij} = \arg\min_{S_{ij}} \sum_{y_i} c$$

A new LRT line whose links are $Y^*$ and stops are $X^*$ are added there. We address the problem such that $X^*$ and $Y^*$ should be located to minimize total traveling cost which is the sum of minimum costs of the routes of all nodes $x_i$ to all nodes $x_j$. This problem is the same as that for finding the optimal location which minimizes the sum of Flow value with costs on each link.

$$\min_{X^*, Y^*} \sum_{i} \sum_{j} \sum_{P_{ij}} c$$

If we are to lay the LRT line on an existent road, $X^* X$ and $Y^* Y$, and this problem becomes an optimal combinatorial problem to choose $X^*$ and $Y^*$ among finite set $X$, $Y$. But, there are an enormous number of combinations, and it is difficult to formulate constraint conditions. We thus work out the problem simplified as follows. The simplified problem becomes one of how to locate the network of LRT whose topology of line and stops is given.

Location of the network is determined not discretely, but continuously, and we thus consider the problem of optimal location in continuous space for the network. We assume that the shortest distance between 2 nodes can be measured as Euclidean distance, and the LRT line and stops are arranged there. Using private cars, people can travel by Euclidian distance. But the cost of car travel is relatively high. The LRT route is fixed and people cannot go straight to the destination if they use LRT, but they can move with less cost on LRT. They compare paths and choose the best path which minimizes the cost. If they can reach the destination with lower cost by way of LRT route, they use LRT. Otherwise, they don't use LRT. Whether the paths they choose include the LRT line or not depends on the layout of the LRT line and stations, the location of the origin and destination, and the geometrical relation of those locations. Fig 4.

The solution method for this problem is partly introduced in Kawasaki & Kishimoto (2005). Details are omitted in this paper, but stochastic descent method used in neural network models is used for solution.

**Optimal Location in Maebashi City**

To solve the problem in Maebashi city, we divided the whole of Maebashi city into 20 by 20 meshes and set uniform OD distribution there, and then set an initial route of the LRT network and the number of the stops. Some stations have connections with existent railways. We set travel cost $c$ by car per a unit distance as ten times of $c$ by LRT. Optimal location is found with the solution method.

Optimal layout of LRT lines was investigated in two types of lines with different network topologies. The first was a loop line, and the second was a combination of a loop and 3 separate lines. Initially LRT lines were located randomly. Through the iterative process of stochastic descent method, their optimal locations can be found. Strictly speaking, these may not be the global optimal, but local optimal,
because the problem is a non-convex non-linear problem. These results are shown in Fig.5.

Analyses: the Effects of Introducing LRT

Based on the two optimal layout results in section 3, two patterns of LRT lines and stops layout were set in Maebashi city so as to fit to an existent road network. A comparison of two LRT optimal layouts concerning Flow value and C_depth value yield the following results.

Flow values are calculated and shown in Fig.6~7. Fig 6~7 show flow and C_depth values at each link by color. Comparative total or average values are shown as listed in Table 2. Without LRT lines, the total length of the lines is 16.9 km. The total length of the LRT lines in type A is just 6.2km. In type B the LRT lines are a total of 22.6km long. Type B has a wider range network than type A. The average number of passengers in type B is larger than in type A. More people use LRT, and the average cost by car traffic is smaller than in type A. But the average travel time is slightly larger. This is because people tend to
choose LRT not for the reason of lower time cost, but for the lower money cost.

In reality, in practical situations, it takes more time to use LRT than private cars. When traveling by car, people don’t need transfer at stations, and don’t need to wait for trains. They can travel point to point and cars are inherently more convenient than LRT. In these case studies, not so many people use LRT lines. This is clear from the Flow map. The Flow on main streets is still red and there are not many differences from Fig 2 (the case without LRT). By connection of LRT and existent railway lines, usability increases, but the priority of car traffic is still the same. LRT requires more time to reach destination.

When we solved the optimal location problem in section 3, the cost of LRT was set quite small, but a more realistically set cost cannot be so small, we thus need to consider other conditions to promote LRT. Policies that could be considered in this regard include road-pricings, toll system for cars, additional tax for cars, subsidies for the public transportation companies, and discount fares for transportation.
Conclusion

In this paper, the location problem of lines and stations of public transportation have been considered. This problem requires an evaluation of traffic, and we have proposed the two indexes of Flow and C_depth, on the condition that people choose minimum cost path. We defined the optimal location problem which minimizes the total cost (sum of Flow by cost on each link), and provided an example of location using the case of Maebashi city. Detailed simulation of Flow and C_depth in Maebashi was shown under practical conditions and the effects of LRT were analyzed. The characteristics of route network map were clarified. But the Flow on LRT is much lower than the flow on main streets, and the effects are rather small in the simulation.

In further studies, simulation with other auxiliary measures, such as road-pricings and discount LRT fares, should be implemented. Through such simulations and optimal location studies, analysis of the effects of specific policy measures will contribute to the advancement of planning location study.
References


Table 1:
Details to calculate flow values and C_depth values

Table 2:
Comparisons of the effects of LRT (bottom)

<table>
<thead>
<tr>
<th>Cost</th>
<th>All costs are converted into amount of money and summed.</th>
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<tr>
<td>Time Cost</td>
<td>The time cost: 1000 yen per hour.</td>
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<tr>
<td>Time length for passing link</td>
<td>Time length required from the origin to the destination</td>
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<tr>
<td></td>
<td>= Σ length of link / speed on link</td>
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<tr>
<td>Road Speed</td>
<td>Car: 5km/h in case width under 1.5m, 10 km/h in case width 1.5-3m, 20 km/h in case width 3-5.5m, 30 km/h in case width 5.5-13m, 40 km/h in case width over 13m, and 80 km/h in highway</td>
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<tr>
<td>LRT Speed</td>
<td>Railway and LRT speed; 60 km/h in JR line, 40 km/h in Jomo-line</td>
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<tr>
<td>Time to Transfer</td>
<td>Transfer time: assumed to cost three minutes for boarding or exiting the railway. Neither the transfer time nor the amount of money from LRT to the railway is considered.</td>
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<tr>
<td>CO2</td>
<td>Exhaust cost CO2: 9450 yen/ton</td>
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<td>Gasoline Fee Current Cost</td>
<td>Car: Gasoline cost 15yen/km, Initial cost: 15yen/km</td>
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<td>Fare</td>
<td>Railway and LRT: 200yen /one trip.</td>
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</table>

<table>
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<tr>
<th>Total length of lines(km)</th>
<th>Number of stations</th>
<th>average passenger at stations</th>
<th>LRT Train and usage rate(%)</th>
<th>LRT Train and LRT Cost(yen)</th>
<th>Average Cost by Car (yen)</th>
<th>Average Traveling Time(m)</th>
<th>CO2 Emission (g)</th>
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