EVALUATION OF URBAN RAILWAY SERVICE AND FACILITY LEVEL
– A Basic Study Focusing on Japanese Local Metropolises –

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abstract:
The railway service and facility level of local metropolises in Japan are lower compared with that of European countries. One of the most important problems regarding the investment of railway in such areas is lack of a proper index of railway service and facility level. In this paper, we gave attention to access to CBD and proposed a new index by using a generalized cost concept. In the course of setting up the index, we were able to express accessibility between the distribution of inhabitants and the railway track network in metropolises by making use of the GIS.

1. FOREWORD

The railway service and facility level of local metropolises in Japan are lower compared with that of overseas, especially in the European countries. However, it has been required to enhance the railway service and facility level in local metropolises in order to reduce road congestion, to save transportation energy consumption, to reconstruct of urban structures, to provide the mobility for the traffic poor, and to improve the urban transport environment.

Lack of a proper index of railway service and facility level in local metropolises is one of the most important problems regarding the investment of railway in such areas: in the metropolitan areas such as Tokyo, Osaka, Nagoya, the index of the congestion rate leads to the execution of investment in the construction of new lines, four-track lines, and the increase of rolling stocks. In local metropolises, therefore, it is necessary to propose the new index of urban railway service and facility level.

In this paper, we would like to propose an index of urban railway service and facility level that can include the structure of population distribution in metropolises by using mesh data of the national census. And we would like to apply the new index to 29 local metropolises having a population of over 500,000 and verify its validity by comparing the modal share of railway.

In Japan, the unit of macroscopic analysis, which is related to urban railway service and facility level, has often been based on cities towns and villages: in this study, it is based on the unit of urban areas in consideration of the actual flow of passengers. The urban area has been defined as " 10% areas " in 1990 national census. (If the number of commuters and scholars those commute or go to school from B-town to A-city is over 10% of all commuters and scholars of B town, B town is defined as "10% areas" of A city.)

2. LIMIT OF TRADITIONAL TYPE INDEX

Traditionally, we have been using "railway route length per capita or in an area" or "number of stations per capita or in an area "as the index for measuring urban railway service and facility level. However, these indexes have not been able to properly explain the gap of modal share of railway in each local metropolises.

FIG. 1 and FIG. 2 show the relation between the number of stations per capita, number of stations in an area, and the modal share of railway in 29 metropolises. The modal share of railway has been calculated using data from in a 1990 national census report: the share is over 20 %, such as 26.8 %, 23.1 % in Sapporo and Fukuoka, 10% to 20 % in each metropolises, such as Sendai, Mito, Toyohashi, Himeji, Wakayama, Hiroshima, Takamatsu, and Kitakyushu, and less than 10 % in other metropolises.

However, the number of stations per capita or in an area does not always reflect the trend of the modal share of railway: for example, each metropolises, such as Toyama, Fukui, and Kochi have over 15 stations per a population of 100,000; such modal share of railway are less than 10 %, (9.1 %, 5.0 %, and 5.5 % respectively). The service and facility situation of other traffic means, which are under competitive relations with urban railways, has not been considered: however, the index of the number of stations per capita or in an area does not always properly explain the degree of passenger convenience of railway.

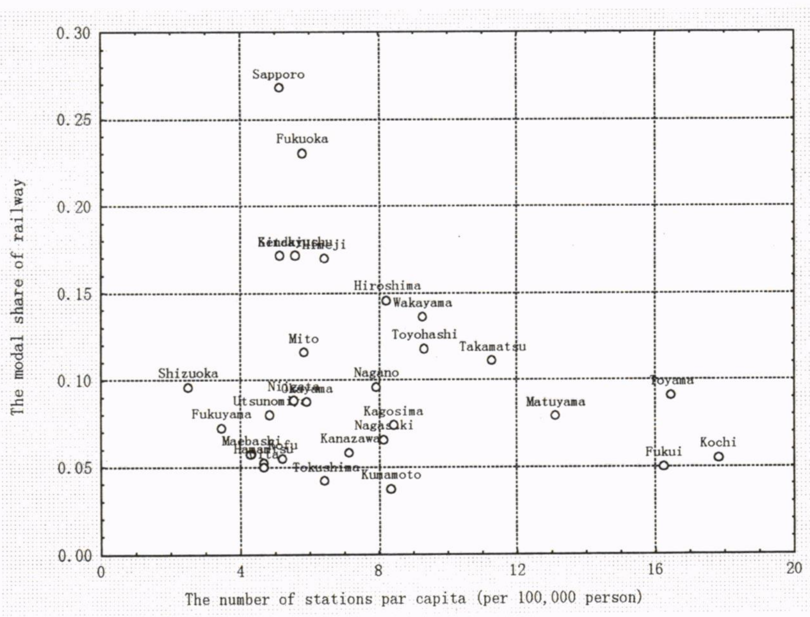

FIG.1 The relation between the number of stations per capita and the modal share of railway .

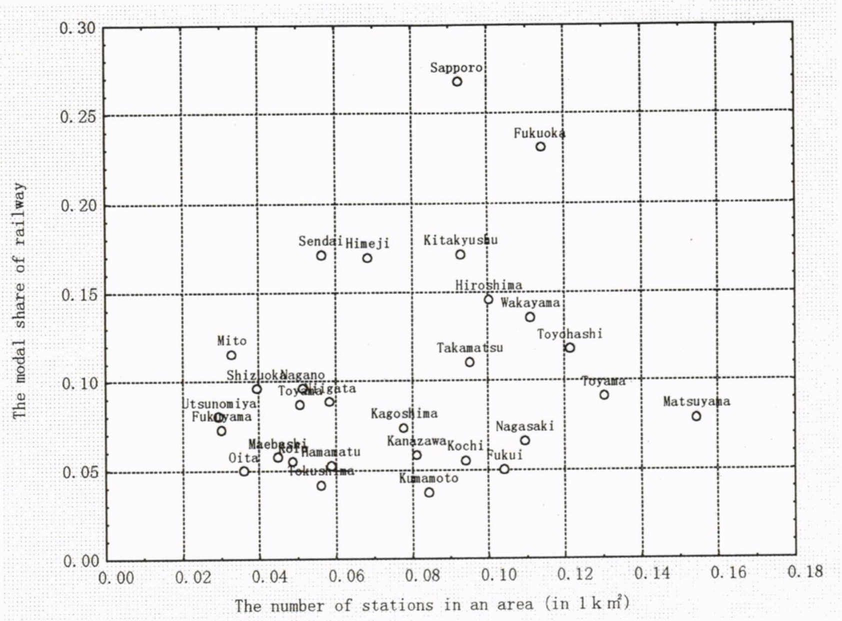

FIG.2 The relation between the number of stations in an area and the modal share of railway

3. PROPOSAL OF INDEX OF SERVICE AND FACILITY LEVEL BASED ON A GENERALIZED COST CONCEPT

Under such background, we propose in this study an index of urban railway service and facility level based on a generalized cost concept by using mesh data of 1990 national census: after having reviewed its validity by comparison and analysis of the modal share of railway.

When proposing the index of service and facility level, we have given attention to the access to CBD (Central Business District). In local metropolises, since commercial and business center is located in CBD, it is one of the most important tasks to secure better access to CBD from each district of such areas.

In this study, as an index of urban railway service and facility level, we propose an average of generalized cost by using railway tracks from each mesh of such areas to CBD. However, it is necessary to make proper adjustments for metropolises having large gaps in area when comparing the individual metropolises, because average generalized cost has a tendency of becoming higher in accordance with a larger area. In consideration of such a situation, as an index of expressing the scale of metropolises, we have given attention to the average distance (geographical distance) to CBD. We have made adjustments by dividing generalized cost by the average distance to CBD.

Definition of Each Index:

① Generalized Cost from Mesh i to CBD

$$GC_i = ACT_i \cdot ACTV + LHT_i \cdot LHTV + WAT_i \cdot WATV + EGT_i \cdot EGTV + F_i$$

GC_i: Generalized Cost from Mesh i to CBD (Japanese Yen)
ACT_i: Access Time from Mesh i to Station (minute)
LHT_i: Riding Time (minute)
WAT_i: Waiting Time · Transfer Time (minute)
EGT_i: Egress Time from Station to CBD (minute)
$ACTV$: Access Time Value (33 Yen / minute)
$LHTV$: Riding Time Value (26 Yen / minute)
$WATV$: Waiting Time·Transfer Time Value (45 Yen / minute)
$EGTV$: Egress Time Valuation (40 Yen / minute)
F_i: Fares for Railway Track (Yen)

※ Time Value has been calculated by Iwakura, S. (1994)

② Average Generalized Cost

$$AVG \cdot GC = \sum_i (GC_i \cdot POP_i) / \sum_i POP_i$$

$AVG \cdot GC$: Average Generalized Cost (Yen)
POP_i: Population for Mesh i (person)

③ Generalized Cost per Distance

$$AVG \cdot GCL = AVG \cdot GC / DIST$$

$AVG \cdot GCL$: Generalized Cost per Distance (Yen / km)
$DIST$: Average Distance from each Mesh to CBD (km)

Taking Sapporo for reference, we will show the figure (FIG.4) which consists of the distribution of inhabitants, station position and the generalized cost contour line (500 Yen interval) .

The following improvement is expected by expressing urban railway service and facility level by average generalized cost per distance based on the above definition.

1) Accessibility between the distribution of inhabitants and the railway track network in metropolises can be expressed by making use of the mesh data. The mesh data can express the urban structure of metropolises.

2) Difference of system characteristics (subways, streetcars, or others) can be expressed by calculating average velocity.

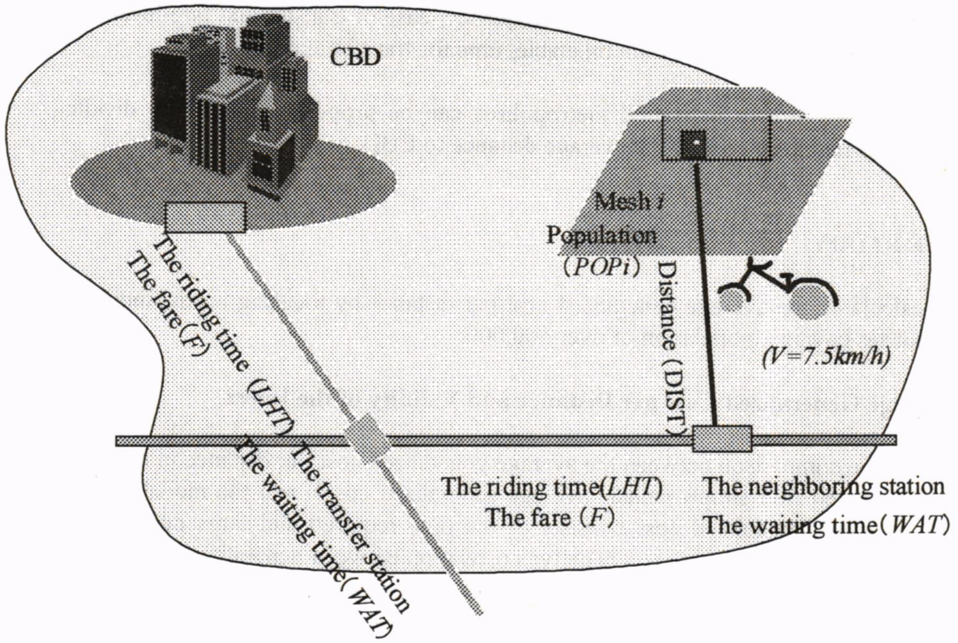

FIG.3 The structural element of average generalized cost

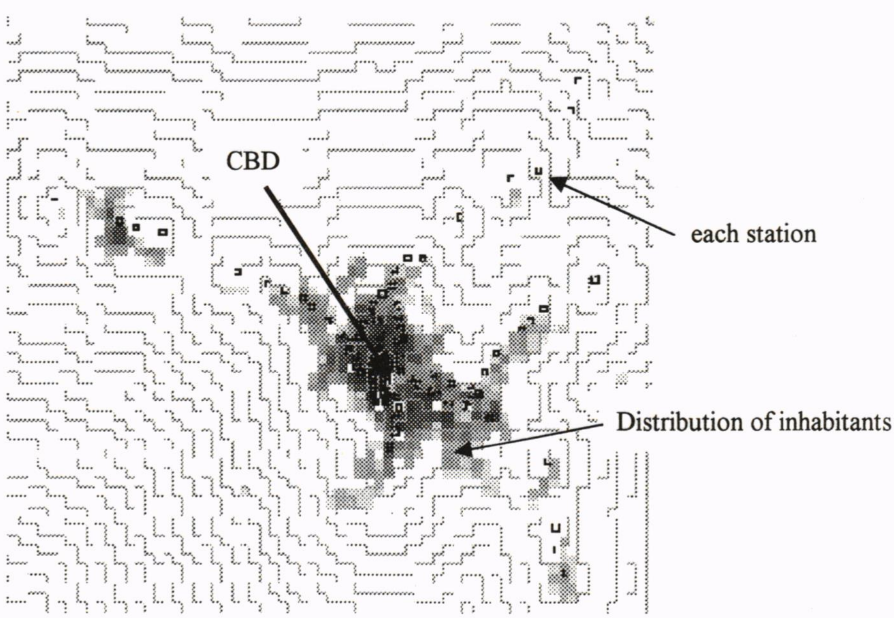

FIG. 4 Contour Line of generalized cost (Case of Sapporo Metropolis)

3) Service level in soft aspects, including frequency, ease of transfer and fare level , can be expressed by involving a train timetable, time for transfer and fares.

4) Difference of size in individual metropolises can be properly adjusted by dividing average generalized cost by the average distance to CBD.

4. CASE STUDY

We have calculated the average generalized cost per distance by focusing on the individual 29 metropolises having a population of over 500,000.

(1) Average Generalized Cost per Distance and Validity of the Index

FIG.5 shows the comparison between the average generalized cost per distance in individual metropolises (hereinafter simply called "average generalized cost") and the modal share of railway. Average generalized cost consists of the time required and fares due to using railway tracks. Therefore, there is a negative correlation between generalized cost and the modal share, since the higher a value of the average generalized cost is, the stronger the resistance against using railway tracks. Metropolises are largely divided into two groups, A and B; under the same usage of railway tracks, generalized cost of group A is relatively high, and that of group B is low. Group B includes metropolises, such as Kitakyushu, Shizuoka, Hamamatsu, and Fukuyama: in such metropolises CBD is located around JR's central station, and it is not necessary to consider the egress from central station to CBD; such metropolises are positioned as "any egress is not necessarily considered", and have been adjusted generalized cost.

We have carried out a regression analysis: by putting modal share of railway as endogenous variable and by putting average generalized cost as exogenous variable; both indexes are based on natural logarithm. Metropolises of group B have been implemented by dummy variable which shows as the metropolises in which "any egress is not necessarily considered".

The result of analysis is shown as follows.

$$\ln(RR) = \underset{(6.2006)}{13.75862} - \underset{(-7.2744)}{3.01747 \times \ln(GCL)} - \underset{(-5.0708)}{0.71384 \times DUMMY} \quad (1)$$

R=0.8232 R^2=0.6777 $\bar{R}^2$=0.6529

RR : Modal share of railway
GCL: Average generalized cost per distance (Yen/km)
DUMMY: Dummy variable for egress: Group A; 0, Group B; 1

When rewriting the above relative formula:

$$RR = 944697.5 \times GCL^{-3.01747} \quad \text{(Group A)}$$
$$RR = 462675.0 \times GCL^{-3.01747} \quad \text{(Group B)}$$

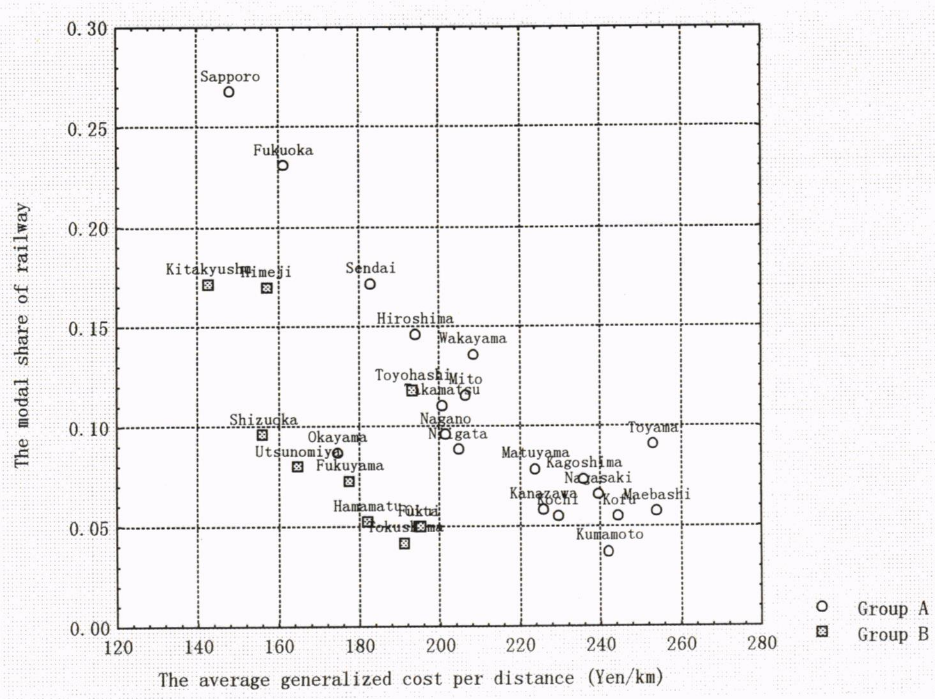

FIG.5 The comparison between the average generalized cost per distance and the modal share of railway.

If we assume that the modal share of group A coincide with that of group B, the following relative formula can be set up between the generalized cost of both groups.

$$GCL_B \,/\, GCL_A = 0.789331 \quad (2)$$

This is the coefficient of adjustment when railway service and facility level is compared between metropolises of group A and those of group B.

As a result of regression analysis , correlation coefficient between modal share of railway and average generalized cost becomes 0.82. Although this analysis has not included any factors which have shown service and facility level of other transport means, such as roads, as exogenous variable, correlation coefficient has shown such a high value. Based on this result, it is concluded that the average generalized cost has confirmed valid as the index of railway service and facility level in metropolises.

Table 1 shows a generalized cost in the individual metropolises. When such calculation is implemented, adjustments between group A and group B are made by using the adjustment coefficient indicated in formula (2). These metropolises are shown in ascending order of generalized cost.

These values express comprehensively the railway service and facility level in metropolises. As a result, Sapporo shows the highest value in service and facility level among the 29 metropolises, although it is the lowest at 148.3 Yen / km in the comprehensive index. Maebashi is the lowest in service and facility level, 254.1 Yen/km.

TAB.1 The average generalized cost to CBD

Order	Metropolises	Average Generalized Cost per Distance (Yen/km)	Average Generalized Cost (Yen)	Distance To CBD (km)	group
1	Sapporo	148.3	1,567	10.6	group-A
2	Fukuoka	161.4	1,748	10.8	group-A
3	Okayama	174.6	2,362	13.5	group-A
4	Kitakyushu	180.8	1,764	12.4	group-B
5	Sendai	183.0	1,916	10.5	group-A
6	Hiroshima	193.9	2,214	11.4	group-A
7	Shizuoka	197.9	1,363	8.7	group-B
8	Himeji	199.0	1,569	10.0	group-B
9	Takamatsu	200.5	1,845	9.2	group-A
10	Nagano	201.5	1,693	8.4	group-A
11	Niigata	204.6	2,482	12.1	group-A
12	Mito	206.5	2,112	10.2	group-A
13	Wakayama	208.3	1,602	7.7	group-A
14	Utsunomiya	208.6	1,725	10.5	group-B
15	Matsuyama	223.9	1,273	5.7	group-A
16	Fukuyama	224.9	1,728	9.7	group-B
17	Kanazawa	225.8	1,711	7.6	group-A
18	Kochi	229.4	2,321	10.1	group-A
19	Hamamatsu	230.4	1,476	8.1	group-B
20	Kagoshima	235.9	1,880	8.0	group-A
21	Nagasaki	239.4	1,632	6.8	group-A
22	Kumamoto	242.1	2,008	8.3	group-A
23	Tokushima	242.2	1,728	9.0	group-B
24	Kofu	244.6	1,917	7.8	group-A
25	Toyohashi	244.9	1,180	6.1	group-B
26	Fukui	246.7	1,811	9.3	group-B
27	Oita	247.5	1,916	9.8	group-B
28	Toyama	253.1	2,061	8.1	group-A
29	Maebashi	254.1	1,788	7.0	group-A

Note: Adjustments between group A and group B are made by using the adjustment coefficient indicated in formula (2)

(2) Structural Element of Average Generalized Cost

A generalized cost is regarded as a comprehensive index. This index mainly consists of four elements: access and egress time, riding time, waiting and transfer time, and fares. So, we have noticed station accessibility, average velocity of railway, the ratio of waiting and transfer time and fare per distance as indexes indicating these four elements.

When we pay attention to each element forming the comprehensive index, we can obtain a strong point and a weak point of the individual metropolises. FIG.6 indicates, by each separate element, service and facility level in metropolises of Sapporo and Maebashi. The value of each element is the standard value calculated in accordance with the following formula.

$$SV_i = (RV_i - AVG_i) / STD_i$$

SV_i: Standard Value of i - Element
RV_i: Measurement Value of i - Element
AVG_i: Average Value of i - Element (Average Value of 29 metropolises)
STD_i: Standard Deviation Value of i - Element (Standard Deviation Value of 29 metropolises)

In FIG.6, we arranged standard values so as to indicate that the optimum value is "5" and pessimum value is "0". As a result, Sapporo shows a well-balanced level in all items except fare level, especially accessibility. On the other hand, Maebashi is substantially inferior especially in accessibility, resulting in lowering the comprehensive evaluation.

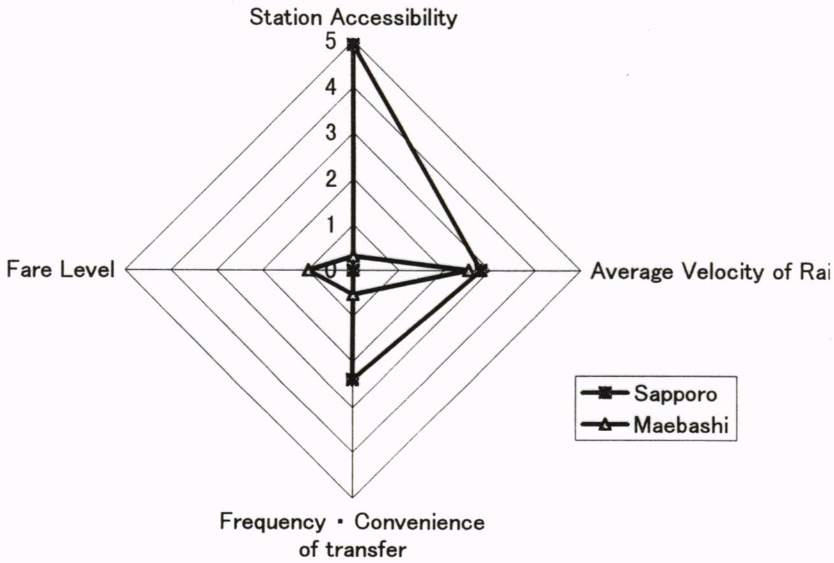

FIG.6 Evaluation of Service and Facility Level regarding Each Element

Note: We arranged standard values so as to indicate that the optimum value is "5" and pessimum value is "0".

(3) Station Accessibility (Element 1)

We evaluate service and facility level of metropolises with regard to the individual four elements structuring a comprehensive index. First, structural element 1 is station accessibility. Accessibility between the distribution of inhabitants and the railway track network in metropolises can be expressed by this element. FIG.7 shows an average distance of access to the station in each metropolises (average value per capita): the shortest in access, 2.18 km for Toyohashi, the second shortest, 2.25 km for Sapporo, and the following 2.26 km for Kitakyushu: on the other hand, the longest, 6.28 km for Toyama, and the second 6.03 km for Maebashi.

Especially, Toyama has a problem that existing stations do not construct an effective network for accessing to CBD, although Toyama received a high evaluation that it is one of the richest metropolises in terms of the number of stations per capita or in area.

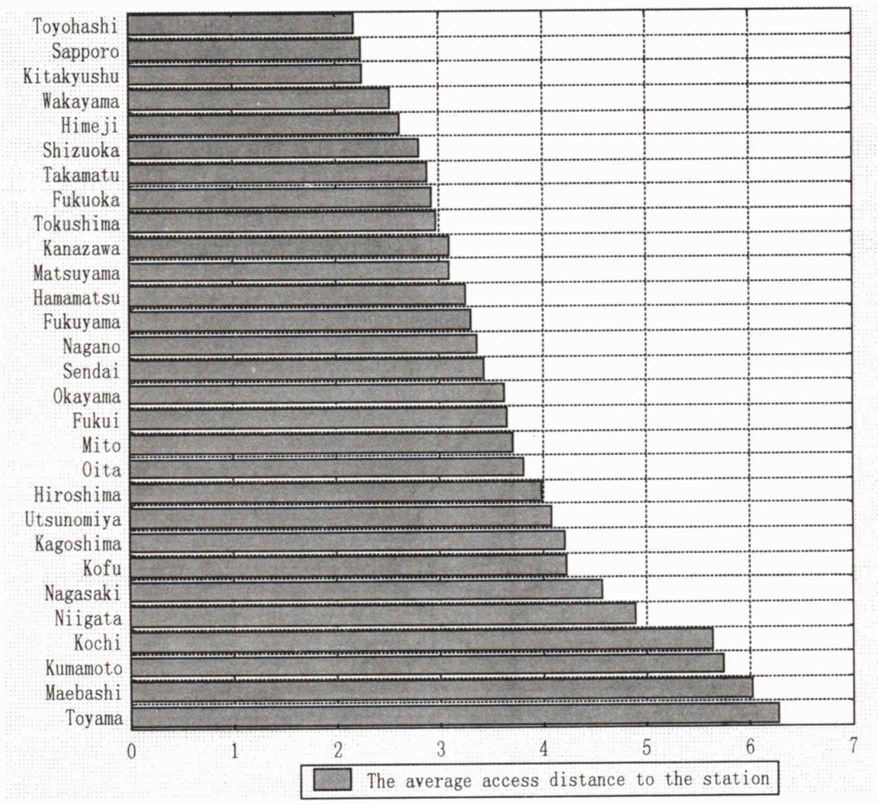

FIG.7 The average distance of access to the station
(average value per capita)

(4) Average Velocity of railway (Element 2)

Second, structural element 2 is average velocity of a railway track system: expressing high velocity; FIG 8 shows an average velocity of railway (average value per capita). As a result, there are some metropolises whose average velocity is over 50 km/h : metropolises having subway system, such as Sapporo and Fukuoka, where one is 40km/h: Nagasaki, Kumamoto, and Kochi, where main city areas are networked by streetcars, show a low velocity such as 15～25 km/h.

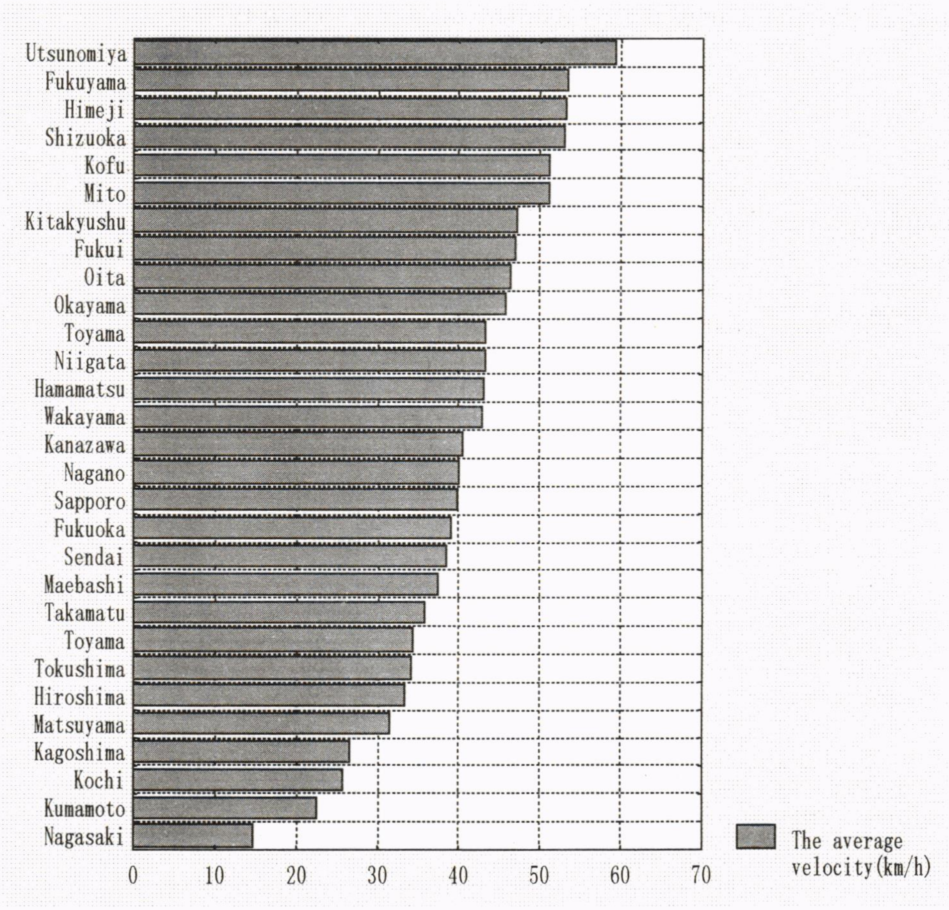

FIG.8 Average Velocity of Railway (average value per capita)

(5) Frequency and Convenience of Transfer (Element 3)

Third, structural element 3 is waiting and transfer time: expressing frequency and convenience of transfer. FIG 9 shows the ratio of waiting and transfer time in the individual metropolises (a proportion of waiting and transfer time against the total time between departure station to arrival station).

Metropolises exceeding 50 % at this rate, whose area's waiting and transfer time is longer than the riding time, are Mito, Maebashi, Niigata, Toyama, Kofu, and Nagano: indicating necessity for improvement in soft measures including train service frequency or harmonization of train timetables. On the other hand, the area at the lower rate is Nagasaki, who establishes a superior system in frequency mainly on a streetcar system.

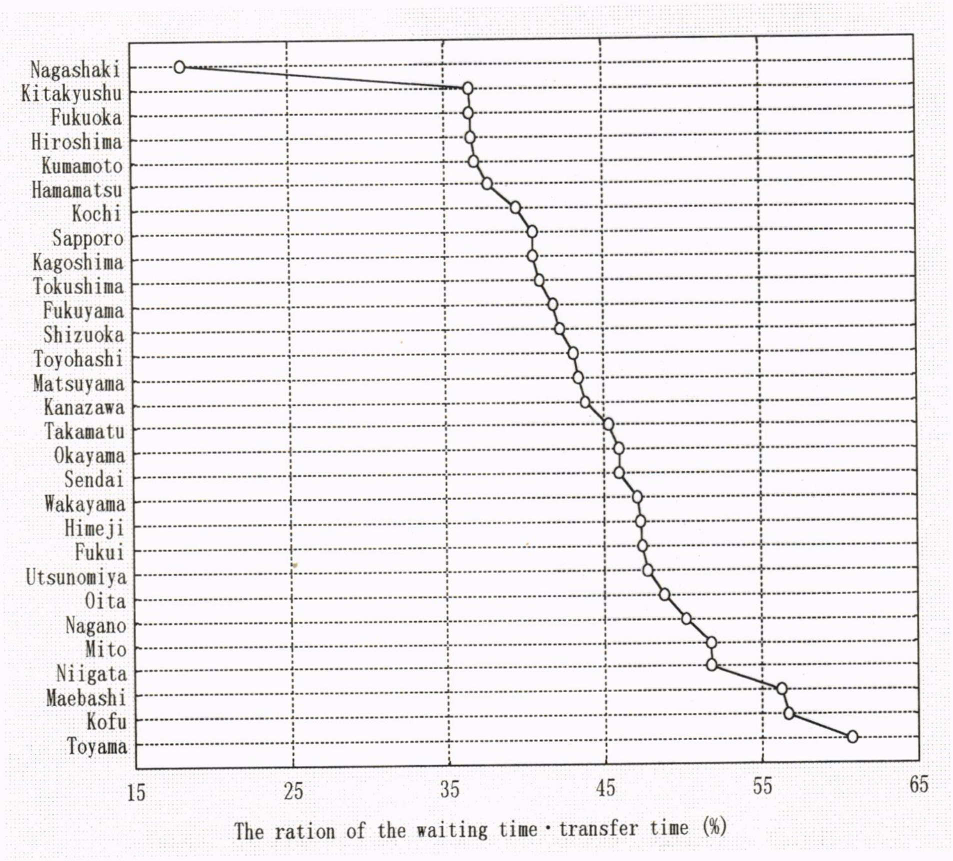

FIG.9 The ratio of waiting and transfer time
(average value per capita)

Note : Ratio of waiting and transfer time
=(Waiting and transfer time) / (Riding time + Waiting and transfer time)

(6) Fare Structure and Fare Level (Element 4)

Fourth, structural element 4 is fare structure and fare level: expressing passenger fare cost. FIG 10 shows fare rate per distance(average value per capita). Metropolises, indicating a comparatively higher rate of fares, where main city areas are networked by subways or local private railways, are Sapporo, Sendai, Maebashi, and Matsuyama. In particular, metropolises having plural railway corporations, such as Sapporo and Fukuoka, show a tendency of comparatively expensive fares against the same distance. On the other hand, an inexpensive metropolis is Nagasaki. It is due to 100 Yen fares on all streetcar.

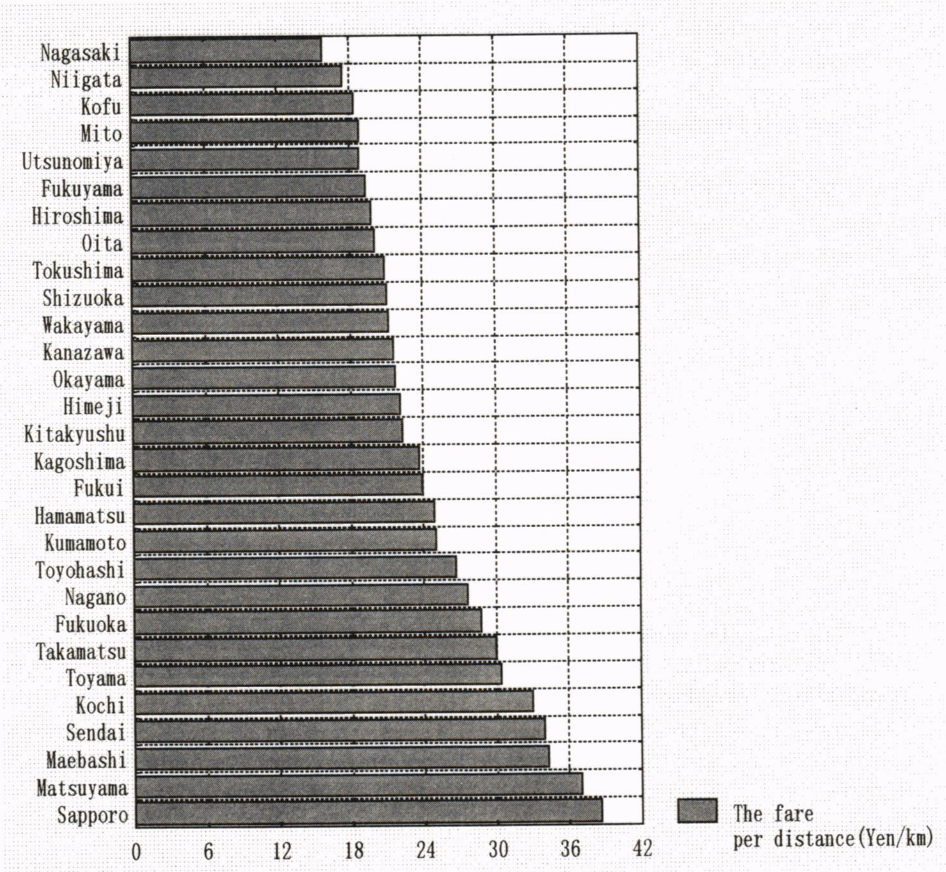

FIG.10 The fare per distance (average value per capita)

5. CONCLUSIONS

In this study, we have given attention to access to CBD, that is an important issue on transport policies in local metropolises, and have proposed a new index indicating an urban railway service and facility level by using a generalized cost concept. In the course of setting up the index, we were able to express accessibility between the distribution of inhabitants and the railway track network in metropolises by making use of the mesh data from the national census. The mesh data can express the urban structure of metropolises.

So, we have calculated this index for the individual 29 local metropolises, and confirmed the validity of the index by having analyzed correlation with the modal share of railway tracks. Further, we have evaluated urban railway service and facility level of local metropolises in relation to station accessibility, average velocity of railway, frequency and convenience of transfer, and passenger fare cost, and we could have obtained a strong point and a weak point of the individual metropolises.

From now, we intend to make a macroscopic analysis of the modal split structure in metropolises, as well as to carry out international comparison and evaluation related to urban railway service and facility level by calculating the index value in overseas metropolises.

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