METHODOLOGY OF CITY ANALYSIS FOR EVALUATING COMPACTNESS USING GIS

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Abstract. A method to evaluate convenience for daily life focusing on proximity and accessibility is proposed. First, a set of indicators related to convenience for daily life was developed, and comprehensive evaluation on physical environments of a city was conducted by utilizing GIS, statistical, and other surveyed data. Then, a proposed evaluation procedure with a weighting method using the age categories of residents was applied to clarify the areas that could attain high convenience. Additionally, the change of convenience associated with the change in future demographic characteristics was examined based on the estimated population and demographic characteristics in 2040. Potential "cores" were identified that can efficiently enhance the force of centralization needed for realization of a compact city. It was also suggested that the evaluation method developed in this research can be used as a tool to address and realize sustainability in cities.

Keywords. City analysis; compact city; GIS; big data.

1. Introduction

Japan is now rapidly becoming a depopulating society, and Japanese cities, which serve as centres of activity, are considered to be at the turning point that should aim at the sustainable city. Japan has suffered from a number of urban problems, such as urban sprawl caused by motorization, and the trend
of depopulation is exacerbating these problems. Under these circumstances, the idea of a "compact city" is attracting attention as an essential concept to realize a sustainable city. It is basically a model to improve the conveniences of daily life by contracting the city’s scale and functions in order to produce a city in which residents can live without the need for vehicles. Realization of a compact city can contribute to optimization of energy use by contracting the city’s functions and reducing the environmental load by promotion of public transportation (Kaido, 2001; OECD, 2012). In Japan, the concept of a compact city is regarded by the Ministry of Land, Infrastructure, Transport and Tourism as one of the important strategies towards urban revitalization and reconstruction, and this concept has been introduced in urban plans by the governments and local municipalities in Japan. However, only a few cases of practical restructuring of actual urban spaces have succeeded. In addition, considering the depopulation trend in Japan, detecting the core district that has high convenience for daily life from among existing urbanized areas, and investing in such districts intensively, would be the most efficient way to increase their force of centralization. On the other hand, it is also important to predict the future conditions of cities taking into account vital statistics, since frequently used city functions and the scope of activities mostly depend on the age levels of residents.

The purpose of this study is to evaluate the targeted city’s compactness focusing on proximity and accessibility, and to identify potential districts that can become the cores for a compact city. Moreover, population estimation was conducted based on the detailed data of small towns and districts in order to simulate the future evaluation of each district’s convenience corresponding to future changes in vital statistics.

2. Research method

2.1. TARGET AREA OF RESEARCH

Suita city, in Osaka, Japan, was selected as the target area. Suita city is one of several cities located around Osaka city and functions as a dormitory suburb. It was the first large-scale "new town" in Japan, but also has typical new-town problems, such as an aging community and an increasing number of superannuated buildings. However, Suita city is centrally located between Osaka, Kyoto, and Kobe, and the convenient access to such big cities because of the several railroads that converge in this city make it a popular residential area (Figures 1 & 2, Table 1). For this study, 181 cho-cho-moku units (the smallest address unit used in Japan) were selected. There are a total of 190 cho-cho-moku units in Suita city, but 9 cho-cho-moku units were excluded from the analysis because of unavailable population data.
2.2. EVALUATION INDICATORS USED FOR THE RESEARCH

The indicators to evaluate daily convenience of cho-cho-moku units by focusing on proximity and accessibility were proposed in our previous study (Takeda et al, 2013), and these indicators were modified and applied in the present study (Table 2). Table 3 shows daily facilities defined in this study and Table 4 shows the data and the resources used in this research. To calculate the straight-line distance from the facilities mentioned above to cho-cho-moku units, cho-cho-moku units’ representative points, which can be downloaded from the Position Reference Information (MLIT, 2013b), were used as base points, and Hubeny’s formula was utilized (Sugimoto, 2013).

Table 2. Evaluation indicators.

<table>
<thead>
<tr>
<th>Evaluation Indicators</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to Train Station</td>
<td>Required time to the nearest train station</td>
</tr>
<tr>
<td>Number of Buses</td>
<td>Total amount of average number of buses that come to the bus stops within the area reachable by 10-min walk* on weekdays</td>
</tr>
<tr>
<td>Accessibility to the City Centre</td>
<td>[Total number of trains that come to the stations located in the area and that are headed to the city centre of Osaka] / [Calculated required time]</td>
</tr>
<tr>
<td></td>
<td>= [Required minutes to the station] / [Required time spent on a train] / [(Number of trains) / (9.8 min**)]</td>
</tr>
<tr>
<td>Distance to Large-scale Retail Shop</td>
<td>Required time to the nearest large-scale retail shop that sells food</td>
</tr>
<tr>
<td>Average Distance to Daily Facilities</td>
<td>Average required time to 11 kinds of daily facilities</td>
</tr>
</tbody>
</table>

*Reachable area by 10-min walk: age 6-64 years = 600 m, age ≥65 years = 460m
**Compared to the railway trip that does not require changing trains, the one requiring people to change trains is more burdensome for people both mentally and physically, even when the total travel time is the same. According to a previous study (Mori et al, 1984), commuters sitting on a seat for 9.8 min feel the same level of load as those that transfer trains once.

Table 3. Daily facilities.

| Medical facilities               | Hospital (walk-ins welcome), Clinic                                     |
| Large-scale retail shop          | Large-scale retail shop that sells food (over 1,000 m²)                |
| Public facilities                | City hall and Branch office, Kindergarten and Nursery, Welfare facility for elderly, Post office |
| Convenience facilities           | Bank, Convenience store, Fresh food store, Drugstore, Dry-cleaning shop |
2.3. EVALUATION WEIGHTED BY AGE CATEGORIES

First, the population data were divided into two age categories: age category 1 (age: 6–64 years) and age category 2 (age: ≤ 5 and ≥ 65 years). Then, the scores calculated by the evaluation indicators were weighted using the age categories. For the calculation of the distance that people can walk within 10 min, 600 m was set for age category 1, and 460 m was set for age category 2. Thus, two results were obtained for each indicator. Next, based on the weighted scoring system shown in Table 5, each indicator obtained the weighted score for the following comprehensive evaluation. Then, the ratio of household, which includes those who are categorized in each age category, was calculated, and each evaluation score was multiplied by the calculated ratio for each area, respectively. The calculated evaluation scores for both age categories 1 and 2 were then summed for each indicator. Finally, the total scores for all indicators were calculated for use in the comprehensive evaluation.

2.4. ESTIMATED POPULATION IN SUITA CITY AS OF 2040

To visualize changes in the evaluation of convenience corresponding to the trends in residents’ demographic characteristics with the assumption of no renewal of buildings and tenancies, the demographic characteristics of 2040 were estimated. The estimation method developed by the National Institute for Land and Infrastructure Management was used as a reference (NILIM,
2013), and the estimated population was calculated for each choaza unit (the second-smallest unit of address used in Japan). Since smaller units of address can cause larger error when utilizing this estimation method, the estimated populations were corrected by the entire city’s estimated population of 2040 calculated by the National Institute of Population and Social Security Research (NIPSSR, 2013) in the final phase of the estimation procedure. Finally, statistical data from 2010 were selected as the current population data. Further, the population data of 2000 and 2005 calculated in 5-year groups for each small town and district were used for estimation. The estimated population pyramid is shown in Fig. 3.

2.5. COMPARISON OF EVALUATIONS OF CONVENIENT DAILY FACILITIES IN 2010 AND 2040

The evaluation indicators were adopted for the data set of 2040 in section 2.4, and the calculated results were used for comprehensive evaluation by the same method shown in section 2.3. The results of both data sets were compared and analysed in order to see if there will be any changes of convenience due to the change in residents’ demographic characteristics.

3. Results of adopting each evaluation indicator

Fig. 4 shows the results of adopting the evaluation indicators into age category 1. Examining the results of distances to train stations and that of the number of buses, it was found that the areas and districts with a large number of buses are distributed within a certain distance from train stations. Moreover, the areas and districts where Suita station, Momoyamado station, and Kita-senri station are located have a large number of buses, and it was revealed that these three stations function as a hub to link bus routes and railroads. Additionally, the distances to large-scale retail shops indicate that large-scale retail shops that sell food are distributed almost uniformly, but
there are some areas and districts that are not in proximity to large-scale retail shops in the southeast part of the city. Moreover, the average distance to daily facilities indicates that most of the *cho-cho-moku* units have 11 kinds of daily facilities accessible within 10 min or less. However, approximately one-third of the units have seven or less types of daily facilities accessible within 10 min or less in the value for sufficiency of daily facilities. Therefore, it cannot be said that the entire city has sufficient accessibility.

![Figure 4. Result of the evaluation indicators for age category 1 (6-64 years old).](image)

In the calculation for the distance that people can walk within 10 min, two distances are set according to the two age categories: 600 m for age category 1 and 460 m for age category 2. Consequently, most of the scores for
age category 2 are lower than those for age category 1, but there are some highly convenient areas or districts that obtained the same scores for both age categories 1 and 2.

4. Change of comprehensive evaluation with aging city

4.1. COMPARISON OF COMPREHENSIVE EVALUATIONS

Fig. 5 shows the results of the comprehensive evaluation for both the 2010 and 2040 data. The areas and districts located around Suita station, Minami-senri station, and Kita-senri station were evaluated highly in both 2010 and 2040, and other areas and districts that obtained comparatively high evaluation results are located around railroad stations.

Next, Fig. 6 visualizes the number of cho-cho-moku units including each level of scores while showing the percentage of the population aged 65 or older in each level. The percentage of the population of all units in Suita city aged 65 or older is assumed to become larger; therefore, the calculated scores decreased in 2040 as a whole. However, the ratios of aging in units with high scores based on the comprehensive evaluation of 2010 increase slightly more than others. Overall, the ratio of aging is assumed to become about 35% in 2040, and it does not show significant correlation with the results of the comprehensive evaluation. Moreover, examining the difference
between the scores of the comprehensive evaluation for 2010 and 2040 in Fig. 7, the highly evaluated units are assumed to have a small increase or decrease in the scores, but some of the other units have the same tendency.

4.2. COMPARISON OF EVALUATION WITHOUT THE INDICATORS RELATED TO RAILROADS

In the previous section, the cho-cho-moku units that are located around railroad stations obtain comparatively high evaluation results. The land prices around railroad stations are comparatively higher than others, and development tends to be concentrated in these areas in Japan. However, considering the variety of living conditions for various kinds of people, it is important to consider the development of the areas that are not located around a station or along a railroad. Hence, the scores of the comprehensive evaluation without the indicators related to railroads (distance to train station, accessibility to the city centre) were calculated, and the results are shown in Fig. 8. The difference between the evaluation of 2010 and that of 2040 is shown in Fig. 9. Without the indicators related to railroads, the areas around stations are evaluated highly, but also Yamada-nishi area and Saidera-minamigaoka area, both of which are located in the city centre, obtained high evaluations. Moreover, these two areas have high scores in the 2040 evaluation. However, looking at the differences in the evaluations for 2010 and 2040, the Saidera-minamigaoka area shows a drastic decrease. This result indicated that the convenience of the area will decrease in accordance with the change in demographic characteristics of the residents.
5. Conclusion

A set of indicators was developed to evaluate daily convenience focusing on proximity and accessibility. An evaluation procedure with a weighting method using age categories of residents was also proposed, and the assumption of daily convenience in 2010 and 2040 was assessed based on the estimated demographic characteristics. The following are the major findings of this study.

1) In Suita city, four highly convenient areas were found in the areas around train stations. Assessment based on population estimation towards 2040 shows that the decline in convenience in these areas due to an aging population is very small.

2) When excluding indicators related to railroads, two additional areas away from railroad lines also received high scores. However, one of those areas will suffer from lower convenience over time.

Based on the knowledge obtained in this research, the potential "core" that can efficiently enhance the force of centralization for Suita city has been identified as the city pursues a compact city. The method for evaluating daily convenience used in this study was developed based on the information about infrastructure. Future studies will need to include other factors in the evaluation.

The indicators suggested in this research are applicable to other cities in Japan, because the data resources used for evaluation are available in all cities in Japan. However, the indicator contents will need to be changed according to the characteristics of the target city. When the indicators are applied to a city in Japan having an independent commercial domain, for
instance, "accessibility to the city centre" should be changed to "accessibility or proximity to the workplace". On the other hand, when the indicators are applied to an overseas city, daily facilities must be considered because of differences in culture, lifestyle, transportation infrastructure and so on.

Endnotes

1. At first, referring to the walking speeds of people separated into 5-year age groups in a previous study (Akutsu, 1975), each walking speed for three groups (≤ 5 years old, 6–64 years old, ≥ 65 years old) was calculated. However, walking speed rate (1 = walking speed of those 6–64 years old, 0.75 = walking speed of those ≤ 5 years old, and 0.77 = walking speed of those ≥ 65 years old) was employed because the current situation is likely different from that in the 1970s. Because 0.75 and 0.77 are very close, the average (0.76) was multiplied by 600 m to obtain 460 m.

References