Is Compact Urban Spatial Structure Effective for Public Transportation Mode?

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Key Words : CC and SC, HD and LD, Characteristics of Travel behavior, Mode Choice, Accessibility, CAI

요 약

본 연구는 도시공간구조와 통행행태 및 접근성 분석을 통하여 어떠한 형태의 도시구조가 대중교통의 활성화에 보다 적합한지를 모색하는 데 목적이 있다. 분석대상도시는 한국과 일본의 도시를 대상으로 하였으며 지구(district) 수준에까지 분석의 범위를 증가함으로써 연구결과의 적용성을 높이고자 하였다. 비교분석구조로서 각 나라 및 도시에서 각각 컴팩트형도시 및 분산형도시, 고밀지구 및 저밀지구를 설정하였고, 통행행태분석은 로짓모형을 이용하였다. 또한, 접근성지표(CAI)를 이용하여 주거공간분포에 따른 대중교통에의 접근성을 분석하였다.

분석결과, 첫째, 고밀도시 및 지구의 거주자가 보다 짧은 통근거리로 나타났다. 둘째, 통근행태에 있어서 저밀지구의 거주자들이 훨씬 더 높은 자가용승용차의 이용율을 보이는 나타났다. 셋째, 고밀도시에서 자가용승용차의 시간 및 비용에 대중교통의 교차편업성이 저밀도시보다 큰 것으로 나타났다. 넷째, 접근성지표(CAI)의 분석결과, 대중교통으로의 접근성은 단순한 주거밀도보다는 밀도의 공간분포와 더 깊은 관련성을 갖는 것으로 나타났다.
I. Introduction

Interest in both energy efficient urban forms and ESSD(Environmentally Sound and Sustainable Development)\(^1\) has been increasing. Urban form has been conceptualized in terms of energy efficiency in three main ways: centralization in compact cities, decentralization in sprawled cities and decentralized concentration, which accepts the merits of both compact cities and sprawled cities.

The three conceptual categories of urban form refer to spatial structures that facilitate both the use of public transportation modes and green modes known as low energy consumption modes of transportation, such as bicycling or walking.

Previous efforts to research energy efficient urban forms have tried to find a relationship between spatial structure and transportation energy consumption. Little empirical research, however, has been conducted on Asian cities, and few analyses have been conducted at the block or district level. Furthermore, the behavioral characteristics of travelers, including pedestrians, have not been considered. Consideration of public transportation accessibility is also lacking.

The purpose of this study was to determine the characteristics of travel behavior and accessibility, in terms of spatial structure, between Compact Cities(CC) and Sprawled Cities(SC) and between High Residential Density Districts(HDs) and Low Residential Density Districts(LDs).

II. The Research Methodology

1. Research Process

Four steps have been undertaken in this study to analyze the characteristics of travel behavior and accessibility in terms of spatial structure:

Step1: classify cities and districts using spatial structure analysis methods

Step2: collect data

Step3: establish analysis structure

Step4: analyze the differences between the CC and SC and between the HDs and LDs

Step1 involved classifying the two cities, in terms of their spatial structure, as compact and sprawled cities. Songnam, Korea and Fukuoka, Japan were first classified as either a compact city or a sprawled city according to the values of their z-scores\(^3\), GINI coefficients, Mean of Deviation Distance (MDD), Standard Deviation of Deviation Distance (SDDD), and Skewness of Deviation Distance (SDD).

The GINI coefficients were 0.742 for Songnam and 0.397 for Fukuoka\(^4\). The MDDs, which indicate the average distance from zone centers to city centers, were 2,707 and 30,163 for Songnam and Fukuoka, respectively. The values of the SDDDs\(^5\) and SDDs\(^6\) represent the same results. The results from Step1 support the classification of Songnam as a compact city and Fukuoka as a sprawled city.

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1) WCED. 1987. Our common future
2) These are conceptual classification according to an analysis of the spatial distribution of population, facilities and etc. It was stated in chapter II, step 1.
3) The Z-scores of Songnam are ranked as 11th, 5th and 25th out of 79 cities for net population density, average residential population and average commercial population, respectively. Fukuoka’s Z-scores for the aforementioned attributes are ranked 12th, 11th and 10th out of 12 cities, respectively.
4) GINI coefficient ranges from 0 to 1, where 0 means perfect equal distribution and 1 means absolutely inequitable distribution.
5) SDDD describes the degree of population scatter. If values are large, the population is widely scattered. If the values are small, the population is compact. The values are based on the difference between the mean center point and each center point.
6) SDD represents the distribution of the population, and whether it is distributed in the direction of the population center.
Table 1) The Results of Spatial Analysis

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Cities</th>
<th>Songnam</th>
<th>Fukuoka</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>GINI coefficient</td>
<td></td>
<td>0.7472</td>
<td>0.3973</td>
<td>Population Density (person/m²)</td>
</tr>
<tr>
<td>Mean of Deviation Distance</td>
<td></td>
<td>2707.73</td>
<td>30163.938</td>
<td>Population (person)</td>
</tr>
<tr>
<td>Standard Deviation of Deviation Distance</td>
<td></td>
<td>2,012.73</td>
<td>27,558.66</td>
<td>Population (person)</td>
</tr>
<tr>
<td>Skewness of Deviation Distance</td>
<td></td>
<td>3.232</td>
<td>-1.020</td>
<td>Population (person)</td>
</tr>
</tbody>
</table>

Table 2) Descriptive Statistics for Data Surveyed

<table>
<thead>
<tr>
<th>S ng o n a m</th>
<th></th>
<th>Total</th>
<th>Missing data</th>
<th>Valid data</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td></td>
<td>723</td>
<td>176</td>
<td>547</td>
</tr>
<tr>
<td>Ehae- dong</td>
<td></td>
<td>121</td>
<td>32</td>
<td>89</td>
</tr>
<tr>
<td>Seoheyeon- dong</td>
<td></td>
<td>145</td>
<td>31</td>
<td>114</td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td>266</td>
<td>63</td>
<td>203</td>
</tr>
<tr>
<td>High1</td>
<td></td>
<td>121</td>
<td>38</td>
<td>83</td>
</tr>
<tr>
<td>Ikinomata- tubara</td>
<td></td>
<td>114</td>
<td>19</td>
<td>95</td>
</tr>
<tr>
<td>Low1</td>
<td></td>
<td>121</td>
<td>33</td>
<td>88</td>
</tr>
<tr>
<td>Iki- dani</td>
<td></td>
<td>101</td>
<td>23</td>
<td>78</td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td>457</td>
<td>113</td>
<td>344</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>F u k u o k a</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td></td>
<td>121</td>
<td>38</td>
<td>83</td>
</tr>
<tr>
<td>Kitama- danriti</td>
<td></td>
<td>114</td>
<td>19</td>
<td>95</td>
</tr>
<tr>
<td>Low1</td>
<td></td>
<td>121</td>
<td>33</td>
<td>88</td>
</tr>
<tr>
<td>Hosinhara- danritt</td>
<td></td>
<td>101</td>
<td>23</td>
<td>78</td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td>457</td>
<td>113</td>
<td>344</td>
</tr>
</tbody>
</table>

Note 1) The survey included questions regarding socioeconomic characteristics, commuting modes, commuter job location, travel time to work, frequency of non-work trips, etc.

Note 2) Here, the results of mode choice in person’s daily trips means revealed preference (RP). SP (Stated Preference) data means the results of choice for many choice sets or alternatives in specific situation virtually.

For a more detailed analysis, we tried to classify density at the district level for both cities using residential population density and Popdist (Population * Distance) within a radius of 1km from each subway station. 'Tong' and 'Machi' collected population and area data for each cell analyzed.

Step2 involved the collection of data for behavioral analysis. Data were collected from the residents of Songnam, Korea and Fukuoka, Japan. The survey was conducted in each city, and utilized face-to-face interviews and survey sheets. The survey was conducted between October 2000 and January 2001 in Songnam and during December 2000 in Fukuoka. There were 547 valid replies.

The comparative structure was established in Step3 (Figure 1). Finally, in Step4, we used the logit model and Complementary Accessibility Index (CAI) to conduct analyses of the characteristics of travel behavior and accessibility as affected by spatial structure between CC and SC and between HD and LD.

![Figure 1) Comparison Structure](image)

2. Complementary Accessibility Index

The CAI was only introduced as a tool to...
calculate accessibility. The cumulative curve, as shown in (Figure 2), was defined as the summation of accessible opportunities from a starting point to an arrival point in a certain time or distance.

To obtain the value of \( K_i \), the marginal distance or time must be established, and \( K_i \) would be changed by this marginal value.

\[
K_i = \int_0^D A(X)dx
\]  

(Figure 2) Accessibility Indicator \( K_i \)

However, if we adopt the residual area, \( Q_i \), as an accessibility indicator, neither marginal time nor distance are needed and the comparative analysis among regions is easier.

Therefore, in this research, the complementary accessibility indicator was adopted as Eq(2). A low value of \( Q_i \) represents high accessibility due to compact distribution.

\[
Q_i = \text{average} K_i = \int_0^\infty (1 - A(d)) \, dt
\]  

(Figure 3) The CAI Concept

III. The Characteristics of Travel Behaviors

1. Location of Workplace

Workplace location is an important factor to consider when attempting to achieve an energy efficient urban form. The jobs-housing mismatch creates long commuting distances and necessitates higher commuting costs.

The workplace of the LD residents living in the CC fell mostly within the city limits of Seoul((Figure 4)). For residents in the HD, however, there was a very high ratio of Central Business Districts(CBD) within the CC. This means that workers in the HD tend to commute shorter distances. Also, high-income commuters, who likely own homes and hold white-collar occupations, tend to commute over significantly longer distances (Yoon · Kim, 2003)

(Figure 4) Location of Workplace

2. Modes and Travel Time to Work

The ratio of people who use a private car to commute is generally known to be very high in cities and districts. The same results were found in the case study areas.

The use of private cars for commuting in the LD of the CC was 71.6% of individuals. The use of private vehicles for commuting in the
HD of the CC was comparatively low. Bus usage was higher in HD than in LD.

Workers in the CC and HD have shorter commuting times than those in the SC and the LD. (Figure 6). The percentage of HD residents in the CC who spent under 20 minutes commuting was 47.3%, while only 9.7% of the LD residents in the CC spent under 20 minutes commuting.

The percentage of residents who spent over 50 minutes commuting was 22.1% for the HD in the CC and 47.6% for LD in the CC. The percentage of commuters spending greater than 50 minutes commuting was 36.8% for HD residents and 42.5% for LD residents in the SC.

The results from the analysis of commuting modes and time indicate that CC and HD save energy more effectively than lower density urban forms by offering shorter commuting distances and energy efficient commuting modes.

3. Mode Choices and Elasticities

1) Establishment of models and modal split

In this section, we adopted a logit model to analyze travel behavior. Six functions were proposed to analyze mode choice behavior using the data surveyed and shown (Figure 2).

Two functions were proposed to compare the CC to the SC, and four models were established for two districts in each city. LIMDEP was used to estimate the parameters of the variables. The basic utility function of the logit model is described below.

① Utility Function of CC

\[ U_{mi} = a_{mi} + a_{Time_{mi}} + \beta_{Cost_{mi}} + \lambda_{SUBT_{mi}} + \phi_{Jloca_{mi}} + \chi_{Eco_{mi}} \]  

where, \( U_{mi} \) : utility of resident \( m \) for alternative \( i \)

\( i \) : 1(private car), 2(bus), 3(subway), 4(others)

\( Time_{mi} \) : commuting time of resident \( m \) for alternative \( i \)
\[ \text{Cost}_{mi} : \text{cost of resident } m \text{ for alternative } i \]

\[ \text{SUBT}_{mi} : \text{distance from subway station of resident } m \text{ for alternative } i \]

\[ \text{Jloca}_{mi} : \text{workplace of resident } m \]

\[ \chi_{Eco_{mi}} : \text{socioeconomic variables} \]

\[ a, \beta, \lambda, \varphi, x : \text{parameters of independent variables} \]

(2) Utility Function of SC

\[ U_{mi} = a_y + a_{Time_{mi}} + \beta \text{Cost}_{mi} + \lambda \text{Station}_{mi} + \varphi \text{Jloca}_{mi} + \chi \text{Eco}_{mi} \]

\[ U_{mi} : \text{utility of resident } m \text{ for alternative } i \]

\[ 1(\text{private car}), 2(\text{bicycle}), 3(\text{bus}), 4(\text{subway}), 5(\text{taxi}) \]

\[ \text{Station}_{mi} : \text{subway station of resident } m \]

* Other variables are same as above equation (1)

The values of parameters of the abovementioned utility functions were estimated as shown in (Table 3). All of the estimated coefficients have the expected sign however, not all the coefficients estimated were significantly different from zero using standard 5% or 10% levels of significance.

The value of \( \rho^2 \), which explains the fitness of the model, shows 0.2902 for CC and 0.2973 for SC. Therefore, the two regions’ models are statistically significant.

The model output a modal split for private cars in SC that was higher than in CC, but the public transportation modes in CC were higher than in SC (Table 4). The use of private cars for commuting in SC is higher than in CC, hence public transportation modes was effectively encouraged in the CC.

The higher percentage of private car use was predicted than was revealed by the data.

The results were mixed because data from both LDs and HDs were integrated. Therefore, it was necessary to analyze smaller areas to clarify the density characteristics between LDs and HDs.

2) Mode Choice Between LDs and HDs

(Table 5) shows the results from the calculation of modal split between HD and LD for each

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10) It means shortest approach route from their home
city. The differences were 2.9% for private cars and 5.9% for public transportation modes between the HDs in each city.

The differences for the LDs in the two cities were 10.4% and 6.1%, respectively. The results imply that residential density could be one of the factors that affect the use of public transportation.

(Table 5) Model Split between LDs and HDs

<table>
<thead>
<tr>
<th>CITIES</th>
<th>modes</th>
<th>HD(%) (A)</th>
<th>LD(%) (B)</th>
<th>A-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC(A')</td>
<td>P</td>
<td>71.6</td>
<td>89.6</td>
<td>-18.0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>4.5</td>
<td>4.3</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>12.5</td>
<td>6.1</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>others</td>
<td>11.4</td>
<td>0</td>
<td>11.4</td>
</tr>
<tr>
<td>SC(B')</td>
<td>P</td>
<td>68.7</td>
<td>100</td>
<td>-31.3</td>
</tr>
<tr>
<td></td>
<td>Bi</td>
<td>20.9</td>
<td>0</td>
<td>20.9</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>10.4</td>
<td>0</td>
<td>10.4</td>
</tr>
<tr>
<td>international difference between LD and HD (A'-B')</td>
<td>P</td>
<td>2.9</td>
<td>10.4</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>5.9</td>
<td>6.1</td>
<td>-10.2</td>
</tr>
</tbody>
</table>

note: P-private vehicle, B-bus, S-subway, Bi-bicycle, O-other modes

3) Elasticity of Time and Cost

The elasticity of the models represents the responsiveness of an individual’s choice probability to the change in the value of one or more attributes. Results from the direct elasticity analysis, presented in (Table 6), show that the elasticity of Time was higher than that of Cost in both cities. In the CC, the elasticity of time for subway usage was about three times higher than the elasticity of cost.

Results from the cross elasticity analysis, presented in (Table 7), show that the change of both time and cost for private cars generally affects the demand for public transportation modes in the CC. This means that the increasing cost of travel in private cars, resulting from congestion, increased parking fees and tolls, would yield an increase in the demand for buses and subways.

However, the change of time and cost for buses did not affect the demand for private cars as much as it did for the subways. The demand for buses affected by the alteration of subway travel times was very elastic.

Results from the cross elasticity analysis, presented in (Table 8), show that the cross elasticity of time was higher than that of cost. Despite the discrepancy, the elasticity was still very low for most modes. Changes to travel time and cost for private cars were elastic to the demand for other modes. Also, the change of travel time for bicycles was inelastic to the demand for private cars but elastic to the demand for buses.

This means that the users of private cars would not be likely to change their travel mode, even if time saving policies were implemented for
the bicycle. This result is slightly different than that found for the CC. Therefore, the user share of bicycles and buses would be diverted easily to each other in the SC.

4. Appraisal of the Accessibility to Subway

Accessibility is considered to be one of the most important factors in encouraging the use of public modes of transportation. Uneasiness regarding accessibility is a main defect of public transportation modes as compared with private cars.

Accessibility of public transportation from a certain district is related to population density distribution. Understanding the ease of access allows the evaluation of the probability of effectively encouraging public transportation use.

We wanted to determine which city is public transportation friendly in terms of accessibility. The CAI was used to establish this trait, and analyses were conducted at both the city and district levels.

Firstly, data were only collected within a specific buffer zone of subway lines to avoid bias from the direct comparison of two cities and districts that have different characteristics over a broader geographic range.

Buffer zones of 500m and 1000m around all stations were created, and statistics within the buffer zones were calculated for both cities using population data and geographic information system (GIS).\(^\text{11}\)

The populations within a radius 500m of the station were 34.6% and 24.0% of the total populations of the SC and CC, respectively. Within a radius 1000m of the station, the population represented within the area increased to 49.7% and 67.3% for the SC and CC, respectively.

Table 9) Population Ratio from the Stations

<table>
<thead>
<tr>
<th>Distance from each station(m)</th>
<th>SC Cumulative population percent(%)</th>
<th>CC Cumulative population ratio(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>500</td>
<td>34</td>
<td>24</td>
</tr>
<tr>
<td>1000</td>
<td>49.7</td>
<td>67.3</td>
</tr>
<tr>
<td>over 1000</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Total Population</td>
<td>1,270,513</td>
<td>924,383</td>
</tr>
</tbody>
</table>

Table 10) Accessibilities Estimation Results

<table>
<thead>
<tr>
<th>Cities and Districts</th>
<th>Ki</th>
<th>CAI</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC(up to 500m)</td>
<td>0.347</td>
<td>0.653</td>
</tr>
<tr>
<td>SC(up to 500m)</td>
<td>0.500</td>
<td>0.500</td>
</tr>
<tr>
<td>CC(up to 1000m)</td>
<td>0.429</td>
<td>0.571</td>
</tr>
<tr>
<td>SC(up to 1000m)</td>
<td>0.599</td>
<td>0.401</td>
</tr>
<tr>
<td>Namhansansung station</td>
<td>0.8691</td>
<td>0.6309</td>
</tr>
<tr>
<td>Songnam (up to 1000m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meinohama station, Fukuoka (up to 1000m)</td>
<td>0.45340974</td>
<td>0.5466</td>
</tr>
</tbody>
</table>

\(^\text{11}\) Each analyzed unit includes 30 or 100 families per unit, if it is on the boundary, the population is assigned according to the ratio of area.
Each area analyzed consists of a circular area with a 1km radius from each station center.

These areas include 327 blocks and 332 blocks for Namhansansung and Meinohama stations, respectively. The following table shows the results of the CAI. The CAI value for Namhansansung station was calculated to be 0.6309, indicating that the average total distance from home to station was about 631m.

The CAI for the Meinohama station was calculated to be 0.5466.

This is lower than the value determined for the Namhansansung station, indicating that the SC and LD have a high degree of accessibility as compared to the CC and HD; this is despite the sprawled structure classification assigned to the SC and LD.

IV. Summary and Conclusion

This study tried to determine the different characteristics of travel behavior and accessibility associated with the spatial structures of compact cities and sprawled cities. It also looked at differences between high residential density districts and low residential density districts. Analysis yielded the following results.

First, HD residents had a shorter commuting distance than the LD residents. This suggests that CCs and HDs save energy more effectively by offering shorter commuting times and energy efficient commuting modes.

Second, behavior models showed that the use of private cars for commuting in SCs was found to be greater than private car use in CCs, and that public transportation modes would be encouraged in CCs. These results are similar to other research findings that suggest that high-income commuters who are likely to own homes and hold white-collar occupations tend to commute over significantly longer distances (Yoon·Kim, 2003). Therefore, the CC and the HD rivaled the SC and the LD regarding the encouragement of public transportation.

Third, changes associated with the time and cost of commuting by private car generally affect the demand for public transportation modes in the CC. Also, analysis of cross elasticity suggests that changes of subway travel time affect the demand for buses very elastically. Therefore, effective policies to encourage the use of public transportation would include strong TDM policies, such as increased parking fees and tolls for private cars, as well as policies that would increase time savings associated with subway use. Such policies would contribute to a diversion from other transportation modes to the subway.

Fourth, according to the CAI, the use of public transportation modes was more heavily influenced by spatial distribution of population density rather than by simple density, even though the SC and LD were classified as inefficient urban forms in terms of spatial structure. Despite this finding, it was concluded that the CC and HD urban spatial structures more effectively encourage the use of public transportation modes. The spatial distribution of population was also found to be an important factor affecting accessibility and energy savings.

References


15. Songnam city (1996~9), Songnam Statistical Yearbook, Songnam Korea


