■ 論 文 ■

Is Compact Urban Spatial Structure Effective for Public Transportation Mode?

컴팩트형 공간구조가 대중교통수단의 이용활성화에 보다 효과적인가?

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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 좁힘으로써 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 통근거리를 나타냈다. 둘째, 통근통행에 있어서 저밀지구의 거주자들이 훨씬 더 높은 자가용승용차의 이용율을 보이는 나타났다. 셋째, 고밀도시에서 자가용승용차의 시간 및 비용에 대중교통의 교차탄력성이 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(LD[2]).

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

Indicators \ Cities	Songnam	Fukuoka	Unit
GINI coefficient	0.7472	0.3973	Population Density (person/km²)
Mean of Deviation Distance	2707.73	30163.938	Population (person)
Standard Deviation of Deviation Distance	2,012..73	27,558.66	Population (person)
Skewness of Deviation Distance	3.232	-1.020	Population (person)

〈Table 2〉 Descriptive Statistics for Data Surveyed

			Total	Missing data	Valid data
Collected Data			723	176	547
Songnam	High	Enhaeng-dong[1]	121	32	89
	Low	Seohyeon-dong[2]	145	31	114
	Subtotal		266	63	203
Fukuoka	High1	Ikinoma-tubara	121	38	83
	High2	Ikimatu-daidannti	114	19	95
	Low1	Iki-dannti	121	33	88
	Low2	Hosinohara-dannti	101	23	78
	Subtotal		457	113	344

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

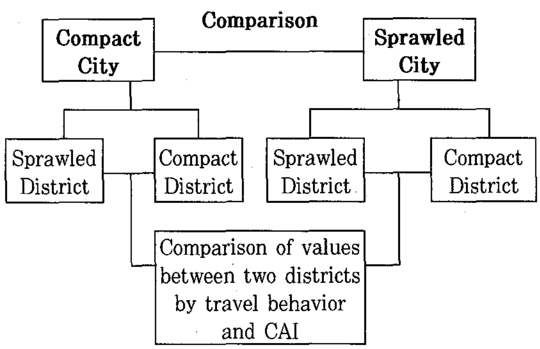
note 2) Here, the results of mode choice in person's daily trips means revealed preference(RP). SP(Stated Preference) data means the results of choice for many choice sets or alternatives in specific situation virtually.

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'[7] and 'Machi'[8] 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

2. Complementary Accessibility Index[9]

The CAI was only introduced as a tool to

point or away from the population center point. A high, positive value of skewness of deviation distance represents a centralized distribution, but a low positive value represents a decentralized population distribution. A negative value indicates a population distribution outside of a city.

7) The smallest applicable unit in the Korean address system.

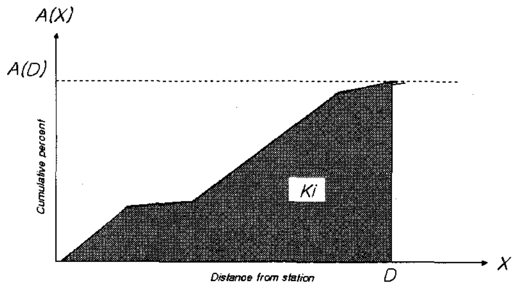
8) The smallest unit in the Japanese address system

9) Theoretical background was recreated from Satoru Hino, et. al(2000) and the simulation model was suggested by Shigeyuki Kurose

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.

$$K_i = \int_0^D A(X)dx \qquad (1)$$

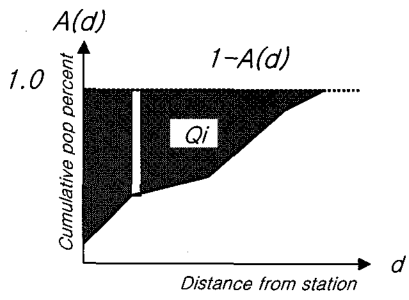


⟨Figure 2⟩ Accessibility Indicator K_i

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.

$$Q_i = average K_i = \int_0^\infty \{1 - A(d)\}dt \qquad (2)$$



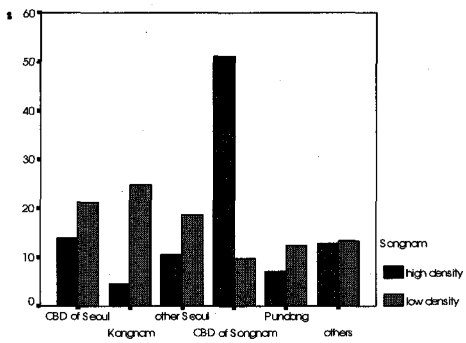
⟨Figure 3⟩ The CAI Concept

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.

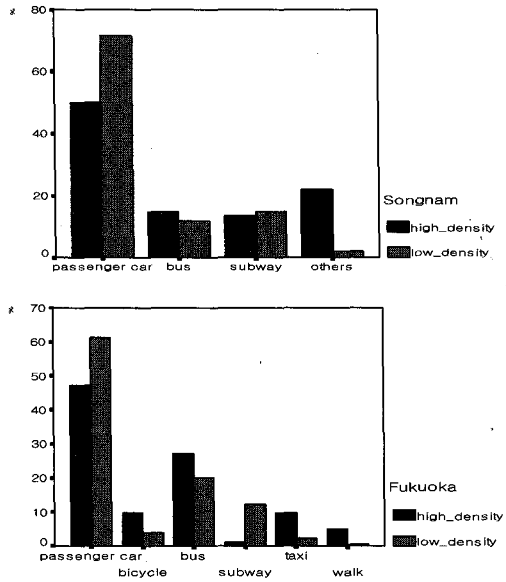
The use of private cars for commuting in the LD of the CC was 71.6%of individuals. The use of private vehicles for commuting in the

HD of the CC was comparatively low. Bus usage was higher in HD than in LD.

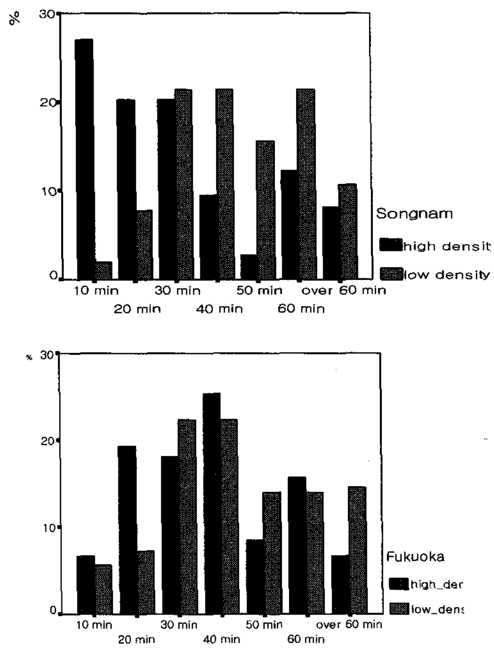
Workers in the CC and HD have shorter commuting times than those in the SC and the LD(〈Figure 6〉). The percentage of HD residents in the CC who spent under 20 minutes commuting was 47.3%, while only 9.7% of the LD residents in the CC spent under 20 minutes commuting.

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.



〈Figure 5〉 Commuting Modes



〈Figure 6〉 Commuting Time

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 〈Table 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 (3)

$$U_{mi} = a_{mi} + \alpha Time_{mi} + \beta Cost_{mi} + \lambda SUBT_{mi} + \varphi Jloca_{mi} + \chi Eco_{mi}$$

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

$Cost_{mi}$: cost of resident m for alternative i

$SUBT_{mi}$: distance from subway station of resident m for alternative i [10)]

$Jloca_{mi}$: workplace of resident m

χEco_{mi} : socioeconomic variables of resident m(age, sex, income, family members, car own)

$\alpha, \beta, \lambda, \varphi, x$: parameters of independent variables

② Utility Function of SC (4)

U_{mi} : $a_{Jj} + \alpha Time_{mi} + \beta Cost_{mi} + \lambda Station_{mi} + \varphi Jloca_{mi} + \chi Eco_{mi}$

U_{mi} : utility of resident m for alternative

i : 1(private car), 2(bicycle), 3(bus), 4(subway), 5(taxi)

$Station_{mi}$: 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 ρ^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.

⟨Table 3⟩ Estimation of Model for CC and SC

Variables	CC		SC	
	Coefficient	t-ratio	Coefficient	t-ratio
D_CAR	0.48481	0.698	0.80708	1.477
D_BI	-	-	2.5360	4.436
D_BUS	0.65411	2.130	1.0269	2.086
D_SUB	-0.26770	-0.742	-0.80279	-1.503
TIME	-0.10384	-3.021	-0.63352E-01	-6.389
COST	-0.99366E-03	-2.848	-0.56818E-03	-2.219
SUB_T(s)	1.0269	2.367	-	-
REG(p,b)	-0.66923	-1.839	0.24921	0.814
SEX(p)	-0.45251	-1.234	-	-
AGE(p)	0.79469	2.429	0.25459	1.063
EDU(p)	0.89527	2.522	-	-
INCO(p)	0.44179	1.341	-	-
H_FORM(p)		-	0.21140	0.907
J_LOCA(p)	-0.16594	-0.415	-0.62150	-2.388
FAMI(p)	0.54977	1.204	0.38435	1.268
SUBWAY(s)	-	-	0.64517	1.498
observations		203		344
Log-Likelihood		-199.7562		-387.9090
Restricted (Slopes=0)		-281.4178		-552.0372
Chi-Squared		163.3231		328.2564
Significance Level		0.00000		0.00000
ρ^2		0.2902		0.2973

* The value of Log Likelihood(L(0)) means the value when all parameters are zero(i.e., when the alternatives are assumed to have equal probability of being chosen)

⟨Table 4⟩ Modal Split by Model

	private car	bicycle	bus	subway	Total
CC(A)	85.2%	-	6.0%	8.8%	100%
SC(B)	90.4%	8.7	0.9%	-	100%
Difference (A-B)	5.2	-	5.1	-	

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

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〉 Modal Split between LDs and HDs

CITIES	modes	HD(%) (A)	LD(%) (B)	A-B
CC(A′)	P	71.6	89.6	-18.0
	B	4.5	4.3	0.2
	S	12.5	6.1	6.4
	others	11.4	0	11.4
SC(B′)	P	68.7	100	-31.3
	Bi	20.9	0	20.9
	B	10.4	0	10.4
international difference between LD and HD (A′-B′)	P	2.9	10.4	13.3
	B	5.9	6.1	-10.2

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

〈Table 6〉 Direct Elasticity

Variables	CC		SC	
	Time	Cost	Time	Cost
private Car	-0.578	-0.5202	-0.2258	-0.0968
Bicycle	-	-	-4.33	0
Bus	-4	-2	-3	0
Subway	-5.556	-1.6667	0	0
Taxi	-	-	0	0
Others	-10	-10	-	-

〈Table 7〉 Cross Elasticity of CC

variables \ mode		private Car	Bus	Subway	Others
private Car	time	-	2	4.4444	0
	cost	-	2	3.8889	0
Bus	time	0.1156	-	0.5556	5
	cost	0.0578	-	0.5556	0
Subway	time	0.4624	2	-	0
	cost	0.1734	0	-	0
Others	time	0.5780	2	0	-
	cost	0.5780	2	0	-

〈Table 8〉 Cross Elasticity of SC

variables \ mode		private Car	Bicycle	Bus	Subway	Taxi
private Car	time	-	0	23	0	0
	cost	-	0	10	0	0
Bicycle	time	0.12903	-	30	0	0
	cost	0	-	0	0	0
Bus	time	0.0323	0	-	0	0
	cost	0	0	-	0	0

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 oftravel 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)[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%

〈Table 9〉 Population Ratio from the Stations

Distance from each station(m)	SC Cumulative population percent(%)	CC Cumulative population ratio(%)
0	0	0
500	34	24
1000	49.7	67.3
over 1000	100	100
Total Population	1,270,513	924,383

〈Table 10〉 Accessibilities Estimation Results

Cities and Districts	Ki	CAI
CC(up to 500m)	0.347	0.653
SC(up to 500m)	0.500	0.500
CC(up to 1000m)	0.429	0.571
SC(up to 1000m)	0.599	0.401
Namhansansung station, Songnam (up to 1000m)	0.3691	0.6309
Meinohama station, Fukuoka (up to 1000m)	0.45340374	0.5466

and 67.3% for the SC and CC, respectively.

〈Table 10〉 shows the CAI calculated using the cumulative curve for the population ratio from all stations in the CC and SC.

To analyze CAI, we need population and distance from the stations to each analyzed unit. The population of each unit was calculated combining statistic data and digital map. The distance from each unit was calculated through network analysis of Arcview program.

For up to 500m, the CAIs of the CC and SC were 0.653 and 0.50, respectively. Up to 1000m, the CAIs of the CC and SC were 0.571 and 0.402, respectively.

The CAI results show that public transportation accessibility in the SC surpasses that found in the CC in both cases. However, public transportation accessibility in the CC was better than that in the SC for distances greater than 1000m.

Secondly, for analysis at the district level, the CAI was calculated for Songnam's Namhansansung station and for Fukuoka's Meinohama station.

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 1㎞ 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 researchfindings 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 affectthe demand for public transportation modes in the CC. Also, analysis of cross elasticity suggests that changesof 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 policieswould 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.

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