Impact of Individual Traits, Urban Form, and Urban Character on Selecting Cars as Transportation Mode using the Hierarchical Generalized Linear Model

Gunwon Lee¹, Yunnam Jeong² and Seiyong Kim*³

¹Research Professor, Department of Architecture, Korea University, Korea
²Visiting Professor, Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Italy
³Professor, Department of Architecture, Korea University, Korea

Abstract
This study investigates certain correlations of the impacts of the individual level, urban character, and urban form on individuals’ selection of cars as a means of transportation. It applies the 5Ds (density, diversity, design, destination accessibility, distance to transit), major elements of urban character and form which are believed to decrease the frequency of choosing to use a car. This expanded concept is widely understood to comprise means to promote walking while reducing automobile use. According to urban form theories, the compact city concept is deemed to reduce both vehicle travel and transport energy consumption. The study applies a hierarchical generalized linear model (HGLM), a statistical technique that simultaneously analyzes individual- and urban-level characteristics. The analysis results show that control at the individual level is required in order to properly analyze effective urban character and urban form elements; this enables a reduction in the choice of using a car. The 5Ds demonstrate a significant relation to decreasing the frequency of deciding to use a car. In contrast to existing research, this study drew more elaborate results by introducing a new research method for the more effective examination of individual- and urban-level characteristics.

Keywords: compact city; low-carbon city; 5Ds (density, diversity, design, destination accessibility, distance to transit); HGLM (Hierarchical Generalized Linear Model); urban form

1. Introduction
For some time now, global warming stemming from human actions, climate change, and various other environmental topics have been perceived as pressing worldwide issues. Since the Rio de Janeiro environmental conferences of 1972 and 1992, the paradigm of focusing first on economic growth has been shifting toward giving priority to sustainable development as a means to address these environmental and urban concerns. Such issues have brought considerable attention to bear on cities, since they consume 60 to 80 percent of global energy and, consequently, generate more than 80 percent of CO₂ emissions (SERI, 2009). Since cities are the main source of these problems, it is essential to address them. Cities provide the root source of many elements of human culture. In fact, changing the structure of cities may in itself provide us with a response to many environmental problems. Against this backdrop, the Nottingham Declaration of 2000 and the Hukuda Vision of 2008 each recognized the necessity of approaches at the urban level and sought solutions to cope with climate change.

About 10 to 30 percent of the CO₂ generated in cities stems from the transportation sector, and cars are considered the primary culprit. The purpose of urban research on reducing the preference for choosing cars over other means of transportation is to identify urban structures that stimulate or discourage the choice of taking a car. Previous studies have mainly focused on ascertaining whether a city with a compressed spatial structure shows a greater preference on the part of its residents for using cars as a transportation mode compared to another city without such a structure. However, accurate results have not yet been reported. This study approaches three aspects of the choice of cars as a transportation means by individuals in order to investigate their correlations and the related trends: the individual level, urban character, and urban form. This study seeks an answer to issues related to minimizing the preference for cars and determining which urban policies would be effective in transforming cities into low-carbon environments.

*Contact Author: Seiyong Kim, Professor, Department of Architecture, #314, Engineering Building, Korea University, Anam-dong, Seongbuk-gu, Seoul, 136-713, Korea
Tel: +82-2-3290-3914 Fax: +82-2-921-7947
E-mail: kksy@korea.ac.kr
(Received April 5, 2015; accepted February 12, 2016)
DOI http://doi.org/10.3130/jaabe.15.223
2. Literature Review and Hypothesis

2.1 Literature Review

As mentioned in the introduction, the main goal of a number of urban studies is responding to the question "Which form of city impacts the decision to use a car?" However, controversy still surrounds the response. Related studies have reported divergent results, as described below.

First, research has been reported which supports urban planning focusing on high density and complexity by concluding that increased density and complex land uses result in less car traffic. One of the most advanced studies in this regard is that by Newman & Kenworthy (1989), which concludes on the basis of an investigation of gasoline consumption and density in 32 cities worldwide that land use characterized by high density is indeed efficient for decreasing energy consumption. Cervero & Kockelman (1997) classify urban character and methods through the 3Ds (density, diversity, design) and conclude that these systems can be highly effective in reducing the choice to use a car. Ewing et al. (2008) concludes that it is reasonable to also consider the 2Ds (distance to transit, destination accessibility), the planning factors related to accessing transportation facilities, in addition to the existing 3D system proposed by Cevero.

Second, certain other research efforts contradict the above-mentioned studies. According to these studies, development with high density and complex features does not positively affect a reduction in the decision to use a car, and therefore high density and complex development are not universally sustainable urban structures. Gordon & Richardson (1989) proposed this opinion the year after the study by Newman & Kenworthy was released. They asserted that in the large urban area of Los Angeles it is not density, but rather the price of gasoline or the lifestyle of residents that show a greater effect on energy consumption. Owen (1991) raises questions regarding the energy efficiency of highly dense cities, citing the example of London. Rather, they actually increase distances and would instead result in greater car use.

2.2 Hypothesis

A review of the previous research shows that compact cities, cites with low car traffic, and sustainable cities cannot be equated with each other for the following three reasons:

First, as indicated by Handy et al. (2005), every region or city features unique factors that reduce car traffic. That is, there may be possibilities for cities to demonstrate a range of car choice patterns.

Secondly, most existing studies that analyzed the relationship between the 5Ds (the 3Ds proposed by Cevero & Kockelman plus the 2Ds appended by Ewing et al.) and preference for cars did not exclude the various factors which may be important in affecting car decisions, as indicated by Ewing & Cevero (2001) and Handy et al. (2005). Therefore, when individual factors are excluded from the study, the resulting conclusions may in fact differ from those preceding them.

Third, similar to the findings regarding cities in Europe (De Bourdeaudhuij, I. et al., 2003), Korean cities that are already highly dense and complex show a high likelihood of exhibiting different tendencies in terms of the correlation between the 5Ds and car traffic volume. The hypotheses to be proposed in this study on the basis of the questions above are as follows:

1. Car choice patterns differ among cities.
2. Individual variations including age, gender, and income affect car choice. That is, it is necessary to control such variables at different levels in order to examine the impact of variables at the urban level on car choice.
3. As shown previously, the factors known as the 5Ds do affect a decline in car choice.
4. South Korean cities with high density and complexity will have a more significant relation with the other three elements than with density and variety.

3. Analysis System

3.1 Analytical System

This study applies HLM as a tool for analysis in order to verify the hypotheses drawn from proceeding studies and overcome their limits. To that end, Model 1 (Base Model or Null Model) will first be used to ascertain the validity and suitability of HLM. Next, Models 2 to 4, utilizing variables from existing
research, will be applied as more appropriate models. Variables in this study are mainly comprised of those at the individual and the urban levels. Model 2 consists of those at the individual level, which simply indicate which cities are inhabited by which individuals. Model 3 includes variables at the urban level in addition to the variables from Model 2. Model 3, in particular, will apply the 3Ds introduced by Cervero & Kockelman (1997) and the 2Ds proposed by Ewing et al. (2008). Model 4, on which this study focuses, includes variables measuring urban form added to those from Model 3. The best model will be chosen based on a verification of the explanatory power of these three models. That model will be used to determine an answer to the common question from the existing research, 'What character and form of a city will reduce car usage by city dwellers?' The analysis system of this study is shown in the form of a diagram in Fig.1.

ArcGIS 10.3, Stata 13.0, and HLM 7.1 were used for the establishment and analysis of data in this study. For the analysis and interpretation of each variable, the minimum level of significance was limited to 10%.

3.2 Analysis Models

The study utilizes hierarchical linear modeling (HLM) for the simultaneous examination of two different models of individuals and their nested cities in order to verify the hypotheses above.

However, considering the fact that the dependent variable for the study is binary data juxtaposing the choice of using a car (coded "1") against that of public transportation (coded "0"), the study uses an HGLM (Hierarchical Generalized Logit Model), which combines the binary logit model (representative nonlinear model) and HLM. The models used in the study are expressed through the following formula:

\[
\text{Prob}(M_{ij} = 1 | \beta_i) = \Phi_{ij} \quad \ldots \quad (1a)
\]

\[
\log\left(\frac{\Phi_{ij}}{1 - \Phi_{ij}}\right) = LM_{ij} \quad \ldots \quad (1b)
\]

\[
LM_{ij} = \beta_{0j} + \sum_{k=1}^{i} \beta_{kj} X_{kij} + r_{ij}, \quad r_{ij} \sim N(0, \sigma^2) \quad \ldots \quad (2)
\]

\[
\beta_{0j} = \gamma_{00} + \sum_{s=1}^{m} \gamma_{s0} Y_{s0j} + \mu_{0j}, \quad \mu_{0j} \sim N(0, \tau_{00}) \quad \ldots \quad (3)
\]

\[
\beta_{kj} = \gamma_{k0} \quad \ldots \quad (k)
\]

Equation (1a) and equation (1b) are the odds of \( M_{ij} \), the probability of an individual's selection of public transport (=0) versus automobile traffic means (=1), substituted into logarithms. Therefore, these two equations can be replaced with \( LM_{ij} \).

Equation (2) is the model at a different level of selecting passage means. \( LM_{ij} \) is the dependent variable with the discrete form of choosing a car against public transportation; \( X_{kij} \) is the \( k \)th independent variable of the \( i \)th person in the city \( j \); \( \beta_{0j} \) is the intercept of the city \( j \); \( \beta_{ij} \) is the regression coefficient of \( X_{kij} \) in the city of \( j \); and \( r_{ij} \) is the random error in the \( i \)th person in the city \( j \). This assumes a distribution with an average of zero and a standard deviation of \( \sigma^2 \). Here, the regression coefficient \( \beta_{ij} \) shows how the choice of means of passage by an individual is distributed according to the socio-economic variables within the city \( j \). As stated above, the HGLM model, a model with level two having constant terms and level one having a dependent variable, and equation (3) show the idea.

Equation (3) is the urban level of the intercept. \( \beta_{0j} \) is the intercept of the city \( j \); \( \gamma_{00} \) is the intercept in the model at the urban level; \( Y_{s0} \) is the \( s \)th urban character or urban form variable in the city \( j \); \( \gamma_{0j} \) is the regression coefficient of \( Y_{s0} \), and \( \mu_{0j} \) is the random order of the city \( j \). It is assumed that \( \mu_{0j} \) has an average of zero and a standard deviation of \( \tau_{00} \) in the distribution. Similar to equation (3), equation (k) is an urban level model with a regression coefficient of \( \beta_{kj} \) rather than with the intercept, and shows the repetition of \( k \) as \( \beta_{k} \) repeats \( k \) times. Equation (k) should have the intercept of \( \gamma_{k0} \), urban level variable of \( Y_{s0j} \), and random error of the city \( j \) with \( \mu_{0j} \). However, this study did not consider the fact that introducing the independent variables leads only to the average difference among cities and not to the differences within each city, nor did it take into account the interaction between variables at the urban level and those at the individual level.

3.3 Variables Analyzed and Data Collection

Eight variables at different levels are used in the study, including gender, age, and income (Home ownership status). The analysis was performed by using the 3Ds proposed by Cervero & Kockelman (1997) and the additional 2Ds which are planning factors suggested by Ewing et al. (2008) in relation to accessibility to public transport.

In order to control the differences that may arise from addressing a wide range of cities, this study introduced two basic control variables: area ratio in the urban area and distance to the national capital of Seoul. Area ratio in the urban area is a variable designed to control the size of the city, while distance to the capital is a variable allowing the control of the geographic location of each city.

Furthermore, this study employed a range of variables for measuring the compactness of urban form by dividing the concept into degrees of imbalance, dispersion and clustering, together with the standard deviation distance as suggested by Tsai (2005). Table 1. shows the definition of each variable, including the variables described below.

The study utilizes micro data at the 2% level provided by the Micro Data Service System (MDSS) from the 2005 Population and Housing Census Data at the personal level. In the data, people over 18 years old able to drive and commute to a workplace or school were included. Next, samples including people who live in cities of the same urban level and who use cars or public transportation (subway, bus,
train) to commute were selected. Data were extracted with different variables from among 79 cities with a population between 60 thousand and 1.45 million in order to minimize the differences between the cities in terms of urban level. Finally, data concerning 93,081 people and 79 cities were employed for the study. The data for the descriptive status of each variable are shown in Table 2. and 3. below.

Table 1. Definition of the Variables

| Specification          | Operational definition                                                                 |
|------------------------|----------------------------------------------------------------------------------------|
| Individual-level       |                                                                                       |
| Gender                 | 0: Male, 1: Female                                                                     |
| Age                    | 18 to 75 years old                                                                     |
| Marital status         | 0: Unmarried, 1: Married                                                               |
| Commuter status        | 0: Commute, 1: Commute to school                                                       |
| Transit time           | 0: 0-4, 1: 5-9, …, 24: over 120 min.                                                  |
| Place of residence     | 0: Inner city, 1: Suburb                                                                |
| Home ownership status  | 0: Yes, 1: No                                                                          |
| Urban-level            |                                                                                       |
| Area ratio in the urban area | Urbanization area=Administrative zone area                                           |
| Distance to the national capital | Calculating the distance to the national capital using the geographical coordinates of each city |
| Population density     | Population=Urbanization area                                                           |
| Employment density     | Employment density=Total no. of employees=Urbanization area                             |
| Job-housing balance    | No. of employed=Population                                                             |
| Industrial mix         | No. employed in tertiary industry=Total no. of employees                                |
| Total road ratio       | Total length of roads=Urbanization area                                                |
| Local road ratio       | Total length of local roads=Urbanization area                                           |
| Local road density     | Density of crossroads=Total length of crossroads=Total length of roads                 |
| Design                 |                                                                                       |
| ACR**                  | SDD of mixed use buildings                                                            |
| AH***                  | SDD of multi-family residential                                                        |
| AB***                  | SDD of business facilities                                                            |
| Density of parking lots| Parking lot area=Urbanized area                                                        |
| Accessibility to bus   | No. of bus stops=Urbanized area                                                        |
| Accessibility to subway| Subway influence area=Urbanized area                                                   |
| Urban Form             |                                                                                       |
| Gini's Centrality Ratio| $\frac{1}{n} \sum_{i=1}^{n} x_i (y_i + 1) - x_i y_i$                                   |
| Entropy                | $\sum_{i=1}^{n} \log \left( \frac{1}{x_i y_i + 1} \right) N \log (N) / \log (x_i y_i + 1)$ |
| Moran's I              | $\frac{1}{n(n-1)} \sum_{i=1}^{n} \sum_{j=1, i \neq j}^{n} \frac{(x_i - \bar{x})(x_j - \bar{x})}{s_i s_j}$ |
| SDD                    | Refer to equation 4                                                                    |

Table 2. Ratio by Code of Dummy Coding Variables

| Variables                  | Ratio               |
|----------------------------|---------------------|
| Gender                     | 0: 62.10%, 1: 37.90%|
| Marital status             | 0: 26.68%, 1: 73.32%|
| Commuter status            | 0: 89.98%, 1: 10.02%|
| Place of residence         | 0: 77.79%, 1: 22.21%|
| Home ownership status      | 0: 87.68%, 1: 12.32%|
| Choice of car              | 0: 46.69%, 1: 53.31%|

Table 3. Descriptive Statistics of Numerical Variables

| Variables                  | Avg. | SD  | Min | Max  |
|----------------------------|------|-----|-----|------|
| Age                       | 39.04| 10.04| 18  | 85   |
| Transit time              | 6.77 | 3.68 | 0   | 24   |
| Area ratio in the urban area | 40.33 | 22.13 | 5.01 | 121.92 |
| Distance to the national capital (km) | 108.52 | 43.17 | 13  | 316  |
| Population density        | 9251.5 | 7746.2 | 1469.9 | 31517 |
| Employment density        | 2001.7 | 1561.7 | 279.81 | 7147.1 |
| Job-housing balance       | 0.22 | 0.07 | 0.12 | 0.55 |
| Industrial mix            | 0.6  | 0.16 | 0.26 | 0.88 |
| Density of crossroads     | 2.88 | 1.49 | 1   | 10.9 |
| Total road ratio          | 13   | 6.19 | 3.22 | 26.14 |
| Local road ratio          | 6.15 | 3.52 | 0.32 | 13.69 |
| ACR                       | 2.31 | 0.67 | 0.91 | 4.15 |
| AH                        | 3.60 | 1.00 | 1.21 | 7.67 |
| AB                        | 0.96 | 0.51 | 0.37 | 1.97 |
| Density of parking lots   | 0.2  | 0.17 | 0.02 | 0.72 |
| Accessibility to bus      | 2.08 | 2.60 | 0   | 15.35 |
| Accessibility to subway   | 0.05 | 0.14 | 0.09 | 0.95 |
| Moran's I                 | 0.14 | 0.21 | -0.24 | 0.93 |
| SDD                       | 6.22 | 2.49 | 1.45 | 12.51 |

4. Analysis Results

4.1 Validity Review of Applying the HLM Method

A preliminary inspection of the meaningfulness of HLM should first be undertaken. This can be ascertained by examining whether individuals’ car use differs by city. According to the result, it can be determined whether to use HLM or a general regression model. One model used for this process is called a null model, which is presented in this paper as Model 1.

If the intercept of this model is not significant, then car-use patterns among individuals are similar between cities. Such homoscedasticity is one of the fundamental assumptions in traditional regression analysis. Therefore, if there is homoscedasticity, general regression analysis can be applied. On the other hand, if the intercept is significant, each city shows distinct scedasticity, or in other words, the data has heteroscedasticity. This violates the assumption of general regression analysis, and therefore this technique cannot be used and HLM should be applied.

An analysis of the results of Model 1 shows that individuals’ car use patterns do in fact differ among the cities in question. The significance level of the constant was 0.0000 (less than 0.01), indicating it was meaningful at the 1% level (Table 5.). Through this, the authors were able to verify that in this study HLM

\[ SDD = \sqrt{\frac{\sum_{i=1}^{n} P_i (x_i - \bar{x})^2}{\sum_{i=1}^{n} P_i} + \frac{\sum_{i=1}^{n} P_i (y_i - \bar{y})^2}{\sum_{i=1}^{n} P_i}} \]  

(1)
does in fact prove to be a more appropriate method than general regression analysis. It was also confirmed that car use patterns by individuals differ among cities. In other words, cities affect individuals’ use of cars.

4.2 Model Comparisons

This study employed four models including the null model. An examination of the final model, Model 4, will follow a comparison between each model’s reliability, explanatory power, degrees of freedom and other important factors. In order to review model fit by comparing nested models, this study adopted the $\chi^2$ test using changes in deviance and degree of freedom in relation to each model. In the case of Model 3, since the degree of freedom decreased by 15 and the deviance dropped by 102.8 in relation to Model 2, findings were significant at the 95% significance level. As for Model 4, the degree of freedom decreased by 2 and deviance fell by about 29.9, which also indicated a significant difference at the 95% level. Findings of the $\chi^2$ test confirmed that Model 3 was more suitable for use than Model 2, and Model 4 more so than Model 3. This also verified not only the validity of introducing the already-tested HLM method, but also the validity of the model that assumes the existence of a mean difference ($\mu_o$) between cities, which was introduced at the urban level.

With respect to the explanatory power of the models, HLM analysis commonly performs a procedure for selecting a model with greater explanatory power by conducting intra-class correlation (ICC) analyses and comparing the ICC values of each model. ICC analysis is computed by comparing $\sigma^2$ (level-1 variance) and $\tau_{00}$ (level-2 variance), through which the explanatory effect can be observed. Moreover, this can measure the explanatory effect resulting from the introduction of additional independent variables in each model by comparing the ICC values of the models. According to Snijers & Bosker (1999), however, it is impossible to estimate level-1 variance through a logistic regression model, since it cannot measure coefficients or error variance. Therefore, for all logistic regression models, the error variance is always fixed to the same number, calculated as $\pi^2/3=3.29$ ($\pi=3.14$), based on which ICC values can be substituted. Computation of the replaced ICC values resulted in a figure of 12.88% for Model 1 (null model). In other words, 12.88% of individual automobile choice was determined by urban character and form, with individual traits responsible for the remainder (87.12%). Observing the decline in ICC values following the input of independent variables yielded the following results: the 12.88% deviance in Model 1 through in-group correlation fell to 3.24% and 2.09% in Models 3 and 4, respectively. This highlighted the strong effect of adding variables related to the 5Ds and urban form. In other words, the addition of variables in serial order from Models 2 to 4 exerted considerable control over the correlation effect among individuals living in the same city. Although this study failed to find and introduce a variable able to lower the deviance in Model 4 to the point of insignificance, it was undeniably a meaningful model in that it reduced the ICC value by 10.79%. Such a result might be obtainable through the introduction of correlation variables between individual-level variables and urban-level variables together with additional independent variables. However, further studies must be carried out in the future in order to evaluate the introduction of interactive and independent variables.

| Model | Deviance | d.f. | ICC | $\tau_{00}$ |
|-------|----------|------|-----|-------------|
| Model 1 | 250464.3 | 12.88% | 250434.4 | 61 |
| Model 2 | 250567.1 | 268675.4 | 2.09% | 59 |
| Model 3 | 250564.7 | 12.19% | 250465.8 | 61 |
| Model 4 | 250547.5 | 59 |

4.3 Model Diagnostics

Model diagnosis was conducted for Model 4, the model eventually selected by means of the above process. In the diagnosis, multicollinearity and residuals (one of the errors) were examined, and among residuals the three characteristics of normality, independence, and homoscedasticity were examined.

First, in order to verify the multicollinearity of Model 4, the Variance Inflation Factor (VIF) of urban-level variables was examined. Employment density shows the greatest VIF at 8.83, and its mean value is 4.01. This figure is less than the standard level of 10, indicating Model 4 does not demonstrate multicollinearity.

| VIF = 8.83 | 2.09% |
| 4.01 | 25.00 |
| >5.99 | >25.00 |

Second, as for residuals, the normality of residuals was reviewed as a starting point. For the examination of normality, tests for skewness and kurtosis were performed, the results of which were all 0.000 and thus revealed normality. A histogram of residuals that can illustrate this result is shown in Fig.2. To allow a stricter analysis, a Shapiro-Wilk test was carried out as well. The $p$-value of the result was 0.0784 (greater than 0.05).
than 0.05), which could not dismiss the null hypothesis, and therefore it presented a normal distribution. Although this figure is close to a normal distribution, it is not precisely identical. This result is reflected in the histogram. As for the independence test for residuals, an autocorrelation test was conducted. The coefficient of the results ranged from 0.046 to 0.06, and its absolute value was less than 0.3, indicating that the residuals are independent. For a more refined examination, a Durbin-Watson test was performed. In this case, the absolute value of the coefficient was 1.8944, slightly greater than 1.8. These two tests showed that the residuals are independent of each other.

Lastly, a Breusch-Pagan test was carried out for homoscedasticity. The P-value of the result was 0.3582 (greater than 0.05), which could not dismiss the null hypothesis, and therefore it showed homoscedasticity. As a result of tests for multicollinearity and residuals, it was confirmed that Model 4 is appropriate for analysis. In the following section, analysis was performed using this model.

4.4 Analysis of Results
The results of the analysis of the variables are as follows. All of the variables show significance at the individual level, and the impact is higher than a certain level even though the coefficient is not especially significant. This result indicates that studies that simply examine the relationship between car choice and urban form variables, such as density, character, urban form, and spatial structure without controlling variables not related to a different level cannot help but obtain errors.

According to the variables at the individual level, more women than men use public transportation, at a very high level of −1.757. Moreover, it is found that older people use cars more often, but their power is very slight. It is judged that the choice of using a car increases as people age and decreases once a particular age is exceeded. Marital status shows a similar trend in that married people have a 1.5 times greater likelihood to use cars than do their single counterparts.

The variables at the urban level are as follows. First, density shows that car choice increases with larger urban areas. Higher density means greater use of public transportation, while higher density of employment results in more car choice. The two variables of density are significant and the changes in Models 3 and 4 are not large. This leads to the conclusion that the density variable shows a particular relationship with car choice, regardless of controlling the urban form variables. In addition, it is determined that car choice declines with higher density and narrower urban area. However, the influences are −0.001 and 1.028, which are in actuality minuscule.

As for the diversity variables, none were significant. In particular, standard error was substantial. This is due to the fact that differences in the diversity index were not great by region, but the difference in choosing to use a car was. The result that most of the diversity variables were not significant is contrary to research results from other countries, and it is concluded that this finding is a reflection of unique South Korean circumstances.

In addition, it is found that increasing the density of crossroads (one design factor) is more effective for reducing the car option than is extending roads.

For the aspect of destination accessibility, it is determined that higher accessibility results in higher car choice. However, due to the relationship with the urban form variables, the significance and correlation do in fact change after controlling these variables. In addition, the two residential-related variables and the one business-related variable show correlation changes both before and after managing the urban form variables. This indicates that changing residence to urban mixed residence and improving accessibility by pursuing high density are highly effective for discouraging the choice to use cars when urban form is considered. Meanwhile, the effects on the accessibility of business facilities are fairly high at -12.622 and -0.640, but it is concluded that they are mainly similar to the results of changing the urban form. That is, if it is difficult to alter the urban form, then it is effective to increase the density of business facilities in order to reduce the choice of using a car.

Next, accessibility to public transportation shows that both bus and subway are effective in decreasing the choice to use a car. Accessibility to bus and subway are −1.023 and −1.124, respectively, both decreasing the choice of cars.

Lastly, Gini's centrality ratio, Entropy, and Moran's I, known as indicators for measuring urban form, all demonstrate that the car option shrinks with more imbalanced, more concentrated, and shorter Standard Deviation Distance (SDD) in a city, confirming that a compressed city is indeed effective in terms of reducing the car option.

5. Conclusions and Discussion
Verifying the hypothesis configured above on the basis of the study's results leads to the following conclusions. First, the choice of making use of cars shows differences between cities. (Model 1) Similar to the results of existing research, the findings here demonstrate that car choices differ among cities.

Next, individual differences exist between passages with cars. This may be confirmed in Model 2 and shows that it is essential to take personal factors into consideration. This result may indicate that reassessment is required of existing research that did not control or consider variables at the individual level.

Thirdly, an examination of the results of Model 4 showed that, unlike the results of existing research performed on U.S. cities, all factors, including density and accessibility to public transit but excluding diversity, showed an effect on reducing car usage, although this effect was less than extensive. One
**Table 5. Analysis Results of Each Model**

|          | Model 1 | Model 2 | Model 3 | Model 4 |
|----------|---------|---------|---------|---------|
|          | Coeff. (S.E.) | Odds Ratio | Coeff. (S.E.) | Odds Ratio | Coeff. (S.E.) | Odds Ratio | Coeff. (S.E.) | Odds Ratio |
| **Gender** | -1.756 (0.053) | 0.172 | -1.756 (0.053) | 0.172 | -1.757 (0.053) | 0.172 | |
| **Age** | 0.025 (0.002) | 1.026 | 0.025 (0.002) | 1.026 | 0.025 (0.002) | 1.026 | |
| **Marital status** | 0.415 (0.020) | 1.514 | 0.415 (0.020) | 1.515 | 0.415 (0.020) | 1.515 | |
| **Commuter status** | -0.61 (0.085) | 0.542 | -0.61 (0.085) | 0.541 | -0.611 (0.084) | 0.542 | |
| **Transit time** | -0.123 (0.005) | 0.883 | -0.123 (0.005) | 0.884 | -0.123 (0.005) | 0.884 | |
| **Place of residence** | 0.18 (0.071) | 1.198 | 0.163 (0.072) | 1.177 | 0.167 (0.072) | 1.182 | |
| **Home ownership status** | -0.303 (0.041) | 0.738 | -0.303 (0.041) | 0.738 | -0.303 (0.041) | 0.738 | |
| **Individual Level Characteristics** | | | | | |
| **Control Variables** | | | | | |
| Area ratio in the urban area | 0.015 (0.006) | 1.013 | 0.022 (0.007) | 1.022 | |
| Distance to the national capital | -1.862 (3.992) | 0.155 | -5.276 (0.005) | 0.995 | |
| **DENSITY** | | | | | |
| Population density | -0.001 (0.000) | 0.999 | -0.001 (0.000) | 0.999 | |
| Employment density | 0.581 (0.215) | 1.000 | 1.028 (0.476) | 2.796 | |
| **DIVERSITY** | | | | | |
| Job-Housing balance | -0.029 (0.941) | 1.029 | -1.556 (0.968) | 0.210 | |
| Industrial mixture | 0.201 (0.472) | 1.223 | -0.251 (0.777) | | |
| **DESIGN** | | | | | |
| Density of crossroads | -0.077 (0.019) | 0.887 | -0.097 (0.027) | 0.907 | |
| Total road ratio | -0.010 (0.011) | 0.985 | -0.012 (0.011) | 0.987 | |
| Local road ratio | -0.012 (0.038) | 0.978 | -0.019 (0.034) | 0.980 | |
| **DESTINATION ACCESSIBILITY** | | | | | |
| ACR | -0.010 (0.045) | 0.989 | -0.031 (0.036) | 0.969 | |
| AH | -1.068 (0.564) | 0.343 | -1.081 (0.516) | 0.339 | |
| AB | -2.62 (7.125) | 0.001 | -0.640 (5.458) | 0.527 | |
| **DISTANCE to TRANSIT** | | | | | |
| Density of parking lots | 0.629 (0.389) | 1.875 | 0.604 (0.394) | 1.899 | |
| Accessibility to bus | -1.021 (0.314) | 0.356 | -1.023 (0.319) | 0.359 | |
| Accessibility to subway | -1.121 (0.420) | 0.321 | -1.124 (0.424) | 0.324 | |
| **Urban Form** | | | | | |
| Gini's centrality ratio | -1.53 (0.701) | 0.216 | -1.393 (0.547) | 0.248 | |
| Entropy | -1.53 (0.701) | 0.216 | -1.393 (0.547) | 0.248 | |
| Moran's I | -0.313 (0.172) | 0.730 | 0.001 (0.000) | 1.000 | |
| SDD | -0.001 (0.000) | 1.000 | -0.002 (0.000) | 1.000 | |
| **Constant** | 1.548 (0.079) | 4.706 | 2.148 (0.217) | 8.573 | 3.501 (0.612) | 33.159 | 5.181 (0.832) | 177.86 | |

<0.1; , <0.05; †, <0.01; **

possible explanation is that since Korea already has a considerable degree of diversity in comparison to the U.S., this factor does not have a substantial effect on car use.

Fourthly, as previously mentioned, in contrast with the findings from other existing research, density and diversity show low to no correlation in South Korea. Rather, it is found here that destination accessibility, accessibility of public transportation, and design are all more effective variables. By observing studies from European countries such as the UK, it may be concluded that differences in these two features do not generally affect car choice in those South Korean cities that are already equipped with substantial density and diversity. In other words, considering the conditions in Korean cities, it would be more effective to improve accessibility to public transit, expand mixed-use urban housing, reorganize land use from the perspective of urban form and reduce block sizes by creating more intersections.

Lastly, as stated above, rather than considering the 5Ds alone, considering the 5D factors and urban form together proved to be more effective in explaining car usage. This was found by verifying the adequacy of Model 4 compared to Model 3. As mentioned previously, this is presumably due to the high degree of existing diversity in Korean cities. To reiterate, many Korean cities have been designed for a specific purpose and with the nation’s population highly concentrated in and around Seoul, urban form differs considerably.
from city to city. However, such results are only valid within the boundaries of the local-level analysis conducted in this study. More studies are required to determine whether models that account for urban form, such as Model 4, are more explanatory at the microscopic neighborhood level.

Further study is required as to whether this difference in vehicle hours traveled exists by city or by region/culture, since this current investigation only looked at individual cities and did not consider the possibility of categorizing them. In other words, in order to ascertain whether the differences actually derive from the city itself, or from types of city, country, continent, or culture, follow-up research that classifies Korean cities according to urban form and characteristics and analyzes car use pattern by means of such classification should be conducted.

Moreover, research on differences at the urban level that consider the personal level have never controlled or considered existing urban level research. This study clarifies this matter, but complex and specific studies are additionally required in order to determine the manners in which age, income, educational background, and occupation affect the selection of cars as a transportation mode and how they interact with urban character and urban form variables to impact automobile use. It is expected that this could help establish more specific and detailed policies for moderating the choice of cars within cities.

This study is differentiated from existing research in three aspects. First, it uses HLM in order to overcome the methodological limits of previous research. This enables more systematic research on the relevant issues. Second, the scope of the research subject was expanded compared to existing studies. As pointed out by Bourdeaudhuij et al. (2003), the form for sustainable cities and urban character affecting car choice varies by region. Unlike previous research focusing on American and European cities, this study examined Asian cities in terms of similar issues. The results show that while the 5Ds and urban form variables of compact cities are meaningful for reducing car choice, density and diversity are in fact less meaningful in a Korean context.

Lastly, it combined planning elements causing a decrease in car choice, the 3Ds and 2Ds, with form elements of cities, particularly those of compact cities, in order to establish more comprehensive models. So far, research on these 5Ds and urban form, which share a similar purpose and variables, have been carried out in different directions. This study is meaningful in that it has created an integrated model using both elements to establish the relationship between the two.

Acknowledgement
This research was supported by a Korea University Grant.
This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT & Future Planning(NRF-2015R1C1A1A01055076).

References
1) Cervero, R. & Kockelman, K. (1997). Travel demand and the 3Ds: Density, Diversity and Design. Transportation Research D, 2(3), pp.199-219.
2) De Bourdeaudhuij, I., Salisz, J.F. & Saelens, B.E. (2003). Environmental Correlates of Physical Activity in a sample of Belgian Adults. American Journal of Health Promotion, 18(1), pp.83-92.
3) Ewing, R. & Cervero, R. (2001). Travel and the Built Environment: A Synthesis. Transportation Research Record, 1780, pp.87-114.
4) Ewing, R., Bartholomew, K. & Winkelman, S. et al. (2008). Growing Cooler: Evidence on urban development and climate change. Washington, DC: Urban Land Institute.
5) Gordon, P. & Richardson, H.W. (1989). Gasoline Consumption and Cities: A reply. Journal of the American Planning Association, 55(3), pp.342-346.
6) Gunwon, L., Yunnam., J., & Seiyong, K. (2015). The Effect of the Built Environment on Pedestrian Volume in Microscopic Space: Focusing on the Comparison Between OLS (Ordinary Least Square) and Poisson Regression, Journal of Asian Architecture and Building Engineering, 14(2), pp.601-608.
7) Gunwon, L., Yunnam., J., & Seiyong, K. (2015). Impact of Individual and Urban Traits and Urban Form on Vehicle Hours Traveled, Journal of Asian Architecture and Building Engineering, 14(3), pp.601-608.
8) Handy, S.L., Cao, X. & Mohkhtarian, P.L. (2005). Correlation or Causality between the built environment and travel behavior? Evidence from North California. Transportation Research D, 10(6), pp.427-444.
9) Hox, J.J. (2010). Multilevel Analysis: Techniques and Applications (2nd Ed.), New York: Routledge.
10) Newman, P.W.G. & Kenworthy, J.R. (1989). Gasoline consumption and cities: A comparison of US cities with a global survey. Journal of the American Planning Association, 55(1), pp.24-37.
11) Owens, S.E. (1991). Energy-conscious Planning: The Case for Action. London: Council for the Protection of Rural England.
12) Raudenbush, A.W. & Bryk, A.S. (2002). Hierarchical Linear Models: Applications and Data Analysis Methods (2nd Ed.), Thousand Oaks: Sage Publications.
13) Samsung Economic Research Institute (SERI) (2009) Increment of the ‘Carbon Zero’ City, SERI management Note 24.
14) Seung-Jae, L., & Kyung-Hoon, L. (2014). Suggestion for a Visual Dynamics Analysis Model Using a Natural Movement Model, Journal of Asian Architecture and Building Engineering, 13(2), pp.381-388.
15) Tatsuya S., Tohru Y., & Ryo S. (2015). Formulation of a Quantitative Method to Evaluate the Accessibility to Food Facilities Based on the Load of the Facility Utilization for Analysis of Population Distribution, Journal of Asian Architecture and Building Engineering, 14(2), pp.355-362.
16) Kun L., Jianguo W., & Peng T. (2015). Sprawling Urban Form and Expanding Living Space: A Study on the Relationship of Residential Space Development and Urban Built-up Area Expansion in Nanjing, China, Journal of Asian Architecture and Building Engineering, 14(2), pp.387-394.
17) Tsai, Y.H. (2005). Quantifying Urban Form: Compactness versus Sprawl, Urban Studies, 42(1), pp.141-161.