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# Factor Analysis for Land Value Index in Urban Areas Using Agent Analysis Indicator

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## 1 ABSTRACT

The factors affecting a land value index such as land assessments are important for the development and growth of urban areas. Ota and Kaneda (2018) conducted a comparative analysis of a land value index in the central Nagoya area of Japan and reported that the factor structure could be explained by three factors: distance from the nearest station as an accessibility factor; the concentration of neighborhood commercial and business uses as a facility volume factor; and the integration value of the entire area as an indicator of the street network centrality of the vis graph analysis of space syntax theory, or "VGA", as a space configuration factor.

In an urban area, a busy street's land value index is considered to be higher. The integration value of the VGA indicator, which represents the street network centrality as a space configuration, has been used as a busy street factor. However, high street network centrality is not always needed for a busy street. Therefore, it is a possible that simulating actual pedestrians from the space configuration is a stronger factor for a busy street than a high street network centrality. Simulating actual pedestrians from the space configuration can be conducted using agent analysis, or "AA."

In this paper, we examine a multiple regression model for the factors and a land value index of the Kanayama area of Nagoya City using a VGA indicator and then replacing the VGA indicator with the AA indicator as a new factor. By comparing the two models, we explore the potential for using the AA indicator as a land value index factor.

In conclusion, the global integration value of the VGA indicator was selected as a factor for a busy street with a multiple correlation coefficient of 0.750, a coefficient of determination of 0.562, and an Akaike information criterion (AIC) of 352.093 with a standard partial regression coefficient of 0.362 in the conventional factor structure. On the other hand, when the number of AA footprints (station occurrences) of the AA indicator was selected as a factor for a busy street, it had a multiple correlation coefficient of 0.830, a coefficient of determination of 0.689, and an AIC of 294.477 with a standard partial regression coefficient of 0.618 in the new factor structure. Thus, we discovered that replacing the VGA indicator with the AA indicator could significantly improve the land value factor structure model.

Keywords: space syntax, space configuration, land value, visibility graph analysis, agent analysis

## 2 INTRODUCTION

In considering urban development, it is important to understand the factors that contribute to the formation of land value. In the past, multiple regression models have been used to analyze these factors, namely, transportation accessibility (i.e., distance from the nearest station), facility volume (i.e., land use), and space configuration (i.e., accessibility to automobile traffic and street width) (Okubo, 1983). Subsequently, the UCL group explored space syntax (SS) theory and proposed visibility graph analysis (VGA), which quantifies the characteristics of a street network by introducing a fine grid and thus calculates indicators such as street network centrality, visible area, and land value. The factorial analysis of these indicators is described below. In this paper, these indicators are collectively referred to as VGA indicators. Ota and Kaneda (2020) examined the factors of land value indices before 1935 and after 1965, using as factor variable candidates the distance from the nearest Nagoya streetcar stop as accessibility, the concentration of neighborhood commercial business uses as the facility volume, and the VGA as the urban area form. The VGA indicator was adopted using statistical tests in two periods and its validity as a land value factor was confirmed. The analysis was conducted using a model of three groups of factors: space configuration, facility volume (land use), and transportation accessibility.

In an urban area, a land value index is considered to be higher for a busy street, and the integration value of a VGA indicator, which represents the street network centrality as a space configuration, has been used as a factor of a busy street. However, a high street network centrality is not always needed for a busy street.

Therefore, it is possible that simulating pedestrians in the space configuration is a stronger factor for a busy street than a high street network centrality. Simulating actual pedestrians from the space configuration can be done using agent analysis (AA).

The analysis using SS theory is not only VGA, but also AA using exosomatic visual architecture (EVA), which is a vision-driven agent simulation on a fine grid. Penn et al. (2001) applied AA to the spatial distribution of the number of pedestrians in a department store and reported a correlation coefficient (single correlation) of 0.75 between the number of pedestrians calculated by the AA indicator and the cross-sectional traffic volume of a grocery store. When considering the number of pedestrians as bustle, a busy street can quite possibly be a factor of the land value index. Using the AA indicator as an alternative to the VGA indicators as a factor of a land value index is promising, but no factor analysis of a land value index using the AA indicator has yet been conducted.

Therefore, in this paper, we use a multiple regression model for a land value index in the Kanayama district of Nagoya City, Japan using a VGA indicator and then construct a multiple regression model using the AA indicator instead. Comparing the two models and exploring the potential of the AA indicator as a factor for a land value index is the contribution that this study provides to the literature.

## 3 THEORETICAL BACKGROUND

In existing reports on the factor analysis of land value indices using VGA indicators, Min et al. (2007) conducted a single regression analysis of public land values using street network centrality as a VGA indicator and reported a single correlation coefficient of 0.750. Wang et al. (2010) conducted a multiple regression analysis of public land values with street network centrality as the VGA indicator and the floor-area ratio as a second factor and reported a multiple correlation coefficient of 0.692 for the model. Ota and Kaneda (2020) analyzed the factors forming a land value index pre-1935 and post-1965, using the global integration value (GIV) and the street network centrality as the VGA indicator. The multiple regression model for 1935 had a multiple correlation coefficient of 0.808, while the multiple regression model for 1965 had a multiple correlation of 0.807. The VGA indicator was adopted using statistical tests in the two periods, confirming its validity as a factor for determining land value.

In addition to Penn et al., Kaneda et al. (2020) compared the VGA and AA indicators for a factor analysis of the number of using an encounter survey and reported that the AA indicator model was superior to the VGA indicator model. In Japan, Zhang et al. (2019) conducted a correlation analysis between AA indicators and store rents and reported a single correlation of 0.491, confirming a low level of correlation.

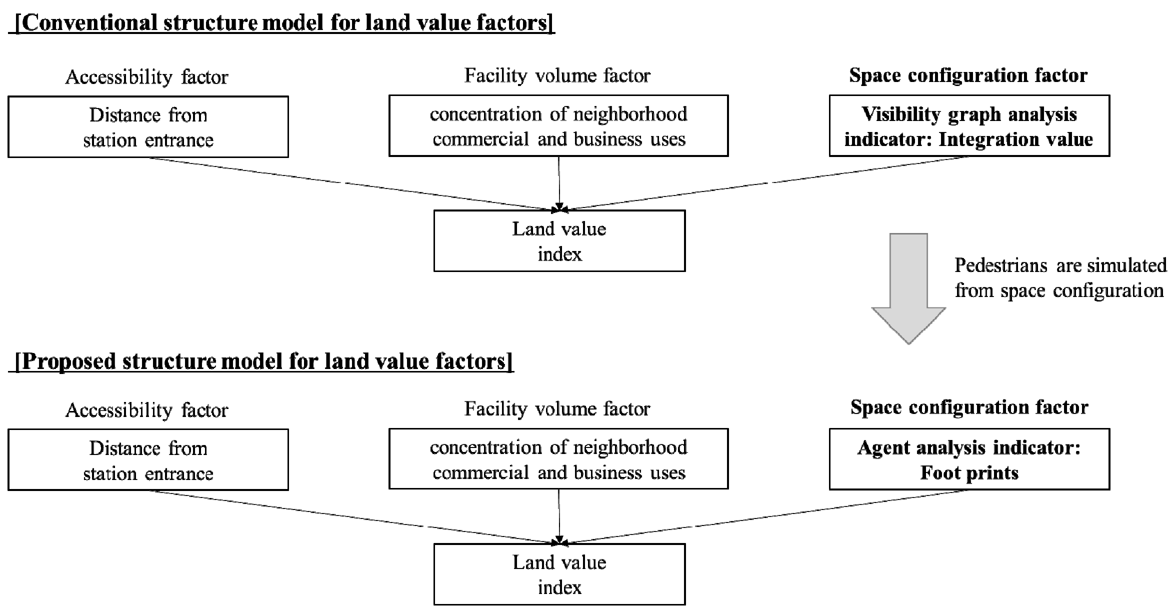


Fig. 1: Land value factor structure models

In a report using mobile phone location data as an alternative indicator for the number of pedestrians, Kaneda et al. (2022) conducted a comparative study using a model that replaced the number of pedestrians from the encounter survey with mobile phone location data and found no significant difference.

For a land value factor structure model, the distance from the nearest station is an accessibility factor, the concentration of neighborhood commercial and business uses is a facility volume factor, and the integration value of the entire area is an indicator of the street network centrality as a space configuration factor. However, the AA indicator, which actually simulates pedestrians from the space configuration is a stronger factor for a busy street than a high street network centrality. Therefore, a novelty of this study is that it creates a land value factor structure model that substitutes the AA indicator for the VGA indicator as a conventional factor, as shown in Fig. 1.

# 4 KANAYAMA DISTRICT OF NAGOYA CITY AND LAND VALUE INDEX AS AN OBJECTIVE VARIABLE

## 4.1 Overview of Kanayama District of Nagoya City

The scope of the Kanayama district in Nagoya City, Aichi Prefecture, which is the subject of this study, is based on the “Kanayama Station District Community Development Concept” (2017). Its scope and the distribution of its facilities are shown in Fig. 2. Kanayama Station, located in the Kanayama district, served approximately 440,000 passengers daily in 2016, with five train lines serving the area, making it the second-largest terminal station in Aichi Prefecture after Nagoya Station. The Kanayama area is characterized by public and cultural facilities such as the Kanayama Minami Building, Asnal Kanayama, and the Civic Hall.

To understand the regional characteristics of the target area, we calculated the total floor area according to use in the Kanayama district using geographic information system data from the “2011 Building Use Survey.” For buildings with a total floor area of 10,000 square meters (m2) or more, the use of each floor was checked using the “2016 ZENRIN Residential Maps,” and the figures were corrected. Residential uses totaled 234,301 m2 (36% of the total), office/school uses totaled 210,402 m2 (32%), commercial uses totaled 130,816 m2 (20%), accommodation uses totaled 39,189 m2 (6%), and cultural facilities totaled 39,157 m2 (6%). Residential use and office/school use each accounted for more than 30%, followed by commercial use. Therefore, the area is a mixed residential/commercial area.

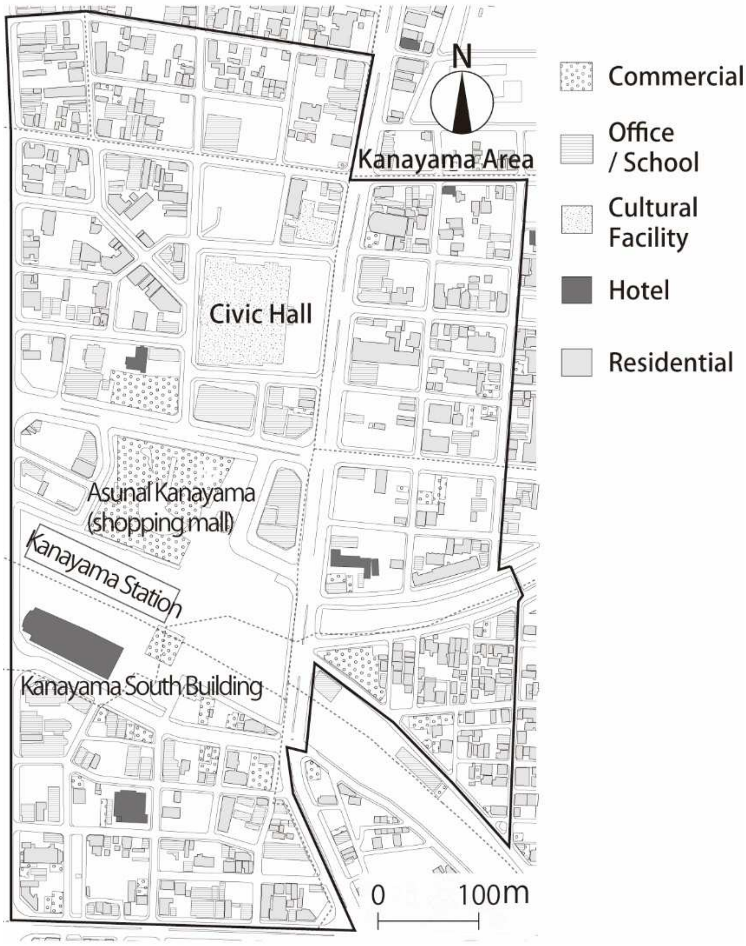


Fig. 2: Spatial distribution in the Kanayama district


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## 4.2 Land Value Index as an Objective Variable

The land value index used roadside land value, which is the value per square meter (m) of standard land (i.e., 1,000 yen) facing a roadside used to evaluate land in areas in which roadside land values have been established. Roadside land values are the basis for calculating the taxable value of land for inheritance taxes and gift taxes and are considered the official land value indices published by Japan's National Tax Agency. In this study, roadside land values for 2016 were used.

A total of 178 streets in the target district were included in the study, but nine streets for which the land value index (i.e., road value) could not be obtained were excluded, resulting in a sample size of 169 streets.

# 5 FACTOR ANALYSIS OF THE LAND VALUE INDEX USING VISIBILITY GRAPH ANALYSIS INDICATORS

## 5.1 Methods of Factor Analysis Used in this Study

In this study, multiple regression analysis was conducted using data for 169 streets to factor the land value index from candidate variables belonging to three candidate factor groups: space configuration, facility volume (land use), and transportation accessibility. The first candidate factor (group), accessibility, is (X1) the distance from station entrances and exits. This is the shortest distance from a station entrance, of which there are eight in total, to the midpoint of the street in question. Four variables—(X2) the commercial floor-area ratio, (X3) office and school floor-area ratio, (X4) the hotel floor-area ratio, and (X5) the cultural facility floor-area ratio—are used to determine the quantity of facilities for the second candidate factor group.

## 5.2 Visibility Graph Analysis Indicators as Candidate Factor Variables

While the factor groups for accessibility and the quantity of facilities are straightforward indicators of the OD of the walking trip, i.e., the point of departure or arrival, the third candidate factor group, the space configuration factor group, is an indicator brought about by the form of space configuration. Here two VGA indicators, (X6) visible area and (X7) the GIV, which are urban morphology indicators, are provided as VGA indicators. The walking space to be analyzed includes not only the sidewalks and city blocks excluding the building site, but also the crosswalks between the roadways and passageways inside of stations in the building site. In this case, the roadways, the interiors of other buildings, and railroads are considered to be nonwalkable spaces. The visible area is calculated as the total number of all points visible from a given point. The integration value indicates the strength of spatial connectivity; if the value is high at a point, the point has less depth from its surroundings and is more central in space. This creation method follows Ota et al. (2021). In both cases, Depthmap X software was used and a 1-meter square grid was set up for the measurements.

| VIF / Correlation coefficient | (Y) Land value index (JPY'000 /sqm) | (X1) Distance from station entrance (m) | (X2) Floor area ratio Commercial | (X3) Floor area ratio Office / School | (X4) Floor area ratio Hotel | (X5) Floor area ratio Cultural facility | (X6) Visible area | (X7) Global integration value | (X8)Density of AA footprints' flow (station generated) | (X9) Mobile phone location data (weekday) | (X10) Mobile phone location data (weekend) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (Y)Land value index (JPY'000 /sqm) | | 1.670 | 1.099 | 1.169 | 1.017 | 1.000 | 1.038 | 1.325 | 2.564 | 1.937 | 1.960 |
| (X1)Distance from station entrance (m) | -0.634 | | 1.286 | 1.122 | 1.023 | 1.001 | 1.000 | 1.044 | 1.504 | 1.441 | 1.428 |
| (X2)Floor area ratio : Commercial | 0.300 | -0.472 | | 1.034 | 1.095 | 1.003 | 1.005 | 1.000 | 1.171 | 1.160 | 1.171 |
| (X3)Floor area ratio : Office / School | 0.380 | -0.329 | -0.181 | | 1.002 | 1.002 | 1.000 | 1.059 | 1.064 | 1.022 | 1.014 |
| (X4)Floor area ratio : Hotel | 0.130 | -0.149 | 0.294 | -0.048 | | 1.024 | 1.007 | 1.002 | 1.001 | 1.016 | 1.011 |
| (X5)Floor area ratio : Cultural facility | 0.013 | -0.036 | -0.051 | -0.042 | 0.154 | | 1.128 | 1.020 | 1.006 | 1.002 | 1.002 |
| (X6)Visible area | 0.190 | -0.017 | -0.071 | -0.006 | 0.085 | 0.337 | | 1.237 | 1.018 | 1.003 | 1.005 |
| (X7)Global integration value | 0.495 | -0.205 | 0.015 | 0.236 | 0.048 | 0.140 | 0.438 | | 1.153 | 1.079 | 1.088 |
| (X8)Density of AA footprints' flow (station generated) | 0.781 | -0.579 | 0.382 | 0.246 | 0.027 | -0.080 | 0.132 | 0.364 | | 1.846 | 1.985 |
| (X9)Mobile phone location data (weekday) | 0.696 | -0.553 | 0.371 | 0.146 | 0.125 | 0.047 | 0.051 | 0.270 | 0.677 | | 35.559 |
| (X10)Mobile phone location data (weekend) | 0.700 | -0.548 | 0.382 | 0.119 | 0.102 | 0.045 | 0.069 | 0.284 | 0.705 | 0.986 | |

Table 1: Correlation coefficient and variance inflation factors between the land value index and candidate factor variables

We also added (X8) the density of AA footprint flow (station-generated), (X9) mobile phone location data for weekdays, and (X10) mobile phone location data for weekends as candidate factor variables.

### 5.3 Correlation Analysis for the Land Value Index and Candidate Factor Variables

Table 1 shows the correlation matrix (lower left half) and variance inflation factors (VIFs) (upper right half) for all of the variables used in this analysis.

Examining the correlations between the land value index and the candidate factor variables, the correlations with the land value index were high for (X8) density of AA footprint flow (station-generated) (0.781), and (X10) mobile phone location data for weekends (0.700), while the correlations with (X9) mobile phone location data for weekdays (0.696) and (X1) distance from station entrances and exits (−0.634), resulting in a slightly higher correlation with (X1).

The VIFs between each candidate factor variable were all less than 2, except for (X9) mobile phone location data for weekdays and (X10) mobile phone location data for weekends (35.559). Other than not using these candidate factor variables simultaneously, the prohibition for avoiding multicollinearity was not applied.

### 5.4 Examination of Selected Multiple Regression Models

Multiple regression analysis was conducted using seven candidate factor variables ranging from (X1) distance from station entrances and exits to (X7) the GIV. For multiple regression analysis, a model was selected that minimized the AIC using the stepwise variable increasing/decreasing method.

A four-variable model was ultimately selected (see Table 2). The multiple correlation coefficient was 0.750 (coefficient of determination of 0.562), and the AIC was 2,363.726. The variables adopted in the model are shown below, organized by accessibility, facility volume (land use), and space configuration, as follows: (X1) distance from station entrances and exits (standard partial regression coefficient: −0.452, first rank) as accessibility, (X3) office/school floor-area ratio (standard partial regression coefficient: 0.166, third rank) as facility volume, (X2) commercial floor-area ratio (standard partial regression coefficient: 0.111, fourth rank), and (X7) the GIV (standard partial regression coefficient: 0.362, second rank) as space configuration.

Multiple correlation coefficient：0.750
Coefficient of determination：0.562 AIC：2,363.726

| | Standard partial regression coefficient | Partial regression coefficient | t value | p value |
|---|---|---|---|---|
| Constant | — | 105.319 | 0.847 | — |
| (X1)Distance from station entrance | -0.452 | -1.582 | -6.721 | 0.000 |
| (X7)Global integration value | 0.362 | 205.688 | 6.732 | 0.000 |
| (X3)Floor area ratio Office / School | 0.166 | 0.407 | 2.736 | 0.007 |
| (X2)Floor area ratio Commercial | 0.111 | 0.539 | 1.735 | 0.085 |

Table 2: Results of factor analysis (multiple regression model selection) for the land value index using VGA indicators

## 6 FACTOR ANALYSIS OF THE LAND VALUE INDEX USING THE AGENT ANALYSIS INDICATOR

### 6.1 Overview of Agent Analysis and the Calculation Results

The pedestrian agent in the EVA has a 170-degree field of view centered on the direction of travel, and the area ratio of the segmented field of view is used to select the direction of travel. In this case, the pedestrian agent does not have an OD pair and acts only based on the obstacles in his or her field of view. For the agent onset condition, we used a selective onset in which the agent onset point and the agent onset ratio are determined in advance. In this study, the station is used as the point of the selection generated, so it is referred to as "station-generated." This simulation was conducted under the following conditions for the movement of agents and the generation of agents at the stations.

- Number of agents: 2,000.
- Agent movement distance: A uniform distribution between 0 and 1,500 m (average of 750 m).

- Points at which agent stations are generated: Eight entrances and exits at Kanayama Station.
- Ratio of agent stations: Results of a cross-sectional traffic survey (the amount of outflow from the station to the Kanayama area).

Each pedestrian agent is assumed to leave a footprint once per second in the walking space, and the indicator is the number of footprints per meter of street length in each street space after the simulation is completed. The units are (number/m) by definition. It can be seen that the larger the walkable space area and the closer to the station, the denser the walking trajectory. The reasons for this may be due to the behavioral characteristics of the agents and the influence of the agent's point of origin (see Fig. 3).

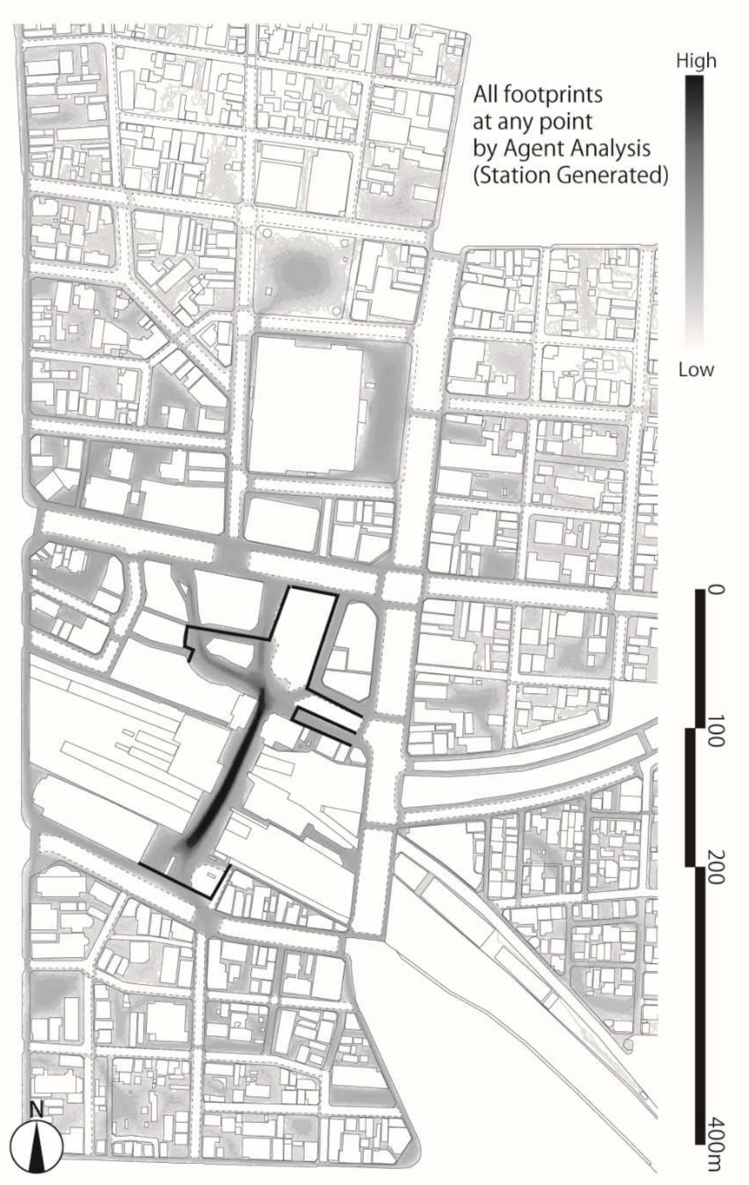


Fig. 3: Spatial distribution of the number of footprints (agent analysis, station-generated)

### 6.2 The Correlation Between the Land Value Index and the Agent Analysis Indicator

The correlation coefficient between the number of (X8) density of AA footprint flow (station-generated, per meter of street length) as an AA indicator and the land value index was 0.781, as shown in Table 1, confirming a high correlation between the two.

### 6.3 Factor Analysis Using the Agent Analysis (Station-Generated) Indicator

The same analysis was conducted for the land value index, replacing (X6) visible area and (X7) the GIV as the VGA indicator in the candidate factor variables with (X8) density of AA footprint flow (station-generated) in Table 3.

Multiple correlation coefficient: 0.830
Coefficient of determination: 0.689 AIC: 2,306.111

| | Standard partial regression coefficient | Partial regression coefficient | t value | p value |
|---|---|---|---|---|
| Constant | – | 446.506 | 7.772 | – |
| (X8)Density of AA footprints' flow (station generated) | 0.618 | 143.513 | 11.500 | 0.000 |
| (X1)Distance from station entrance | -0.208 | -0.729 | -3.723 | 0.000 |
| (X3)Floor area ratio Office / School | 0.164 | 0.402 | 3.524 | 0.001 |
| (X4)Floor area ratio Hotel | 0.090 | 0.830 | 2.037 | 0.043 |

Table 3: Results of factor analysis (multiple regression model selection) for the land value index using the agent analysis (station-generated) indicator

As a result, a four-variable model was selected. The multiple correlation coefficient was 0.830 (coefficient of determination of 0.689), and the AIC was 2,306.111. Compared to the model in Section 3, the multiple correlation coefficient and the AIC both improved. As accessibility, (X1) distance from station entrances and exits (standard partial regression coefficient: −0.208, second rank), as facility volume (land use), (X3) office/school floor-area ratio (same: 0.164, 3rd rank), (X4) hotel facility floor-area ratio (same: 0.090, fourth rank), and (X8) density of AA footprint flow (station-generated) (same: 0.618, first rank) as space configuration, were adopted.

The variables were adopted from the accessibility, facility volume (land use), and space configuration groups without any missing variables and have the same structure as the model in Section 3. The strength of the AA (station-generated) indicator is greater than that of the VGA indicator based on the magnitude of the standard partial regression coefficient, which supports the validity of the AA (station-generated) indicator as a factor. It also exceeds the intensity of the accessibility indicator, which is the physical distance from the station ticket gate.

## 7 FACTOR ANALYSIS USING MOBILE PHONE LOCATION DATA

In this subsection, we conduct factor analysis by replacing the AA (station-generated) indicator, an explanatory variable, with mobile phone location data and compare the results against the analytical framework used in the previous section. The mobile phone location data is the main pedestrian flow data indicator obtained from the KDDI Location Analyzer (KLA) site, which is an extended estimation process based on the global positioning system location data obtained from the smartphone users of the Japanese mobile phone service company, KDDI, and official population statistics. The average values for weekdays and weekends were used for each day (5:00 a.m. that day until 29:00 a.m. the next day) from March 22, 2019 to March 21, 2020.

In the analysis using KLA mobile phone location data, a three-variable model for both weekdays and weekends (hereafter, the KLA model), the factors (X1) distance from station entrances and exits, (X3) office/school floor-area ratio, (X9) mobile phone location data for weekdays, or (X10) mobile phone location data for weekends were adopted. Table 4 and 5 show the results. A comparison of the VGA model and the AA model is shown in Table 6.

Multiple correlation coefficient: 0.783
Coefficient of determination: 0.613 AIC: 2,340.653

| | Standard partial regression coefficient | Partial regression coefficient | t value | p value |
|---|---|---|---|---|
| Constant | – | 492.787 | 7.622 | – |
| (X9)Mobile phone location data (weekday) | 0.508 | 0.001 | 8.741 | 0.000 |
| (X1)Distance from station entrance | -0.282 | -0.987 | -4.628 | 0.000 |
| (X3)Floor area ratio Office / School | 0.213 | 0.523 | 4.152 | 0.000 |

Table 4: Results of factor analysis (multiple regression model selection) for the land value index using the mobile phone location data (weekday)


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Multiple correlation coefficient: 0.791
Coefficient of determination: 0.625 AIC: 2,335.345

| | Standard partial regression coefficient | Partial regression coefficient | t value | p value |
|---|---|---|---|---|
| Constant | — | 493.367 | 7.863 | — |
| (X10)Mobile phone location data (weekend) | 0.524 | 0.001 | 9.171 | 0.000 |
| (X1)Distance from station entrance | -0.271 | -0.950 | -4.519 | 0.000 |
| (X3)Floor area ratio Office / School | 0.228 | 0.560 | 4.506 | 0.000 |

Table 5: Results of factor analysis (multiple regression model selection) for the land value index using the mobile phone location data (weekend)

| | VGA model | AA model | KLA model (weekday) | KLA model (weekend) |
|---|---|---|---|---|
| Number of factor variables | 4 | 4 | 3 | 3 |
| Multiple correlation coefficient | 0.750 | 0.830 | 0.783 | 0.791 |
| Coefficient of determination | 0.562 | 0.689 | 0.613 | 0.625 |
| AIC | 2,363.726 | 2,306.111 | 2,340.653 | 2,335.345 |

Table 6: Comparison of the visibilitty graph analysis model, the agent analysis model, and the KLA model

The AA model has the best multiple correlation coefficient (coefficient of determination) and AIC, followed by the KLA model for weekends, the KLA model for weekdays, and the VGA model. This supports the validity of the AA indicator as a factor for determining land value.

The high correlation coefficient of mobile phone location data with the number of AA footprints (station-generated) suggests the possibility of a model with a structure similar to that of Fig. 4, for example. Therefore, further study of the model structure should be conducted.

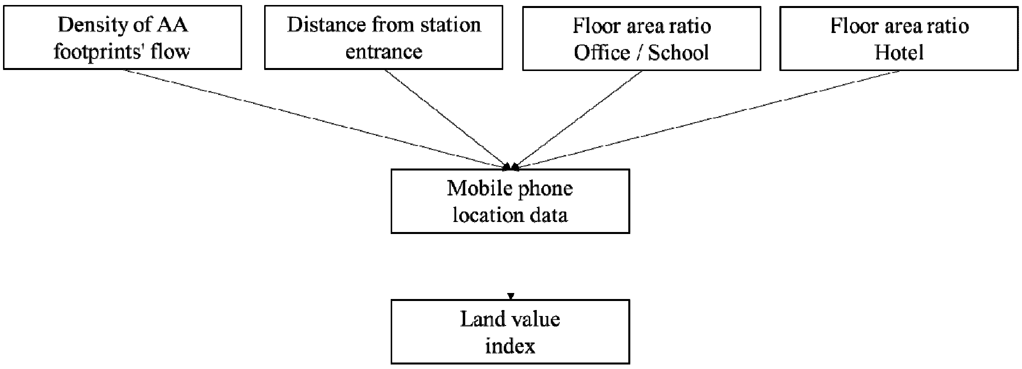


Fig. 4: Further consideration of the structure for a land value index as an example

## 8 CONCLUSION

In this paper, to explain the land value index in the Kanayama district of Nagoya City in Japan, we selected a multiple regression model with a VGA indicator and then compared it to a multiple regression model with an AA indicator instead. We also created a model using mobile phone location data instead of the AA indicator and compared the results.

In conclusion, the GIV of the VGA indicator is selected as a factor for a busy street with a multiple correlation coefficient of 0.750 (coefficient of determination of 0.562) and an AIC of 352.093 with a standard partial regression coefficient of 0.362 in the conventional factor structure with the VGA indicator. On the other hand, the number of AA footprints (station occurrence) of the AA indicator is selected as a factor for a busy street instead of the VGA indicator with a multiple correlation coefficient of 0.830 (coefficient of determination of 0.689) and an AIC of 294.477 with a standard partial regression coefficient of 0.618 in the new factor structure with the AA indicator. Thus, we discovered that replacing the VGA indicator with the AA indicator could significantly improve the land value factor structure model.

In addition, the model with the AA indicator was found to be superior than the model using mobile phone location data in terms of the multiple correlation coefficient, the coefficient of determination, and the AIC.

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