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画像類似度に基づいた新幹線駅地区土地利用パターンに関する研究

A Study on the Land Development Patterns of Shinkansen Station Areas Based on an Image Matching Approach

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In concern of the continuous expanding Shinkansen network and the unprecedented nationwide depopulation in Japan, this study systematically summarized the current land development situation around 91 existing Shinkansen high-speed railway stations. Specifically, with the land-use pattern comparison method based on image matching algorithms, this study compared the land-use situation between 91 existing Shinkansen station areas, classified the land-use patterns into 6 types, and clarified the features of each group. Besides, this study compared the land-use situation of 91 station areas between 2009 and 2016, thus identifying the transformation situation of Shinkansen station areas and elucidating the location trend of the land-use changes.

Keywords : Shinkansen station, Land-use pattern, Land use transformation, Image matching
新幹線駅，土地利用パターン，土地利用の変遷，画像マッチング

1. Introduction

1.1 Background

Faced with the unprecedented nationwide aging and depopulation, in the "*Grand Design of National Spatial Development towards 2050*", the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) pointed that the development of high-speed connections, including the Shinkansen (high-speed railway lines) network, is essential to the formation of a compact regional network which is the key to achieve agglomeration economies and support the effective services delivery and regional innovation in a population decreasing society.(1) Currently, the Shinkansen network has expanded to 92*1) stations, connecting the southernmost city of the Kyushu island - Kagoshima to the Northernmost island - Hokkaido. Besides, the Hokkaido Shinkansen, Hokuriku Shinkansen, Nagasaki section of Kyushu Shinkansen, and the Linear Chuo Shinkansen is under construction, the Shinkansen network will connect more cities.

For over half a century, the construction of Shinkansen has been planned to drive the urban development of the surrounding areas and promote the economic development of station cities. However, most of the studies about the Shinkansen area development were based on the successful cases along the early constructed line, particularly the Tokaido Shinkansen and Sanyo Shinkansen. With the Shinkansen network expanding to remote areas, researchers found that Shinkansen's effects have not necessarily been consistently positive.(2) It was argued that the success of the early Shinkansen (Tokaido and Sanyo Line) was closely related to the increasing population and high transport demands in the rapid post-war economic growth period. (3) However, the recent extended Shinkansen was built between small cities, a major concern has been the trade-off between the benefits of extending the network to the remote regions against the huge investment. (4) Therefore, it is necessary to clarify the current land development situation of the Shinkansen station areas, which will help us better understand the significant issues in the Shinkansen station area development and provide reference to the decision-making for the future development plan.

1.2 Literature Review

Concerning the land development around Shinkansen stations, considerable research achievements have been

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accumulated(5–10). However, most of them are case reports of one or some specific stations, it is hard to evaluate how much their findings represent the general situation. Besides, Moon C., Sato S., and Tonuma K. (1997) analyzed urban improvement projects around 56 Shinkansen stations and clarified the time serial and spatial characteristics of the development process around Shinkansen stations.(11) This study systematically summarized the urban development patterns around Shinkansen stations based on the planning documents from municipalities. Nevertheless, it is a qualitative analysis, and it was conducted over 20 years ago. In addition, Matsumoto E., Ubaura M. (2013) analyzed the land development situation around 17 Shinkansen stations in the suburbs and clarified the problems in the process of urbanization through case studies.(12) This study classified suburb Shinkansen station areas into different types based on only station areas' non-spatial properties such as the land use composition, without considering the spatial relationships inside the station areas. Besides, this study did not involve the situation around the non-suburb stations. There currently lacks a study that comprehensively and systematically explains the current land-use situation and land use transformation situation of the existing Shinkansen stations, thus clarifying the land development patterns in the Shinkansen station areas.

As to the method of land-use pattern identification, it is essentially a sub-branch of spatial comparison. Long J., Robertson C. (2018) reviewed the existing spatial comparison method and highlighted current issues in the traditional spatial comparison method.(13) Remarkably, they pointed out the existing quantitative spatial comparison methods generally ignore the interdependence between the composition and configuration of spatial patterns due to the absence of a single metric that can individually summarize the compositional and configurational features of spatial patterns. A previous study has been conducted to develop a novel land-use comparison method based on image matching approaches. In contrast to previous existing land-use pattern comparison approaches which are based on some specific indices that measure certain aspects of a land-use pattern, the image matching approach treats land-use maps as images, employing the image smoothing algorithm to integratively extract the land-use pattern features and numerically represents it as a land-use pattern descriptor. The land-use pattern descriptor not only characterizes the compositional and configurational features of a land-use pattern, but also captures both the global level features throughout the study areas and the local level features around each individual land-use cell. Therefore, instead of traditional land-use comparison approaches, this study will employ the image matching approach to identify the patterns of the land-use situation and the land use transformation situation around existing Shinkansen stations.

1.3 Study Purpose

The purpose of this study is to make clear the current land development pattern around Shinkansen stations. In this study, *land development* has two meanings: the static current land-use situation and the dynamic land-use transformation situation. Land development pattern refers to the trend of the land-use situation and the land-use transformation situation. Specifically, this study analyzes the land-use situation and the land use transformation situation around 91*2) existing Shinkansen stations, identifies the patterns of the land-use situation and the location trend of land-use transformation in Shinkansen station areas, thus providing a comprehensive and systematic summary of what is happening around Shinkansen stations.

2. Study Objects and Methods

2.1 Study Objects

This study focuses on the land-use situation and land use transformation situation in the 1-kilometer radius range around each 91 existing Shinkansen stations, as Figure 1 suggests. The land-use data is the 100-meter land use subdivision mesh data of the urban area of 2009 and 2016 published by the Policy Bureau of the Ministry of Land, Infrastructure, Transportation, and Tourism. The land-use map data is as Figure 1 shows, every square land-use unit in the map corresponds to a 100×100 m^2 area in the city. Besides, the original land-use data has 17 subdivisions, including some subdivisions that are not interested. Therefore, we merged the subdivision into 7 categories, as Table 1 suggests.

2.2 Study Flow and Method

To clarify the land development pattern of Shinkansen station areas, this study is composed of 2 parts: ① identifying the patterns of the current land-use situation through comparison between 91 existing Shinkansen areas and ② clarifying the trend of land-use transformation situation through comparison between station areas' land-use patterns of 2009 and 2016. The land-use pattern comparison will be based on the image matching approach, which compares land-use patterns based on the land-use pattern feature descriptors of the original land-use maps. The specific study flow is shown in Figure 2.

2.2.1 The Land-use Pattern Comparison Method Based Image Matching

The image matching approach treats land-use maps as images where the feature value of each pixel represents the

Table 1 The Subdivision of the Land Use Data

ID	Land-use categories	Abbrev.	Description
1	Tall Building Land (高層建物地)	TB	Urban area dominated by buildings with 4 floors or more
2	Dense Low-rise Building Land (低層建物密集地)	DLB	Urban area where buildings of 3 stories or less are densely concentrated
3	Low-rise Building Land(低層建物地)	LB	Urban area where buildings of 3 stories or less are distributed collectively and in a relatively low-density form
4	Industrial Building Land (工場建物地)	IB	Urban area dominated by industrial buildings
5	Transportation Land	Trans	Urban area dominated by land for transportation uses, includes the road (道路) and rail (鉄道) in the original subdivision data.
6	Open Land	OpenL	Urban area dominated by open land including the public facility land (公共施設等用地), open space (空地), park and greenland (公園・緑地), golf course (ゴルフ場) in the original subdivision.
7	Non-construction Land	N	Corresponds to other land-use categories in the original subdivision, including farmland(田), other agricultural land (その他の農用地),forest(森林), wasteland (荒地), rivers and lakes (河川地及び湖沼), seaside (海浜),and sea(海水域).

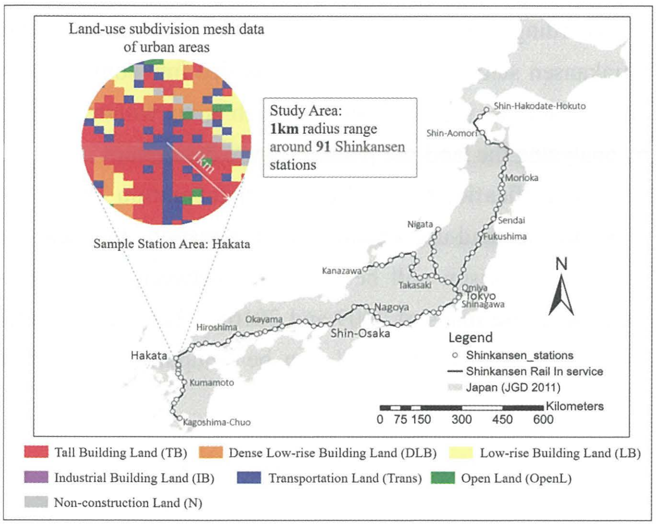


Fig. 1 Study Objects: 91 Shinkansen Stations and the Range of a Station Area

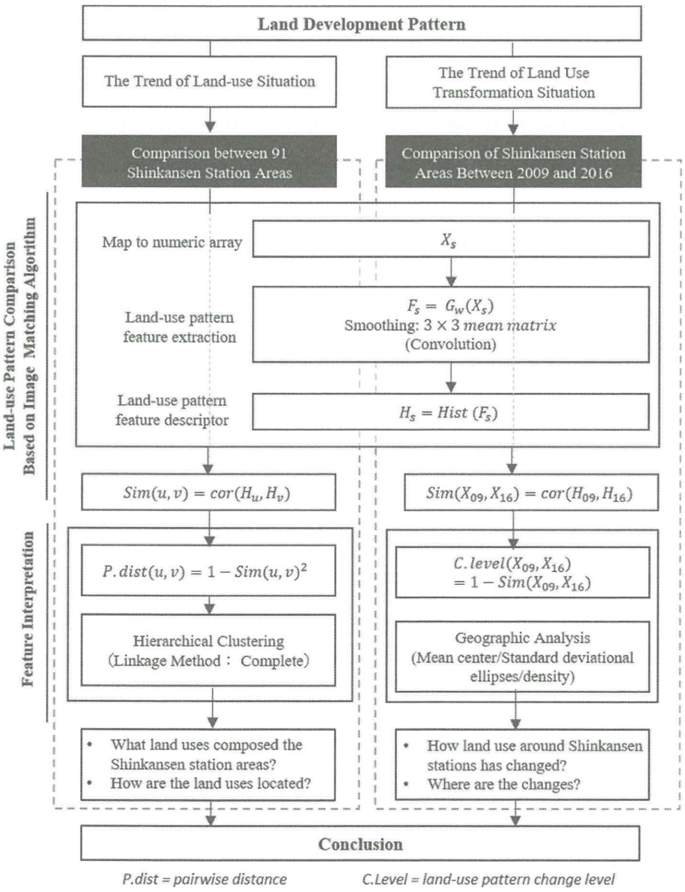


Fig. 2 Study Flow and Method

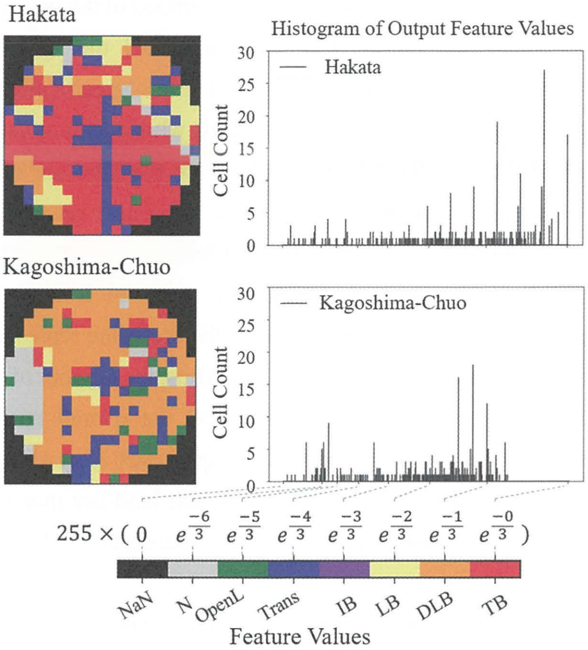


Fig. 3 Land-use Pattern Feature Descriptors: Histogram of Output Feature Values after Smoothing with 3×3 mean matrix

land-use category of the corresponding land-use cell. In this study, the feature values that represent the land-use categories are called the *land-use feature values*, and they are generated based on Equation (1).

$$a_i = \begin{cases} \frac{255}{e^{\frac{i}{3}}} & (i = 0,1,2,\dots,n-2) \\ 0 & (i = n-1) \end{cases} \qquad (1)$$

where i is the index for each land-use category, n is the number of land use categories that constitute the maps.

Specifically, the maps are composed of 7 land-use categories in this study, as Table 1 suggests. Besides, the image background area (NaN) needs another feature value. Therefore, we need to generate 8 initial feature values in total.

Accordingly, each land-use map were represented by a numeric array, in which the feature value represent the land-use categories as $255 \times$ [TB $= e^{\frac{-0}{3}}$, DLB $= e^{\frac{-1}{3}}$, LB $= e^{\frac{-2}{3}}$, IB $= e^{\frac{-3}{3}}$, Trans $= e^{\frac{-4}{3}}$, OpenL $= e^{\frac{-5}{3}}$, N $= e^{\frac{-6}{3}}$, NaN $= 0$], as Figure 3 shows.

Then, according to the image smoothing operation with a 3×3 mean matrix, the feature value of a land-use cell $g(i,j)$ will be converted to a linear combination of its 3×3 neighbor cells' land-use feature values $F(i,j)$. The image smoothing operation is implemented by a discrete convolution process, which can be denoted as:

$$F(i,j) = \sum\sum_{(x,y)\in 3} \frac{1}{3\times 3} g(x,y) \tag{2}$$

In this way, the output feature value no longer represents the land-use category of an individual cell but corresponds to the land-use combinations in the 3×3 neighborhood of the land-use cell. Namely, the output feature values label the land-use contiguity relation at the neighborhood level. Specifically, in the output map after smoothing, the cells whose feature value remained the initialized feature values are the land-use cells whose neighbor cells are the same land-use categories. Therefore, the cell counts of initialized feature values reflected the areal occupancy and aggregation level of a land-use category. Besides, each unique output feature value represents a location relation in the neighborhood. Thus, the number of the different output feature values reflected the overall spatial variation of the spatial relation between land uses. Accordingly, the land-use pattern features of the original land-use map can be represented by the histogram of the output feature values, as Figure 3 suggests.

The similarity between land-use patterns can be computed by the correlation between the land-use pattern feature descriptors, i.e., the histogram correlation, which can be represented as:

$$sim(H_1,H_2) = \frac{\sum_I (H_1(I)-\overline{H}_1)(H_2(I)-\overline{H}_2)}{\sqrt{\sum_I (H_1(I)-\overline{H}_1)^2 \sum_I (H_2(I)-\overline{H}_2)^2}} \tag{3}$$

where $\overline{H}_k = \frac{1}{N}\sum_J H_k(J)$. N is the total number of histogram bins, to avoid the inaccuracy problem brought by the merge of histogram bins, here $N = 12000$ *3).

With histogram correlation, the similarity level between two land-use patterns will be evaluated by a value between [-1,1], where the correlation value closer to 1 suggests greater similarity, while correlation value closer to 0 indicates greater difference, and a value closer to -1 indicates an inverse relationship between land-use patterns.

2.2.2 Identification of Land-use Patterns

The pattern of land-use situation is identified by clustering the land-use patterns of existing Shinkansen station areas into different groups. Based on the similarity computed by the image matching method, the pairwise distances of the land-use pattern features $P.dist(u,v)$ can be computed according to equation (4):

$$P.dist(u,v) = 1 - Sim(u,v)^2 \tag{4}$$

Where $Sim(u,v)$ denotes the histogram correlation between the land-use patterns of two maps.

We take the squared form of the similarity for it avoids dealing with minus correlations, and it corresponds to the form of Euclidean distance for standardized data, therefore, it usually preserves the original resemblances better. Besides, for the process of iteratively merging clusters to clusters, the complete-linkage method is employed for it is more robust to outliers and allows us to find compact clusters. (14)

According to hierarchical clustering, the land-use of existing Shinkansen station areas will be classified into some groups, and the land-use pattern features of each group will be clarified by analyzing the land-use pattern feature descriptors.

2.2.3 Identification of Land Use Transformation Trend

As to the land-use transformation situation, the land-use pattern comparison will be conducted between each station area's land-use maps of 2009 and 2016*4). The level of land-use pattern changes $C.level$ can be computed by equation (5):

$$C.level = 1 - sim(X_{09}, X_{16}) \tag{5}$$

Where $sim(X_{09}, X_{16})$ denotes the similarity level between the land-use pattern of a station area in 2009 and 2016.

Accordingly, this study identifies the station areas that have dynamically developed and those that stagnated during 2009 and 2016.

Then based on geographic analysis, this study clarifies the location trends of the land-use changes around stations based on geographic analysis. Specifically, as Figure 4 suggests, the station areas will be rotated to match the form of the standard station area, making the horizontal axis coincides with the extension direction of the Shinkansen railway and the positive direction of the vertical axis indicates the orientation of the central city (city hall), then the frequency of the land-use changes at each 100×100-meter cell in the standardized station area will be summarized for the observation of the location trends of the land-use changes. In this study, the location trend includes the *circumferential distribution trend,* and the *radial distribution trend* of the land-use changes relative to the station. The circumferential distribution trend will be examined according to the mean center and standard deviational ellipses, which indicate whether the land-use changes differ on the different orientations of the station. The radial distribution trend is identified by summarizing the density of the land-use changes in every 100-meter circular ring region around a station, thus observing whether the land-use changes vary with the distance to the station. Accordingly, this part will clarify how the land-use of Shinkansen areas has changed and identify where are the changes.

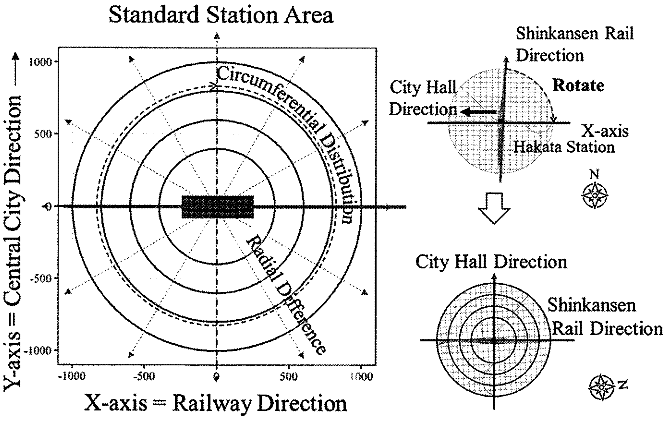


Fig. 5 The Diagram for the Standardization of a Station Area

3. The Patterns of the Land-use Situation of the Shinkansen Station Area

Based on the pairwise distances calculated from the land-use pattern feature similarities and the complete-linkage method, the dendrogram is as Figure 5. Accordingly, the land-use patterns of 91 existing Shinkansen station areas were classified into 6 groups.

To clarify the land-use pattern features of each group, the histograms of the output feature values were plotted in Table 2 to help visualize the land-use pattern feature descriptors of each group. The histogram for each station area was given an opacity $alpha = 1/((the\ number\ of\ group\ members))$ so that only the common parts for all group members will have 100% opacity. Take Type-I as an example, it contains 28 station areas, therefore, the histogram of each station area in Type-I had an opacity of 1/28. In this way, when putting all 28 histograms together, the common part will be 100% opaque, as Table 2 suggests. Accordingly, the land-use pattern features of each group can be interpreted from the histograms. The land-use pattern features include both the land-use composition and spatial relationship at the global and local levels.

3.1 The Global Land-use Pattern Features

The land-use pattern features at the global level refer to the overall land-use composition and distribution situation throughout the station area. Specifically, composition refers to the areal proportions of land use categories. The distribution situation can be concluded by the aggregation level of each land-use category and the spatial variations of the location relationships between land-use categories. In the histograms, the composition proportions are reflected by the skewness, the

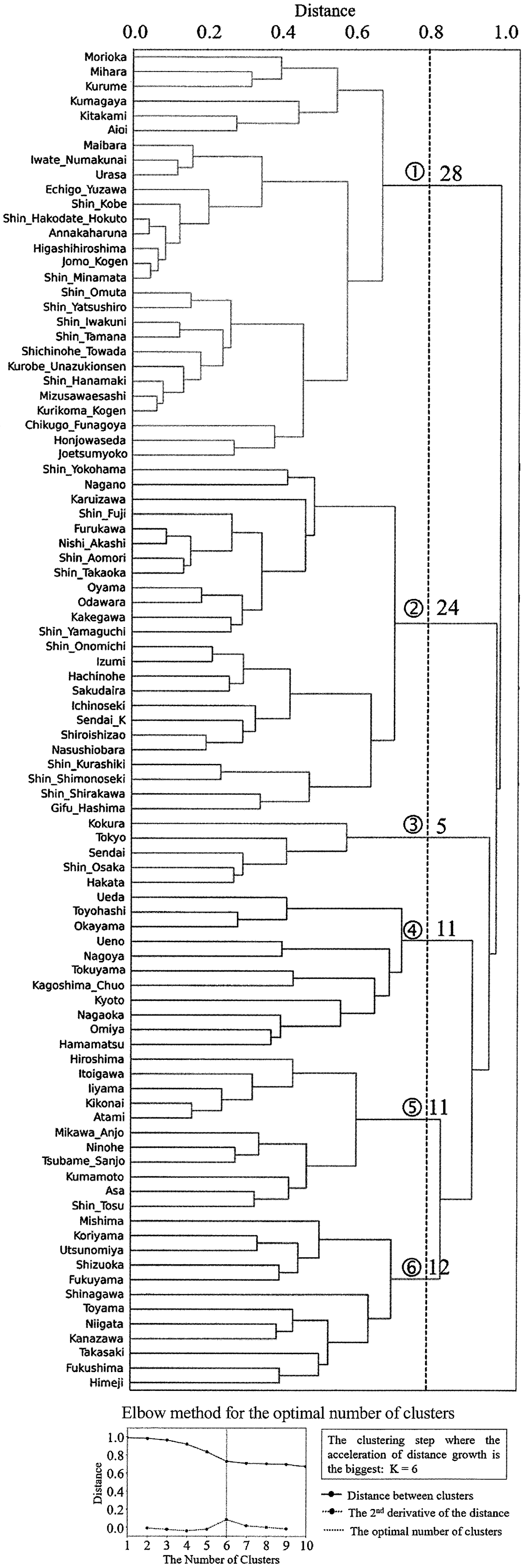
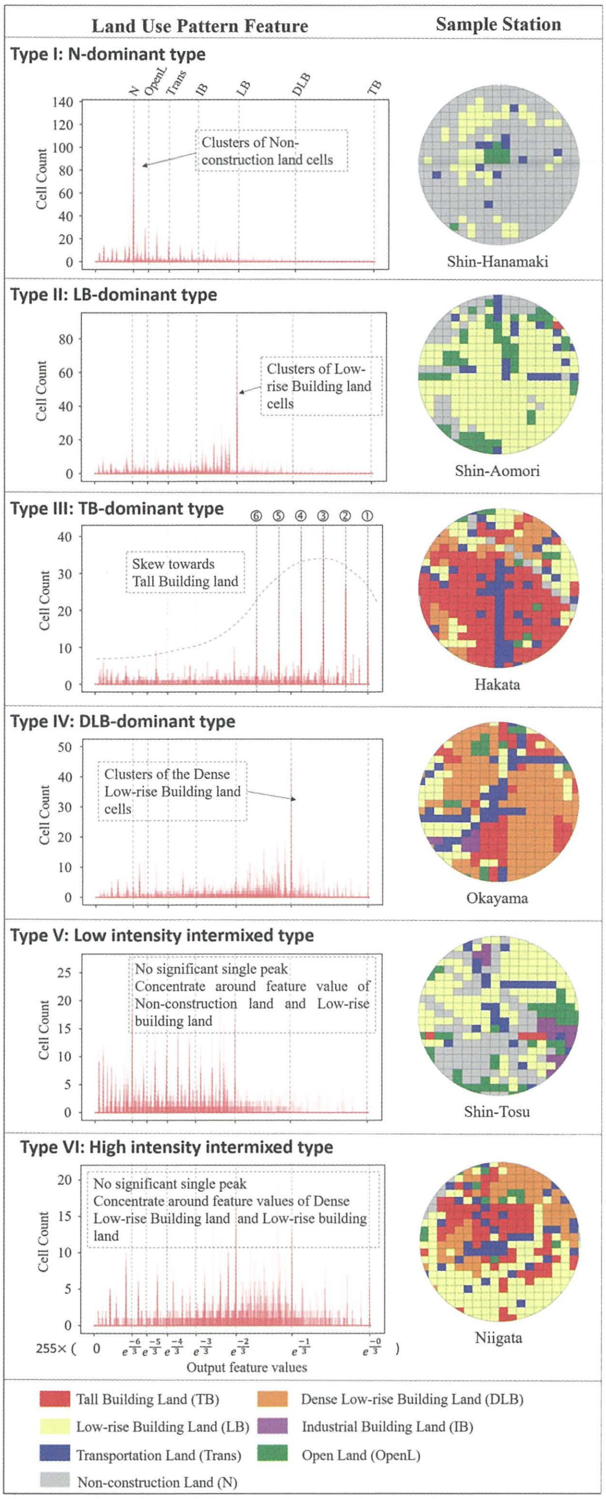


Fig. 4 Dendrogram for Land-use Pattern Clustering

Table 2 The Land-use Patterns Features



aggregation level of each land-use category is reflected by the count of the initialized land-use feature value, and the spatial variation is reflected by the number of unique output feature values, which can be observed from the fluctuations of the histogram. Accordingly, the global land-use pattern features of the 6 types of station areas can be interpreted as follows:

Type-I N-dominant type (28 stations): The histograms of Type-I have the single peak at the cell count of $255 \times e^{\wedge}(-2)$, which corresponds to the land-use feature value of N, and the output values concentrated around N. Moreover, there are barely any output feature values located between the initial feature values of LB and TB, indicating station areas of Type-I generally do not contain the TB and DLB. Therefore, Type-I can be concluded as the N-dominant type. In these station areas, the Non-construction land not only takes the most areal proportion but is also highly aggregated, forming large continuous unconstructed areas, whereas other land-use categories have much less occupancy and are dispersed in the station areas, as the sample station Shin-Hanamaki suggests.

Fig. 6 Diagram of the Major Land Use Contiguity Relation at the Neighborhood Level in Different Land-use Patterns

Type-II LB-dominant type (24 stations): The histograms of Type-II have the single peak at the cell count of $255\times e^{\wedge}((-2)/3)$, which is the initial land-use feature value of the Low-rise Building land. There are few output feature values located between the initial feature value of LB and TB. Therefore, Type-II can be named the LB-dominant type. Station areas in this group are characterized by a large continuous area of buildings of 3 stories or less, which are distributed collectively in a low-density form, whereas other land-use categories take much less areal proportions and are dispersed in the station area. Shin-Aomori station is a typical example of this group.

Type-III TB-dominant type (5 stations): The histograms of Type-III are distinct from other groups for it has significantly more cell counts at 255, indicating the land-use clusters of TB. Besides, if we trace the land-use combinations represented by the feature values of the peaks at ①~⑥, it can be found they represent land uses cells whose neighborhood is composed of TB: Trans = ①9:0, ②8:1, ③7:2, ④6:3, ⑤5:4, and ⑥4:5, respectively. Besides, comprehensively the histograms skew towards the initial land-use feature value of TB. Thus, the land-use pattern features of Type-III can be concluded as the TB-dominant type. In these station areas, Tall-building land takes the most areal occupancy. However, instead of forming a large continuous area, the TB cells intermixed with Trans cells. A typical example of Type-III is the Hakata station.

Type-IV DLB-dominant type (11 stations): The histograms of Type-IV differ from other groups for the significant single peak at the output feature value represent the cluster of DLB. Meanwhile, the majority of the output feature values distribute around the feature value of the DLB cluster. Therefore, Type-IV was named the DLB-dominant type. In station areas of this group, DLB cells take the most areal occupancy. They are highly aggregated, forming large continuous areas of land where buildings of 3 stories or less densely concentrated. In contrast, other land use categories take minor occupancy and distribute dispersedly in the station area. Okayama station is a typical example of Type-IV.

Type-V Low-intensity intermixed type (11 stations): the histograms of Type-V are distinct from type-I ~ IV for they have no significant single peak. Instead, the cell counts at the output feature values for N and LB are equally both slightly higher than other feature values. Besides, the majority of feature values distribute between $[0, 255\times e\hat{}((-2)/3)]$, and the histograms have more fluctuations than Type-I ~ IV. Accordingly, the pattern features of Type-V are concluded as the Low-intensity intermixed type. These station areas are mainly formed by the low-intensity land-use categories, i.e., N and LB cells. They clustered as small patches and intermixed, forming a fragmented pattern. A typical example of this group is the Shin-Tosu station.

Type-VI High-intensity intermixed type (12 stations): the histograms of Type-VI do not have a significant single peak either. However, in contrast to Type-V, the histograms of this group have small peaks at the output feature values represent the clusters of TB (255), DLB ($255\times e\hat{}((-1)/3)$), Trans ($255\times e\hat{}((-2)/3)$), indicating these station areas have relatively large number of TB cells, DLB cells, and LB cells. Besides, most output feature values distribute around the initial land-use feature values for DLB and LB, indicating these two land-use categories take relatively greater areal proportion than other land-use categories, suggesting a relatively high construction intensity. Also, the fluctuations of the histograms of this group indicate that the land-use cells in these station areas are intermixed, and the land-use pattern is fragmented. Therefore, Type-VI can be named as the High-intensity intermixed type. A typical representation of this group is the Niigata station.

3.2 The Local Land-use Pattern Features

The local land-use pattern feature refers to the composition and distribution situation in each land-use cell's neighborhood. In this study, we employed the mean matrix in the smoothing operation, thus the $300\times 300\,m^2$ neighborhood has been defined as a spatial indifference zone. Therefore, the local land-use pattern features here will only be interpreted as the land-use compositions in the neighborhood. Since every different land-use composition situation in the 3×3 neighborhood corresponds to a unique output feature value, by tracing back the most frequent output feature values in the station area, we can identify the major land-use contiguity relation in the station areas. Figure 6 is the diagram for the first 5 frequent neighborhood land-use composition situations in each land-use pattern type. The percentages represent the proportion of the land-use cells whose neighborhood is the corresponding land-use composition situation in the whole land-use cells.

Accordingly, it can be found in station areas of Type-I, the N-dominant type, the most frequent feature value corresponds to the situation where the 3×3 neighborhood is composed of only the N cells, and its percentage of 15.7% suggests a significant pattern feature. Besides, the first five frequent neighborhood land-use combinations suggested that Type-I's major spatial contiguity relation at the neighborhood level is between N cells and LB cells, where N cells usually take more than 50% of the areal occupancy. For station areas of Type-II, the LB-dominant type, the 5 most frequent land-use combinations in the 3×3 neighborhood are composed of LB cells, N cells, and Trans cells. Nevertheless, in either case, N cells and Trans cells take less than 2/9 of the neighborhood. For station areas of Type-III, the TB-dominant type, there is no single feature value concentrated significantly more cells than others. Instead, the first 5 frequent feature values correspond to the land-use combinations of TB cells and Trans cells in the 3×3 neighborhood, indicating the major contiguity relationship in these station areas is between TB and Trans. In the station areas of Type IV, the DLB-dominant type, the 5 most frequent feature values correspond to the neighborhood land-use combinations of DLB, LB, and Trans, where the DLB cells are always dominant in the neighborhood. In contrast, in station areas of Type-V and Type-VI, none feature value has a significantly higher percentage than others, which corresponds to the global features of higher spatial variation and a fragmented pattern in these station areas. However, we can still observe that the first 5 frequent neighborhood land-use combinations in Type-V are composed of the N and LB cells, while in Type-VI are the LB and DLB cells. These reflected the difference in the construction intensity between Type-V and Type-VI.

We can find consistency between the local pattern features and the global pattern features. The local features give an insight into the location relation of land uses in the defined neighborhood ($300 \times 300\ m^2$), specifically, the contiguity relationship between different land use categories. Takes Type-I for example, with 15.7% of land use cells' neighborhood is composed of Non-construction land, and almost 30% of land use cells' neighborhood is formed by N and LB cells, among which the occupancy of LB cells is always less than 50%, when assembling all this neighborhood pattern together, we will get a station area where the Non-construction land covers most of the station area while small patches of Low-rise Building land scatters in the non-construction area. Similarly, for other types, we can depict the land-use pattern feature of the whole station area by assembling the neighborhood land-use combinations together. The local pattern features help us understand how different land-use categories are intermixed and how land uses are arranged to form the land-use pattern of the whole station area.

3.3 The Trend of Land-use Patterns of Station Areas in Cities of Different Population Scales

So far, this study has identified 6 types of land use patterns in 91 existing Shinkansen station areas and clarified the land-use pattern features of each type. Then, this section will discuss the relation between land-use patterns and the property of the station cities. Specifically, we classified the Shinkansen station cities into 4 groups according to the city population because the population scale usually reflects the integrative city development potential and dynamics. Specifically, small cities are cities whose population is under 100 thousand, mid-sized cities are cities whose population is between 100 and 300 thousand, core cities are cities whose population is over 300 thousand, and the government ordinance designated cities are cities that have a population greater than 500 thousand and have been designated as such by order of the Cabinet of Japan according to the Local Autonomy Law. Figure 7 summarizes the composition of the city's population scale in each land-use pattern type group.

Accordingly, Type-I, the N-dominant type, is mainly observed in small and mid-sized cities whose population is less than 300 thousand. These stations areas are characterized by large continuous unconstructed land. The formation of the large unconstructed area has various causes. Some are related to the development stages, such as station areas in the initial development period, especially the newly constructed suburb stations along recently extended Shinkansen lines like Shin-Omuta stations and Shin-Hakodate-Hokuto stations, etc. Also, there are suburb station areas whose development has stagnated for years, such as Shin-Hanamaki station, Higashihiroshima station, etc. Besides, there are also major city stations in this group, such as Morioka station and Shin-Kobe station. These stations are located near great rivers or mountains. In such station areas, unconstructed land is formed due to the topographic limitation.

The land-use pattern Type-II, the LB-dominant type, is mainly identified in station areas in cities with a population of less than 300 thousand, particularly in cities with a population of between 100-300 thousand. Station areas of Type-III, the TB-dominant type, are all located in government ordinance designated cities and typically the central cities of major metropolitan areas. Such station areas are characterized by high-intensity land development and remarkable transportation property, usually serving as centers for aggregating city functions and the national-level transportation hubs. Station areas of Type-IV, the DLB-dominant type, are all located in cities whose population is over 100 thousand, among which over half are designated cities, and many are located in cities along the Tokaido Line and Sanyo Line. These station areas usually have a relatively long development history, such as Okayama station and Hamamatsu station. Type-V, the Low-intensity intermixed type, is mainly observed in station areas of cities whose population is less than 100 thousand. These station areas are either recently constructed stations in suburb areas like Shin-Tosu station, Tsubame-Sanjo station, or station areas limited by the topography or constructions in the built-up areas, such as Atami station and Kumamoto station. Finally, Type-VI, the High-intensity intermixed type, is mainly observed in station areas of cities that have a population of over 100 thousand, particularly cities whose population is over 300 thousand. In these station areas, TB, DLB, LB cells aggregate as small patches, intermixing together, forming some discernable land-use zones. These station areas are mainly located in the built-up areas of regional center cities, with a relatively long development history. However, the urban redevelopment of these areas is generally less dynamic than the station areas of Type-III and usually have minor scales. The different land use zones in the station areas reflect different stages of the redevelopment process in these station areas.

In summary, this section systematically summarized the trend of land-use patterns in cities of different population scales, thus clarifying the current land-use situation around Shinkansen. According to the clustering result, the construction situation around the existing Shinkansen station becomes clear. In contrast to the previous existing clustering approaches, which tend to classify station areas based on the land-use composition proportions, development intensity, station scales, or station cities properties, the image matching approach identifies the land-use pattern based on the location situation of land-use cells in the station areas. Therefore, the clustering result reveals the feature of land-use patterns regardless of the specific spatial process or the underlying influential factors. For example, we can observe that the station areas of Type-I, the N-dominant type, include station areas that are newly developed, station areas whose development has stagnated for years due to their isolated locations, and also major city stations whose land development is limited by the topography. According to the clustering result and the background information of the station areas, we can find due to various influential factors, these station areas with different properties formed the same land-use pattern in the time slice we observed.

4. The Land Use Transformation Situation of Shinkansen Station Areas

This section clarifies the dynamic land-use transformation situation in Shinkansen station areas by comparing Shinkansen station areas' land-use patterns in 2009 and 2016.

4.1 The Overall Land-use Transformation Situation at Shinkansen Station Areas

Table 3 summarizes the overall land-use composition situation of 91 existing Shinkansen station areas in 2009 and 2016. To examine whether the differences between land-use composition proportions are statistically significant, this study implemented the Wilcoxon signed-rank test. Accordingly, it can be found, except for the Industrial Building land and the Open land, the p-values of the Wilcoxon test for the mean differences are all less than 0.001, suggesting the mean of composition proportions in 2016 are statistically different with composition proportions in 2009. The average composition proportions of the Tall Building land and the Transportation land increased 3.66% and 5.41%, respectively. In contrast, the Dense Low-rise Building land, Low-rise Building land, and Non-construction land decreased by 2.87%, 4.34%, and 1.85%, respectively, indicating the land development comprehensively in 91 existing Shinkansen station areas were becoming more intensive.

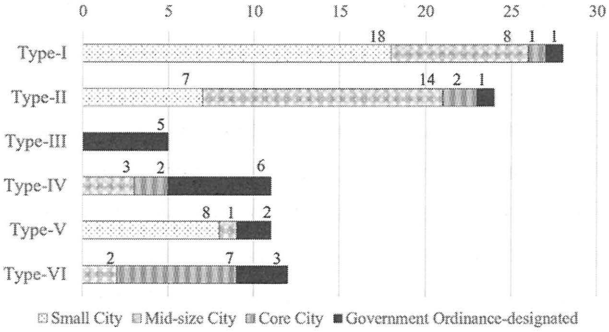


Fig. 7 The Trend of Land-use Pattern of Shinkansen Station Areas in Cities of Different Population Scales

Table 3 Land-use Change around Shinkansen Stations between 2009 - 2016

Land-use	2009 mean.	2009 sd.	2016 mean.	2016 sd.	Δmean.	P((Wilcoxon test))	
TB	5.01%	10.83%	8.67%	13.38%	3.66%	<0.001	****
DLB	15.58%	19.25%	12.71%	16.26%	-2.87%	<0.001	****
LB	38.07%	19.07%	33.72%	17.68%	-4.34%	<0.001	****
IB	1.97%	4.22%	1.62%	3.43%	-0.34%	0.042	*
Trans	3.93%	3.32%	9.34%	5.35%	5.41%	<0.001	****
OpenL	5.75%	5.19%	6.09%	4.57%	0.33%	0.027	*
N	29.69%	26.83%	27.85%	24.97%	-1.85%	<0.001	****

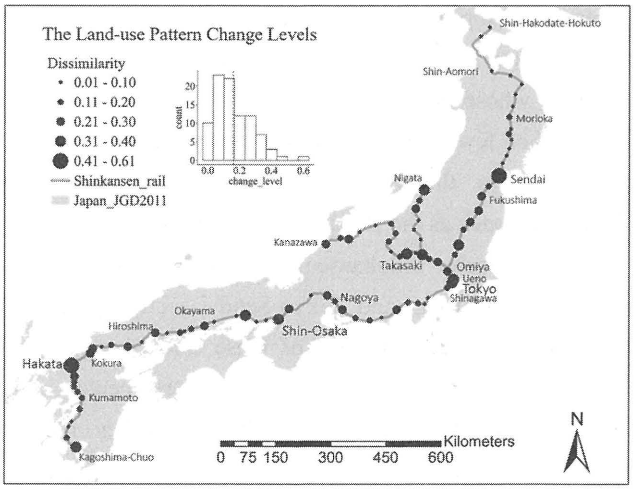


Fig. 8 The Level of Land-use Pattern Change of the Shinkansen Station Areas

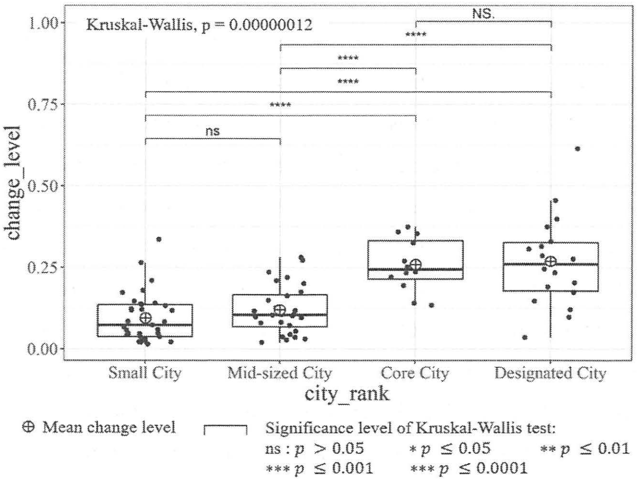


Fig. 9 The Boxplot of the Land-use Pattern Change Level of Station Areas in Cities of Different Population Scales

Figure 8 displayed the land-use change level of 91 exiting station areas, illustrating where the land use transformation was. The change level is computed based on the land-use maps of 2009 and 2016 (Equation 5). Accordingly, the mean of land-use pattern change levels is about 0.16, nevertheless, 54 station areas' change levels are under the average, indicating the majority of the land development concentrated in a small part of stations. To examine the trend of land-use change level in cities of different population scales, Figure 9 summarized the land-use pattern change levels according to the population scale of station cities. Accordingly, it can be observed that the mean change levels between the station areas of small and mid-sized cities are not statistically different, either are the differences between the core cities and designated cities. However, the station areas in core and designated cities have significantly more dynamic land-use changes than station areas in small and mid-size cities. Additionally, by observing Figure 8, it can be found that the station areas that have greater change levels are mostly regional center cities, particularly the central cities of the major metropolitans such as Tokyo, Shin-Osaka, Hakata, and Sendai, etc. As to the intermediate stations in small or mid-size cities whose population is less than 300 thousand, they generally had few changes, however, among them, the station areas close to the metropolitan centers changed more dynamically, such as the stations along the Hakata-Kumamoto section of Kyushu Shinkansen, Tokyo-Takasaki section of Hokuriku Shinkansen, and Tokyo-Sendai section of Tohoku Shinkansen. The development of these station areas might relate to their connection with the regional center cities, however, for the specific influential factors, further empirical studies are needed.

4.2 The Location Trends of the Land-use Transformation of Shinkansen Stations

This section focused on the location trends of land-use transformation in Shinkansen station areas. This section selected the station areas whose land-use pattern change level is over 0.10, to reduce the influence of the inherent differences of the land use data deriving from the land-use discrimination biases *5). Thereby, 58 stations were selected, including 14 station areas in small cities, 16 station areas in mid-sized cities, 12 station areas in core cities, and 16 station areas of the government ordinance designated cities. Besides, section 4.1 has demonstrated that the change of Industrial land and Open land is not statistically significant, hence, this section will not discuss their location trends, in other words, this section will only discuss the location trend of the newly developed TB, DLB, LB, and Trans cells.

As explained in section 2.2.3, the station areas were rotated to let the extension of the Shinkansen railway horizontal and the orientation of the central city (city hall direction) upwards (as Figure 4 suggests). The locations of the newly developed land-use cells were summarized. In order to clarify the location trend of the land-use changes in station areas of cities of different population scales, the locations of newly increased TB, DLB, LB, and Trans cells were summarized according to the population scales of the station cities, as Figure 10 shown. The newly developed TB mainly concentrated in station areas of the core cities and designated cities, while more newly developed LB was at the station areas of small and mid-sized cities. The amount of the newly developed DLB did not differ significantly in station areas of mid-size cities, core cities, and the designated cities, but significantly less in station areas of small cities. Besides, the amount of the newly increased Trans generally correlates to the population scale of the station cities. Accordingly, the composition characteristics of the land-use changes in different cities groups can be concluded as: the majority of land-use changes in station areas of small and mid-sized cities are from non-construction to low-intensity construction, whereas the land-use changes in core cities and designated cities are characterized by transformation from low-intensity to high-intensity.

As to the spatial relation of the land-use changes in the station areas, we implemented geographic analysis to examine the circumferential distribution trends and the radial distribution trends of the land-use changes around stations, to make clear whether the land-use changes differ in different orientations around the station and whether the land-use transformation situation varies with the distance to the station.

4.2.1 The Circumferential Distribution Trends of Land Development

To examine the circumferential distribution characteristics of the land-use changes, we plotted the *mean center* and the *standard deviational ellipse* to each plot of Figure 10.

The mean center is calculated by the average of all newly developed land use cells' geometry center coordinates. The standard deviational ellipse is defined by the standard deviation of the newly developed land use cells' x-coordinates and y-coordinates from the mean center. The mean center reflects the central tendency of the newly developed land uses. The ellipse allows us to see if the distributions of the newly developed land uses are elongated and hence have a particular orientation. Also, the length of the major and minor axes of the ellipse reflects the dispersion trends of the newly developed land uses.

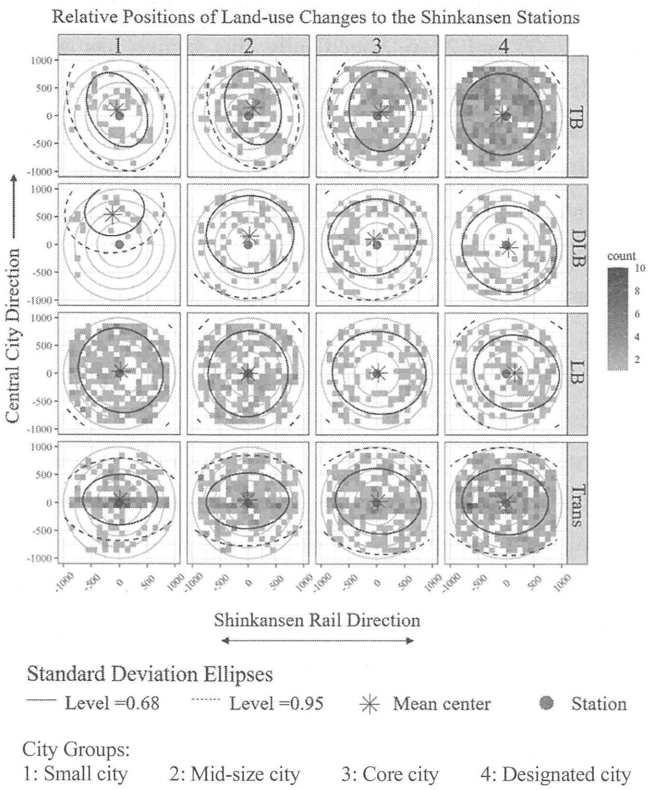


Fig. 10 The Circumferential Distribution of Land Development around Shinkansen Stations

Accordingly, it can be observed that different newly developed land uses indeed have different location trends around stations. The circumferential distribution trend of each land use category can be summarized as follow:

1) Tall Building land (TB): In station areas of the designated cities, the newly developed TB cells are uniformly distributed around stations, there is no clear directional trend. However, in small cities, mid-sized cities, and core cities, the major axes of the ellipse are almost perpendicular to the direction of the railway extension, indicating in station areas of these cities, the development of TB has the directional trend in the perpendicular direction of the railway, and the development extends on both sides of the railway. According to the mean center, the development of TB in station areas of small and mid-sized cities is located slightly more on the side towards the city center.

2) Dense Low-rise Building land (DLB): The circumferential distribution trend of the newly developed DLB cells has no remarkable differences in station areas of mid-size cities, core cities, and designated cities. The length of the major and minor axes of the standard deviational ellipse is almost equal, and the mean centers are close to the station, indicating that the development of DLB has no significant directional trend in station areas of these cities. In contrast, the mean center of the newly developed DLB cells is located in the center city side, and it is distant from the station, indicating the development of DLB in small cities concentrates on the central city side of the stations.

3) Low-rise Building land (LB): as the standard deviational ellipse suggests, in station areas of either city group, the length of the major axes and the minor axes are almost equal, and the mean center is close to the station, indicating the development of the LB locates uniformly in either orientation around the station.

4) Transportation land (Trans): it can be observed the major axes of standard deviational ellipses of the newly developed Trans cells in station areas of 4 city groups are parallel with the extension of railways and concentrated along the railway. However, in station areas of core cities and designated cities, the minor axes of the ellipse are longer than the ellipse of the station areas in small and mid-sized cities. Therefore, apart from the construction of the railway, in the station areas of the core cities and designated cities, there might also be a large number of land development for the improvement of inner traffic quality of the station area.

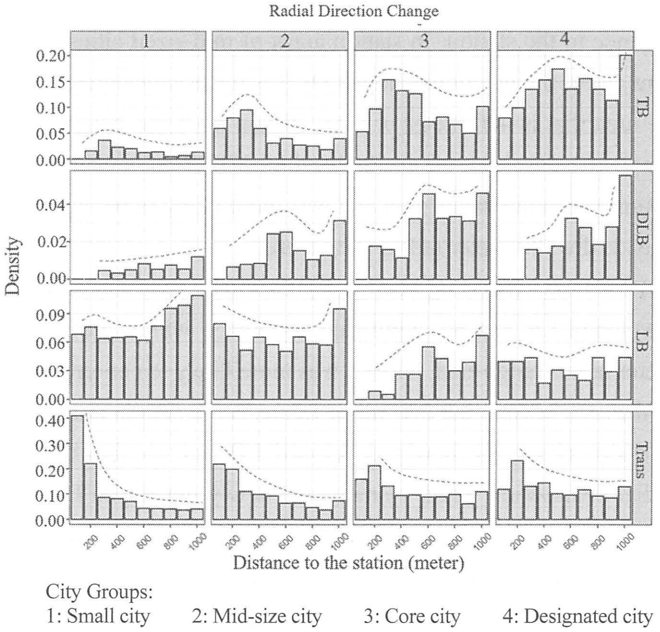


Fig. 11 The Radial Distribution of Land Use Changes to The Central Station

4.2.2 The Radial Distribution of Land Use Changes

To analyze the radial distribution trends of land-use transformation with the distance to the station, Figure 11 summarized the density of the changed land-use cells in every 100-meter circular ring region around the station. Because the area of the circular ring increases with the distance to the station, it is naturally more likely to observe more land-use changes. Therefore, instead of summarizing the total area of the changed land-use cells in each circular ring region, we calculated the density, that is, the total area of the newly increased land use cell dividing by the area of the circular ring. Accordingly, the radial distribution trends of the newly developed Tall Building land, Dense Low-rise Building Land, Low-rise Building land, and Transportation land in station areas of cities of different population scales are shown in Figure 11.

1) Tall Building land (TB): In station areas of small and mid-sized cities, the newly developed TB cells concentrated more within the 400-meter radius area. In contrast, in station areas of core cities, the newly developed TB concentrated more between the 200~500-meter radius area. As to station areas of designated cities, the density of newly developed TB increased with the distance to the station within the 500-meter radius range of that station area, however, on average there is no significant increase or decrease trend in the range of the 200~1000-meter radius area.

2) Dense Low-rise Building land (DLB): The newly developed DLB has the location trend to distant from the station. Generally, there is barely any newly developed DLB within the 200-meter radius range station area. In the station areas of small cities, the newly developed DLB slightly increases with the distance to the station. In station areas of mid-sized cities and core cities, the newly developed DLB is more concentrated in the area that is 400-meter or more distant from the station. In the designated cities, the newly developed DLB was outside the 200-meter radius range area and was more likely to be located outside the 500-meter radius station area.

3) Low-rise Building land (LB): In small cities, the newly developed LB has no significant difference within the 600-meter radius range area, while it was more likely to concentrate in the area outside the 600-meter range. As to station areas of mid-size cities, the newly developed LB has no significant radial distribution trend. Namely, the newly developed LB is distributed uniformly in the 1000-meter radius range station area. In station areas of core cities, it can be observed that the newly developed LB is generally outside the 300-meter radius range of the station area and is more concentrated outside the 600-meter radius station areas. As to the station areas of designated cities, there is no remarkable radial distribution trend.

4) Transportation land (Trans): The newly developed Trans is generally more concentrated near stations. However, in station areas of core cities and designated cities, this concentration trend is much less significant than in small and mid-sized cities. This can be related to the fact that there are more newly opened Shinkansen stations in small and mid-sized cities, therefore, it is more likely to observe the land development related to the railway construction in these areas.

In summary, this section clarified the land-use transformation situation of existing Shinkansen station areas during 2009 and 2016. Specifically, this section has testified that the comprehensive land development intensity around Shinkansen stations has significantly increased during 2009 and 2016. However, the majority of land-use transformation concentrated in less than half of the station areas, particularly station areas located in cities whose population is over 300 thousand. Besides, for stations in cities of different population scales, the land-use transformation has different composition and location trends: for small and mid-sized cities, the major land-use transformation in station area was from non-construction to low-density construction, while the development of Tall Building land in these station areas generally aggregated in the 400-meter range of station areas and mainly on the central city side; On the other hand, for station areas in core cities and designated cities, the land development during 2009 and 2016 has the trend of increasing land development intensity and improving the inner traffic quality of the whole station area.

To some extent, the land-use transformation situation in station areas of different city groups reflected various development stages these station areas were going through. In small and mid-sized cities, many stations were newly constructed in the suburb, the land development tends to be low-intensity and close to the station, whereas in core cities and designated cities, the station areas are mostly located in the built-up area, therefore, the land development is mainly a redevelopment process to increase the intensity and quality, and tend to disperse in the station area. However, notably, this section discussed the trend based on the average situation in station areas of each city group, further study is needed when discussing the situation in a specific station area.

5. Conclusion and Discussion

In conclusion, this study analyzed the current land-use situation and the dynamic land-use transformation situation around Shinkansen stations. By applying the land-use pattern comparison method based on image matching, this study identified 6 types of land-use patterns around 91 existing Shinkansen stations and clarified the trend of land-use patterns of station areas in cities of different population scales. Besides, this study also analyzed the land-use transformation situation in Shinkansen station areas by comparing station areas' land-use patterns of 2009 and 2016, and clarified the location trends of land-use transformation in station areas.

By systematically summarizing the current land development situation in existing Shinkansen stations, this study provided a comprehensive insight into what is happening in Shinkansen station areas. As a result, we found that the land development situation of Shinkansen station areas generally corresponds to the city scales: the station areas in major cities generally have more intensive and more dynamic development, whereas station areas in small cities generally have less intensive and less dynamic development. It seems nothing to surprise or anything like a Shinkansen magic has been observed in the current situation. However, among station areas of each city group, the specific situation varies. For example, this study has identified the station areas along the Hakata-Kumamoto section of Kyushu Shinkansen, Tokyo-Takasaki section of Hokuriku Shinkansen, and Tokyo-Sendai section of Tohoku Shinkansen had more dynamic changes than the average small stations in other regions. These might relate to their location close to the central metropolitan cities, but the specific reasons need further studies. The influential factors of land development can be complicated and vary in different cities, which is out of the research scope of this study. Moreover, this study only focused on the development situation during 2009-2016, which is an extremely limited period to the whole development history of a Shinkansen station area. Therefore, the result of this study cannot reflect Shinkansen's influence on the station city.

The major contribution of this study is clarifying what is happening in the Shinkansen station areas in our observed time slice, thus providing a reference for urban planners and policymakers to rethink future development strategies. Besides, another contribution of this study is introducing the image matching approach to the study of land-use patterns. The image matching approach allows us to efficiently identify land-use patterns from a large number of study areas with integrative consideration of land-use composition and spatial relation. By combining the clustering result with the background information of stations such as development history, station city properties, topographic information, we can get a deeper understanding of how land-use patterns are formed under different influential factors.

Notes

*1). It is generally accepted that the maximum running speed of a high-speed rail should be in excess of 200Km/h, thus the Akita Shinkansen and Yamagata Shinkansen were not discussed in this study for their maximum running speed is 130Km/h.

*2) Among 92 existing Shinkansen station areas, Okutsugaru-Imabetsu station is located in a rural area, thus it is not included in the urban land-use subdivision mesh data published by the Policy Bureau of the Ministry of Land, Infrastructure, Transport, and Tourism. Therefore, the situation of Okutsugaru-Imabetsu station is excluded in this study.

*3) With 3×3 mean matrix, the land-use pattern feature descriptor extracted by image smoothing operation will be composed of 11440 elements (unique feature values). When the number of bins less than 11440, the merge of histogram bin will lead to inaccuracy problem in the similarity evaluation. While the number of bins goes great will bring inefficiency problem in computation. Therefore, with integrative consideration of the accuracy and computation efficiency, this study set $N = 12000$.

*4) The latest urban land-use subdivision mesh data published by the Policy Bureau of the Ministry of Land, Infrastructure, Transport, and Tourism was the land-use data of 2016.

*5) The land-use subdivision mesh data provided by the Policy Bureau of the Ministry of Land, Infrastructure, Transport, and Tourism is based on the discrimination of satellite maps. Due to the quality of the satellite map and land-use discrimination algorithm, there are inherent biases in the results. Therefore, the land-use data between different years have inherent differences caused in the data collection process.

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