Chapter 15
Neighborhood Interaction in Urban Land-Use Changes Using Cellular Automata-Based Geo-Simulation*

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15.1 Introduction

Cities can be understood as complex systems with intrinsic characteristics of emergence, self-organization, self-similarity, and non-linear behavior of land-use dynamics (Barredo et al. 2003; Batty 2005). Cities incessantly undergo a dynamic and complex process of urban land-use changes. This complex process has direct impacts on the urban environment (Jusuf et al. 2007; Pauleit et al. 2005), and may even profoundly disrupt the structure and function of ecosystems on a global scale (Lambin et al. 2001; Turner et al. 1990). Therefore, the complex spatial processes of urban land-use changes must be thoroughly understood in order to provide municipal and urban planners with a basis for assessing the ecological impacts of urban land-use changes, and to support spatial decision-making. For this purpose, various spatial dynamic models of urban land-use change, in particular cellular automata (CA), multi-agent systems (MAS), and geographical information system (GIS)-based urban geo-simulation models, have been constructed and successfully

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applied to many cities (Barredo and Demicheli 2003; Batty et al. 1999; Torrens 2006; White and Engelen 2000; Yeh and Li 2002). In such geo-simulation models, neighborhood interaction is an important component (Batty 1991; Wu 1998; Zhao and Murayama 2007). Neighborhood interaction means local spatial interactions between neighborhood land-use categories such as facilities, residential areas, and industries in urban areas. Here, "neighborhood" means "close to", i.e., neighborhood land-use parcels may or may not be contiguous (touching). Such interaction has a great impact on the spatial processes of urban land-use changes (Batty 2005; Couclelis 1989). This type of factor is known as the neighborhood effect of urban land-use changes. The neighborhood effect plus exogenous factors (like spatial interactions between cities) and endogenous factors (like transportation networks in urban areas) determine the spatial process of urban land-use change (White and Engelen 2000). Furthermore, it is often cited as the main factor which decides urban land-use change patterns, since other factors are comparatively stable in the spatial process of urban land-use change during a set period.

In fact, neighborhood interactions are always a focus in the field of CA research. This standpoint can be derived from the basic definition of CA offered in von Neumann's lecture of 1951 (von Neumann 1951). There are four elements in a basic CA structure, namely, automata size, state, neighborhood, and the transition rule of automata state. Under a certain size and prescribed state, automata dynamics is controlled by the transition rule, which is established only by considering the interaction of automata in the neighborhood area. In the early phase of the application of CA to urban studies, urban geo-simulation models came from the basic definition of CA (Batty 1991; Couclelis 1989; Phipps 1989). At that time, urban geo-simulation models were mainly used to explore the intrinsic characteristics of urban systems such as self-organization and self-similarity (Batty and Longley 1994; Batty and Xie 1994; White and Engelen 1993, 1994). Later, scholars moved to focus on the simulation of actual urban land-use dynamics using CA models, and therefore CA models were updated by adding components or adjusting neighborhood configurations for this purpose (Batty et al. 1999; Clarke et al. 1997; White and Engelen 2000; Wu 1998). Some scholars also proposed MAS for urban land-use geo-simulation to overcome the weakness of the CA approach (Le et al. 2008; Parker et al. 2001). However, neighborhood interaction still is deemed an important component in urban geo-simulation models whether they are based on MAS or updated CA (Torrens and Benenson 2005).

Although neighborhood interaction has been highlighted in studies of urban land-use changes (White and Engelen 2000; Yang and Billings 2000; Zhao and Murayama 2007), there is still much that is unknown about its characteristics, although these provide the basic information which constitute the neighborhood effect rules for urban geo-simulation models. For example, neighborhoods in urban geo-simulation models generally adopt either the von Neumann 3×3 (or 5×5) or the Moore 3×3 configuration for simplicity (Batty 1998; Wu 1998; Yeh and Li 2001). Some scholars have enlarged the size of the configuration in neighborhood interaction models to give sufficient consideration to the human characteristics of urban systems (White and Engelen 1993; Zhao and Murayama 2007). However, few

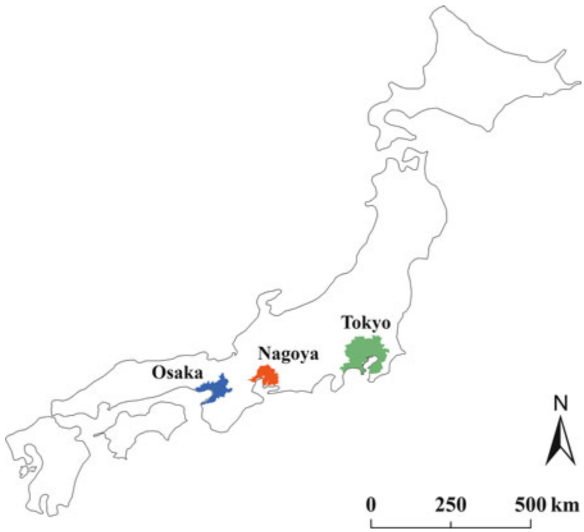


Fig. 15.1 Locations of the three Japanese metropolitan areas

studies have focused on the reason why such neighborhood configurations are selected and modeled, and what the mechanism of the neighborhood effect is. In particular, there are very few discussions in the literature about whether the issues that are characteristic of neighborhood interactions are the same in different cities. The answer to this question is very important for an understanding of the mechanism of the neighborhood effect on urban land-use changes, and for constructing a universal urban geo-simulation model which may be applied to any city in Japan. This research focuses on this issue, and tries to interpret the similarities and differences in the characteristics of neighborhood interactions in urban land-use changes by comparing three metropolitan areas in Japan, i.e., Tokyo, Nagoya, and Osaka, using such aids as the neighborhood interaction model and the similarity measure function. The results of this research will provide important information for constructing effective and operational neighborhood effect modules in urban geo-simulation systems.

15.2 Methodology

15.2.1 Study Areas

The three Japanese metropolitan areas of Tokyo, Nagoya, and Osaka were selected for a comparative study. Figure 15.1 shows the location and range of the study areas. These three metropolitan areas are the business, economic, political, and population centers of Japan. In the period after World War II, in particular, a large proportion of the Japanese population congregated in these areas (Murayama 2000), so that by 2005, these three areas accounted for more than 50% of Japan's total population.

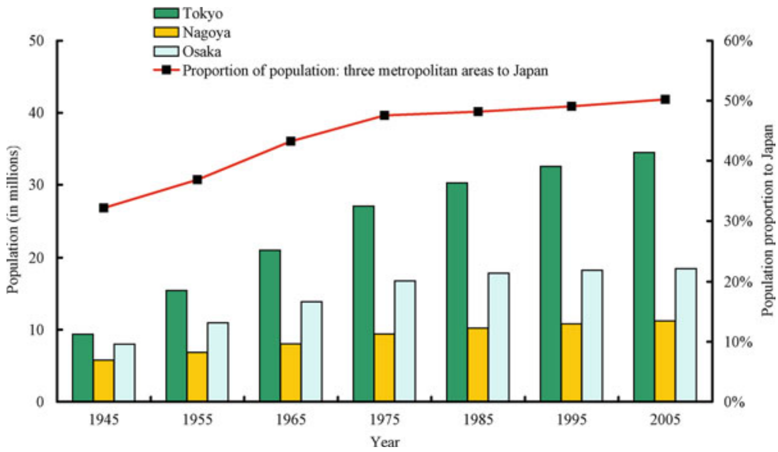


Fig. 15.2 Population increase in the three metropolitan areas and their proportions of Japan's population from 1945 to 2005 (*Source*: Statistics Bureau, Ministry of Internal Affairs and Communications of Japan)

Figure 15.2 illustrates the population increase in the three metropolitan areas and their respective proportions of the population of the whole country from 1945 to 2005. With the increases in population, the urbanized areas expanded into the surrounding regions of the three metropolitan areas at an astounding pace. As well as urban growth, urban functions in the existing urban areas also experienced a process of self-adjustment (Takahashi and Taniuchi 1994). Therefore, these three metropolitan areas are appropriate study areas for gaining an understanding of the spatial processes of urban land-use changes in Japan, as well as the characteristics of neighborhood interactions at that time.

15.2.2 Data Set

Detailed digital information of the metropolitan areas (10 m grid land-use; DDIMA10 m) of Tokyo, Nagoya, and Osaka was produced by the Geographical Survey Institute of the Ministry of Construction of Japan. DDIMA10 m of Tokyo was investigated in 1974, 1979, 1984, 1989, and 1994; DDIMA10 m of Nagoya in 1977, 1982, 1987, 1991, and 1997; and DDIMA10 m of Osaka was investigated in 1974, 1979, 1985, 1991, and 1996. DDIMA10 m provides an abundant and detailed urban land-use classification system, which includes a range of socio-economic information over a period of time. There are 15 categories of land-use in these data sets, namely (A) forest and wasteland, (B) paddy field, (C) dry field and other farm-land, (D) construction areas, (E) vacant land, (F) industrial land, (G) low-storey residential land, (H) densely developed low-storey residential land, (I) medium and high-storey residential land, (J) commercial land, (K) roads, (L) parks, (M) public facilities, (N) water, and (O) other. Here, in order to reach a clear understanding of the main characteristics of urban land-use changes, land-use is grouped into the following ten categories: (1) vacant land, (2) industrial land, (3) residential land, (4) commercial land, (5) roads, (6) public land, (7) special land, (8) forest and wasteland, (9) cropland, and (10) water. Here, land-uses (D) and (E) in the original data set are combined into land-use (1); (G), (H), and (I) into (3); (L) and (M) into (6); and (B) and (C) into (9). The others remain in their original categories.

The grouped land-use classification system reflects the intrinsic characteristics of urban land-use changes. "Water" represents fixed features, i.e., it is assumed that it will not change, and therefore it is not involved in land-use dynamics in order to protect the living environment. Forest, wasteland and cropland are passive features that play a role in the process of land-use changes, but the changes are not driven by an exogenous demand for land. They appear or disappear in response to active functions of land being used or abandoned. The active functions are four land-use categories which are forced into existence by demands for land generated exogenously in response to changes in the urbanized areas: vacant, industrial, residential, and commercial land. Roads, public, and special lands are active features which are the dynamics of the model, but they are mainly controlled by the municipal government through urban land-use planning.

15.2.3 Data Processing

Urban land-use changes are driven by multiple factors such as urban and region planning policy, environmental characteristics, local-scale neighborhood characteristics, the spatial characteristics of cities, and so forth (Carver 1991; Voogd 1983). These factors can be divided into two types: natural forces and human activities. Over a short time-scale, the effects of both natural forces and human activities are comparatively stable for a certain area (Zhao et al. 2010). Therefore, short time-intervals, here about 5 years, are used to extract land-use change patterns in order to interpret the characteristics of neighborhood interactions. The latest time-intervals are selected from DDIMA10 m data sets as follows: Tokyo Metropolitan Area, 1989–1994; Nagoya Metropolitan Area, 1991–1997; Osaka Metropolitan Area, 1991–1996. Although there are slight differences in the study periods in these metropolitan areas, land-use policies in the whole country during such short periods do not change very much. Therefore, it is assumed that the tiny differences will not influence the understanding of the characteristics of neighborhood interactions.

Considering the huge data sets from the three metropolitan areas and the resulting time-consuming computations, the grid size of the land-use data set was set at 100 m × 100 m by aggregating the original 10 m × 10 m cells by a majority rule (in the process of aggregation, the land-use category of a 100 m × 100 m grid area is determined by the maximum proportion of land-use categories of the 10 m × 10 m grids which are located in that 100 m × 100 m grid area).

Urban land-use changes in the three metropolitan areas were extracted from data sets from two adjacent time-sections. Land-use changes in the area at a distance of less than 600 m to the boundary of the study area were deleted in order to eliminate the boundary effect. Appropriate sample numbers were selected randomly in order to create an approximately 1:1 ratio of transformed to non-transformed cells.

15.2.4 Neighborhood Interaction Model

"Neighborhood" has no determinate configuration in many correlative studies (Barredo et al. 2003; Batty 1998; Li and Yeh 2001; White and Engelen 1997). According to Zhao and Murayama (2007), an extended neighborhood configuration is defined as an area within a radius of eight cells from the central developable cell in a model which contains 196 cells. The contribution of one cell in the neighborhood is associated with its state and its distance to the central developable cell i based on Tobler's first law of geography (Tobler 1970). The neighborhood effect on the probability N of the conversion of a cell to land-use k is described as a function of a set of aggregated effects of cells in the neighborhood:

$$\text{Log}\left(\frac{N_{ik}}{1-N_{ik}}\right)=\beta'_{0i}+\sum_{k}\beta'_{ihk}\sum_{m}\frac{A_m}{d_{mi}^2}I_{mh} \tag{15.1}$$

where m is the number of cells in the neighborhood, A_m is the area of cell m (here in square meters), d_{mi} is the Euclidean distance between the central developable cell i and cell m in the neighborhood area, β'_{ihk} is the constant of the effect of land-use h on the transition to land-use k, + stands for positive, – stands for repulsive, I_{mh} is the index of cells, and $I_{mh}=1$ if the state of cell m is equal to h; otherwise $I_{mh}=0$. β'_{0i} and β'_{ihk} are the coefficients to be calibrated with a maximum likelihood estimation. The coefficients stand for the effects of different land-use categories in the neighborhood on the change in transformation odds ($N_{ik}/(1-N_{ik})$) of central cell i to land-use category k. If β'_{ikh} is positive, the odds will add to the increase in the aggregated effect of land-use type k, and vice versa. If one of the coefficients does not pass the hypothesis test at the 0.05 level, $\beta'_{ikh}=0$, indicating that the corresponding land-use category does not affect the transformation of the central developable cell i. The values of the coefficients represent the intensity of the effect on the transformation odds. The greater the value, the more intense the effect. Obviously, the coefficients are suitable indices which can be used to analyze the effect of land-use categories in neighborhoods on the transformation of cells. Herein, the coefficients are used to interpret the neighborhood interactions in urban land-use changes in the three metropolitan areas.

15.2.5 Similarity Measure Function

As this research focuses on land-use changes in urbanized areas, all seven urban land-use categories, i.e., vacant, industrial, residential, commercial, road, public, and special land, in neighborhood areas should affect the transformation of the four active land-use categories in metropolitan areas. In these seven urban land-use categories, special land comprises military, royal, and other special land which is always closed to the public. Therefore, it is assumed that the effect of special land on the transformation of active land-use categories is very limited and can be omitted from an understanding of urban land-use changes. Accordingly, the values of the six remaining effect coefficients β'_{ihk} can be obtained for one active land-use category in any metropolitan area.

The values of the coefficients for different metropolitan areas are compared using the high-dimension similarity measure function Hsim(*X*, *Y*) (Yang and Zhu 2004):

$$\mathrm{Hsim}(X,Y) = \frac{\sum_{i=1}^{d} \frac{1}{1+|x_i - y_i|}}{d} \tag{15.2}$$

where *X* and *Y* are two sets (objects) with dimension *d* which are compared for similarity, and x_i and y_i stand for the data of *X* and *Y* in the *i*th dimension.

This function represents the degree of similarity of two objects *X* and *Y*. The higher the value of Hsim(*X*, *Y*), the more similar the two objects are. If the minimum value of Hsim(*X*, *Y*) is 0, *X* and *Y* are not similar at all. The maximum value of Hsim(*X*, *Y*) is 1, meaning that *X* and *Y* are identical. In this research, *X* and *Y* stand for the same active land-use category in different metropolitan areas, and x_i or y_i stand for the values of the coefficients of the neighborhood interaction in urban land-use changes. Higher values of Hsim(*X*, *Y*) indicate a higher degree of similarity of neighborhood interactions in different metropolitan areas.

15.3 Results and Discussion

15.3.1 Urban Land-Use Structure and Changes in the Three Metropolitan Areas

Land-use patterns and structure in the three metropolitan areas showed a similar mode in the base years of 1989 in Tokyo, 1991 in Nagoya, and 1991 in Osaka (Fig. 15.3a, c, e). Residential land is dominant in the urban land-use structure of these three metropolitan areas, accounting for more than 43% of urban land in the three areas. The area proportion of residential land in Tokyo even reached 48.7%. The high values of this proportion illustrate the residential function of the metropolitan areas in Japan. The area of public land is the second highest proportion at more than 14%. Public land in urbanized areas mainly includes public service facilities (such as educational facilities, city hall) and open spaces like parks. The higher proportion of public land in the metropolitan areas indicates the efforts of municipal governments to provide residents with more public service facilities and open spaces.

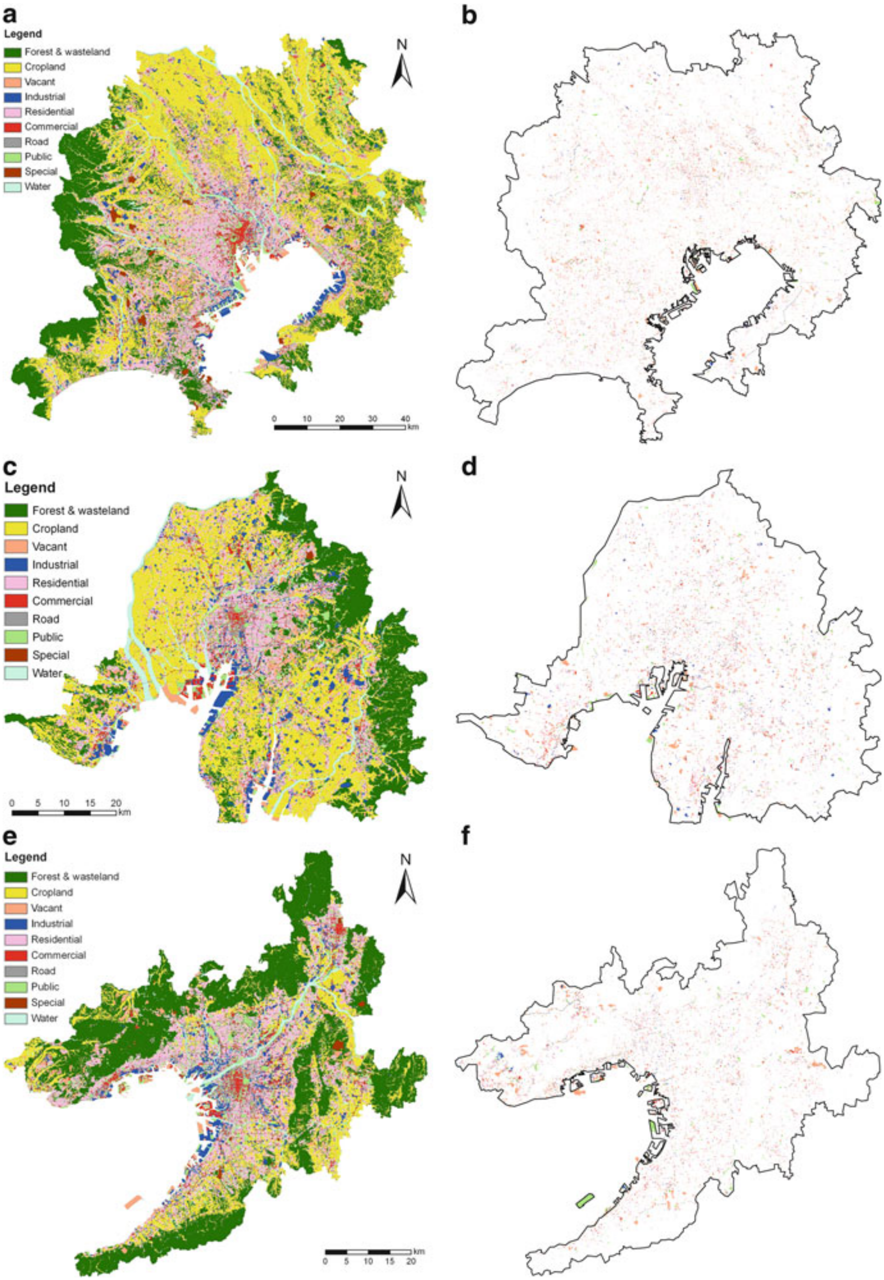
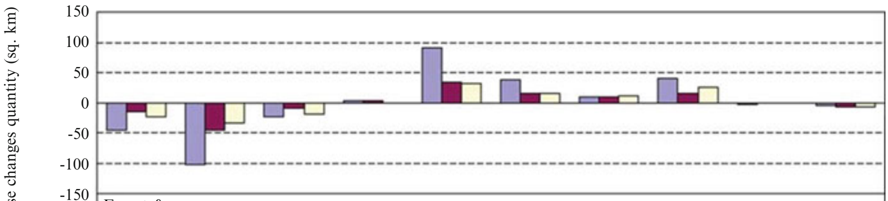


Fig. 15.3 Land-use patterns in the three metropolitan areas in the base year land-use map of: (**a**) Tokyo 1989; (**c**) Nagoya 1991; (**e**) Osaka 1991; and land-use changes (*changed areas*) in: (**b**) Tokyo from 1989 to 1994; (**d**) Nagoya from 1991 to 1997; (**f**) Osaka from 1991 to 1996



	Forest & wasteland	Cropland	Vacant	Industrial	Residential	Commercial	Road	Public	Special	Sea
Tokyo	-46.87	-102.85	-24.03	4.00	90.93	37.02	9.22	40.19	-2.84	-4.80
Nagoya	-14.70	-45.07	-9.45	3.52	34.20	14.79	8.32	15.44	-0.01	-7.07
Osaka	-23.70	-32.73	-18.50	-1.02	30.65	15.16	11.23	25.14	-0.01	-6.30

Land-use category and changes quantity (sq. km)

Fig. 15.4 Urban land-use changes in the three metropolitan areas (Tokyo, 1989–1994; Nagoya, 1991–1997; Osaka, 1991–1996)

The third highest proportion is vacant land, which represents land being prepared for, or subjected to, construction. Its proportion in urbanized areas is generally more than 10%, indicating the potential dynamics of urban areas in the three metropolitan areas. Industrial land is always either located along the coast of the three metropolitan areas or agglomerated in the suburbs. The proportion of industrial land to urbanized areas in Tokyo and Osaka is less than 10%, whereas that in Nagoya is at a higher level of 13.6%. Compared with other metropolitan areas, Nagoya is a city with an agglomeration of industries, especially automobile industries. The higher area proportion of industrial land indicates the degree of industrialization in Nagoya.

Commercial land is generally located in the center of metropolitan areas and near subway or railway stations. The proportion of commercial land to urbanized area in one metropolitan area is about 7%. The CBD (central business district) in the center of the metropolitan area and the sub-CBD near main subway stations are notable in land-use maps of the three metropolitan areas (Fig. 15.3a, c, e). The proportion of road land in the three metropolitan areas is not low, reflecting the high density of roads in metropolitan areas in Japan. The proportion of special land is not significant except for Tokyo with 1.7%.

The spread of urbanized areas has different development potential in the three metropolitan areas in terms of the whole land-use patterns (Fig. 15.3a, c, e). Agricultural land accounts for the main proportion of suburban areas in Tokyo and Nagoya. These areas are flat with smooth topography, which provides prime development space. However, the suburban areas in Osaka are mainly mountainous areas where urban land-use patterns are limited by the rugged topography. Urban areas cannot easily spread to such places.

The changes in land-use structure and patterns mainly show the trend in urban growth during the study period in the three metropolitan areas (Figs. 15.3b, d, f, and 15.4). Areas of cropland, vacant land, forest, and wasteland decreased to 173.75 km^2 in Tokyo, to 69.22 km^2 in Nagoya, and to 74.93 km^2 in Osaka. Increases in residential, commercial, and public land are notable. Most of the land parcels of cropland, forest, and wasteland which had decreased had become residential and public land. The residential and public-oriented strategy of urban development is well illustrated by this phenomenon. In addition, as the three metropolitan areas are coastal cities, the urbanized areas also spread out into the sea. During the relatively short study period, a considerable amount of the marine area was reclaimed and converted into urban area: 4.80 km^2 in Tokyo, 7.07 km^2 in Nagoya, and 6.30 km^2 in Osaka (Fig. 15.4). Except for industrial land in Osaka, all of the urbanized areas of industrial, residential, commercial, roads, and public land in the three metropolitan areas increased, but at different rates. Land covered by roads only increased a little during the 5 years, and industrial land showed less change than residential or commercial land in the three metropolitan areas. Industrial land in Osaka decreased slightly during the period. Patterns of land-use changes showed varying characteristics. The land-use parcels which changed were widely dispersed, and did not agglomerate in the study areas (Fig. 15.3b, d, f).

15.3.2 Characteristics of Neighborhood Interaction in Urban Land-Use Changes

The coefficient β'_{ikh} of different land-use categories in the neighborhoods was regressed at the 0.05 level of the hypothesis test for urban land-use changes in the four active categories in the three metropolitan areas. The coefficient β'_{ikh} stands for the intensity of the neighborhood effect on the probability of an active land-use category, i.e., the neighborhood interaction in urban land-use changes. Considering its particular nature, special land is assumed not to be involved in the interaction. Figure 15.5 shows the results of regression. Here, the horizontal axis stands for the land-use categories which affect the transformation of the four active land-use categories in the neighborhood. The vertical axis represents the value of the regression coefficient β'_{ikh}. Figure 15.5 shows that the value of the regressed coefficient of each active land-use category on its own transformation is always more than that of the other land-use categories, especially industrial and commercial land. For vacant land, the values of the coefficient itself in the three metropolitan areas are more than 0.5, whereas those of other land-use categories are less than 0.4. This difference is similar for residential land, but is more notable for industrial land. For industrial land, the values of the coefficient itself are near to, or greater than, 1.0, while those of other categories are less than 0.5.

The values of the coefficient of commercial land also are greater than those of other land-use categories for commercial land. This phenomenon represents the effect of spatial autocorrelation in the spatial process of urban land-use changes in the three metropolitan areas (Zhao and Murayama 2006), which cause the spatial aggregation of the same urban land-use category (Herold et al. 2005; Palivos and Wang 1996). This result is in line with the characteristics of agglomeration of industrial and commercial land allocation in Japan (Baba and Shibuya 2000; Ida 2006), and also certifies the effectiveness of the neighborhood interaction model selected.

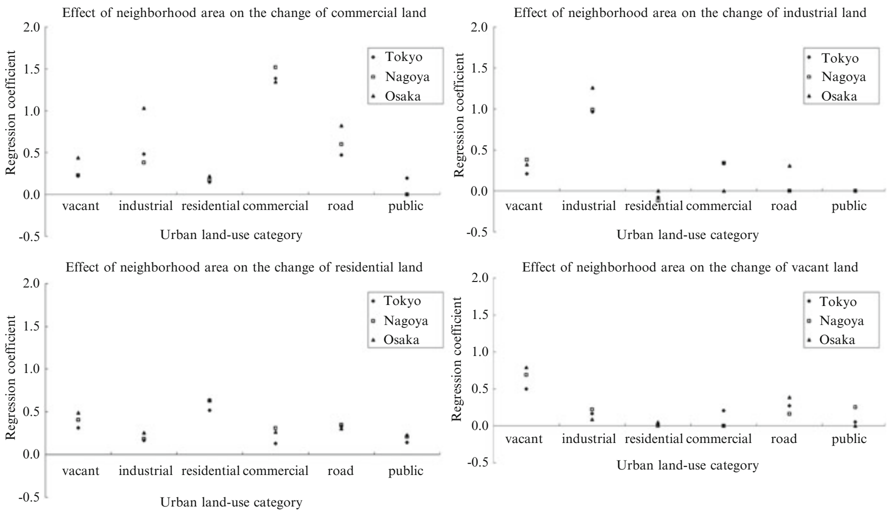


Fig. 15.5 Value of the regression coefficient of neighborhood interactions for the three metropolitan areas

The characteristics of the neighborhood effect on changes in urban land-use categories for different active land-use categories are quite different among the metropolitan areas, meaning that the mechanism of urban land-use changes is different from that of land-use categories. For changes in vacant land, the intensity of the effect of land-use categories in the neighborhood is less strong. The effect of other land-use categories in the neighborhood is close to 0. This shows that in the change process, vacant land rarely interacts with other land-use categories in the same neighborhood area. Moreover, the values of the percentage correctly predicted (PCP) and the relative operating characteristic (ROC) of logistical regression tests for vacant land are smaller than those for other land-use categories. This may be because of the complex definition of vacant land, and it also indicates that the location of vacant land would mainly be determined by factors other than neighborhood effects.

Industrial land shows similar characteristics to vacant land. However, the intensity of the effect of industrial land in the neighborhood on itself is stronger than the effect of vacant land on itself, indicating the strong degree of spatial aggregation of industrial land. The effects of other land-use categories in the neighborhood on residential land show approximately the same intensity, whereas the effect on commercial land shows a different intensity. Roads and industrial and commercial land in the neighborhood obviously impact on the allocation of commercial land.

The differences in neighborhood interactions among urban land-use categories suggest that attention should be paid to the land-use classification system when constructing an urban geo-simulation model. An urban area is composed of many categories of land-use. Owing to the difficulty of obtaining land-use information in urbanized areas or other reasons (Batty 1971), urbanized areas are classified as one

Table 15.1 Comparison of the similarity measure of neighborhood interaction in urban land-use changes between the three metropolitan areas during the study period

Type of land	Tokyo–Nagoya	Nagoya–Osaka	Tokyo–Osaka
Vacant	0.889	0.894	0.892
Industrial	0.965	0.857	0.852
Residential	0.926	0.958	0.906
Commercial	0.914	0.843	0.823

Table 15.2 Comparison of the similarity measure of neighborhood interaction in urban land-use changes between the three metropolitan areas during the late 1980s

Type of land	Tokyo–Nagoya	Nagoya–Osaka	Tokyo–Osaka
Vacant	0.904	0.886	0.924
Industrial	0.826	0.785	0.923
Residential	0.911	0.925	0.921
Commercial	0.950	0.897	0.882

land-use category in much of the literature (Benenson 2007; Clarke et al. 1997). Thus, the mechanism of interaction among different urban land-use categories may be concealed. This makes it more difficult to understand the real processes and mechanisms of urban land-use changes, and may even lead to mistakes. Zhao and Murayama (2006) analyzed the characteristics of the effects of land-use classification systems on spatial patterns of land use.

Figure 15.5 illustrates that neighborhood interaction for one active land-use category in the spatial process of urban land-use changes generally shows similar characteristics in the three metropolitan areas, although neighborhood interaction is different for every other active land-use category. The similarity of neighborhood interaction in urban land-use changes between the three metropolitan areas during the study period was calculated using the similarity measure function Hsim(X, Y) to quantitatively describe the degree of similarity (Table 15.1). In the similarity measure function Hsim(X, Y), the values of coefficient β'_{ikh} of land-use categories of vacant, industrial, residential, commercial, roads, and public land comprise a vector with six dimensions. All the values of similarity measures between metropolitan areas were at least 0.823, with one even reaching 0.965, indicating a high degree of similarity of neighborhood interaction in urban land-use changes between the three metropolitan areas, although their land-use change patterns were not correlated.

The similarity measure of neighborhood interaction in urban land-use changes between the three metropolitan areas during the late 1980s (Tokyo, 1984–1989; Nagoya, 1987–1991; Osaka, 1985–1991) was calculated to avoid error and contingency in the calculation of the similarity measure function above (Table 15.2). The similarity measure during the period also shows high values of at least 0.826, except for 0.785 for the industrial land between the Nagoya and Osaka metropolitan areas. This result validates the finding that the characteristics of neighborhood interaction in urban land-use changes are similar in different urban areas. It may be concluded that the finding is universal for all cities in Japan.

This finding may have two meanings in the study of urban land-use changes in Japan. One is that the mechanism of urban land-use changes in neighborhood interaction at the local level would be similar for different cities. The other is that in the creation of urban geo-simulation systems, the values of the coefficients of neighborhood effect in urban land-use changes may be applied to different cities in Japan.

15.4 Concluding Remarks

Tokyo, Nagoya, and Osaka are three main metropolitan areas in Japan. Land-use patterns and structure show similar characteristics in the three metropolitan areas. Residential and public land occupies about 60% of the acreage of each metropolitan area. Moreover, in the process of urban growth, most of the lost agriculture and forest land was also transformed into residential and public use. The function of human habitation and the principle of priority of public use in the cities of Japan are empirically demonstrated by the proportion and trend of land-use change.

A city is a huge, complex system. One of the complexities is that urban areas are composed of different kinds of urban land-use categories. The dynamics of these categories form the whole pattern of urban land-use changes. Therefore, an investigation of the mechanism of urban land-use changes should start by exploring the dynamics of every urban land-use category. In this research, the characteristics of the neighborhood effect of urban land-use categories on the changes to four active land-use categories were quite different in each of the three metropolitan areas, illustrating the differences in the mechanisms of the changes in urban land-use categories in the cities. Consequently, the land-use classification system plays an important role in providing a clear understanding of the real mechanism of urban land-use changes. Suitable classification systems should be examined when considering urban land-use changes.

The spatial aggregation of urban land-use categories is illustrated by the spatial autocorrelation of the land-use category presented in the characteristics of neighborhood interaction. Industrial and commercial land displays a particularly strong aggregation of land-use allocation compared with other urban land-use categories in all three metropolitan areas. This finding agrees with the characteristics of agglomeration of industrial and commercial land allocation in Japan, and validates the effectiveness of the neighborhood interaction model.

In the three metropolitan areas, urban land-use changes have different spatial patterns, and urban land-use change patterns do not correlate with each other. However, neighborhood interaction in urban land-use changes generally shows similar characteristics for the transformation of every active land-use category. This implies that neighborhood interaction in any of these three metropolitan areas may be used to understand the mechanism of urban land-use changes in other cities of Japan. These results provide very useful material for constructing universal urban geo-simulation models which may be applied to any city in Japan. Nevertheless, the reason(s) why neighborhood interaction in urban land-use changes in the three metropolitan areas showed similar characteristics need(s) to be further investigated.

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