An Approach for Predicting Land Use Changes in an Urbanization Control Area
- A Case Study of a Japanese Regional Hub City -

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Abstract:

Land use in an urban area relates closely to urban activities, and greatly influences the formation of the urban environment and urban life in general. Therefore, how urban planning provides for various urban land uses is important. Uses that are efficient and harmonize with the environment are strongly sought. This study aims to analyze changes in the structure of land use in an urbanization control area based on land use classification composition rates in a mesh (250m×250m), and from a copy of the development permission register in a regional hub city of Japan. Finally, a proposal is made for the construction of a system to forecast land use by creating a detailed land use change model that utilizes a neural network in a case study involving Fukuoka City.

1. Introduction

An Urbanization Control Area is a zone where urbanization is controlled under the Town Planning and Zoning Act. However, some development projects such as the location of some facilities that might be unsuitable for the surrounding environment, such as large-scale, commercial and leisure facilities are permitted. On the other hand, population decreases and declining birthrates with the resultant growing proportion of elderly people cause villages to suffer from depopulation. Therefore, in an Urbanization Control Area, appropriate land use planning, regulations and guides are required for good urban development. To ensure this, it is important to first analyze the actual existent conditions and any transitional changes of land use, and to dynamically ascertain urban growth or decline.

The many reports concerning land use can roughly be divided into two types; ones discussed the relationship between land use and the factors for its change, the others the construction of models forecasting land use. The former deals with the influence of changes to the structure of land use by adjustment of zoning regulations[1)2)3)]. The latter involving the construction of regression and simulation models by looking at the present land use conditions and social economy indexes as explaining various values. However, while changes of land use are influenced by various factors; these models cannot usually consider many factors influencing land use changes. Therefore, the development of an effective prediction model that does consider more of the various influencing factors is required.

In this study, the structure of the land use changes in a mesh in an urbanization control area is analyzed based on the land-use-classification composition rate and a copy of the register of a development permission system. Next, a model of structural changes of land use in the mesh is constructed using a neural network. Data used is 1/4 mesh data (250m × 250m) based on land use surveys (1977, 1985, 1993, 1998) carried out in Fukuoka City; as well, documents (1977-1998) in the development register based on development permission are used.

Table 1. Number of meshes in the urban planning area

1 period（1977-1985）

	1985			
1977	Urbanization zone	Control Area	Outside urban planning	Sum total
Urbanization zone	2553	0	0	2553
Control Area	0	2923	0	2923
Outside urban planning	0	0	138	138
Sum total	2553	2923	138	5614

2 period（1985-1993）

	1993			
1985	Urbanization zone	Control Area	Outside urban planning	Sum total
Urbanization zone	2543	10	0	2553
Control Area	122	2801	0	2923
Outside urban planning	35	0	103	138
Sum total	2700	2811	103	5614

3 period（1993-1998）

	1998			
1993	Urbanization zone	Control Area	Outside urban planning	Sum total
Urbanization zone	2422	278	0	2700
Control Area	11	2769	31	2811
Outside urban planning	27	0	76	103
Sum total	2460	3047	107	5614

2. Actual conditions of land use changes

Fukuoka City has 4 sets, different time periods, of mesh data regarding land use – 1977,1985,1993,1998. There are 5614 meshes in the urban planning area in Fukuoka City; in the area of study, the urbanization control area of Fukuoka City, there were 2923 mesh zones of 250m × 250m in 1977 and 1985, 2811 in 1993, and 3047 in 1998 (Table 1). In this study, 2765 meshes, the urbanization control area throughout all the sets of data, are analyzed to understand changes of land use. Mesh data is presented as 24 or 25 kinds of land use. This classification was carefully made based on the present conditions of land use. However, in analyzing the present land use or forecasting future land use they are not suitably subdivided to analyze satisfactorily. Therefore, the 24 or 25 subdivisions were adjusted to 13 (Table 2).

Table 2. Division of land use

Division		Contents
1	Public	Government & Public offices , Education and Welfare
2	Residence	Residence
3	Commerce	Business, Commerce, Lodging, and Amusement facilities
4	Industry	Heavy industry, Industry and Suppliance processing facilities
5	Park	Park and Golf course
6	Transportation Facilities	Transportation facilities and Track laying area
7	Road	Road
8	Vacant	Vacant
9	Rice field	Paddy field
10	Field	Field, Orchard, Pasture and Agricultural Facilities
11	Unused	Unused, others
12	Forest	Forest
13	River	River, Water surface, Seashore and Waterway

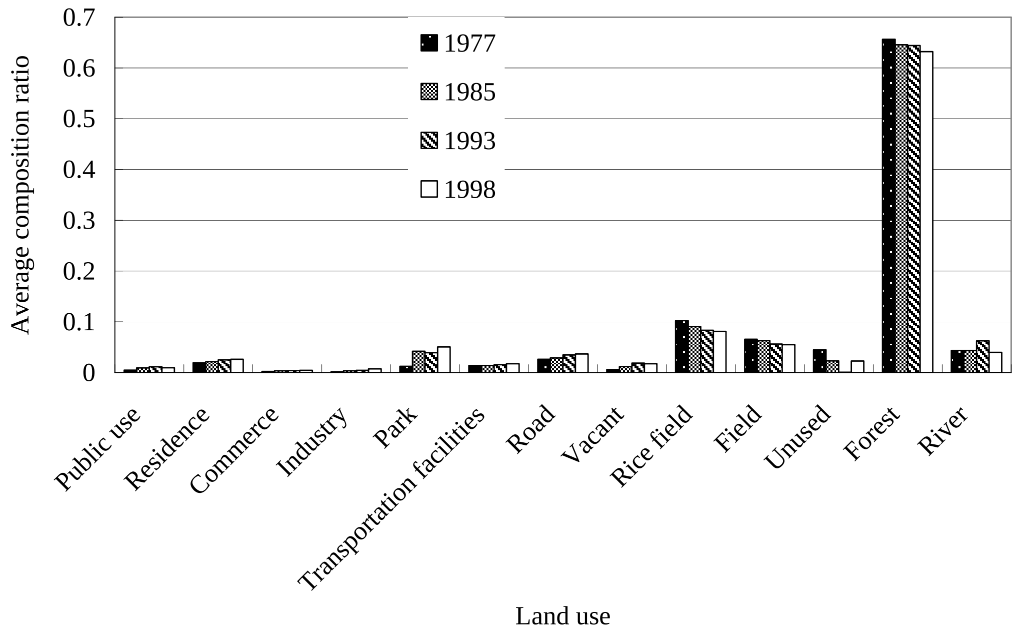


Fig. 1 Average composition ratio of land use (13 divisions)

Table 3 Result of principal component analysis

Period 1

Principal component		Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Eigenvalue		1.71	1.53	1.42	1.34	1.12	1.04	1.01	0.96	0.88	0.83
Proportion		13%	12%	11%	10%	9%	8%	8%	7%	7%	6%
Accumulated proportion		13%	25%	36%	46%	55%	63%	71%	78%	85%	91%
Factor loading	Public use	0.22	0.29	-0.11	-0.29	0.38	0.48	-0.30	0.10	-0.12	0.53
	Residence	0.02	0.03	0.15	0.42	-0.09	0.59	-0.18	-0.27	-0.42	-0.39
	Commerce	-0.03	0.05	0.04	-0.05	0.07	0.40	0.79	0.45	-0.02	-0.08
	Industry	-0.01	-0.26	0.00	-0.03	0.69	0.08	0.13	-0.41	0.42	-0.21
	Park	0.90	-0.28	0.07	-0.04	-0.03	-0.11	0.04	0.00	-0.02	-0.09
	Transportation facilities	0.05	0.12	0.79	-0.23	0.07	-0.03	0.00	-0.06	-0.07	-0.03
	Road	0.08	0.04	0.15	0.44	-0.28	0.31	-0.27	0.27	0.67	0.02
	Vacant	0.23	0.68	-0.12	-0.01	-0.37	-0.14	0.24	-0.33	0.09	0.04
	Rice field	-0.10	-0.73	-0.02	-0.32	-0.26	0.02	-0.15	0.22	-0.08	-0.04
	Field	-0.04	0.37	0.03	0.36	0.43	-0.37	-0.21	0.49	-0.15	-0.25
	Unused	-0.54	-0.26	0.22	0.55	0.02	-0.11	0.19	-0.16	-0.10	0.44
	Forest	-0.70	0.26	-0.09	-0.50	-0.09	0.10	-0.14	-0.01	0.12	-0.27
	River	0.01	-0.10	-0.81	0.20	0.04	0.04	0.03	-0.03	-0.06	-0.05

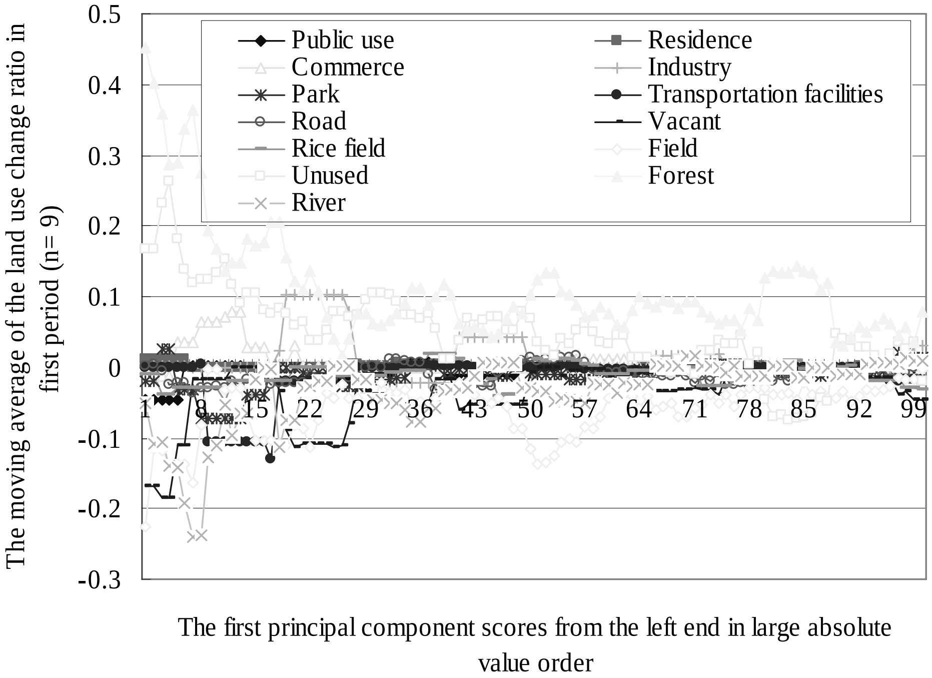
Period 2

Principal component		Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Eigenvalue		1.604	1.547	1.362	1.299	1.133	1.081	1.075	0.959	0.859	0.816
Proportion		12.3%	11.9%	10.5%	10.0%	8.7%	8.3%	8.3%	7.4%	6.6%	6.3%
Accumulated proportion		12.3%	24.2%	34.7%	44.7%	53.4%	61.7%	70.0%	77.4%	84.0%	90.3%
Factor loading	Public use	-0.266	-0.266	0.004	0.376	0.074	0.581	0.088	-0.150	-0.163	-0.554
	Residence	-0.474	0.067	0.277	-0.041	0.425	-0.376	-0.195	-0.156	0.038	-0.220
	Commerce	-0.035	0.006	-0.188	-0.105	-0.348	0.030	-0.560	0.657	-0.003	-0.265
	Industry	0.129	0.073	0.226	-0.054	-0.044	-0.374	0.657	0.368	0.220	-0.395
	Park	0.332	-0.408	0.585	-0.230	0.038	-0.163	-0.175	-0.023	-0.425	-0.022
	Transportation facilities	0.027	0.377	0.447	0.432	0.040	0.136	0.094	0.329	-0.316	0.300
	Road	-0.200	-0.220	0.144	-0.059	0.638	0.267	-0.113	0.344	0.425	0.204
	Vacant	-0.289	-0.183	0.057	0.621	-0.358	-0.384	-0.211	-0.166	0.299	0.102
	Rice field	0.346	0.524	0.188	-0.407	-0.040	0.127	-0.267	-0.297	0.263	-0.173
	Field	-0.145	-0.623	-0.424	-0.368	0.015	-0.133	0.157	0.026	-0.142	0.133
	Unused	0.739	-0.230	-0.111	0.235	-0.024	0.199	0.112	-0.029	0.265	0.077
	Forest	0.061	0.542	-0.626	0.151	0.363	-0.187	0.025	0.038	-0.266	-0.033
	River	-0.605	0.256	0.117	-0.365	-0.390	0.297	0.280	-0.011	0.040	0.192

Period 3

Principal component		Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10
Eigenvalue		1.895	1.684	1.666	1.634	1.235	1.104	1.006	0.904	0.718	0.466
Proportion		14.6%	13.0%	12.8%	12.6%	9.5%	8.5%	7.7%	7.0%	5.5%	3.6%
Accumulated proportion		14.6%	27.5%	40.4%	52.9%	62.4%	70.9%	78.6%	85.6%	91.1%	94.7%
Factor loading	Public use	-0.569	0.383	0.637	0.047	0.013	-0.043	-0.002	0.012	-0.050	-0.097
	Residence	0.035	0.033	0.011	-0.022	-0.105	0.790	-0.004	-0.550	0.234	-0.049
	Commerce	-0.076	0.322	-0.278	0.226	0.288	-0.454	-0.362	-0.274	0.504	-0.063
	Industry	0.591	-0.353	-0.620	-0.116	0.052	-0.047	0.046	0.008	-0.041	-0.119
	Park	0.541	-0.130	0.396	0.621	-0.034	0.030	-0.143	0.021	-0.022	0.334
	Transportation facilities	-0.085	0.505	-0.438	0.470	-0.228	0.108	-0.001	0.058	-0.336	-0.266
	Road	0.146	0.262	0.016	0.011	0.502	0.251	0.534	0.433	0.323	-0.031
	Vacant	0.067	-0.337	0.325	-0.446	0.589	-0.063	-0.105	-0.234	-0.266	-0.181
	Rice field	0.060	-0.421	0.302	-0.244	-0.615	-0.073	-0.077	0.248	0.335	-0.237
	Field	0.009	-0.051	0.064	0.085	-0.230	-0.417	0.738	-0.460	0.005	0.020
	Unused	0.543	0.596	0.171	-0.379	-0.138	-0.054	-0.037	-0.003	0.002	-0.151
	Forest	-0.488	0.152	-0.434	-0.625	-0.149	0.028	-0.008	0.045	0.008	0.344
	River	-0.595	-0.544	-0.181	0.401	0.118	0.078	0.058	0.069	0.063	-0.150

Z1(-)



Z1(+)

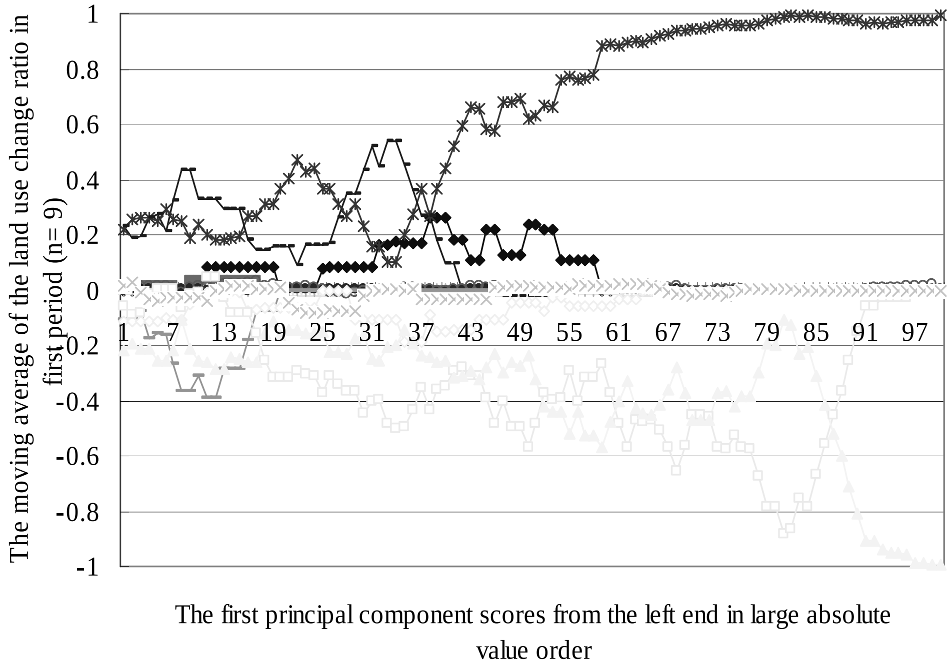


Fig. 2 Curves of the land use change ratio from first principal component scores order in period 1

To understand the change of land use in the urbanization control area of Fukuoka City, the average composition ratio of land use by 13 divisions over every surveyed period is shown in Fig-1. From this figure, 2/3 of the urbanization control area is seen to be occupied by forest.

Further, there are large areas of rice fields, fields, and rivers in the urbanization control area; thus it can be said that there is much land use related to nature; however, these types of land use are decreasing every surveyed year. On the other hand, we can see land use related urbanizations such as residential, parks, and vacant land are increasing. Moreover, although the average composition ratios of each division of land use have almost no changes, there are some meshes in which the land use composition has greatly changed.

Next, the structure change of land use is analyzed in each mesh, and its characteristics are studied. First of all, the changes of the composition ratios by land use division in periods 1 (1977-1985), 2 (1985-1993) and 3 (1993-1998) are analyzed using principal component analysis. The results of analysis in period 1 are shown in Table 3. In all terms, eigenvalues up to the 10th principal component score are over 0.8 and the accumulated proportion is about 90%; thus, the precision of these models is high. But, the principal component scores are different among terms. This means that the changes the structure of land use are different among the periods.

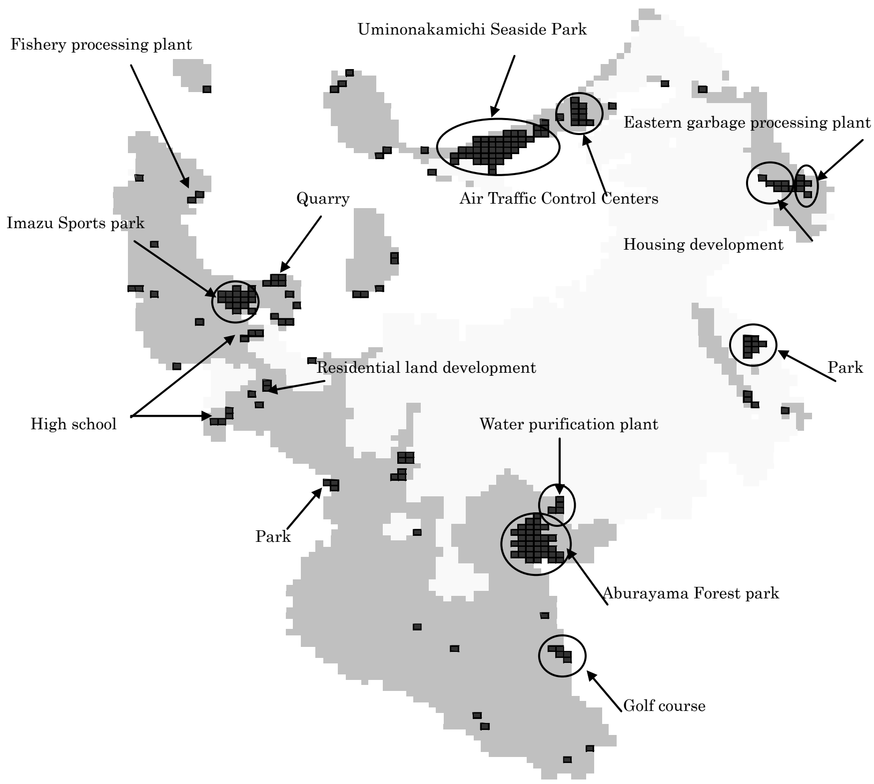


Fig. 3 Relationships between development projects and the land use change ratio in period 1

Next, due to understand the characteristics of land use changes in each period, meshes are arranged in order of large principal component scores and the moving average (n= 9) of the land use change ratio in each period are calculated for each mesh. In Fig-2, the first absolute principal component scores in period 1 above 100 in rank are selected, moving average curve of the principal component scores for changes in land use division are indicated. In the curve of the Z1(-) (see Fig-2) mesh, the first principal component scores are minus and, are arranged from the left end in large absolute value order. In the same way, in the curve of the Z1(+) (see Fig-2) mesh, the first principal component scores are plus and are arranged from the right end in largest absolute value order. In the Z1(-)curve, changes of land use are large in the mesh having absolute principal component score above 25 by rank. Also, in the Z1(+)curve, land use is unstable and easily changes in the mesh having principal component scores above 80 by rank. The characteristics of the changing structure of land use can be understood from the by principal component scores and the moving average of the land use change ratio in each period for each mesh. That is, from the Zi (-) and Zi (+) curves, meshes of a higher rank have large absolute principal component scores and land use has greatly changed in these meshes. On the other hand, land use is little changed in other meshes. Characteristics of the land uses of the meshes with a higher rank are different from others. Therefore, it is convenient to classify the mesh zones into 2 groups.

Here, although it is difficult to clearly set up standard classifications, the mesh zones can be classified by the characteristics of the moving average curve and the sum of positive (or negative) changes in the values of the land use composition ratio over 0.2. Also, the meshes zones group that has their land uses greatly changed are plotted in the Fukuoka City map. It can be understood that development projects have been carried out in most of these meshes (See Fig. 3). Consequently, the mesh zones, which have a change of the land use ratio of over 0.2 and over 0.1 for increasing urbanization of land use (public, commerce, industry, parks, transportation facilities, roads and vacant), are called the project type mesh group (G1 group); while those, which have little change in the land use ratio or a large change of the land use ratio caused by a farmland change, are called the non-project type mesh group (G2 group) in this paper. It is considered that the characteristics of the land use do not change in the land use ratio changes largely caused by a farmland change. As a result, the number of meshes in the G1 group is 213 in period 1, 121 in 2 and 99 in 3.

Next, to understand what kind of land uses can easily change or not in the G1 group, the characteristics of the changes of the average composition ratio of land use division in this group is shown in Fig-4. In the G1 group in period 1, the ratios of forest, unused, rice field and field decreased. Contrarily, the ratios of public, vacant and especially park increased; clarifying that most development projects are improvement of parks.

In the G1 group in period 2 , the ratios of rice field, field and park decreased, while unused greatly decreased. Contrarily, public use, residence, road, vacant, forest, river increased. Unused and park decreased through periods 1 and 2, and forest and the river increased; because the land uses of forest and seaside park are changed into the forest or river divisions from unused or park divisions. In the G1 group in period 3, vacant, rice field, field and public use decreased. Especially forests, rivers and river greatly decreased. On the other hand, industry, road, especially park and unused increased. In the same as in period 1, most development projects are also improvements to parks in periods 2 and 3 of the G1 group.

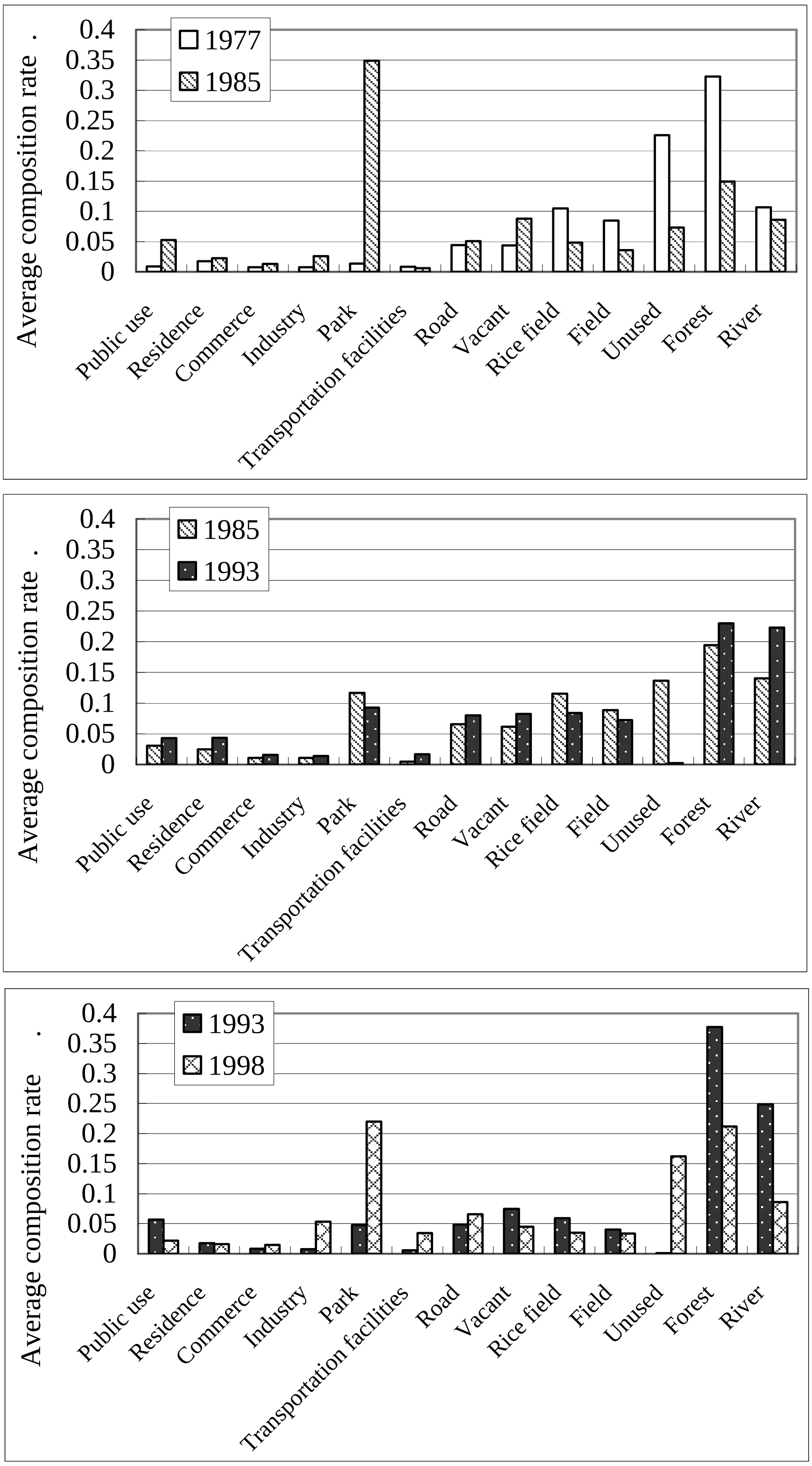


Fig. 4 Average composition ratios of the divisions of land uses in the G1 group

From these results, the characteristics of the development projects in the urbanization control area in Fukuoka City are seen to be mainly improvements and establishment of public facilities such as parks, schools, wastewater treatment plants and water supply facilities. However, some meshes in G1 group also see greatly increasing urbanization of land uses such as residential development, commerce and roading. These development projects are carried out on natural land uses such as in forests, unused, rice fields and fields. Especially, forests and rivers are changed into parks, rice fields are changed into vacant, and unused is changed into residence, public use or vacant.

3. Construction and its application of a land use forecasting system

(1) Land use change factors

For the G1 group, it can be said that the changes in urbanization land use are related to the land use situation of the mesh itself, the land use situation of the surrounded mesh, development projects and the distance from the G1 group mesh. From these results, the following factors of land use change are shown in Table 4. Specifically, " the present conditions of the land uses of the mesh itself", " the present conditions of the land uses of the surrounded mesh", "population density", "the weighted distance from a colony mesh", and "the weighted distance from the G1 group mesh" are selected as social-economic characteristics. "The distance from a nearby station" and "the distance from a central city area" are selected as traffic conditions. "the weighted distance from an urbanization area" is from the urban planning characteristic. "altitude" is from the natural characteristics. The weighted distances from the G1 mesh group are calculated for each urbanization land use division such as public use, residence, commerce, industry, park, transportation facilities, and road use.

Here, the weighted distance is defined as $T=\Sigma(M/R^2)$ (M : change of land use ratio, R : distance from objective mesh).

Table 4 Factors of land use change

	Land use change factor
Social economy characteristic	Present condition of the land uses of the mesh itself (13) Present condition of the land uses of the surrounded mesh (13) Population density Weighted distance from a colony mesh Weighted distance from the G1 group mesh (8)
Traffic characteristic	Distance from a nearby station Distance from a central city area
Natural characteristic	Altitude
Urban planning characteristic	Distance from an urbanization promotion area

(2) A land use forecasting model using a neural network (NN)

Conventionally, forecasting models have constructed models using fewer factors as explanatory variables. However, land use changes are influenced by various factors; so it is important to consider all the various factors in a land use forecasting model. Therefore, in this study, a land use change forecasting model is constructed using a neural network (NN) that can consider a variety of factors and determines the structure of the model by a learning algorithm. In the land use change NN model, the land use composition ratios of the next period (the length of one period is about eight years) are estimated using land use factors for the period mentioned above as explanatory variables in the 1/4 mesh (250m x 250m).

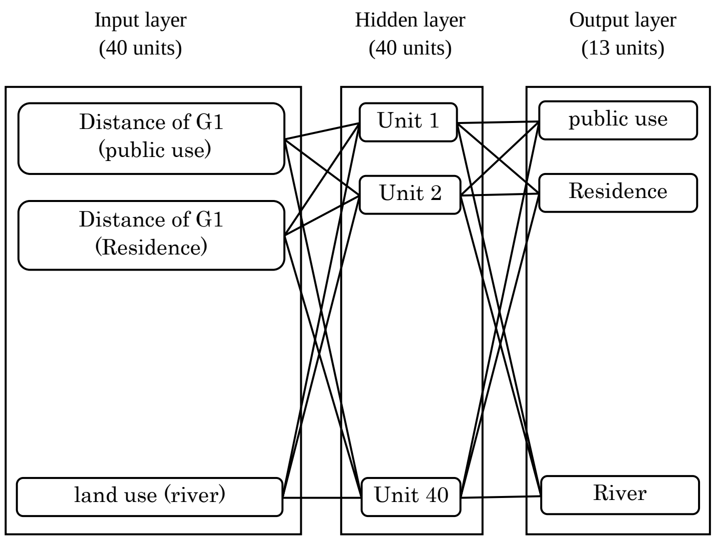


Fig. 5 Network structure of the land use change NN model

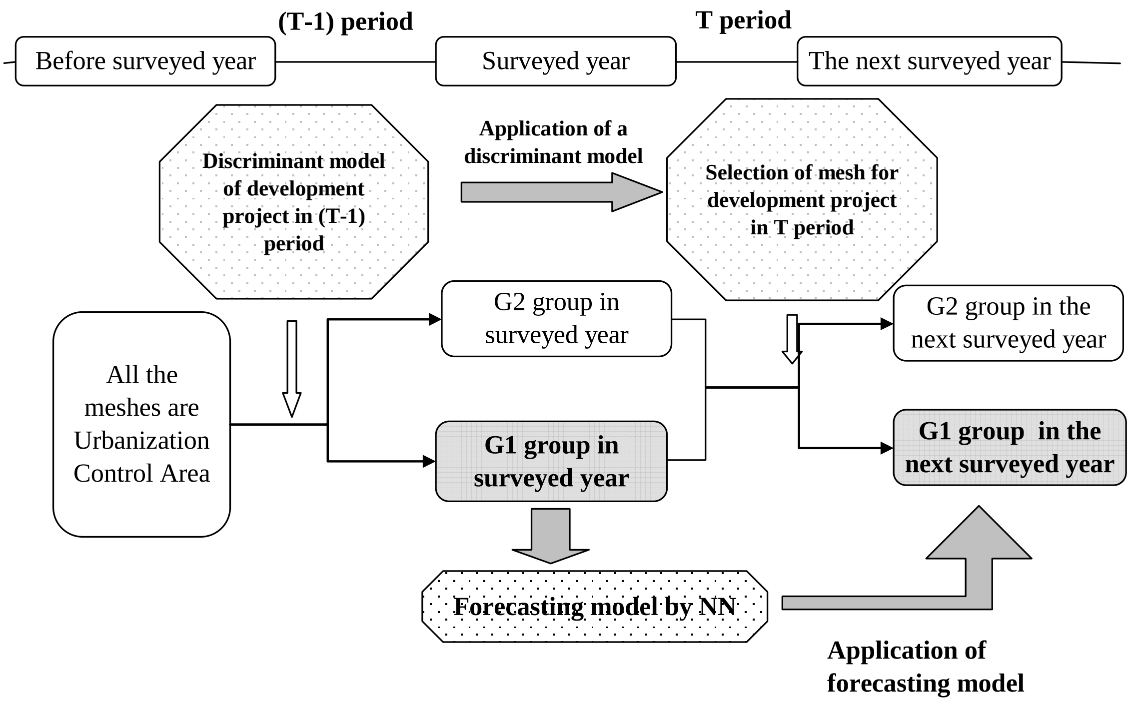


Fig. 6 Flow of land use prediction in an urban control area

The network structure of the land use change NN model formulated in this study is shown in Fig-5. This model is a reverse propagation errors model with a 3 layer structure that consists of an input layer, an output layer and one hidden layer. The number of units in the input layer is 40 land use change factors. The units of the output layer are 13 land use division composition ratios for the next period as independent variables. Also, the hidden layer is classified into 40 units. Calculations are repeated until errors between the estimated value (each unit value of the output layer) and the teaching input value are sufficiently minimized. As a result of the construction of the land use change NN model concerning the G1 group (121 meshes) for period 2 (1985-1993) (the number of learning times is about 7600), the correlation coefficient is 0.99. It can thus be said that the reproducibility of the model is high.

(3) Application of the land use forecasting system

Our Land use forecasting model using a neural network is constructed in the G1 mesh group. However, to predict the land use change in the urban control area, it is necessary to construct the model in all meshes of the urban control area. However, in the case of the urban control area, the proportion of forest is high and land use in most meshes does not change; so that the number of meshes in which the land use changed is relatively low. It is considered that the reproducibility by the model of meshes in which the land use changed is low. Therefore, it is difficult to predict land use considering all meshes. Therefore, in this study, to predict the land use of the urbanization control area, a new approach for a land use forecasting system is proposed. This system uses both discriminate and NN models. The flow of this system is shown in Fig-6.

In this prediction system; first, the mesh group (G1 mesh group) in which land use changed under the influence of a development project carried out during period (T-1) is classified using discriminant analysis. Explanatory variables are 32 land change factors, except the distance from the G1 mesh group, and the added existence of development projects in the development permission system. The total is then 33 factors and the results are shown in Table-5. The hit ratio is 88.4% and the correlation ratio 0.18.

Next, using the mesh group classified as the G1 mesh group, and using a discriminate model, the land use change NN model is constructed. The land use composition ratios of period T are estimated by applying these two constructed models; from this it is possible to make a precise model of the land use changes. To investigate the temporal transferability of our proposed model according to this flow, the constructed models are applied to predict the land use composition ratios in period 3. The result is shown in Table 6; from which the hit ratio of the discriminant model is 86%. Moreover, the result of the NN model shows an average correlation coefficient of 0.69. On the other hand, compared to our proposed model, a land use change NN model considering all meshes in period 2 is constructed; the result of the temporal transferability of this model is shown in Table 7. The average correlation coefficient is 0.54; thus it is obvious that this model gives a worse result than our proposed model. Therefore, to predict land uses in the urbanization control area, our proposed model is meaningful.

Table 5 Results of the discriminant model

variables		DC	variables		DC
	Distance from a nearby station	1.22	Surrounding mesh	Public use	-26.76
	Distance from a central city area	-1.85		Residence	-31.48
	Altitude	-0.07		Commerce	-59.15
	Population density	-12.13		Industry	-22.72
	Distance from an urbanization promotion area	-0.10		Park	-46.63
	Weighted distance from a colony mesh	-4.16		Transportation facilities	-33.68
	existence of development project	-3.96		Road	-45.21
Mesh itself	Public use	-370.0		Vacant	-36.81
	Residence	-347.6		Rice field	-31.28
	Commerce	-370.0		Field	-33.42
	Industry	-372.3		Unused	-22.13
	Park	-358.4		Forest	-33.90
	Transportation facilities	-363.8		River	-36.56
	Road	-369.1	Constant		403.71
	Vacant	-373.1	F-value		18.23
	Rice field	-366.3	Correlation ratio		0.18
	Field	-364.7	Hit ratio		88.4%
	Unused	-381.8			
	Forest	-365.1			
	River	-367.3			

DC : Discriminant coefficient

Table 6 Application results for period 3 from the model created in the 2 preceding periods for gradual prediction

	Estimated group	
Actual group	G1	G2
G1	40	59
G2	323	2343
Hit ratio		86%

	Land use	Correlation coefficient		Land use	Correlation coefficient
1	Public	0.21	8	Vacant	0.71
2	Residence	0.67	9	Rice field	0.88
3	Commerce	0.32	10	Field	0.67
4	Industry	0.79	11	Unused	0.20
5	Park	0.86	12	Forest	0.54
6	Transportation Facilities	0.65	13	River	0.13
7	Road	0.69		Total	0.69

The result of applying this prediction system is that the precision of temporal transferability is not always high. However, meshes are classified into project type and non-project type meshes, and the characteristics of land use changes in each type are adequately understood. Also, the influences of various factors such as the social economic situation to land use changes can be discussed. It is thought that the proposed model is a macroscopic land use forecasting model and is suitable for predicting land use in the short term. It is possible to use the model to discuss urban policies of how to control development projects in the urbanization control area.

Table 7 Application results for period 3 of the bundled-up type land use change NN model of 2 preceding periods

	Land use	Correlation coefficient		Land use	Correlation coefficient
1	Public	0.19	8	Vacant	0.63
2	Residence	0.55	9	Rice field	0.65
3	Commerce	0.53	10	Field	0.54
4	Industry	0.40	11	Unused	-0.01
5	Park	0.70	12	Forest	0.49
6	Transportation Facilities	0.40	13	River	0.07
7	Road	0.57		Total	0.54

4. Conclusion

In this study, the structure of the land use changes in a mesh in an urbanization control area is analyzed based on the land-use-classification composition ratios and a copy of the register of the development permission system. A structural change model of land use in the mesh is constructed using a neural network. From this, a land use forecasting system using a discriminate model and neural network are proposed. The results are as follows:

(1) All the meshes in the urbanization control area in Fukuoka City were classified into 13 divisions by land use composition. Based on the classifications, spatial and structural changes of land use were studied. 2/3 of the urbanization control area is occupied by forest; thus much land use was related to nature. However, these types of land use are decreasing every surveyed year.

(2) Land use is greatly changed by development projects. The characteristics of development projects in the urbanization control area in Fukuoka City are mainly improvements and the establishment of public facilities such as parks, schools, wastewater treatment plants and water supply facilities. These development projects are carried out on natural land uses such as forest, unused, rice fields and fields. Especially, forests and rivers are changed into parks, rice fields are changed into vacant, and unused are changed into residence, public use and vacant.

(3) Land use change is influenced by various factors, which are important to consider in a land use forecasting model. Therefore, in this study, a land use change forecasting model is constructed using a neural network (NN) that can consider a variety of factors. The precision of our proposed model is high.

(4) A land use forecasting system considering development projects was proposed using discriminant analysis and a neural network. Land use changes can be predicted using this system; however, the precision of temporal transferability is not always high. The characteristics of land use changes by project type are adequately understood. Also, the influence of various factors such as the social

economic situation on land use change is discussed. It is thought that the proposed model is a macroscopic land use forecasting model and so is suitable for predicting land use in the short term. It is possible to use this model to discuss urban policies and how to control development projects in an urbanization control area.

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