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The content of this paper is my responsibility and is not meant to represent the policies or opinions of the sponsoring agencies.

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Land Use-Transportation Analysis System for a Metropolitan Area

HIDEO NAKAMURA, YOSHITSUGU HAYASHI, AND KAZUAKI MIYAMOTO

Results are reported of a study conducted to develop a land use-transportation analysis system that will be useful for assessing impacts of transportation improvements. The study consists of two major parts. The purpose of the first part is to develop models that adequately describe the locational behavior of land uses and consequently forecast future land use patterns. The purpose of the second part is to develop a computer-aided analysis system that makes it possible to manage vast amounts of spatial data and to create an easy-to-use system to manage a complex array of integrated programs by man-machine interactive methods. The land use-transportation model has a hierarchic structure that first allocates land use demand into city-sized zones and then into 1-km^2 grids. The allocation model for the zone level has a Lowry-type structure, but each submodel for industrial, business, and residential use is based on its own locational behavior. The allocation model for the grid level describes competition among land uses under constraints of zoning regulations according to the principle of maximization of locational surplus. Transportation conditions are determined by estimating trips generated from new locations. The location of land uses and transportation conditions interact in the model. The computer-aided system contains a data base system for data processing of land use-transportation analysis as well as an interactive operation system that uses computer graphics and a hierarchic menu for program execution. To illustrate this system, future changes of land use and transportation in the Tokyo metropolitan area due to the proposed Tokyo Bay Bridge are forecast.

The relationship between changes in land use and transportation are interactive and highly complex. However, this relationship has tremendous implications for transportation planners who must gauge future traffic generation levels, environmental implications of development, and economic factors affected by future transportation investments, such as land values, employment, and industrial production. Therefore, the assessment of transportation improvement will be greatly aided if more accurate forecasts of land use patterns can be made.

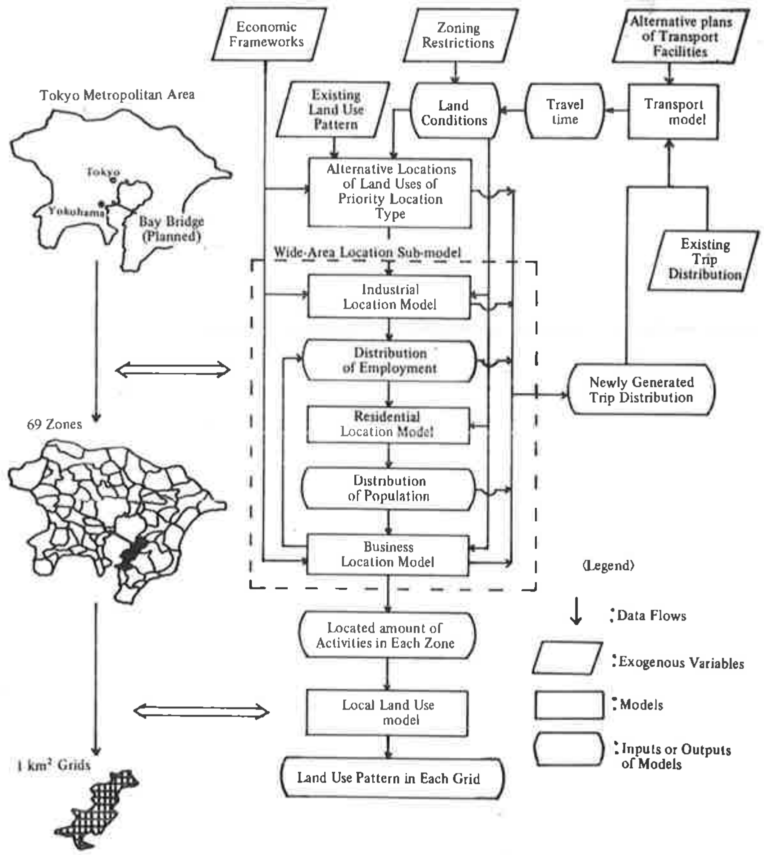
Since the early 1960s, many models have been developed to describe the relationship between land use and transportation. However, in the evaluation of projects in actual practice, these models give less than satisfactory results because the models have one or more of the following deficiencies: simplifications in the modeling of behavioral patterns of location, assumption of rather homogeneous conditions inside each zone, a lack of explicit description of the effect of the level of transportation services, ignorance of the active role of land price in the location process, and less than realistic classification of land use patterns. These difficulties in practice may be caused by one or more of the following:

1. The lack of appropriate data for land use-transportation models,
2. Difficulties in finding behavioral norms to introduce into location models because of a lack of analyses of locational behavior of activities, and
3. The inability of existing computer systems to undertake simulations using large models with vast amounts of data.

During the past few years, these restrictions have been substantially reduced as data and analyses of locational behavior have been accumulated and data processing techniques have advanced along with the development of computer hardware systems.

In this paper, an integrated land use-transportation analysis system for evaluating the impacts of transportation facilities in the Tokyo metropolitan area is described. This system takes into account previous experiences and recent research developments. The major characteristics of the analysis system are the modeling of concepts of locational

Figure 1. Structure of integrated land use-transportation model.



behavior, the creation of a large data base based on regional data, and the application of man-machine interactive operation procedures using the latest computer techniques.

BASIC CONCEPT OF MODEL SYSTEM

Figure 1 shows the total structure of the analysis system.

Allocation of Future Land Use Demand

In this study, total future population and industrial products by sector are assumed to be given by the socioeconomic master plan of the Tokyo metropolitan area. Transportation improvement projects as well as land use policies such as zoning regulations affect the spatial allocation of population and products in the region and generate new and varying land use patterns. This land use-transportation model forecasts the future location of population and industrial and business activities and, consequently, land use patterns and transportation environments.

The Tokyo metropolitan area is disaggregated in two stages (Figure 1). In the first stage, the metropolitan area is divided into 69 zones that correspond to established administrative zones and outstanding physical characteristics of the region. In the second stage, the metropolitan area is divided into about 20,000 1-km² areas called grids, as shown in Figure 1.

In the first stage, it is possible to determine to what extent each land use will develop within the zones, according to locational preference, but at this stage the grid in which the activity will occur cannot be distinguished. The level of activity is estimated by using the assumption of locational order used in Lowry-type models. In the second stage, one can forecast to what extent different land uses will competitively occur within the grid.

Classification of Land Uses

Land uses are classified into 35 patterns according to the standard of national land use maps. Because these land uses are determined by different locational procedures, these patterns are classified into several categories.

The first category includes large-scale facilities such as steel industries and university campuses. These land uses are constrained by conditions such as the availability of large areas of land, large water and energy needs, and environmental factors. Future locations of these land uses are generally foreseen in long-range plans. The locations and the extent of development are to be given in the model as feasible alternatives. Such land uses are called priority location type.

Residential areas and shopping centers are examples of the second category. These uses can be located freely with factors of high development potential, such as transportation availability, as a motivating criterion. Because of such freedom of location, these land uses are called optional location type, and the location and amount of these types of development are to be forecast by models based on the behavioral norms for each land use.

The third type of land use includes uses such as neighborhood stores and primary schools and is referred to as subsequent location type. These land uses are necessarily located according to the locational demand induced by land uses in the first and second categories. Therefore, the amount of development can be forecast in proportion to the amount of the first and second types of use.

Table 1. Land use classification in metropolitan areas used in the model.

Type of Location	Land Use	Activity[a]	Model
Priority	Large-scale basic industry	Chemistry, petroleum, raw metals, mining	Priority location
	Universities and cultural institutions	Service	
	Government offices	Government	
	Major transportation facilities	Transportation and communication	
	Large-scale parks and greens		
	Large-scale sports facilities		
	Public residential quarter		
	Public utilities		
	Military facilities	Government	
Optional	Single-family houses, apartment houses	Residential	Residential location
	Industries	Ceramics, foods, textiles, electric and precision machinery, metal machinery, transport machinery	Industrial location
	Business centers	Retail, wholesale, service, finance and insurance, real estate, electricity and gas supply, government, transportation and communication, construction	Business location
Subsequent	Neighborhood stores	Retail and service	Business location
	Transportation facilities	Transportation and communication	
	Schools and welfare facilities	Service	
	Government offices	Government	
	Neighborhood parks		
Passive	Agricultural areas, forests	Agriculture, forestry, and fishery	
	Open space, wasteland, water		

[a]As defined by the Standard Classification of Industrial Sectors for Japan.

Finally, agricultural uses such as forests and fields are classified as the fourth type of land use, the passive location type. These uses play a passive role because they will continue to be agricultural areas or eventually become developments.

Table 1 gives a classification of all land uses in the four location types. In this table, industrial classification is related to land uses in order to match the total level of land use to the prediction of products within each industry.

Submodels of the Analysis System

Locations of the optional type of land use are described by three submodels according to different patterns of locational behavior: the industrial location model, the business location model, and the residential location model. By using these models, the levels of each activity within 69 zones are estimated, and then, if necessary, more detailed information within the 1-km² grid can be obtained by using a fourth submodel, the local land use model. Characteristics of the transportation environment, such as amount of trip distribution and traffic volume, are forecast for the transportation networks of the given wide area by a fifth submodel, the transportation model. These conditions will affect the location of activities in the next period.

LOCATION MODELS

Industrial Location Model

Basic Concept

Industrial location preference has been studied mainly by economic geographers or economists such as Weber, Hoover, Greenhut, and Isard, who have made important contributions to the theoretical basis for industrial location. These models, however, have theoretical approaches and do not have quantitative bases. On the other hand, some models have been developed for practical application in urban planning. Most of these models are of the aggregate type--e.g., shift-share analysis and econometrics--and do not describe the actual behavior of industrial location preferences from a microscopic point of view.

In most cases, the behavior of industrial plants depends on the characteristics of the firm and the features of the location considered. Thus, in predicting location choices, the behavioral type of model is appropriate.

In this study, the location model has a location preference indicator that is defined by the weighted sum of various location factors gathered through survey data. It is assumed in the model that the total locational demand of manufacturing industries is allocated in industrial zones according to the level of their location preference. The locations of the industrial zones where manufacturing plants are to be located are exogenously inserted into the model as alternative plans. Industries are classified into several groups according to sectors, major markets, major sources of materials, and plants that develop new sites or relocate from other areas.

Questionnaire Survey on Industrial Location

A questionnaire survey was conducted to investigate the location preference of approximately 1,000 plants located in the Tokyo metropolitan area. The questionnaire solicited information about a firm's reasons for locating at the present site and potential alternative sites that were considered.

Modeling of Industrial Location

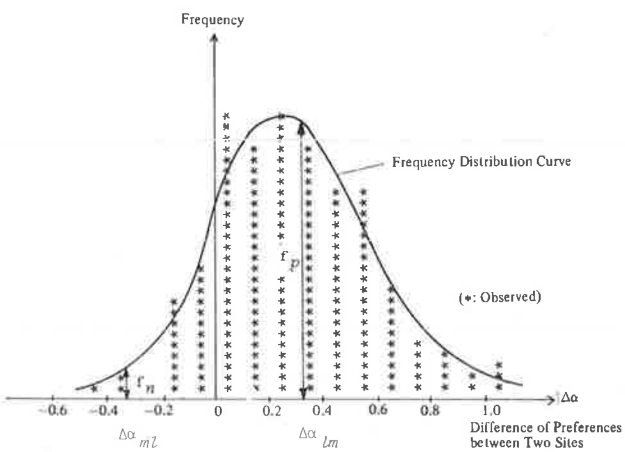
Each industry looking for a new plant site gathers information on location factors such as transportation conditions, land price, and manpower in order to determine the most preferable site. The location preference is assumed to be expressed by an indicator (α) defined by the locational conditions $Z_1^i = (Z_{11}^i, Z_{21}^i, \ldots, Z_{H1}^i)$ for site 1 and plant i as $\alpha_1^i = f(Z_1^i)$. If plant i locates at site 1, the preference of site 1 for plant i is to be greater than that of every other feasible site m. That is,

$$\Delta\alpha_{lm}^i = \alpha_l^i - \alpha_m^i \geq 0 \qquad l = 1, \ldots, L \quad m = 1, \ldots, M \quad (l \neq m) \tag{1}$$

Figure 2. Scores of location preference indicators for industry.

Indicator (Z_i)		Category No.	Category	Number of Samples: Located Group	Number of Samples: Non Located Group	Category Score β_{hj}	Difference (−0.3 −0.2 −0.1 0 0.1 0.2)	Range	Partial Correlation Coefficient
Transport Conditions	Z_1: Average Travel Time to Destinations of Shipment	1	0 – 120 (minutes)	12	6	0.2448		0.4009	0.226
		2	120 – 200	10	8	0.1830			
		3	200 – 320	16	25	0.0560			
		4	320 – 480	17	48	−0.0130			
		5	480 – 900	21	77	−0.0520			
		6(=n_1)	900 –	4	22	−0.1561			
	Z_2: Average Travel Time to Places of Purchase of Materials or Parts	1	0 – 90 (minutes)	34	46	0.0521		0.1318	0.096
		2	90 – 150	23	65	0.0029			
		3	150 – 200	15	42	−0.0203			
		4(=n_2)	200 –	8	33	−0.0797			
Labour Force Conditions	Z_3: Existing Labour Force — Distance to Previous Location	1	0 – 30 (minutes)	13	60	0.3248		0.5417	0.316
		2	30 – 60	21	8	0.1893			
		3	60 – 90	6	23	−0.0836			
		4	90 – 130	8	21	−0.1509			
		5	130 –	4	42	−0.2169			
	Z_3: Existing Labour Force — New Factories	6(=n_3)	—	28	32	0.0024			
	Z_4: Labour Force in New Location	1	0 – 45 (10^3 persons)	14	24	0.0703		0.1660	0.087
		2	45 – 100	28	57	−0.0064			
		3	100 – 200	13	59	−0.0243			
		4(=n_4)	200 –	25	46	−0.0650			
Industrial Site Conditions	Z_5: Rank of Subsidy for Industrial Location	1	Rank 1	47	131	0.0619		0.3175	0.204
		2	2	29	41	−0.0938			
		3(=n_5)	3	4	13	−0.2566			
	Z_6: Water Supply — Water-Consuming Industry	1	More than 500 m^3/month	24	80	0.0443		0.0894	0.088
		2	Less than 500 m^3/month	26	41	0.0133			
	Z_6: Water Supply — Non Water-Consuming Industry	3(=n_6)	—	30	65	−0.0451			
	Z_7: Land Price	1	0 – 11 (10^3 yen)	9	13	0.1916		0.4520	0.344
		2	11 – 20	26	48	0.1369			
		3	20 – 30	26	30	0.0967			
		4	30 – 50	9	32	−0.0184			
		5(=n_7)	50 –	10	63	−0.2604			

Figure 3. Frequency distribution of $\Delta\alpha$.



α is similar to utility in discrete choice models such as the logit model. However, it might be too difficult to formulate this problem directly as in the discrete choice model because the number of feasible location sites is too large. Thus, in the first step, the preference function is defined as

$$\alpha = f(Z) = \sum_{h=1}^{H} g(Z_h) = \sum_{h=1}^{H} \sum_{j=1}^{N_h} \beta_{hj} \cdot \delta_{hj} \quad (2)$$

where $\delta_{hj} = 1$ when $Z_h \in$ category j and $\delta_{hi} = 0$ when $Z_h \notin$ category j.

Category score β_{hj} is estimated by quantification theory 2, which is a variety of discriminant function analysis that uses dummy variables δ_{hj} so as to maximize the occurrence of condition $\alpha_l^i - \alpha_m^i \geq 0$, based on the data z_l^i and z_m^i procured by the questionnaire survey. Figure 2 shows the estimated weights of location condition.

Figure 3 shows a distribution of $\Delta\alpha$ obtained by the estimated preference function in comparing sets of alternative sites. In this figure, the frequency on the positive side ($\Delta\alpha > 0$) indicates that the number of plants that chose the site with α is greater than the alternative. On the other hand, the frequency of $\Delta\alpha < 0$ is the number of plants that located at a site despite the condition that α for the site is less than for the alternative site. This figure shows that more plants locate at the site for which they have a greater preference--that is, where $\Delta\alpha$ has a large positive number (e.g., $\Delta\alpha = +0.3$). On the contrary, few locate at the site for which their preference is less or where $\Delta\alpha$ is negative (e.g., $\Delta\alpha = -0.3$).

Frequency of location at a site for which there is positive preference is denoted by f_p and that at a site for which there is negative preference by f_n. A curve of preference proportion $q = f_p/(f_p + f_n)$ is obtained, as shown in Figure 4. This shows the relationship between difference of preference and likelihood of realization of location. This figure suggests that, when the difference of the location preference indicators α_l and α_m for two alternative sites is zero--that is, when preference for the two sites is indifferential--the same number of plants will be located at both sites.

Allocation Algorithm

Suppose that N plants with the same attributes are to be allocated to three alternative sites (k_1, k_2, and k_3) and that the numbers of plants to be located at each site are p_{k1}, p_{k2}, and p_{k3}. It is reasonable to assume that the proportions of p_{k1}/p_{k2}, p_{k2}/p_{k3}, and p_{k3}/p_{k1} are close to the calculated proportions q_{k1}/q_{k2}, q_{k2}/q_{k3}, and q_{k3}/q_{k1} derived from Figure 4. Thus, allocations p_{k1}, p_{k2}, and p_{k3} can be determined by minimizing the discrepancy,

$$[(p_{k1}/p_{k2})-(q_{k1}/q_{k2})]^2+[(p_{k2}/p_{k3})-(q_{k2}/q_{k3})]^2 + [(p_{k3}/p_{k1})-(q_{k3}/q_{k1})]^2 \quad (3)$$

under the condition of

$$p_{k1}+p_{k2}+p_{k3}=N \quad (4)$$

In general, every plant has more than three feasible alternative sites to consider. In addition, locational demand is grouped into several industrial groups (i). Therefore, the number of locations of each industrial group in each site is estimated by minimizing

$$\sum_{i}^{I}\sum_{l>m}[(p_l^i/p_m^i)-(q_l^i/q_m^i)]^2 \quad (5)$$

subject to

$$S_k \geqslant \sum_{i}^{I} a^i p_k^i$$

and

$$\sum_{k=1}^{K} p_k^i = D^i$$

where

- k = industrial zone = 1, 2, . . . l, . . . m, . . . K;
- i = group of industry = 1, 2, . . . , I;
- D^i = location demand of type i;
- S_k = area size of zone k;
- q_l^i, q_m^i = proportion of location preference for zones l and m, where $q_l^i + q_m^i = 1$;
- p_k^i = location amount of industrial group i located in zone k; and
- a^i = average plottage of a plant of industrial group i.

The minimization is obtained by numerical calculation.

Business Location Model

Basic Concept

In the business location model, it is assumed that, at the level of zones, businesses make their location decisions based on demands for their services and are not as restricted by land conditions as industries in their location choices. Consequently, business location can be described by aggregate-type models that represent the relationship between demand and supply for business services among activities.

Business is classified into sectors such as retail, finance, and services, and each sector has a different relationship to other activities. Moreover, the service patterns of business activities range from neighborhood to areawide. The location of neighborhood services may depend on demand in the respective zone, but the location of areawide services depends on both distance to the service area and the competitive power of the service provided.

Model Formulation

By considering these location characteristics of the business sector, the following type of equation has been developed to estimate the scale of business activity in each zone. It is believed that employment level most adequately represents the scale of each activity.

$$E_i^k = \sum_{k'} \alpha^{kk'} E_i^{k'} + \sum_{k'} \beta^{kk'} \sum_j E_j^{k'} S^{kk'}(r_{ji}) \quad (6)$$

where

- k = a sector;
- k' = a sector served by k;
- E_i^k = employment of sector k in zone i;
- $\alpha^{kk'}$ = coefficient representing employment of sector k per employee of sector k' for neighborhood services;
- $\beta^{kk'}$ = coefficient representing employment of sector k per employee of sector k' for areawide services; and
- $S^{kk'}(r_{ji})$ = share of zone i among all surrounding zones of zone j with regard to trade between sector k and sector k'; i.e.,

$$S^{kk'}(r_{ji}) = A_i^k \cdot f^{kk'}(r_{ji}) / \sum_i A_i^k \cdot f^{kk'}(r_{ji}) \quad (7)$$

where

- A_i^k = agglomeration index of sector k in zone i,
- $f^{kk'}(r_{ji})$ = travel time resistance function for trade between sector k and sector k', and
- r_{ji} = travel time between zone j and zone i.

In Equation 6, the first term represents the scale of activity in zone i for neighborhood services and the second represents the scale of activity for areawide services.

Estimation of Parameters

The parameters of Equation 6 for all sectors are estimated for the cities in the Tokyo metropolitan area by using statistical data on employment; the following equation for the retail sector is an example:

$$E_i^1 = 0.0381 E_i^{11} + 0.0478 \sum_j E_j^{11} S^{1,11}(r_{ji}) \qquad R = 0.994 \quad (8)$$

where

- E_i^1 = employment of retail sector (k = 1) in zone i,
- E_i^{11}, E_j^{11} = populations (k' = 11) in zone i and zone j, and

Figure 4. Relation between difference of preference $\Delta\alpha$ and location preference proportion q.

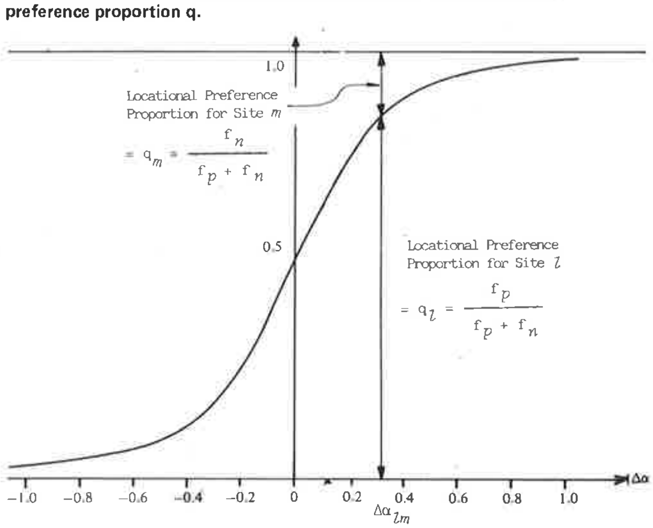


Table 2. Estimated values of $\alpha^{kk'}$ and $\beta^{kk'}$ for each business sector.

Sector k	Sector k′	Retail (k′ = 1)		Manufacturing Industry (k′ = 10)		Population (k′ = 11)		Multiple Correlation Coefficient
		$\alpha^{kk'}$	$\beta^{kk'}$	$\alpha^{kk'}$	$\beta^{kk'}$	$\alpha^{kk'}$	$\beta^{kk'}$	
Retail	k = 1					0.0381	0.0478	0.9994
Wholesale	k = 2	0.0497	0.4586					0.9987
Finance and insurance	k = 3		0.2208			0.0026		0.9986
Real estate	k = 4		0.0776			0.0012		0.9974
Transportation and communication	k = 5				0.2041	0.0532		0.9911
Electricity and gas supply	k = 6				0.0170	0.0004		0.9819
Services	k = 7					0.0500	0.0274	0.9709
Government	k = 8					0.0022	0.0123	0.9941
Construction	k = 9		0.3320			0.0083		0.9900

$S^{1,11}(r_{ji})$ = share of zone i among all surrounding zones of zone j with regard to shopping by inhabitants of zone j.

The parameters estimated for all commercial and business sectors are given in Table 2.

Forecast of Future Activities

Business activities can be forecast by using distributions of population and employment in manufacturing industries that are obtained as the output of the residential location model and the industrial location model. Thus, the amount of located activities for each sector is estimated by successive calculation of the derived equations given in Table 2.

To test fitness, the employment distributions of the sectors are estimated from 1975 to 1978. Although the test period is not quite adequate, the correlation coefficients between estimated and observed results are greater than 0.9200 for all sectors.

Residential Location Model

Basic Concept

It has been observed that in the process of residential location a household prefers to locate in a place where the expected utility is higher and the land price is lower. In other words, a household locates in a place where the consumer's surplus in locating (also called locational surplus, which is the difference between expected utility and land price) is maximized. According to existing residential location theories, a household locates in a place where its utility is maximized under the constraints of financial capability. Because these two explanations of the location of residence coincide in the vicinity of maximum utility for a locater, the first behavioral explanation is adopted in the following model.

It has been explained in existing location theories that the land user who has the maximum utility will locate ahead of other land users, which seems a better explanation of the actual behavior of land users. But, because land price in a place is unique, this can be explained in a different way--i.e., the household whose locational surplus is the maximum will locate there.

In addition, because the concept of maximization of locational surplus is convenient for mathematical formulation, it is better to explain residential location by a principle of maximization of locational surplus than by a principle of maximization of locational utility. The following model is based on this reasoning. The relationship between locational surplus and located amount of activity is described in detail in the following paragraphs.

Suppose a worker lives in a residential place i and works in a place j and suppose that new transportation facilities are to be built between places i and j in year t_b (the construction plan is made public in year t_a). The annual utility [u(t)] to a worker living in residential place i is shown in Figure 5a. The expected utility of the worker who locates in year t [U(t)] is derived by integration of annual utility from year t to year t + T as follows, assuming that the worker expects to use the land for T years. Figure 5b shows the change of U(t) to the worker who locates in year t.

Thus,

$$U(t) = \sum_{l=1}^{T} \frac{u(t+l)}{(1+r)^l}$$

$$= \begin{cases} \sum_{l=1}^{T} \frac{u_a}{(1+r)^l} = U_a & [t < t_a] \quad (9a) \\ \sum_{l=1}^{t_b - t} \frac{u_a}{(1+r)^l} + \sum_{l=t_b-t}^{T} \frac{u_b}{(1+r)^l} & [t_a \leq t < t_b] \quad (9b) \\ \sum_{l=1}^{T} \frac{u_b}{(1+r)^l} = U_b & [t_b \leq t] \quad (9c) \end{cases}$$

where $t < t_a$ for Equation 9a, $t_a \leq t < t_b$ for Equation 9b, and $t_b \leq t$ for Equation 9c, and r is the annual rate of interest.

The price that each land user will bid for land is generally less than the expected utility to be gained from the land. The land user whose bid price is the maximum can locate there, and his bid price forms the land price. Through the alternating process of bidding and locating, the maximum bid price will rise to the expected utility as shown in Figure 5c. Thus, expected utility, which is increased by new transportation facilities, will gradually be transferred to land price, and locational surplus will diminish successively as households locate.

Accordingly, it can be explained that locational surplus to a land user increases where transportation facilities are developed. Therefore, households locate in these areas more than in other places where inhabitants do not gain benefits from the facilities until locational surplus reaches zero. This explanation is applicable to other cases of improvements of infrastructures that enhance the environment.

As mentioned previously, the residential model represents economic behavior more explicitly than simulation models that use potential functions, such as the Lowry model.

Land Price Function

Figure 6 shows the statistically estimated scores of the land price function obtained by using quantification theory 1, which is a variety of multiple re-

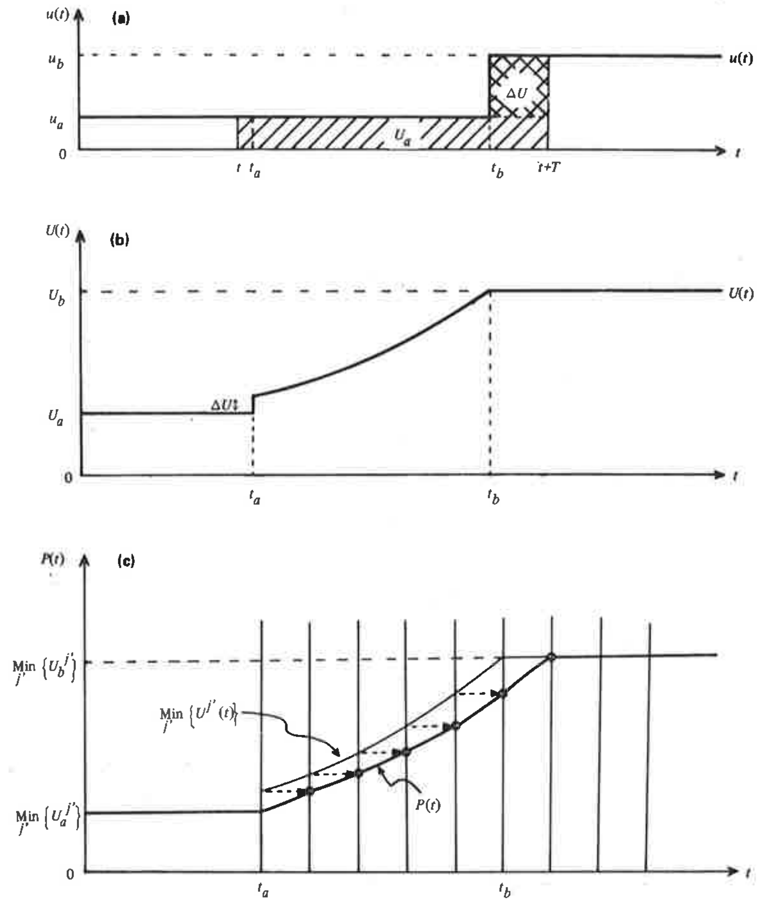


Figure 5. Effect on utility and land price as result of proposed construction of new transportation facilities: change in (a) annual utility, (b) future expected utility, and (c) land price.

Figure 6. Land price function in residential areas.

Factor	Indicator (Z_j)	Category	Number of Samples	Category Score (α_{ij}) (yen/m²)	Difference ('000's yen) −20 −10 0 10 20	Partial Correlation Coefficient
Transport Service	Z_1: Travel Time to Work Places by Train	(minutes) 20 – 50 50 – 60 60 – 70 70 – 80 80 – 90 90 – 120 120 – 160 160 –	86 83 122 94 73 80 66 14	48175 35314 34668 30182 22397 16744 12491 4436		0.690
	Z_2: Distance to Nearest Station	(meters) 0 – 500 500 – 1200 1200 – 2200 2200 – 5000 5000 –	57 215 220 102 24	15344 9571 7185 5229 0		0.268
Natural Environment	Z_3: Terrain Feature	Hills Alluvial Plain	339 279	3113 0		0.140
Availability of Public Utility	Z_4: Level of Gas and Sewerage Availability	One or Both Utilities None	285 333	8236 0		0.317
	Z_5: Percentage of Land Adjustment Area in 1 km² grid	(%) 25 – 100 0 – 25	203 415	3930 0		0.157
Vintage of Residence	Z_6: Percentage of DID Area within 1 km² Grid	(%) 75 – 100 25 – 75 0 – 25	126 105 387	10728 6592 0		0.332
Comfortability	Z_7: Plot Size	(m²) 300 – 180 – 300 0 – 180	129 290 199	2076 1703 0		0.078

Multiple Correlation Coefficient R = 0.844

$$\text{LAND PRICE: } P(Z_1, \cdots, Z_7) = \sum_{i=1}^{7} \sum_{j=1}^{n_i} \alpha_{ij} \cdot \delta_{ij}, \quad \text{where } \delta_{ij} = \begin{cases} 1 & (Z_i \in \text{category } j) \\ 0 & (Z_i \notin \text{category } j) \end{cases}$$

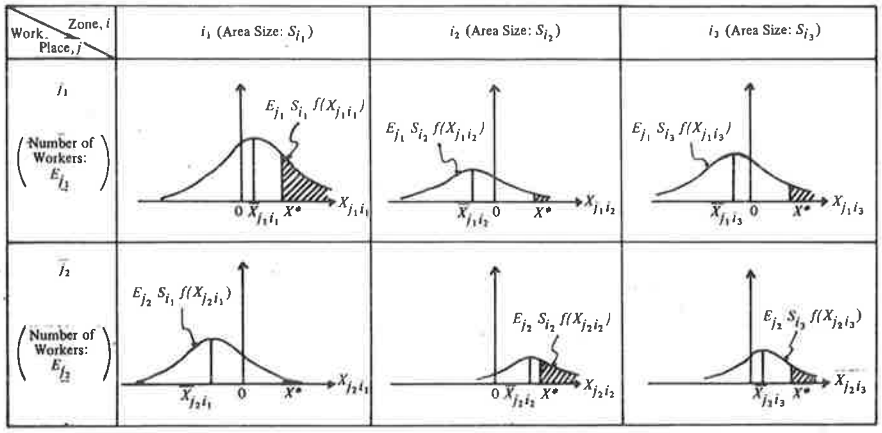


Figure 7. Distribution of locational surplus to a worker determined by considering total locational demand and size of zone.

gression analysis that uses dummy variables and represents the relationship between land price and the location factors in the Tokyo metropolitan area. The figure shows that ease of commuting is the most dominant factor and that the availability of public utilities also has a relatively large effect on land price. Commuting costs do not play a major role in location decisions in the area because of subsidization by employers.

This function was derived from land prices at approximately 600 points measured by the National Land Agency. The values indicate the average land prices for a 1-km^2 grid.

Estimation of Locational Surplus

Because it is too difficult to measure utility, virtual utility is derived by using the following concept. U_a and U_b in Figure 5c show scores of expected utility to a land user not influenced by new transportation facilities and are nearly equal to the land price. If land price can be represented as a function of location factors, U_a and U_b are estimated by using the function. Moreover, annual utilities u_a and u_b are calculated by using Equations 9a and 9c. The expected utility [U(t)] at any time t in the period $t_a \leq t < t_b$, when utility changes are being influenced by expected improvements in infrastructure, is then calculated by using Equation 9b.

The minimum unit size of land in the land price analyses is the 1-km^2 grid. Different workers living in a grid have different values of utility because they commute to different workplaces. The land price function provides the average land price in the 1-km^2 grid, which is regarded as the average value of expected utilities to land users (i.e., workers whose work places are j = 1,2, . . . , J) at all points in the grid in the period $t < t_a$ or $t_b \leq t$, when neither utility nor land price changes. Then, the expected utility U_a^j in $t < t_a$ and U_a^j in $t_b \leq t$ to land user j is calculated by using the land price function and the individual commuting time to workplace j. The expected utility [U(t)] at any time t can be calculated by this method.

Land price [P(t)] at any time t can be estimated for each period under the assumption that, when the demand for location is great enough, land price becomes equal to the expected utility of a land user who located in the preceding period. This procedure can be explained as follows.

To simplify discussion, assume that all land users who locate during a period locate at the same moment in the period. If the demand for the land is great enough, the land price rises to the minimum value of expected utilities to land users located there because no new land user pays a land price that is higher than his utility. If market delay is considered, the land price in a period is identical with the minimum expected utility among land users who located in the preceding period (Figure 5c).

The minimum expected utility is given in the process of calculating allocation in each period. According to the aforementioned concept, expected utility to a land user and land price in a grid can be calculated together with locational surplus.

Allocation of Residential Locational Demand

Locational surplus to land users is distributed inside a zone according to the different characteristics of each grid in the zone as well as various attributes of the land users. The distribution of locational surplus is approximated by the normal distribution. The shape of the distribution depends on the homogeneity across the grids in the zone, and its area is determined by considering the total locational demand of the workplace and the size of the zone, as shown in Figure 7. The locational demand for housing is estimated by housing type by using a disaggregate model that is not described in this paper. If locational surplus is fixed at a certain level (X*), the number of land users by workplace in all zones is obtained as shown in the hatched area in Figure 7. The cutoff level of locational surplus is reduced until all potential land users can be allocated. This allocation procedure can be executed numerically by shifting the surplus level in a stepwise manner.

Applicability of Model

To test the applicability of the residential model, change in residence from 1975 to 1978 was forecast and then compared with actual observations. For the forecast, change in employment during the period is given a priori and population change in each zone is estimated by the residential model. The correlation coefficient between the observed and estimated results is 0.845.

Local Land Use Model

The local land use model describes changes in the land use pattern in the 1-km^2 grid by considering the competition among land uses whereas the areawide location submodel describes the distribution of activities among zones in a metropolitan area. Competition among land uses is modeled to determine priority based on the concept of locational surplus.

This concept is similar to that of the residential location model except that land use zoning restrictions in a grid are considered and industrial and business uses are regarded as would-be users as well as residential users. The competitiveness of different land uses in a grid is determined by the value of locational surplus. The submodel has been tested in a suburb of the Tokyo metropolitan area and has shown good applicability (1).

Transportation Model

The transportation model is based on a classical sequential procedure of travel demand forecasting. However, it has a distinguishing trait in that the distribution of newly generated trips is given by outputs of the location model. This submodel does not need to estimate trip generation and distribution, but only covers the process of modal split and assignment. The inputs of the submodel are information on road and railway networks, existing trip distribution by trip purpose, and the newly generated trip distribution. The network models of railways and roads can reduce computing time of assignment substantially by means of aggregation of the actual networks into virtual ones. The transport submodel makes it easy to analyze impacts due to many alternative plans of networks.

COMPUTER-AIDED LAND USE-TRANSPORTATION ANALYSIS SYSTEM

Basic Concept

The integrated land use-transportation model discussed in this paper is comparatively complex. In addition, its use in analysis requires a large amount of data, such as land conditions in each 1-km^2 grid. Consequently, in order to analyze and evaluate the impacts of alternative plans with the integrated model, the system for data processing and model simulation should also be made operational. Such systems make it possible to save many work hours and improve the reliability of analyses by repeated trials.

The system, which we call a computer-aided land use-transportation analysis system, requires the following functions:

1. A highly productive data base management system for data entry, retrieval, and editing;
2. Easy input of various alternative plans;
3. Immediate monitoring of intermediate results during the analysis;
4. Understandable presentation of outputs; and
5. Simple operations of model analysis.

To satisfy these requirements, the system contains a data base system and a graphic system with a hierarchic menu operation. The computer system makes it easier to do sensitivity analysis and to compare many alternatives related to land use and transportation policies to better ensure the reliability of the analysis.

Example of Analysis

The land use-transportation analysis system was applied to the forecasting of land use changes in the Tokyo metropolitan area from 1975 to 1990 as part of an assessment of the Tokyo Bay Bridge. Figure 8 shows examples of the results (the original photographs are multicolored and more highly detailed). Rail and trunk road networks in the Tokyo metropolitan area (Figure 8a) are used for the calculation of travel time among zones. Examples b to e in the figure represent intermediate and final results for predicting land use changes provided by the residential location model. The locations of industrial and business activities are presented in a form similar to that of the residential model. New traffic patterns as a result of new distributions of activities are also displayed. By using the information on future land use patterns obtained from the model simulation, economic impacts inside the area--such as changes in the value of land, levels of employment, industrial products, traffic generation, and environmental impacts--will be estimated for evaluation of the bridge project.

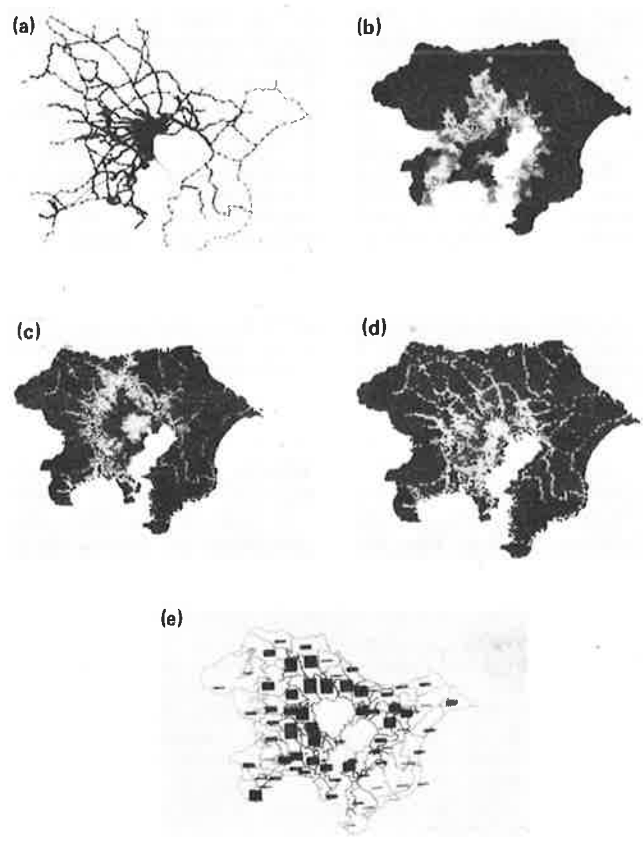
CONCLUSIONS

The significant characteristics of the model described in this paper, in comparison with existing model systems, can be summarized as follows:

1. An integrated model composed of various submodels has been built as a consistent model system.
2. The submodels, which describe the location of different land uses, were developed specifically for this project.
3. Detailed land conditions have been taken into account in forecasting land use.
4. A computer-aided system has been developed for model simulation.

It is believed that this type of operational system will help to improve the reliability of fore-

Figure 8. Examples of application of analysis system to Tokyo metropolitan area: (a) rail network, (b) travel time from every grid to Yokohama in horizon year 1990 (with Bay Bridge), (c) land price in every grid in base year 1975, (d) locational utility in every grid to land user commuting to Yokohama in 1990 (with Bay Bridge), and (e) forecast amount of residential location (1975 to 1990).



casts through the relatively easy evaluation of many alternative scenarios. The system has been applied not only to the Tokyo Bay Bridge project but also to impact studies of other projects, such as the construction or improvement of commuter rail lines in several metropolitan areas in Japan. The model is currently being improved as a result of the experience gained from these studies.

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Use of TOPAZ for Transportation-Land Use Planning in a Suburban County

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Techniques used to create and assess a variety of year 2000 joint land use and highway network patterns for Prince William County, Virginia, are described. The assessment has been done mainly in terms of travel and related impacts. The related impacts include the overall cost of travel, congestion levels, fuel consumption, and air pollution emissions. Volume/capacity ratios on each highway link in the county were also estimated. A sketch-planning procedure called Technique for the Optimum Placement of Activities in Zones (TOPAZ) was used to allocate expected future land use activities to 11 districts in the county so as to minimize overall travel cost. Travel impacts were then analyzed in more depth through separate and more detailed models included in a model called Transportation Integrated Modeling Systems (TRIMS) used by the Metropolitan Washington Council of Governments. The results of these efforts led to several preliminary conclusions concerning not only the techniques themselves but also their place in the comprehensive planning process: (a) residents of the county will be faced with an increase in overall travel costs and congestion no matter which reasonable alternatives are implemented; (b) the most ambitious highway improvement program will reduce costs by about 9 percent, and the proper organization of land use will reduce this by an additional 6 percent; (c) future changes in external factors, such as population and fuel price levels, can have impacts on travel as substantial as those created through new highway construction and proper land use organization in the county; and (d) although TOPAZ supported the Prince William County comprehensive planning effort, it had relatively little direct impact on county decision makers, probably because it was not used at a time when citizens and local elected and appointed officials began to examine the draft comprehensive plan.

Prince William County is located in northeastern Virginia, approximately 25 miles southwest of Washington, D.C. (see Figure 1). It lies in the Piedmont plateau and has the unique features of the Potomac River shoreline on its eastern border and the Bull Run mountains on its northwestern border. The county has an area of 345 square miles (227,000 acres) and a 1980 population of 144,700.

Prince William County has a county executive form of government with a seven-member Board of County Supervisors that appoints the county executive and various boards, committees, and commissions. The Planning Office, which serves as staff to the Planning Commission and the Board of County Supervisors, is charged with the preparation of the comprehensive plan for the county.

In 1980 Prince William County began a rigorous countywide comprehensive planning effort. This was intended to update thoroughly all portions of the 1974 comprehensive plan, including land use, community facilities, water and sewers, and transportation. The update was conducted over a period of 2 years. The transportation element of the plan included extensive use of computer-based analytic tools. The horizon for this element was taken as the year 2000.

The Metropolitan Washington Council of Governments (MWCOG) provided substantial support in the evaluation and development of a recommended highway network for Prince William County. Through the application of the model, Transportation Integrated Modeling Systems (TRIMS), MWCOG prepared detailed traffic forecasts for the year 2000 as well as information on system performance.

However, because the updated comprehensive plan attempts to achieve a strong link between land development and the timely provision of adequate community facilities, county staff believed that there was a need to supplement MWCOG estimates of future travel demand by examining the impact of various land use scenarios on the county transportation system. The sketch-planning procedure, Technique for the Optimum Placement of Activities in Zones (TOPAZ), was the tool selected to help coordinate transportation and land use planning to an extent not previously practiced in the county.

Although TOPAZ has been used in more than 70 applications around the world, this effort offered several unique opportunities:

1. To test the usefulness of the procedure in a still relatively unpopulated, exurban area;
2. To adapt part of its structure to already existing travel models so that the two could be applied consistently and sequentially; and
3. To determine the general usefulness of TOPAZ in the broader comprehensive planning and decision-making process.