Evaluation of Public Services and Land Use Control using a Computable Urban Economic (CUE) Model

– Application of VMcue to the Tokyo Metropolitan Area –

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Abstract

The present study employs a Computable Urban Economic (CUE) model as a tool for policy analysis. The CUE model was developed in the tradition of the Transport-Land Use Interaction (TLUI) model. The CUE model has several benefits in comparison to the older TLUI models. First, the CUE model is based entirely on the urban economic theory of Alonso(1964). A microeconomic foundation in urban economics enables consistent evaluation of policies with standard cost-benefit analysis methodologies. The location choice behaviors of residents and business sectors were described using a logit model following Anas(1984); the demand-supply in land markets were assumed to determine land price distribution in an urban economy. The transport demand for each type of transport service as derived from utility maximizing or profit utility maximizing behaviors and the Wardrop equilibrium of the transport network in tradition was simulated. The present paper aims to demonstrate the impact of public services and land use policies in the Tokyo Metropolitan Area by applying a CUE model to examine whether the polices generated through discussions between policy makers can improve the quality of urban life in Tokyo.

Key Words: urban model, land use, compact city, sustainability, quality of urban life

1. Introduction

Tokyo is the largest metropolitan area in the world and the center of the Japanese national economy. Since the years of rapid economic growth following World War II, Tokyo has attracted huge numbers of people from rural areas, resulting in the monocentric spatial structure of modern Japan. Within the Tokyo Metropolitan Area, population expansion and economic growth have caused serious urban problems such as sprawl at the urban fringes, heavy congestion in both road and rail networks, and severe pollution and environmental damage. Transport infrastructure systems in the metropolitan area have attempted to solve these problems by expanding the coverage and capacity of transportation networks. Although difficult problems remain, transport infrastructure policies have largely succeeded in their goal of improving the quality of urban life amidst a rapidly growing population. However, when considering urban policies for the sustainable development of a compact city, it is necessary to understand the effects of development on various indicators, including the economy, environment, dwellings, living conveniences, and natural disasters. The question at the heart of current policy discussion is how the quality of urban life in the Tokyo Metropolitan Area can be improved through public services and land use control. To answer this question, public services and land use policies must first be evaluated.

In the present study, the Computable Urban Economic (CUE) model was employed as a tool for policy analysis. The CUE model was developed in the tradition of the Transport-Land Use Interaction (TLUI) model. In order to compare or test a Transport-Land use model with another, International Study Group on Land-Use/Transport Interaction (ISGLUTI) was set up in 1981. The CUE model has several advantages over the old TLUI models. First, the CUE model is based entirely on the urban economic theory of Alonso(1964). A microeconomic foundation in urban economics enables the consistent evaluation of policies with standard cost-benefit analysis methodologies. The location choice behaviors of residents and business sectors were described using a logit model following Anas(1984), based on the assumption that demand-supply in land markets determines land price distribution in an urban economy. The transport demand for each type of transport service was derived from utility maximizing or profit utility maximizing behavior and the Wardrop equilibrium of the transport network was simulated.

The CUE model can output a set of variables describing a real-world urban economy. The outputs in the spatial dimension are categorized into two groups. The first type is a group of location-specific variables—distribution of locators or activities including households and firms; distribution of land use including residential, commercial, manufacturing, business, agricultural and other types; and distribution of land price/rent and building price/rent. The second type is a group of flow variables—distribution of passenger trips aggregated by origin-destination pairs, by transport mode, by path or by link and node; and distribution of freight cargo and passenger trips. The CUE can output these variables by working with transport models consistent with microeconomic theory. The CUE model was developed with practical prediction and evaluation capabilities based on research by Yamasaki and Ueda (2004) and Yamasaki and Muto (2003). The model shown below is currently called the Value Management CUE Model (*VMcue*), and it was used a primary tool for evaluating the Tokyo Metropolitan Area by the practitioners.

This paper demonstrates the impact of public services and land use policies in the Tokyo Metropolitan Area by applying the CUE model to examine whether polices generated through discussions between policy makers can improve the quality of urban life in Tokyo.

2. Structure of the Computable Urban Economic model

2.1 Sketch of the model

2.1.1 Features of the model

The CUE, which introduces a microeconomic foundation into the conventional Transportation/ Land-use model, has two primary advantages over other models.

One is the consistency of behavior hypotheses with simulated results. The behaviors of households and firms are formalized on the basis of microeconomics. Micro-econometrics, including the discrete choice model, has enabled the utility-max or the profit-max behaviors to be statistically verified, allowing the microeconomic behavior hypothesis to work as an operational tool.

The other is that the model enables us to evaluate the benefit of a urban policy in the incidence form where the distribution of project benefits among stakeholders in spatial dimension. In contrast, a conventional transport/land-use model measures project benefits in their original form, accounting for only benefits derived from transport users and supplies. Evaluation of shared benefits can provide policy makers with information such as who exactly is benefiting from the policy and where and how much benefit is being generated. This advantage allows a fair balance to be reached among stakeholders in sharing the costs and benefits of a transport project.

In the CUE model, the land and transport markets attain equilibrium simultaneously. The equilibrium of the transport market is attained according to the first Wardrop principle; this is represented by the point where the inverse demand function intersects with the average cost function (link performance function, not the marginal cost function). It is then assumed that users in a road network only consider information on average cost, paying less or no attention to the marginal increase in user costs that occurs when adding an additional user.

Traffic assignment is based on average cost. The composite average cost, which denotes the transportation cost from the specific origin to the destination, is the horizontal summation of the link transportation costs. This inverse demand function indicating the number of OD trips changes its functional form according to the land use at each zone and the trip generation. The composite average cost function shifts to the right horizontally if the number of links increases because of the further increase in OD trips. The change in transport cost causes a change in land use, causing the state of the transport system to shift to a new equilibrium through the change in the inverse demand function.

Equilibrium in the land market is attained by adjusting the rent in each zone. The supply function for land is the marginal cost curve assumed not to shift endogenously. The demand for land is derived by multiplying the population at each zone with the per capita land demand or the individual land demand. The individual land demand is derived from the household's or resident's utility maximization.

The total population is distributed according to the utility values at each zone. Thus, a decrease in transport cost due to road network development would increase the net income (gross income minus commuting cost), the individual land demand and the population at the zone. The limited availability of land at each zone makes the land rent higher and the price mechanism clears the market.

The CUE model attains equilibrium if the transport market is cleared for each OD demand and the supply and demand of the land market are equalized for each zone. Since the CUE model adopts the stochastic approach, a logit model, which assumes the Gambel distribution in the error term, is used for both transport and location choice.

2.1.2 Major assumptions in the model

The CUE model used in the present paper used the following assumptions:

- The Tokyo Metropolitan Area was divided into 197 zones.
- There were households (with an identical preference), firms (with an identical production technology for the composite good) and absentee landowners (each of which representatively own the land).
- Land markets for residential and business use were assumed to exist in each zone.
- All prices except land rents, such as the wage and the composite good price, were assumed to be constant. The total number of households and workers was also given.

Each household maximizes utility under income constraint and chooses a residential zone according to the attractiveness of each zone. Firms maximize their profits by using land and business trips and selling products to households. Firms also choose their location according to their profit. Finally, absentee landlords provide land to households and firms in order to obtain profit from rent. Absentee landlords decide how much land (%) is made available to the market.

As mentioned previously, the CUE model requires simultaneous equilibrium of land and transport markets, which is adjusted by the generalized transport and rent costs. The overall structure of the CUE model is shown in Figure 1.

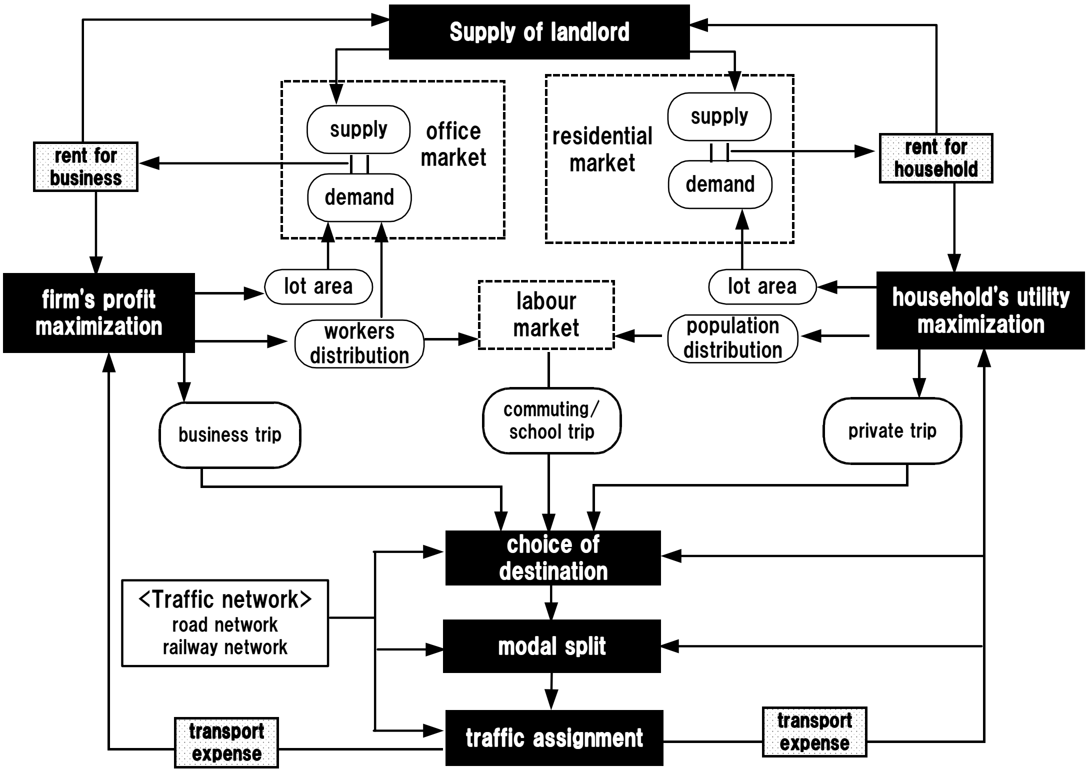


Figure 1 Overall structure of CUE

2.2 Formulation of each agent's behavior

2.2.1 Household behavior model

Households earn income by providing labor and consume composite goods and land services so as to maximize utility under given monetary and time constraints. By incorporating time constraints, consumption of time resources for trips or labor can be considered in the model. In order to consume composite goods, households must travel. These trips can be interpreted as private trips. This utility maximizing behavior can be formulated as follows:

$$V_{i}^{H} = \max_{z_i, a_i, x_i} \left[\alpha_Z \ln z_i + \alpha_a \ln a_i + \alpha_x \ln x_i^p\right] \qquad (1)$$

$$\text{st.} \quad z_i + r_i a_i + q_i^p x_i^p = w\left(T - q_i^w x_i^w - q_i^s x_i^s\right) \qquad (2)$$

$V^H{}_i$: utility level at zone i
Z_i: consumption level of composite good
a_i: land service
$x^P{}_i$: private trip
r_i: residential land rent
$q^P{}_i$: average generalized price of private trip
T: total time available
$x^w{}_i$: number of commuting trips (business)
$x^s{}_i$: number of commuting trips (school)
$q^w{}_i$: commuting cost (business)
$q^s{}_i$: commuting cost (school)
α: distribution parameter

Price q of a private trip is defined as the transport cost multiplied by the wage rate. Constraint thus includes the notion of time as a part of a household's income. The solution of the utility maximization problem defined by (1) and (2) gives a demand function as follows:

$$z_i = \alpha_Z I_i \qquad a_i = \frac{\alpha_a}{r_i} I_i \qquad x_i = \frac{\alpha_x}{q_i} I_i \tag{3}$$
$$I_i = w\left(T - q_i^w x_i^w - q_i^s x_i^s\right)$$

The induced traffic is considered at the generation stage, since the private trip increases as the private and commuting trip costs decrease. The indirect utility function can be obtained by substituting (3) into (1):

$$V_i^H = \ln I_i - \alpha_a \ln r_i - \alpha_x \ln q_i + C \tag{4}$$
$$where, C = \alpha_z \ln \alpha_z + \alpha_a \ln \alpha_a + \alpha_x \ln \alpha_x$$

A household chooses the zone in which to reside according to the distribution of the attractiveness index for each zone, which is given by (4). The probability of a household choosing any residential location is given by the following:

$$P_i^H = \frac{\exp \theta^H V_i^H}{\sum_i \exp \theta^H V_i^H} \tag{5}$$

P^H_i: probability that a household chooses zone i

V^H_i: utility level at zone i

θ_H: logit parameter

(5) is derived from the following problem[1]:

$$S^H = \max_{P_i^H} \sum_i \left[P_i^H V_i^H - \frac{1}{\theta^H} P_i^H \ln P_i^H \right] \tag{6}$$
$$st. \quad \sum_i P_i^H = 1$$

Ueda (1992) shows that the utility level at each zone becomes identical if only situations where the entropy term in (6) can be omitted are considered. When θ^H is large enough, the entropy term can be ignored.

$$S^H = \max_{P_i^H} \left[\sum_i P_i^H v_i^H \right] \tag{7}$$
$$st. \sum_i P_i^H = 1$$

The Kuhn-Tucker condition for the problem is given as follows:

$$L = \sum_i P_i V_i - \lambda \left(1 - \sum_i P_i \right) \tag{8}$$
$$\frac{\partial L}{\partial P_i} = V_i - \lambda \qquad \frac{\partial L}{\partial \lambda} = 1 - \sum_i P_i$$

From the condition above, the relationship below can be derived:

[1]This can be interpreted as the expected utility maximization behavior of the risk averter when a Gambel distribution is assumed for the uncertainty of the utility. See Ueda and Tsutsumi (1999).

$$V_i^H = \lambda \quad if \quad P_i^H \geq 0 \tag{9}$$
$$V_i^H \leq \lambda \quad if \quad P_i^H = 0$$

Thus, (9) suggests that (6) includes the notion of equalized utility in urban economics.

2.2.2 Firm behavior model

A firm produces composite goods by inputting land service and business trips so as to maximize its profit under production technology constraints. This behavior is formulated as follows:

$$\Pi_i^B = \max_{Z_i, A_i, X_i} \left[Z_i - R_i A_i - Q_i X_i \right] \tag{10}$$

$$\text{st.} \quad Z_i = \eta_i E^{\sigma} A_i^{\beta_A} X_i^{\beta_x} \tag{11}$$

Π^B_i: profit at zone i

Z_i: output of composite goods

A_i: land service

X: business trip input

R_i: business land rent

Q_i: average generalized price of business trip

η: parameter regarding production efficiency

σ, β: parameter

Ei: workers at zone i

As is shown in Figure 2, the actual worker density in central Tokyo is much higher than the population density, meaning that there is high productivity resulting from frequent business communication (enabled *by spatial agglomeration*).

In order to describe the mechanism of this spatial agglomeration, positive externality has been introduced into the description of production technology. That is, the total factor productivity of a production function is dependent upon the workers in each zone.

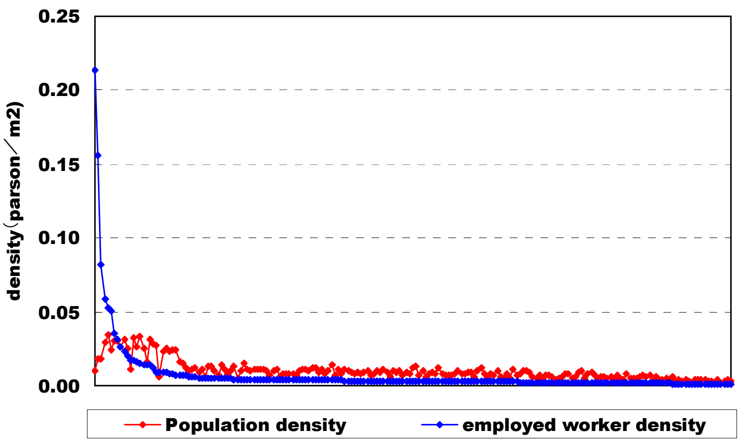


Figure 2 Worker Density and Population Density in Tokyo Metropolitan

The solution of the profit maximizing problem in (10) and (11) yields factor demand functions of *A* and *Xi*, respectively:

$$A_i = \frac{\beta_A}{R_i} Z_i \qquad X_i = \frac{\beta_X}{Q_i} Z_i \tag{12}$$

$$Z_i = \left[\eta_i E^{\sigma} \left(\frac{\beta_A}{R_i} \right)^{\beta_A} \left(\frac{\beta_X}{Q_i} \right)^{\beta_X} \right]^{(\beta_A + \beta_X)} \tag{13}$$

A firm's location choice behavior is formulated in a manner similar to that for a household. As a result, the probability of a firm choosing zone *i* is determined by the following logit-type model:

$$P_i^B = \frac{\exp \theta^B \Pi_i^B}{\sum_i \exp \theta^B \Pi_i^B} \tag{14}$$

2.2.3 Land supply by absentee landlords

Absentee landlords supply land for use by households and firms using the land supply function given in (15). Note that the value in parentheses is assumed to take the range from zero to one.

$$y_i^H = \overline{y_i^H} \cdot \left(1 - \frac{\sigma_i^H}{r_i} \right) \tag{15}$$

$$y_i^B = \overline{y_i^B} \cdot \left(1 - \frac{\sigma_i^B}{R_i} \right) \tag{16}$$

y_i^H: land supply for residential use

y_i^B: land supply for business use

$\overline{y_i^H}, \overline{y_i^B}$: land area available to supply

σ: parameter

2.3 Formulation of transportation behavior

Figure 3 shows the structure of the nested logit model used in the CUE model. Although the structure can be changed due to the reflection of the result of the parameter estimation, the present research adopted the same structure as the conventional four-step estimation. In addition, these structures are basically applied to trips between different zones. The ratio of trips between different zones and trips inside one zone never changes.

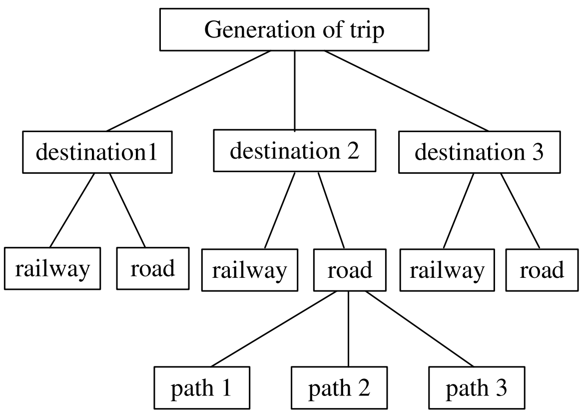


Figure 3 Choice structure of nested logit model

2.3.1 Trip generation model

Since commuting trips (business and school) are not significantly influenced by changes in transportation services, a linear regression model was used for trip simulation. However, it was assumed that the demand function of both private and business trips does not include traffic fares.

2.3.2 Choice of destination and modal split

Destination choice and modal split of each reason to move (e.g., private, business) were formulated using the nested logit model explained above. In order to decide the cost inherent to each zone, C_{ijm}, the present study followed the work of Yoshida et. al. (1999), which introduced a variable dependent upon the amount of zone areas. Generalized transportation cost includes gasoline for automobiles and fare price for railways.

$$P_{ijm} = \frac{\exp[-\theta_1(C_{ijm} + q_{ijm})]}{\sum_m \exp[-\theta_1(C_{ijm} + q_{ijm})]} \tag{17}$$

$$P_{ij} = \frac{\exp[-\theta_2(C_{ij}^D + S_{ij}^D)]}{\sum_j \exp[-\theta_2(C_{ij}^D + S_{ij}^D)]} \tag{18}$$

$$S_{ij}^D = -\frac{1}{\theta_1} \ln \sum_m \exp[-\theta_1\{q_{ijm} + C_{ij}^S\}] \tag{19}$$

P_{ij}: probability of choosing zone j as destination for trip generated at zone i
P_{ijm}: probability of choosing mode m at link ij
S^D_{ij}: expected minimum cost regarding modal split
q_{ijm}: transportation cost of mode m at link ij
C_{ijm}: cost inherent to mode m at link ij (constant)
C^D_{ij}: cost inherent to ij (constant)
$\theta 1, \theta 2$: logit parameter

2.3.3 Traffic assignment

Traffic assignment analysis was carried out using an OD table and road network data. Here, the stochastic user equilibrium traffic assignment was applied. By solving the problem, the probability where route *k* of transportation mode *m* between OD pair *ij* is determined by the following:

$$P_{ijmk} = \frac{\exp[-\theta_3 q_{ijmk}]}{\sum_k \exp[-\theta_3 q_{ijmk}]} \tag{26}$$

The traffic cost of route *k* is the sum of the traffic cost of each link.

$$q_{ijmk} = \sum_a \delta_{ijmk}^a t(x_a) \tag{27}$$

P_{ijmk}: probability of choosing route k of mode m in OD pair ij
q_{ijmk}: transportation cost of route k of mode m in OD pair ij
t: average transportation cost of link a
δ^a_{ijmk}: variable which takes 1 if route k of mode m in OD pair ij includes link a (otherwise 0)
$\theta 3$: logit parameter

3. Model building

3.1 Details of assumptions and settings

3.1.1 Total population and number of workers in the metropolitan area

For the present paper, a reference year of 2000 and prediction year of 2015 were used. The total population is an exogenous valuable in the CUE model. The total population of the Tokyo Metropolitan Area was obtained from “Population Projections by Prefecture (2002 edition)” published by the National Institute of Population and Social Security Research. Because there is no previous work regarding to the number of workers in each prefecture, this was estimated based on the economic growth forecast.

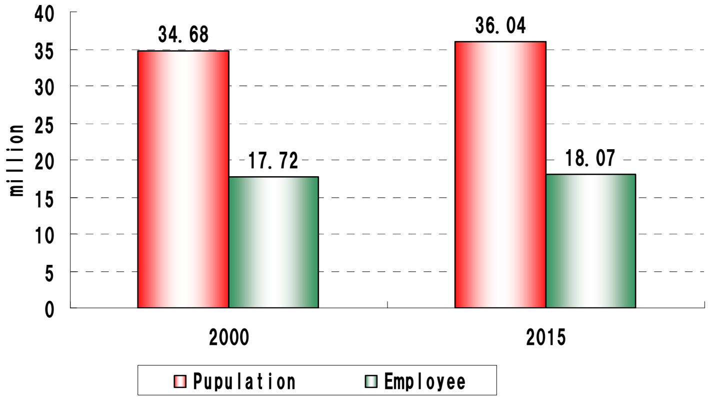


Figure 4 Total population and number of workers in the Tokyo Metropolitan Area

3.1.2 Coverage Area and Transport Infrastructures

The coverage area included the southern part of Ibaraki Prefecture in addition to Tokyo Metropolitan Area (Tokyo, Kanagawa, Chiba and Saitama Prefectures). The coverage area was divided into 197 zones. In central Tokyo, the density of the workers was higher than that of the population.

Figure 5 Coverage Area (197 zones)

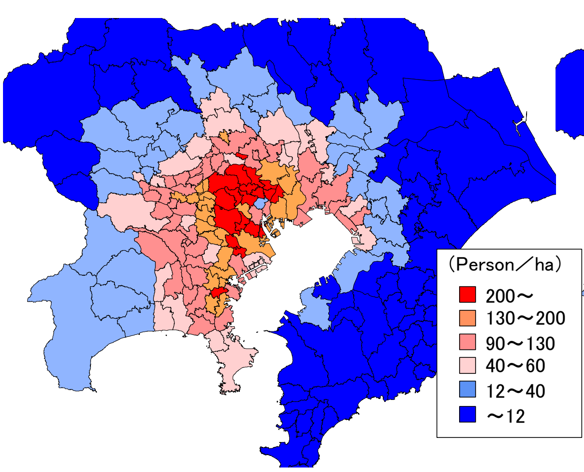


Figure 6 Population density distribution

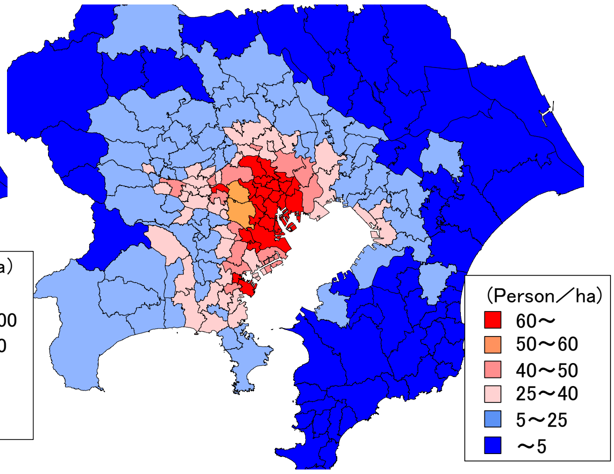


Figure 7 Worker density distribution

Figure 7 shows the road network considered in the present study; local streets were excluded. Figure 8 shows the railway network (only railways located in more than two zones were included).

As for road infrastructure projects, three belt highways, nine radial highways and the Second Coastal Highway are expected to be in service by 2015 according to a plan by the Ministry of Land, Infrastructure and Transport. As for the railway infrastructure projects, the Council for Transport Policy No. 18, submitted to the Ministry, was followed for the present study.

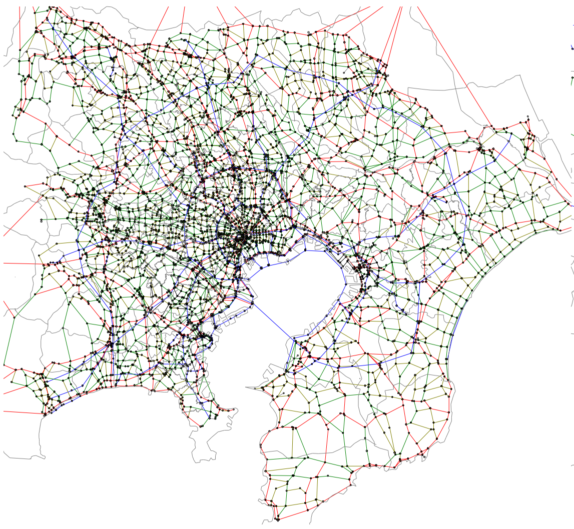


Figure 8 Road Network

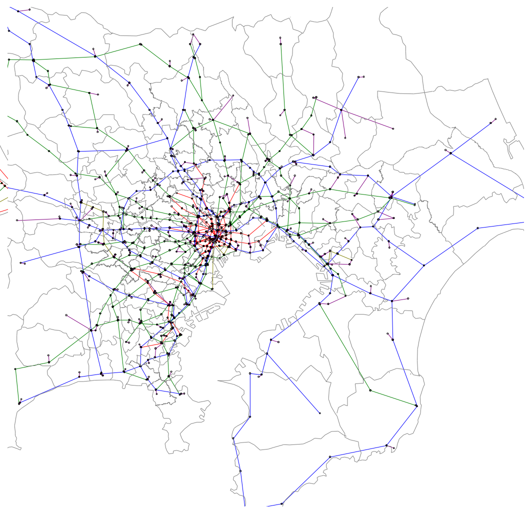


Figure 9 Railway Network

3.2 Estimation of parameters

3.2.1 Distribution parameter of production function

The distribution parameter of a firm was based on "Annual report on prefectural accounts (2003 edition)". Land input was determined by the property income given in the annual report and the gross regional product is used for the composite goods. The business trip input of the firm was calculated using the total transportation cost based on the network distribution.

Table 1 Distribution parameters of production function

	parameters	t-statistic	R-squared
Input of Land (B_A)	0.0062	11.0214	0.4558
Input of Business Trip (B_x)	0.0202	13.2672	0.8710

3.2.2 Parameter of utility function

The parameter of utility function was estimated using "Annual report on prefectural accounts (2003 edition)". Table 2 shows the result; the amount of land demand was approximately 14.4%.

Table 2: Parameter of utility function for households

	Parameters	t-statistic	R-squared
Consumption on Private Trip (α_X)	0.0295	22.8870	0.7287
Consumption on Land (α_a)	0.1769	12.2045	0.2376

3.2.3 Transport section

The estimation result of destination choice and modal split in the transportation model are shown in Tables 3 and 4.

Table 3 Result of parameter estimation for modal split

	Commute		school		Private		Business	
	parameter	t-statistic	parameter	t-statistic	parameter	t-statistic	parameter	t-statistic
Transport Cost	-0.070	-54.99	-0.026	-9.67	-0.061	-36.93	-0.036	-27.13
Density of stations	0.565	17.67	0.129	2.36	0.462	29.23	0.313	32.285
Egress	-0.790	-28.24	-0.311	-6.52	-0.914	-19.46	-1.038	-26.54
Constant	-0.858	-20.98	-1.910	-27.34	0.226	4.892	0.225	6.079
R-squared	0.801		0.752		0.700		0.660	
Sample	5,207		1,182		3,869		3,638	

Table 4 Result of parameter estimation for choice of destination

	Commute		school		Private		Business	
	parameter	t-statistic	parameter	t-statistic	parameter	t-statistic	parameter	t-statistic
Expected minimum cost	-0.030	-88.59	-0.021	-50.93	-0.022	-68.06	-0.018	-69.86
Density of employee	1.162	71.338	0.750	41.861	0.897	54.272	1.053	72.866
R-squared	0.69898		0.56896		0.70227		0.82461	
Sample	11,122		7,507		9,518		9,523	

4. Estimation of Sustainability

4.1 Method for developing sustainable urban polices

Here, the method of thinking behind the development of sustainable urban policies using the CUE model is discussed. First of all, the CUE model is implemented using business as usual (BAU) in Step 1. In Step 2, the future city structure that was output in Step 1 and sustainable indices are taken into consideration and a study of anticipatable (implementable) policies takes place, reflecting the desired urban structure and amount of policy input. In Step 3, the policies are input into the CUE model to get a grasp on the resulting urban structure and on the sustainability of the overall system.

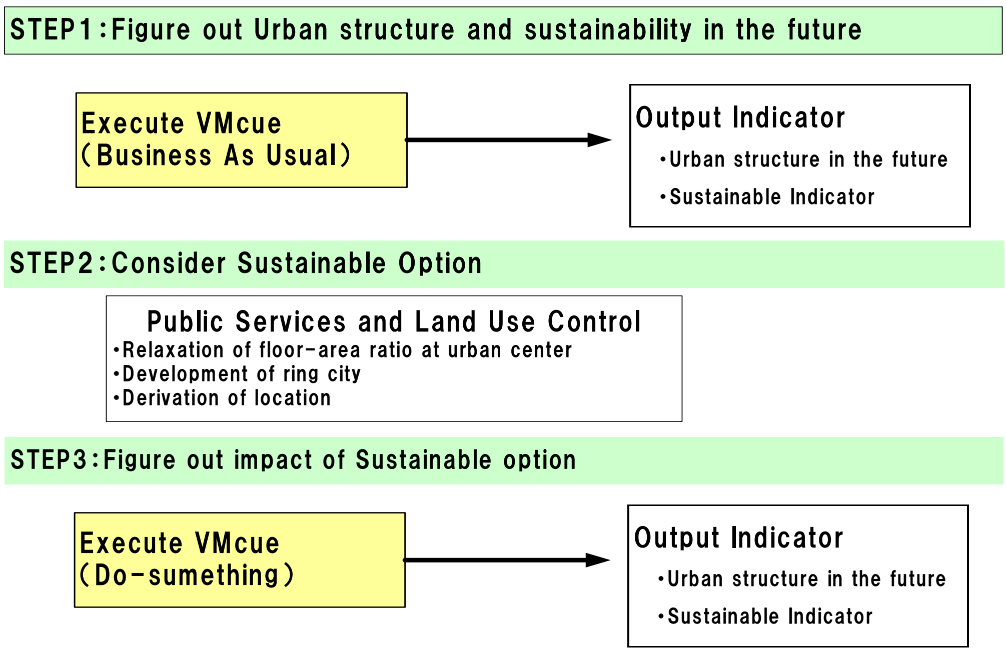


Figure 10 Method for developing sustainable urban policies

The sustainability indicators and urban compactness index are shown below. The sustainability indicators can be divided into three major categories: economic growth, environmental emissions, and quality of life. The urban compactness index looks at two perspectives: spatial compactness (average distance of locations) and sphere of activity (circle of activity) compactness. When considering a compact city, there have been almost no discussions of the physical distribution of urban areas and of which main areas of activity should be the center of focus. For example, when the compactness of a sphere of activity in a city is high—even when the spatial compactness is low—there has been almost no discussion of whether that city can be called a compact city. In addition, in the case of metropolitan policy, even if the compactness of a sphere of activity is low, sometimes the sustainability is high due to the use of public transportation or high-level utilization.

The present research evaluates both sustainability and compactness in a metropolitan area based on these

.

Table 5 Sustainability indicators

Item		Indicator
Economic growth		Gross Regional Product(GRP)
Environmental emission		CO2emisson（Transport）
		CO2emisson（consumer）
Quality of life	Convenience of life	Private passenger trip
	Living space	Floor space of housing
	Damage of disaster	Victims unable to return home
	Convenience of Road	Average speed by car
	Convenience of mass transit	Commuting time
		Share of mass transit
	Diverse needs	Leisure time

Table 6 Compactness index

項目	指標
Average distance of location	Distance between homes
	Distance between firms
Circle of activity	Trip length of commuting
	Trip length of private
	Trip length of business

4.2 Predicting urban structure and sustainability in the future

4.2.1 Changes in urban structure

(1) Changes in population

The Tokyo Metropolitan Area will see an overall increase in population of 1.2 million by the year 2015. However, there will also be major increases in population (20,000 or more per city) along the route of the Tsukuba Express (including the cities of Tsukuba and Kashiwa) and the Metropolitan Intercity Expressway (including the cities of Sagamihara, Machida, and Atsugi). In addition, there will be small increases in population at the heart of the Metropolitan Area. In particular, there will be growth along the route of the Saitama Rapid Railway Line (in the city of Saitama) as well as in inland portions of the cities of Yokohama and Kawasaki. In contrast, a decrease in population is predicted for other areas, including the Boso Peninsula.

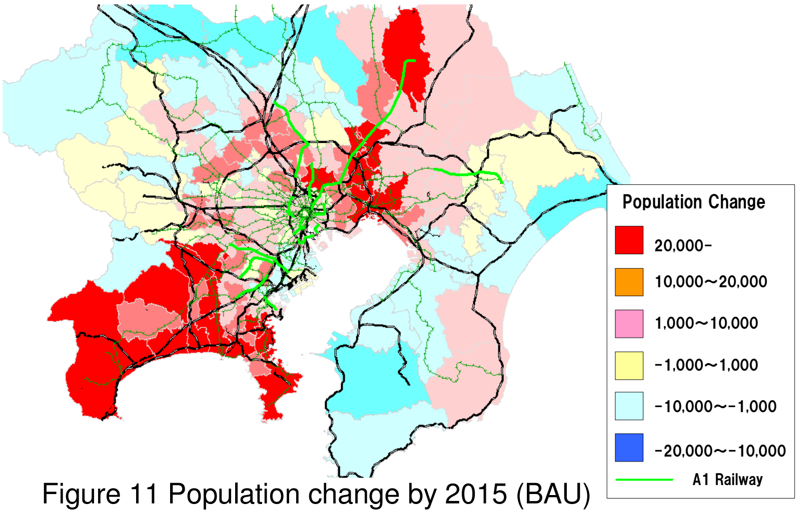


Figure 11 Population change by 2015 (BAU)

(2) Changes in the number of workers

The total workforce in the Tokyo Metropolitan Area is roughly the same it was in the year 2000. Although the number of workers will increase along the route of the Tsukuba Express, it will trend downward in 2015 in most cities, towns and villages in suburban areas while rising significantly at the urban center. In other words, in the future, the workforce (corporations) will seek benefits (higher productivity from the spillover of knowledge) from the compactness that comes with proximity to a large number of workers, and the existing compact points within the metropolitan area (and near railroads) will become further compacted. This is because, as the proximity of offices increases, face-to-face meetings between corporations and within corporations will increase, leading to an increase in productivity. Moreover, as these activities will take place near railway stations, which are large-scale transportation facilities, compactness will lead to further compactness. This is believed to be the same force behind the recent trend toward concentrating IT companies in the center of the metropolitan area; this arrangement is thought to encourage corporations to locate at the center of the metropolitan area, anticipating future changes in industrial structure, the use of IT, and the development of the transportation infrastructure.

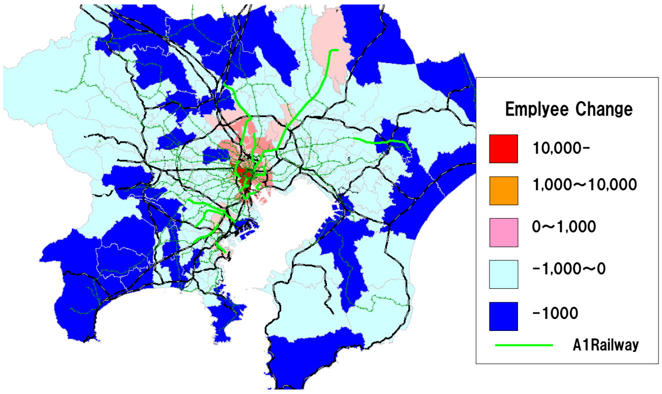


Figure 12 Changes in the number of workers by 2015(BAU)

4.2.2 Change of Compactness index

Results measured using the compactness index are shown in the following table and figure. Based on the spatial compactness index (average distance between workplaces and residential areas), the average distance to the workplace has declined due the high concentration of workers in metropolitan areas. Although the average distance between residential areas has declined, there has been no major change overall. According to the compactness index of the sphere of activity, the length of travel to school, to work and for private business (e.g., for shopping, recreation) has increased, reflecting the concentration of workers in metropolitan areas. However, the length of work-related trips between firms has decreased, reflecting changes in the purpose of these activities.

Table 7 Changes in compactness index (BAU)

		2000	2015	2015/2000
Average distance of location	Distance between homes	46.08	46.06	-0.03%
	Distance between firms	40.82	40.59	-0.56%
Circle of activity	Trip length of commuting	21.79	21.90	0.51%
	Trip length of private	15.59	15.64	0.35%
	Trip length of business	16.98	16.91	-0.40%

Note 1: The average distance between residential areas is an indicator reflecting the compactness of residential areas and showing the average distance between residential zones. A weighted average is applied based on population. Distance is in kilometers. The distance is a measurement of the average road distance between each zone in the model

Note 2: The average distance between workplaces is an indicator reflecting the compactness of the workplace and is the average distance between places of employment. A weighted average is applied based on the number of workers. Distance is in kilometers.

Note 3: The compactness index in a sphere of activity is the average travel distance in kilometers.

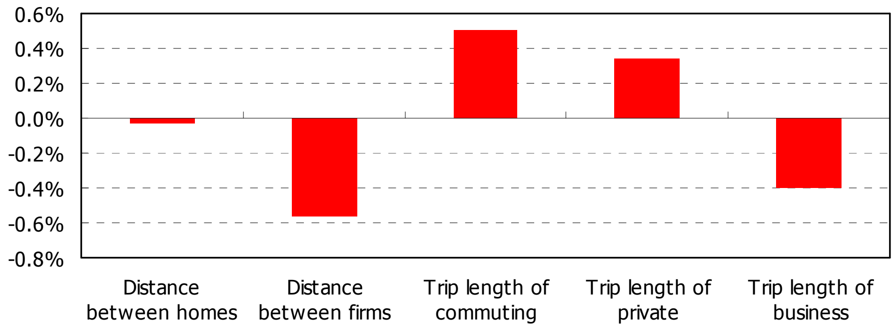


Figure 13 Changes in compactness index (BAU)

4.2.3 Changes in sustainability indicator

Changes in the sustainability indicator are shown in the table below:

Table 8 Changes in sustainability indicators (BAU)

			2000	2015	2015/2000
Economic growth		Gross Regional Product	172.06	179.15	4.12%
Environmental emission		CO2emisson(Transport)	995.84	1,059.30	6.37%
		CO2emisson(consumer)	793.89	868.24	9.37%
Quality of life	Convenience of life	Private passenger trip	0.158	0.163	3.19%
	Living space	Floor space of housing	27.38	28.97	5.81%
	Damage of disaster	Victims unable to return home	508	534	5.26%
	Convenience of Road	Average speed by car	23.79	24.28	2.04%
	Convenience of mass transit	Commuting time	51.57	50.73	-1.64%
		Share of mass transit	63.09%	63.30%	0.34%
	Diverse needs	Leisure time	4.503	4.539	0.81%

Note 1: Total production within a region is compiled as total production within a prefecture in 1 trillion yen units per year.

Note 2: Carbon dioxide emissions are given in units of 10,000 tons C per year.

Note 3: The per capita number of private trips per year refers to the number of times per day trips are made for shopping, leisure, etc. Close travel within a city or town was not included.

Note 4: The living space per capita is in m2 per person.

Note 5: The number of disaster victims unable to return home refers to the probability that people traveling from home on private business when a disaster occurs will be able to return home. If within 10 km of home, all will be able to walk home. If from 10 km to 20 km, the number able to return home will decrease by 10% for each additional kilometer. If greater than 20 km, nearly all would be unable to return home.

Note 6: The average travel speed is the average travel speed of a bicycle and the average of all average travel speeds in a day. The travel speed is in km/h.

Note 7: The work commute and school commute times are the average work and school commute times of those who live in urban areas, in minutes per trip.

Note 8: The railway-automobile travel ratio is the ratio of automobile travel to railway travel, and excludes walking and bicycle travel.

Note 9: The number of leisure hours is the number of hours within a person's daily living time in which that individual can act according to his or her own free will and is the time spent conversing with or entertaining guests, in leisure activities, doing sports, going on outings or walks, pursuing a hobby, pastime or cultural education, enjoying mass media, reading magazines or comics, etc.

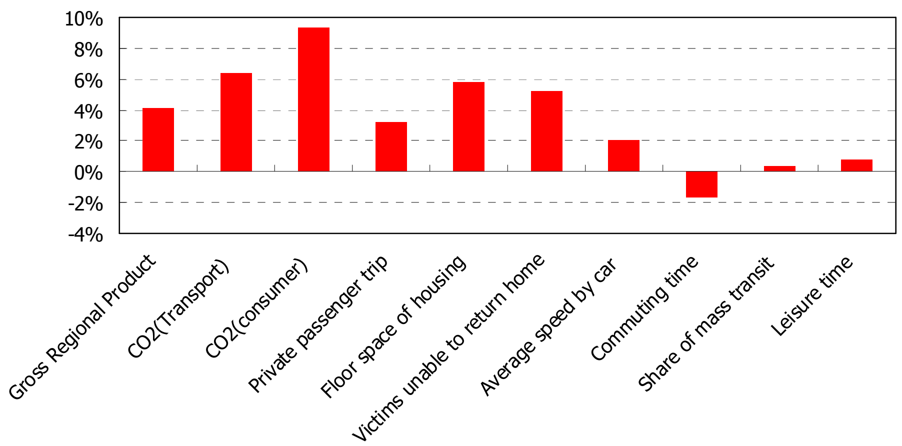


Figure 14 Changes in sustainability indicators by 2015 (BAU)

4.3 Sustainable options for the future

4.3.1 Future perspectives

Based on the analysis discussed up to this point, if the transportation infrastructure currently in planning is provided and a framework is given to the total population in the overall urban area and total number of workers (BAU), and we then look at the outlook for urban structure and compactness and sustainability in the future, the population distribution will increase significantly in areas (such as the cities of Tsukuba and Kashiwa) along new rail lines like the Tsukuba Express as well as in ring cities (e.g., Tachikawa, Tama, Machida, Atsugi). However, although there will be no significant change in the distance between homes, the average travel distance for work, school and private business will rise due to improved transportation, increasing the size of the sphere of activity. As for worker distribution, there be even more workers in central Tokyo, reducing the distance between firms and leading to a reduction in work travel.

Furthermore, sustainability will improve economic growth, basic conveniences, and housing floor space as the convenience of mobility improves; however, sustainability may also fall due to natural disaster damage and CO_2 emissions (produced by transportation and consumers).

4.3.2 Direction of urban policies

(1) Ideal situation

Future problems with sustainability will be the handling of CO_2 emissions from homes and automobiles and response to disasters for victims unable to return home. In other areas, sustainability will largely improve over current levels. This response to the future appears to be headed in two major directions. One is policy for coping with the amount of CO_2 emissions and natural disasters, while the other is policy introducing advantages over the problems.

Of course, the direction of policy development will not be determined in solely one direction or the other, as this varies depending on the social and economic situation, and there will also be compromises. For this reason, it is necessary to select policies that will overcome the identified problems and improve conditions over their current situation in order to improve sustainability. Below, several concrete options are explored.

(2) Policy options

1) Reduction of CO_2 emissions from automobiles

The reduction of CO_2 emissions from automobiles could be achieved by adopting automobiles with better gasoline mileage and lower levels of pollution; however, for urban policy, it is necessary to consider new transport measures that reduce the amount of automobile transportation and travel distances and encourage the use of public transportation. To that end, a conversion to a compact city structure based on an urban structure assuming more than that assumed by BAU is required.

2) Reduction of CO_2 emissions from homes

Like automobiles, the reduction of CO_2 emissions from homes also requires the adoption of measures acting on the source of emissions; however, reducing emissions for an entire city will require the use of energy sources that are currently not being adequately utilized; for example, solar energy and waste heat from garbage disposal facilities. Measures for effectively using existing energy sources, such as co-generation systems, is also required. It is necessary to acquire heat demand for the sake of adopting these systems, and then convert to the compact urban structure.

3) Earthquake disaster countermeasures

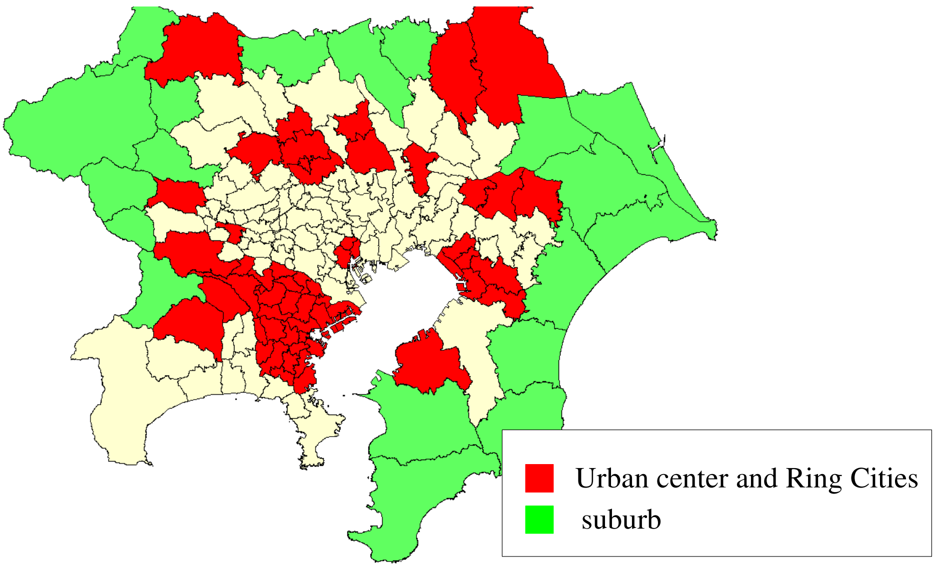
Although related to automobile CO_2 emissions and the sphere of activity, an expansion of the sphere of activity—e.g., for commuting to work and to school and for shopping—will increase the number of disaster victims unable to return home. While an increase in the sphere of activity increases diversity due to expanded living opportunities as well as citizens' degree of satisfaction, it makes disaster response more difficult. For this reason, it is necessary to convert to a compact urban structure and increase the compactness of the sphere of activity. It is assumed that in the future, the compactness of work activity due to higher compactness at the urban center must reduce the size of a family's sphere of activity for commuting to work and school and taking care of private business.

4.3.3 Cases in practice

Model cases were assigned in an urban center, a hub area, and a suburban area, as shown below, based on studies to date. Basically, Cases 1 and 2 are examples of liberalized policies and Case 3 is a planned (or coerced) distribution plan.

Table 9 Setting Case

Case		Urban center	Ring Cities	Suburb
Case 1	Relaxation of floor-area ratio at Urban center	30% Relaxation	—	—
Case 2	Derivation of location	Same as above	Same as on the left	30%Reduction Urban area
Case 3	Development of ring city	—	Set of Ring Cities population as exogenous	—



Note: The red zones in the diagram above are work hub cities and the three central districts of Tokyo. Since towns and villages are gathered in the suburban areas, cities that would not normally be work hub cities are considered to be work hub cities in the above diagram.

Figure 15 Areas of input policy

4.4 Impacts of sustainable options

4.4.1 Changes in urban structure

(1) Changes in population

Compared with BAU, there were no major changes in Case 1 (urban centers with liberalized floor space) and Case 2 (derived locations). However, for Case 2, there were many zones in which the population was falling, and overall the dispersive concentration was advancing. In Case 3 (ring city development), if the population and number of workers in a ring city increases as planned, the surrounding areas, such as the Boso Peninsula and northern part of Saitama Prefecture, will absorb the population, but there will be a major reduction in absorption in the southwest section of the urban center (i.e., the Ota, Setagaya, Suginami and Nerima Wards of Tokyo). In addition, there would also be a reduction in the rate of growth in western Kanagawa Prefecture.

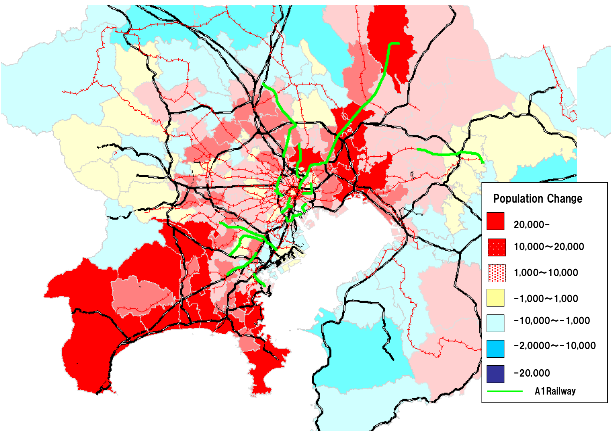


Figure 16 BAU

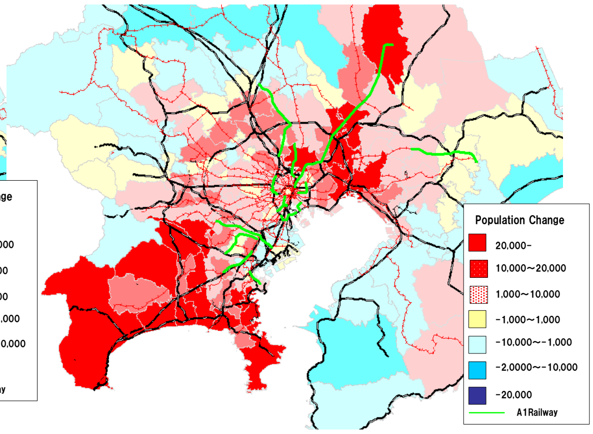


Figure 17 Case 1

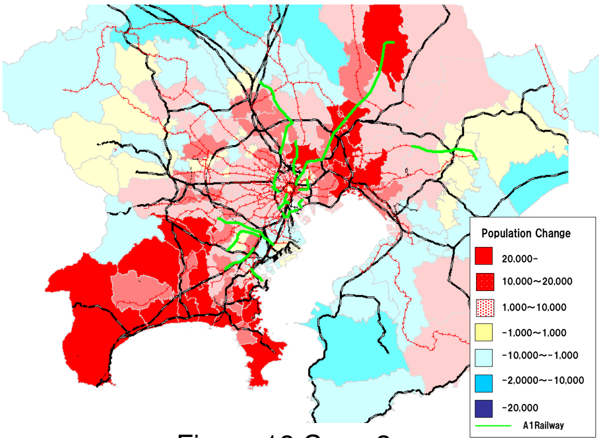


Figure 18 Case 2

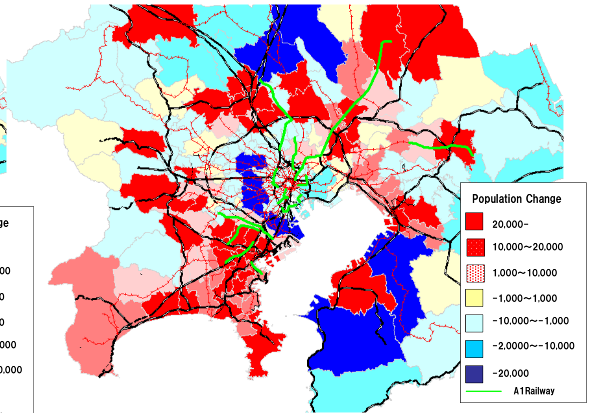


Figure 19 Case 3

(2) Changes in number of workers

There will be a major increase in the number of workers at the urban center due to BAU and a major reduction in the surrounding areas, but for Case 1 (liberalization of floor space at the urban center) there would even be a reduction in Tsukuba and a higher concentration at the urban center. In Case 2 (derived locations), there would be increases in areas like Yokohama, which would attain the dispersive concentration structure. In Case 3 (ring city development), if the ring cities grow as envisioned, there will be major reductions in the surrounding cities and the urban center.

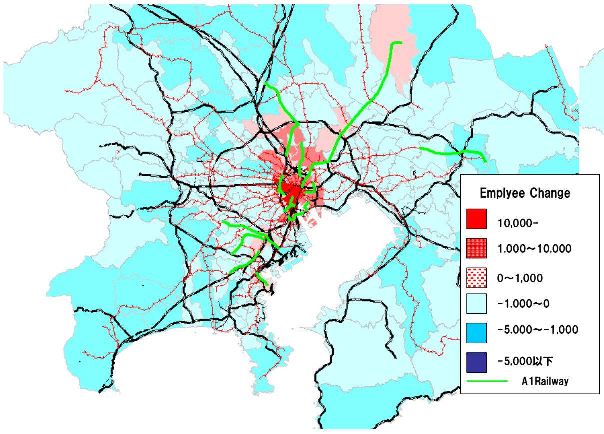


Figure 20 BAU

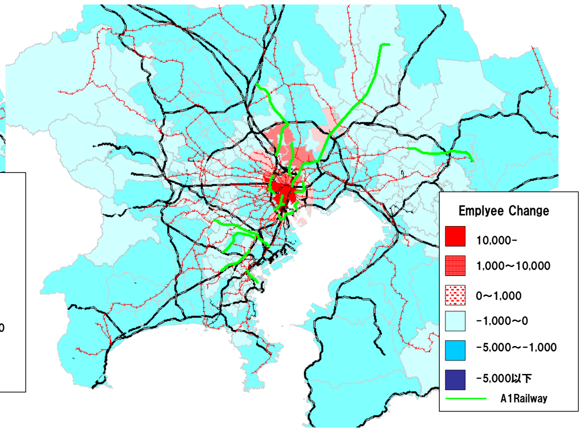


Figure 21 Case 1

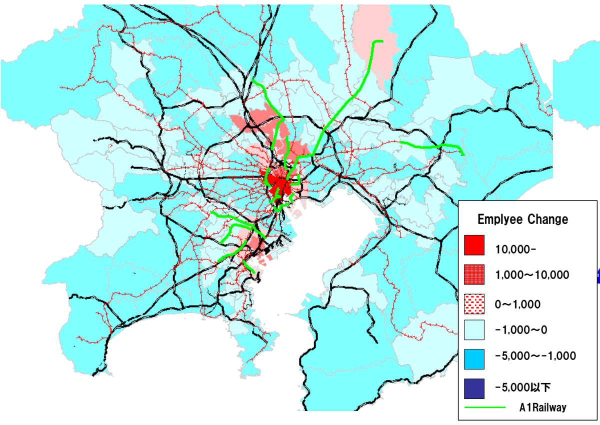


Figure 22 Case 2

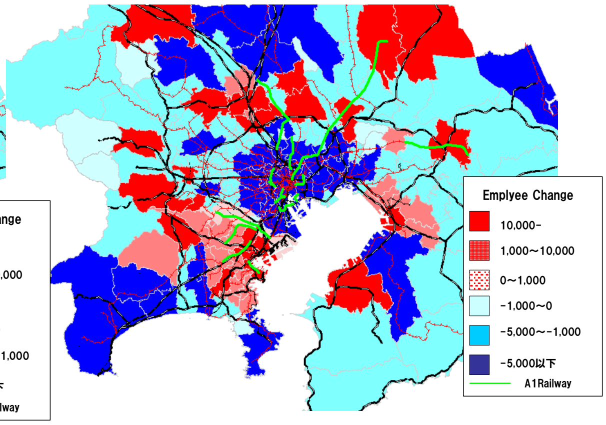


Figure 23 Case 3

4.4.2 Changes in compactness index

Changes in compactness index are shown below. In Cases 1 and 2, the population in the urban center will increase by the year 2015, the distance between homes and between firms will be reduced, and the compactness of residential areas will increase. The length of travel will also fall, further increasing the compactness.

Moreover, in Case 3, the length of travel for commuting to work and school will fall as workplaces and residences become closer, increasing the compactness of the commute area. The compactness index for other items, however, will decrease.

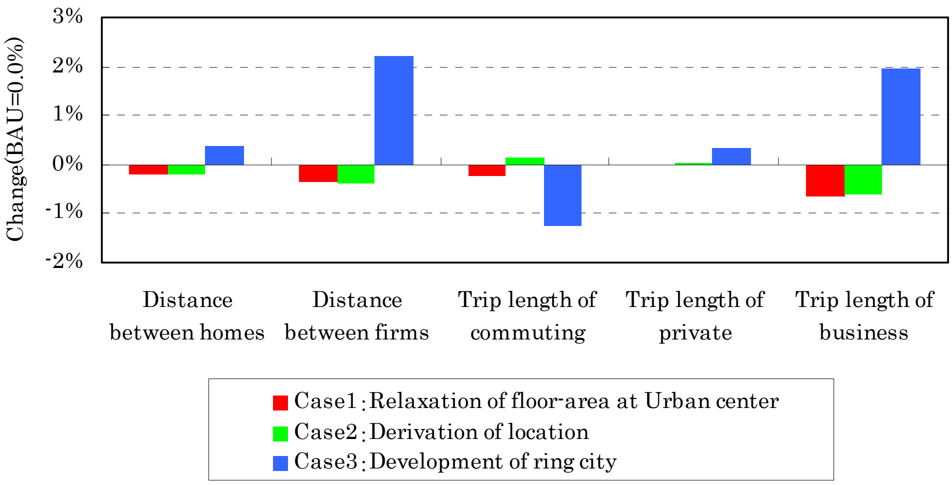


Figure 24 Changes in compactness index (compared with the year 2000)

4.4.3 Changes in sustainability indicators

The sustainability in each case is shown in the following table. For Case 1, in which the average distance between locations decreased, there were improvements in economic growth, environmental emissions and disaster damage compared with BAU, and the sustainability issues indicated by BAU were overcome. Case 1 behaved essentially the same as Case 2; however, economic growth improved more in Case 2 than in Case 1, and disaster damage was smaller than BAU. This makes it difficult to say that Case 2 has overcome the issues of BAU. For Case 3, the amount of CO_2 (consumer), disaster damage, living space and commuting time all improved, but economic growth, the amount of CO_2 (transportation), convenience of mass transit and leisure time were all reduced. This is because in Case 3, which is forced distribution with no relationship to population in the ring city and the market mechanisms of workers, the indicator associated with convenience decreased.

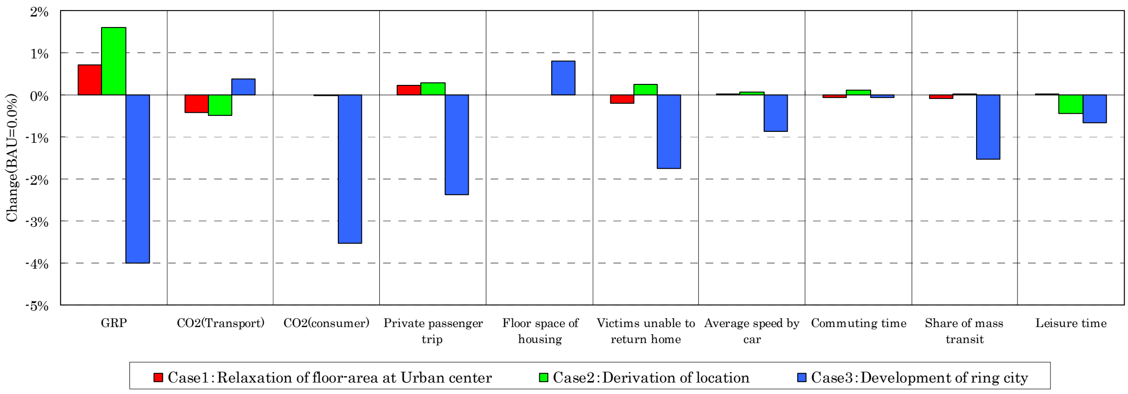


Figure 25 Changes in sustainability (compared with the year 2000)

4.4.4 Benefits

Until now, changes in the compactness index and sustainability have been demonstrated for a metropolitan area. Making use of these indicators, we were not able to evaluate the goodness or badness of the economic entities in the metropolitan area, but were able to evaluate compactness and some (limited) sustainability.

The CUE model used in this research can measure benefit in the strictest sense and evaluate measures as well. For this reason, we are evaluating each measure discussed in the present study. Thus, when evaluating a benefit, BAU can be in a without state and in other cases in a with state.

The results are shown in the following table. If the total amount of benefit is compared for each entity, the benefits for Cases 1 and 2 are positive. Thus, if we ignore the cost of implementing these measures, it would be better to implement them than not to implement them. On the other hand, for Case 3, the benefit is a significant negative, as implementation would lead to a drop in the degree of satisfaction of the economic entity in the metropolitan area. This negative result suggests that if the Tokyo Metropolitan Area were open, there is a potential for households and companies to move to other metropolitan areas in Japan. Metropolitan area policies in Japan have to date concentrated primarily on correcting over-concentration.

If we consider that the main purpose of these policies has been to encourage some of the population to move out of the Tokyo Metropolitan Area, then the nurturing of policy objectives for work hub cities matches policy objectives. However, the Tokyo Metropolitan Area is the center of Japan's economy, society and culture, and in the internationally competitive environment that Japan currently finds itself in, it is necessary to study the appropriateness of measures that create negatives in terms of economic benefits in metropolitan Tokyo from a broad and long-term perspective.

Table 10 Benefits (billions of yen/year)

Actor	Case1	Case2	Case3
Household	0.652	0.811	−6.164
Firm	3.568	8.110	−20.259
Landlord	3.021	10.770	−0.887
Sum total	7.241	19.691	−27.310

5. Conclusion and challenges for the future

5.1 Conclusion

In this paper, VMcue, the Tokyo Metropolitan Area version of the CUE model, was used to evaluate public service and land use control in the Tokyo Metropolitan Area from three perspectives. One was the metropolitan compactness index, an evaluation of two indicators: average distance between locations and the sphere of activity. Although the concept of the compact city has been cited as the epitome of the sustainable city in urban polices, the situation is such that almost nothing has been presented concerning a compactness index. The second perspective was sustainability in the metropolitan area. As for sustainability indicators, a variety of indicators have been assigned, depending on the city. It is difficult to assign a uniform indicator worldwide, but in the present paper, three indicators were assigned and evaluated: economic growth, environmental emissions and quality of life. The third perspective was benefit. Cost-benefit analysis is used to evaluate projects throughout the world and is one criterion in determining whether to take up a project.

If urban policies are evaluated from these three perspectives, first is Case 1: whether an area is compact compared with BAU from a compactness index perspective. This is a measure that increases the level of concentration in an urban center. The concept of a compact city is a government finance issue of independent government municipalities, which are not covered in this paper, and one of the future directions for urban structures. Next, from a sustainability perspective relative to the amount of CO_2 emissions from transportation and consumers and the matter of disaster damage as issues envisioned by BAU, Case 1 represents a successful solution to these issues that simultaneously maintains the benefits of economic growth envisioned by BAU. In Case 2, although economic growth improves more than in Case 1, the problems of BAU cannot be overcome due to disaster damage. Last is Case 3, in which the problems of BAU are overcome, but problems remain in terms of policy development—the good results under BAU, economic growth, CO_2 (transportation), basic conveniences, convenience of mass transportation, and leisure time all decrease precipitously. Therefore, from a sustainability perspective, Case 1 is the most desirable choice. From the perspective of benefits, although Case 2 has the largest benefit, Case 1 also has significant positive benefits. In Case 3, the benefits are negative and should therefore not be adopted. Case 2 is the most desirable from the perspective of benefits. The present paper has evaluated urban policies from these three perspectives; however, research is currently underway to evaluate these in a uniform manner. While there is no optimal solution, Case 1 is believed to be the most desirable among the three perspectives, since it creates no negatives.

5.2 Challenges for the future

The present paper evaluated public services and land use controls from three perspectives: compactness index, sustainability indicators and benefits. However, research to find a uniform method of evaluation that consolidates all three perspectives is now required. In particular, a city is place where diverse groups of people carry out their lives and where evaluation using diverse indicators is necessary. However, at the policy-making level, one proposal must be selected from various alternatives, and the concept and method behind this selection must be well thought out, including consensus building with citizens.

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