EVALUATING ROAD NETWORK IMPROVEMENT: ECONOMIC IMPACTS ON SAN-EN REGION IN JAPAN

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Abstract:
Japan's economy is entering a new phase of economic growth after the so-called "lost 15 years" since 1990. Particularly Tokyo and Aichi prefectures have been drawing attention as engine of new economic growth in Japan. Although the recovery of Japan's economy has resulted in an increase in the demand for transportation, construction of new roads in region-wide areas has been in a serious situation. It is attributed to a decreasing trend in Japan's population and aging which will cause Japan's national budget being reduced in the future. Due to this situation, stricter economic assessment of new roads development in region-wide areas has particularly been required than before. Taking into account these backgrounds, this article aims to present a model integrating the equilibrium concepts of economic and transport network. Moreover this model will be able to be extended into a full spatial equilibrium model. And then setting San-En region in Aichi and Shizuoka prefectures as a study area which consists of many urban and countryside areas, this study also aims to measure the economic impacts of construction of new roads development in this region.

Key words: computable urban economic model, transportation forecasting model, location model

1. Introduction

Under the limited budget for infrastructure, selective investment is required which maximizes the total benefit brought by the investment. The study area is the San-En region which is the industrial base of Japan that also includes many urban and rural areas. The improvement of road network including the construction of high standard roads is necessary to meet the increasing demand for the capacity in logistics. However, there exists a concern over the cost and benefit for/from the road construction. This study aims to develop a model to forecast the total benefit by new roads construction and network improvement in the study area. The concept of benefit is based on the theory of economic equilibrium. The transportation equilibrium model is developed to estimate the benefits which are led back into the economic equilibrium model focusing on the land use (location choice behavior of households and firms). The location choice behavior of economic sectors follows the standard maximization of household's utility function and firm's profit captured in this region.

In the following sections, the authors review the concept of equilibrium and the approaches for the measurement of economic impact by similar existing models. Then, the model for the evaluation of economic impact is proposed. This model is applied to measure the economic impact by alternative scenarios of new roads construction and improvement in the study area.

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The paper concludes with the description of the issues to be improved in the model and the future challenges.

2. Transport Demand Forecasting

2.1 Review of Transport Network Equilibrium Model

The objective of transportation equilibrium model is to estimate the benefits generated by transport network development. In the model transport demand at equilibrium is equated to the economic equilibrium model. The total benefit generated by transport network improvement will be computed as transport users' surplus, in the model travel-demand is calculated by the forecasted combined land-use and transport system at equilibrium. Equilibrium in transport system is linked to the assignment of travelers in road network considering travel cost and travel time to maximize their utility. The transport users' surplus in transport system can be measured from their travel demand as it represents their willingness to pay, that is his or her monetary value of performing activities that are distributed in space (Martinez, 2000). The travel demand in real transportation network depends on the level of transport service between OD pairs. Consequently the travel demand is elastic and the transportation equilibrium model is based on this hypothesis. Furthermore, the equilibrium is based on the principle that no transport user will be able to improve his/her utility by unilaterally switching to another route. In other words, equilibrium is regarded to be achieved when all transport users are in their individual minimum cost paths, or, when travel time is equal in all used paths connecting an origin-destination pair. Travelers' surplus represents a measure of the road network improvement/development in access at zone *i* to travel to get opportunities in zone *j*. This important feature is described in studies of commodity transport, by Samuelson (1952) for competitive markets, Jara-Díaz (1986) for the monopolistic case, and by Mohring (1961, 1976) and Wheaton (1977) in the context of urban-passengers trips.

The integrated transport and economic model is applied to calculate the travelers' surplus in this study, as this study aims to obtain the total benefit where the economic/location choice model and the transport model reach equilibrium simultaneously. It allows for endogenous transportation costs and prices, and is based on the assumptions of individual's rational behavior and optimization of welfare, utility, profit or cost (de la Barra, 1989). Reviews of integrated transport and economic models can be found in Anas (1982), Anas and Duann (1986), Berechman and Gordon (1986), Henderson (1988), Berechman and Small (1988), Webster et al.(1988), and Rietveld (1944), and so on.

2.2 Procedure of Transport Demand Forecasting

The forecasting of transport demand means to obtain the equilibrium transport flow considering socio-economic system of demand side and future transport systems of supply side. The transport model in this study aims to calculate the reduced travel time as the positive effect by road network improvement within transport market in consideration of reduced travel cost. The methodology of demand forecasting is based on the conventional four traditional steps, trip generation/attraction, trip distribution, modal split, and traffic assignment. The trip attraction/generation is firstly forecasted, then, future OD trip volume, modal split, and traffic assignment are calculated. Vehicle OD data is used for calculation because of the limitation of available data. Therefore, modal split step is skipped in this study.

The procedure of transport demand forecasting is shown in Figure 1. The trip generation/attraction model transforms the activities by type per zone estimated by the economic equilibrium model into trip generations and attractions, that is, the number of trips that originate in each zone and the number of trip ends in each zone respectively. The trip distribution model connects generations with attractions to produce a set of origin-destination trip matrices. The resulting OD trips by mode are then assigned to the different routes available in the network by the assignment model.

This study forecasts the OD trip rate by travel purpose considering the performance characteristics of each mode. Consequently the traffic assignment is calculated repeatedly in this paper. In the process of this calculation, the mode distribution rate by trip purpose is multiplied. Then the future traffic is assigned to reach equilibrium. In the last stage, the travel cost in the

equilibrium state is estimated. This effect is fed back to the economic equilibrium model which estimates the socio-economic benefit brought by road network improvement considering location choice.

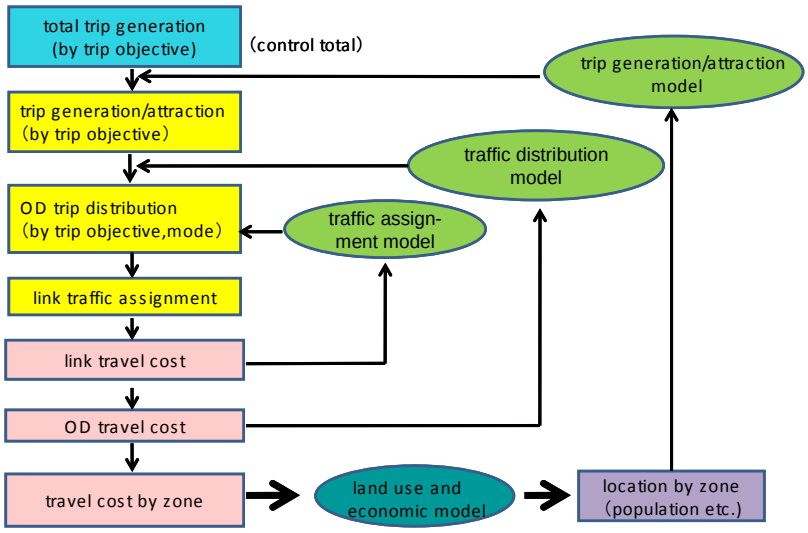

Figure 1. Procedure of Transport Demand Forecasting

2.3 Trip Generation/Attraction Forecasting

The study utilizes data from the national road traffic census, 1999. The case study area is divided into 76 zones based on the definition in the census. Equation (1) is specified as the formulation of trip generation/attraction forecasting model for this case study.

$$\hat{G}_i = \alpha_0 + \sum_{k=1}^{K} \alpha_k X_{ki} \tag{1}$$

where

$\hat{G}_i$: trip generation/attraction from/to zone *i*

$\alpha_{0,} \alpha_k$: parameters

X_{ki} : explanatory variable (the number of population or the number of workers in zone *i*).

The number of population and workers are verified as they significantly affect the trip generation/attraction from the result of correlation analysis. Consequently they are applied as explanatory variables in the model. Other factors related to trip generation/attraction are considered applying factor k_i as follows:

$$G_i = k_i \hat{G}_i \tag{2}$$

In equation (2), k_i represents an adjustment factor which eliminates the gap in the actual and estimated trips. The estimation result of parameters is shown in Table 1. The figures in parentheses show *t* values. From the result, we observe that the parameters of the numbers of population and workers are statistically significant.

Table 1. Result of Parameters Estimation: Trip Generation and Attraction

	trip objective	constant term	population	workers	R^2 value
trip generation	Commuting	2064.7 (3.99)	-	0.370 (9.17)	0.539
	leisure/shopping	460.8 (0.84)	0.215 (7.89)	0.136 (3.12)	0.680
	Business	1298.7 (1.98)	0.176 (5.38)	0.281 (5.37)	0.659
	return home	1811.4 (1.95)	0.419 (10.7)	-	0.615
trip attraction	Commuting	926.5 (2.06)	0.244 (12.8)	-	0.696
	leisure/shopping	877.0 (1.71)	0.247 (9.64)	0.032 (0.78)	0.684
	Business	1208.9 (1.85)	0.194 (5.92)	0.254 (4.84)	0.660
	return home	1694.3 (1.90)	0.266 (5.96)	0.314 (4.40)	0.644

Note: *t* values are in parentheses.

2.4 Future OD Trip Forecasting: Linear Multiple Regression Model and Poisson Regression Model

At this point, the future OD trip associated with a change of travel condition is estimated by the gravity model mentioned below.

$$T_{ij} = k(G_i)^{\alpha}(A_j)^{\beta}\exp(\gamma C_{ij}) \tag{3}$$

where

T_{ij} : number of OD trips between zone *i* and *j*

G_i : trip generation in zone *i*

A_j : trip attraction to zone *j*

C_{ij} : generalized travel time between zones *i* and *j* induced by adding the travel cost in terms of time which is obtained by dividing monetary travel cost by time value

k, α, β, γ : parameters.

In order to estimate the values of parameters in equation (3), we applied two methods; linear multiple regression method and Poisson regression method. Taking logarithm of the both sides in equation (3), the following linear multiple regression models is derived.

$$\ln T_{ij} = \ln k + \alpha \ln G_i + \beta \ln A_j + \gamma C_{ij} \tag{4}$$

$$k = e^{a\,0} \tag{5}$$

The Poisson regression method is applied by assuming that the number of trips between *i* and *j* follows the Poisson distribution with expectation value λ_{ij}. In this method, the values of parameters are estimated by maximum likelihood method.

$$\lambda_{ij} = k(G_i)^{\alpha}(A_j)^{\beta}\exp(\gamma C_{ij}) \tag{6}$$

The parameters are estimated applying the trip distribution. Table 2 shows the results of parameter estimations of both methods. Statistically significant results are obtained referring the *t* values, although the coefficients of correlation R^2 are not so high for the linear multiple regression model. Therefore, these parameters are interpreted as expressing aggregate trend in the study area. Comparing the results among two methods, the results of Poisson regression model is more statistically significant. In addition, the effect of a decrease in traffic volume (value γ) indicated in Figure 2 is higher in the Poisson regression. It can be attributed to the fact that zones with zero trips are to be excluded in the process of estimation with linear regression. Considering the results, Poisson regression model is applied in the evaluation henceforth. In the study, two census data of the years 1999 and 2005 are utilized for parameter estimation. Table 3 shows the estimation results of two period of time applying Poisson regression model.

Table 2. Parameter Estimation Result of OD Trip Model

	Trip Purpose	*k*	*α*	*β*	*γ*	R^2
Linear Multiple Regression Model	commuting	0.143 (-4.13)	0.510 (12.9)	0.433 (12.1)	-0.029 (-31.7)	0.439
	leisure/ shopping	0.479 (-1.22)	0.442 (8.72)	0.370 (7.40)	-0.033 (-28.0)	0.423
	business	1.140 (0.26)	0.347 (9.51)	0.356 (9.50)	-0.036 (-43.4)	0.522
	Return home	0.109 (-4.27)	0.444 (11.3)	0.517 (12.9)	-0.032 (-33.2)	0.431
Poisson Regression Model	commuting	7.18×10^{-6} (21.4)	1.105 (271)	1.106 (306)	-0.050 (-591)	0.493
	leisure/ shopping	4.38×10^{-5} (20.2)	0.921 (233)	1.015 (256)	-0.064 (-593)	0.537
	business	3.66×10^{-6} (21.3)	0.952 (264)	0.938 (265)	-0.052 (-625)	0.589
	Return home	5.56×10^{-6} (24.1)	1.015 (339)	1.075 (332)	-0.055 (-764)	0.537

k: constant, α: trip generation, β: trip attraction, γ: generalized time, *t*: values are in parentheses

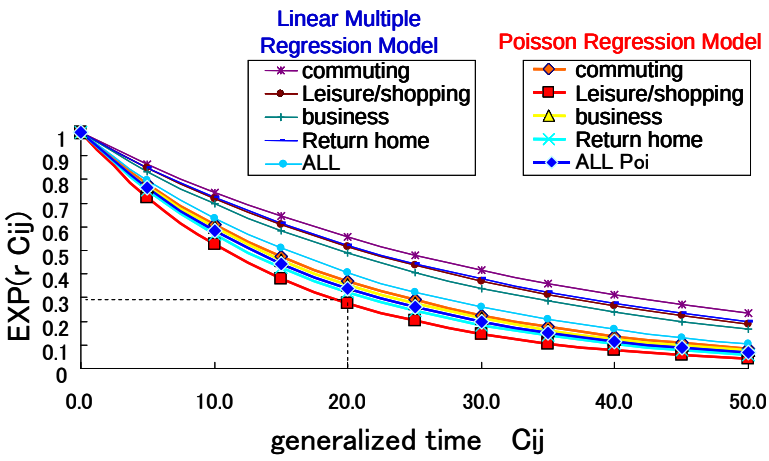

Figure 2. Effect of Travel Cost on Decrease in Traffic Volume

Table 3. Parameter Estimation Result of Trip Distribution (1999 and 2005)

		num.of sample	k	α	β	γ	R^2
commuting	1999	5476	0.718×10^{-5}	1.105	1.016	-0.0496	0.493
	2005	5476	0.957×10^{-5}	1.078	1.004	-0.520	0.447
leisure/ shopping	1999	5476	4.380×10^{-5}	0.921	1.015	-0.0643	0.537
	2005	5476	1.538×10^{-5}	0.998	1.023	-0.0657	0.501
business	1999	5700	3.660×10^{-5}	0.952	0.938	-0.0517	0.589
	2005	5550	5.696×10^{-5}	0.914	0.915	-0.0498	0.541
Return home	1999	5476	0.556×10^{-5}	1.015	1.075	-0.0552	0.537
	2005	5476	0.580×10^{-5}	1.013	1.068	-0.0573	0.523

Note: k: constant, α: trip generation, β: trip attraction, γ: generalized time

3. Land Use and Economic Sectors

In the previous sections, transportation models were emphasized. In turn, land use (location choice behavior) and economic sectors in our model are described referring to Muto et al (2004 and 2006).

3.1 Firms Behavior

Each firm is defined as per worker, that is, the number of workers in each firm is unity. Each firm in this study is assumed to input land, business trips, and labor, and produce single type commodities (composite commodity) maximizing its profit. The behavior of each firm is denoted as:

$$\pi_i^F \equiv max\ Z_i - R_i A_i - Q_i X_i - wL_i - \sum_{j=1}^{I} p_{ij} n_{ij} / E_i \tag{7}$$

with respect to A_i and X_i

subject to

$$Z_i = mA_i^{\beta_A} X_i^{\beta_X} \qquad (0 < \beta_A + \beta_X < 1) \tag{8}$$

where

Z_i : output of a firm (numeraire good)
R_i : land rent for business use
A_i : input of business land
Q_i : generalized price of business trip
X_i : input of business trip
w : wage rate (exogenous variable)
L_i : labor input (= 1)
p_{ij} : commuting cost between zones i and j
n_{ij} : the number of workers residing in zone j and working in zone i
E_i : the number of workers in zone i
m, β_A, β_X : technological parameters in a firm

In the formulation of the above, households' commuting costs are assumed to be paid by firms. Solving this profit maximization problem, demand functions in a firm for business land and business trip can be obtained as;

$$A_i = \left[\frac{m\beta_A}{R_i} \left(\frac{\beta_X}{\beta_A} \right)^{\beta_X} \left(\frac{R_i}{Q_i} \right)^{\beta_\alpha} \right]^{\frac{1}{1-\beta_A-\beta_X}} \tag{9}$$

$$X_i = \left[\frac{m\beta_X}{Q_i} \left(\frac{\beta_A}{\beta_X} \right)^{\beta_A} \left(\frac{Q_i}{R_i} \right)^{\beta_A} \right]^{\frac{1}{1-\beta_A-\beta_X}} \tag{10}$$

These factor demand functions are substituted into the firm's profit yielding the following profit function:

$$\pi^F_i = m \left[\frac{m\beta_A}{R_i} \left(\frac{\beta_X}{\beta_A} \right)^{\beta_X} \left(\frac{R_i}{Q_i} \right)^{\beta_\alpha} \right]^{\frac{\beta_A}{1-\beta_A-\beta_X}} \left[\frac{m\beta_X}{Q_i} \left(\frac{\beta_A}{\beta_X} \right)^{\beta_A} \left(\frac{Q_i}{R_i} \right)^{\beta_A} \right]^{\frac{\beta_X}{1-\beta_A-\beta_X}}$$

$$- R_i \left[\frac{m\beta_A}{R_i} \left(\frac{\beta_X}{\beta_A} \right)^{\beta_X} \left(\frac{R_i}{Q_i} \right)^{\beta_\alpha} \right]^{\frac{1}{1-\beta_A-\beta_X}} - Q_i \left[\frac{m\beta_X}{Q_i} \left(\frac{\beta_A}{\beta_X} \right)^{\beta_A} \left(\frac{Q_i}{R_i} \right)^{\beta_A} \right]^{\frac{1}{1-\beta_A-\beta_X}} - wL_i - \sum_{j=1}^{I} n_{ij} p_{ij} / E_i$$

(11)

Subsequently the firm's location choice probability for zone *i* is obtained by applying the Logit model.

$$P_i^F = \frac{exp\theta^F g_i^F \pi_i^F}{\sum_{k=1}^{I} exp\theta^F g_k^F \pi_k^F} \tag{12}$$

where

P^F_i : location choice probability of a firm for zone *i*

θ^F : Logit parameter in firm's location choice behavior

g_i^F : adjustment parameter (the number of workers in zone *i* is applied to this parameter.)

π^F_i : maximized profit in a firm in zone *i*

3.2 Households Behavior

Households are assumed to be holding the utility maximization behavior. Thus household behavior is specified as;

$$v_i^H \equiv max \;\; z_i^{\alpha_z} a_i^{\alpha_a} x_i^{\alpha_x} f_i^{\alpha_s} \qquad (\alpha_z + \alpha_a + \alpha_x + \alpha_f = 1)$$
$$with\ respect\ to\ z_i, a_i, x_i, f_i \tag{13}$$
$$subject\ to$$

$$z_i + r_i a_i + q_i x_i + w f_i = w \left[T - \sum_{j=1}^{I} n_{ij} t_{ij} / N_i \right] + y_i \tag{14}$$

where

z_i : consumption of composite goods by a household in zone *i* (numeraire good)
a_i : area size of land used by a household in zone *i*
x_i : household trip per capita in zone *i*
f_i : leisure time of a household in zone *i*
r_i : land rent for residence in zone *i*
q_i : generalized price of a household trip in zone *i*
w : wage rate (exogenous variable)
T : total time available of a household
y_i : dividend from firms to a household in zone *i*
n_{ij} : the number of households residing in zone *i* and working in zone *j*
t_{ij} : commuting time between zones *i* and *j*
N_i : the number of households in zone *i*

Solving this utility maximization problem, the following demand functions for a household are derived,

$$z_i = \alpha_z [w(T - \sum_{j=1}^{I} n_{ij} t_{ij} / N_i) + y_i] \tag{15}$$

$$a_i = \alpha_a [w(T - \sum_{j=1}^{I} n_{ij} t_{ij} / N_i) + y_i] / r_i \tag{16}$$

$$x_i = \alpha_x [w(T - \sum_{j=1}^{I} n_{ij} t_{ij} / N_i) + y_i] / q_i \tag{17}$$

$$f_i = \alpha_f [w(T - \sum_{j=1}^{I} n_{ij} t_{ij} / N_i) + y_i] / w \tag{18}$$

Substituting these demand functions into the utility function, the indirect utility function of a household is obtained,

$$v_i^H = \alpha_z^{\alpha_z} \left[\frac{\alpha_a}{r_i}\right]^{\alpha_a} \left[\frac{\alpha_x}{q_i}\right]^{\alpha_x} \left[\frac{\alpha_f}{w}\right]^{\alpha_f} [w(T - \sum_{j=1}^{I} n_{ij} t_{ij} / N_i) + y_i] \tag{19}$$

Finally household's location choice probability for zone *i* is calculated by applying the Logit model,

$$P_i^H = \frac{exp\theta^H g_i^H v_i^H}{\sum_{k=1}^{I} exp\theta^H g_k^H v_k^H} \tag{20}$$

where

P_i^H : household location choice probability for zone *i*

θ^H : Logit parameter in household location choice behavior

g_i^H : adjustment parameter (the number of households in zone *i* is applied to this parameter)

v_i^H : indirect utility function in zone *i*

3.3. Equilibrium Conditions

In the economic sectors mentioned above, we consider only the land market to be equilibrated fixing the commodity price and wage rate. The reason is that the size of the study area is small, so deriving full equilibrium model seemed unrealistic. Extension of the present model into a full equilibrium model is left as an important issue in the future studies. Thus the equilibrium conditions in the land markets are specified as follows:

$$\text{residential areas}: \quad a_i^S = N_i a_i \tag{21}$$

$$\text{business areas}: \quad A_i^S = E_i A_i \tag{22}$$

where

a_i^S : supply of residential area in zone *i* (fixed)

A_i^S : supply of business area in zone *i* (fixed)

The equilibrium demand for land in each zone is obtained through finding land rents which clear the conditions (21) and (22) by the Walras algorithm.

3.4. Parameters in Firms

Parameters in firms and households must be estimated for the empirical study. However available data for parameter estimation is quite limited even in advanced country, since the area size of each zone is very small. So the IO table becomes the most significant data source in parameter calibration.

In this subsection, first, let us explain parameters in firms. Equation (8) shows the technology of a firm being specified as a Cobb-Douglas production function with homogenous degree less than unity. One can add other production factors to equation (8) to transform it with homogenous degree of unity.

$$Z_i = mA_i^{\beta_A} X_i^{\beta_X} L_i^{\beta_L} K_i^{\beta_K} \qquad (\beta_A + \beta_X + \beta_L + \beta_K = 1) \tag{23}$$

where

L_i : labor input of a firm in zone i (= 1)

K_i : input of other production factor in a firm in zone i

Euler's identity yields;

$$Z_i = \frac{\partial Z_i}{\partial A_i} A_i + \frac{\partial Z_i}{\partial X_i} X_i + \frac{\partial Z_i}{\partial L_i} L_i + \frac{\partial Z_i}{\partial K_i} K_i \tag{24}$$

When the firm behaves to maximize its profit, the marginal productivity principle holds leading to;

$$PZ_i = P(\beta_A Z_i + \beta_X Z_i + \beta_L Z_i + \beta_K Z_i) = R_i A_i + Q_i X_i + wL_i + \eta_i K_i \tag{25}$$

where

η_i : price of other production factor

P: price of composite good

The parameters, therefore, in the production function are obtained as follows:

$$\beta_A = R_i A_i / PZ_i \quad \text{and} \quad \beta_X = Q_i X_i / PZ_i \tag{26}$$

Assuming that w, L_i, η_i, and K_i are fixed, the efficiency parameter is calculated as follows:

$$m = Z_i / (A_i^{\beta_A} X_i^{\beta_X}) \tag{27}$$

These parameters are estimated by employing Aichi prefecture's IO table as presented in Table 4. Finally, the Logit parameter in firm's location probability is estimated by the maximum likelihood method,

$$\theta^F = 3.740 \times 10^{-9}, \ t = 61.4, \ R^2 = 0.854 \tag{28}$$

Here the correlation coefficient R^2 is derived from the regression analysis between the actual number of workers and the estimated one obtained by the Logit model.

Table 4. Parameters in Production Function

efficiency parameter m	elasticity parameter β_A	elasticity parameter β_X
19818.465	0.016	0.086

3.5 Parameters in Households

Transforming equations (15) to (18) yields;

$$\alpha_z = 1 \cdot z_i / [w(T - \sum_{j=1}^{I} n_{ij} t_{ij} / N_i) + y_i] \tag{29}$$

$$\alpha_a = r_i a_i / [w(T - \sum_{j=1}^{I} n_{ij} t_{ij} / N_i) + y_i] \tag{30}$$

$$\alpha_x = q_i x_i / [w(T - \sum_{j=1}^{I} n_{ij} t_{ij} / N_i) + y_i] \tag{31}$$

$$\alpha_f = w f_i / [w(T - \sum_{j=1}^{I} n_{ij} t_{ij} / N_i) + y_i] \tag{32}$$

The right hand sides in equations (29) to (32) are observable, thus one can calculate the parameters in household utility function by employing Aichi prefecture's IO table. The calibration results are shown in Table 5.

Same as in the firm's behavior, the Logit parameter in household location choice probability is estimated by the maximum likelihood method.

$$\theta^H = 2.345\times10^{-7},\ \ t = 22.6,\ \ R^2 = 0.988 \tag{33}$$

Here the correlation coefficient is derived from the regression analysis between the actual number of population and the estimated one obtained by the Logit model.

Table 5. Parameters in Household Utility Function

composite good α_z	land α_a	trip α_x	Leisure α_f
0.325	0.086	0.021	0.568

4. Evaluation of Road Network Improvement

4.1. Road Network Improvement Scenarios

Three scenarios are set up for the estimation of the benefit of road network improvement in the study area. Three scenarios assume that the network improvements are implemented gradually. They include road construction in national expressways, inter-regional highways, and a harbor road. Table 6 and Figures 3 to 5 illustrate the outlines of these scenarios.

4.2. Result of Transport User's Surplus Evaluation

In this paper, the total travelers' surplus of 40 years after the improvement of road networks derived from the transport demand forecasting is evaluated. The total generalized cost and time in each scenario is calculated. Then, the benefit in transport and total surplus is calculated. The evaluation results in using two census data are showed in Figure 6. It is indicated that as the road networks are improved to higher level, the benefit will increase. But the marginal efficiency declines as the road network improvement proceeds to the final stage.

Table 6. Outline of Road Network Development Scenarios

	Scenario 1	Scenario 2	Scenario 3
national expressway	Construction of new Tomei expressway	Extension of new Tomei expressway	Extension of San-En-Nanshin Expressway
inter-regional highway	Extension of Road 23	Increase in lanes of Road 259	Increase in lanes of Road 23
harbor road	-	Construction of Mikawa harbor road	Increase in lanes of Mikawa harbor road
number of link	2083	2124	2145
number of node	1406	1431	1442

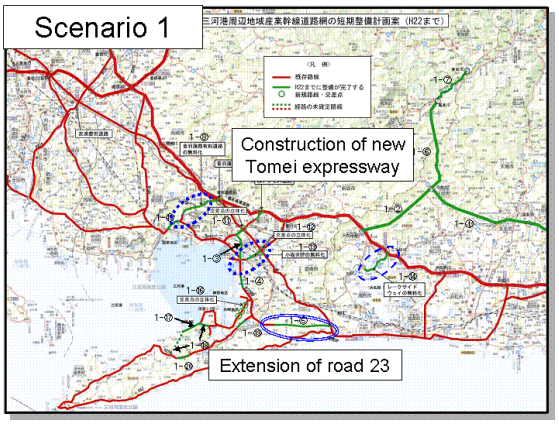

Figure 3. Overview of Scenario 1

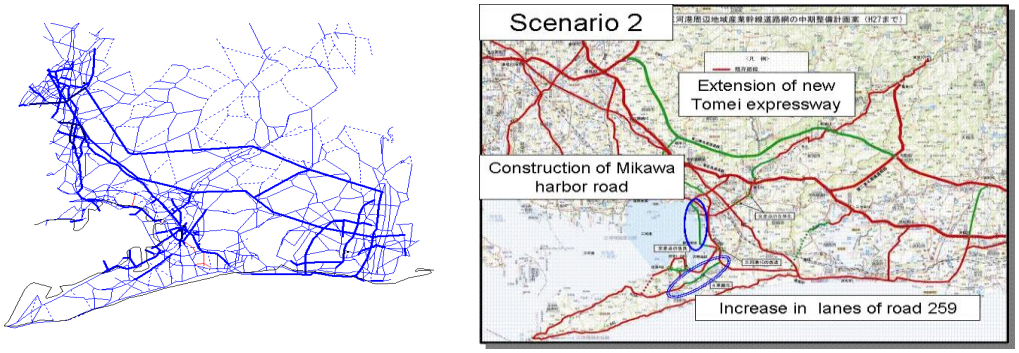

Figure 4. Overview of Scenario 2

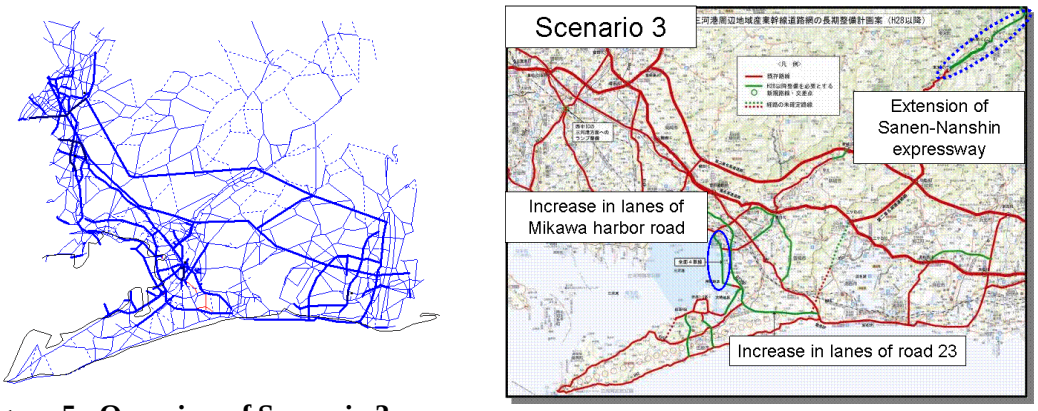

Figure 5. Overview of Scenario 3

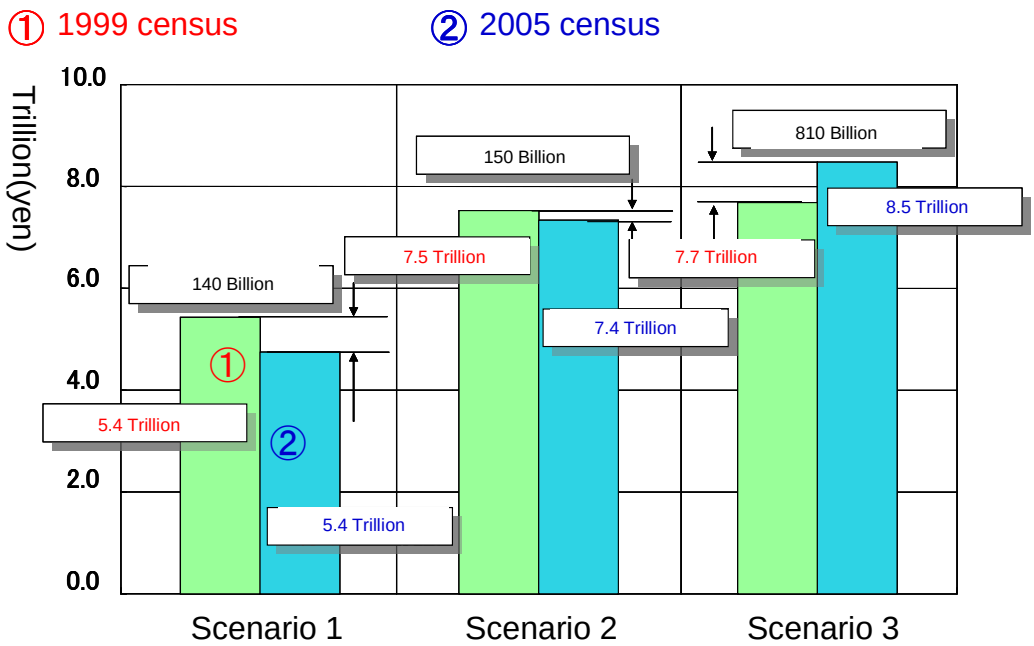

Figure 6. Change in Transport Surplus

4.3 Estimating the Economic Benefit by Zone

In turn, the study is ready to present the economic benefit by zone under the three scenarios. The economic benefit in each zone is defined by the equivalent variation (EV) plus land rent

paid to absentee landowners. EV is defined as an income to compensate a change in household indirect utility, and it can be specified as follows:

$$v_i^H(r_i^A, q_i^A, y_i^A + ZCEV_i) = v_i^H(r_i^B, q_i^B, y_i^B) \tag{34}$$

where

v_i^H : household indirect utility function

A, B : indices expressing the states before and after a project, respectively

$ZCEV_i$: EV per capita in zone i

Since EV by zone is defined for a household, the benefit in each zone is obtained by multiplying the number of population in each zone by EV. Households change their residential places according to a change of transport networks in this model. Thus the benefit by zone differs depending on the number of population before or after a project. Therefore, if one takes the number of households before a project, a change in the number of households after the project is not taken into account at all. Conversely, if one takes the number of households after the project, the benefit may be overestimated or underestimated. To avoid this ambiguity, consideration of migration during the road construction is rational. Therefore we derive the benefit of a project as follows:

$$ZSNB_i = \oint_{A \to B} [N_i(\tau) dZSNB_i(\tau) + d\pi_i^L(\tau)] \tag{35}$$

Formula (35) is expressed by line integral from the state without the project, A, to the state with the project, B. This line integral depends on the process of road construction, however, we assume that the roads are constructed being proportional to time. Thus an approximation of the integral (34) may be written as follows:

$$ZSNB_i = N_i(A)ZCEV_i + \frac{1}{2}(N_i(B) - N_i(A))ZCEV_i + \Delta\pi_i^L \tag{36}$$

where

$N_i(A)$ and $N_i(B)$: the numbers of households before and after the project, respectively

This study employs formula (36) as definitions of the social benefit of the road construction in zone i. Following formula (36), the calculation results of the benefit by zone in Scenarios 1 to 3 are graphically illustrated in Figures 7 to 9.

First of all, the total annual benefits in the three scenarios are estimated as 722 billion yen in Scenario 1, 1,133 billion yen in Scenario 2, and finally 1,602 billion yen in Scenario 3 with census 1999 data as presented in Table 7. On the other hand, they are 1,858 billion yen in Scenario 1, 4,100 billion yen in Scenario 2, and finally 5,700 billion yen in Scenario 3 with census 2005 data. As compared with the GRP in this region, it is estimated as about 8 trillion yen resulting in the fact that the impact ratios are 4.77%, 6.23%, and 6.69%, respectively. Taking into account that the environmental damage in GDP in Japan is estimated 1.5% to 2%, thus it can be said that this project has relatively higher efficiency. Calculating the benefit during 40 years with the social discount rate of 4%, it is 5,423 billion yen in Scenario 1, 7,510 billion yen in Scenario 2, and 7,690 billion yen in Scenario 3 with census 1999 data. They are 5,260 billion yen in Scenario 1, 7,360 billion yen in Scenario 2, and 8,500 billion yen in Scenario 3 with census 2005 data. Comparing these values with the saving of generalized costs is shown in Figure 6, the equilibrium benefits are more than double of the saved costs in the three scenarios in the calculation with census 2005.Moving back to benefit in each zone, benefits of the new Tomei expressway, which connects Tokyo and Nagoya, the bypath of national road 23 and Mikawa harbor road, which connect the east and west regions in Toyohashi, and San-En-Nanshin road, which connects the south area in Nagano prefecture and Toyohashi, are significant as shown in Figures 7 to 9.

Table 7. Results of economic impacts evaluation of road network improvement

scenario	data	annual benefits(yen)	total annual benefit in 40 years(yen)
scenario 1	census 1999	722 billion	5,423 billion
	census 2005	1,858 billion	5,260 billion
scenario 2	census 1999	1,133 billion	7,510 billion
	census 2005	4,100 billion	7,360 billion
scenario 3	census 1999	1,602 billion	7,690 billion
	census 2005	5,700 billion	8,500 billion

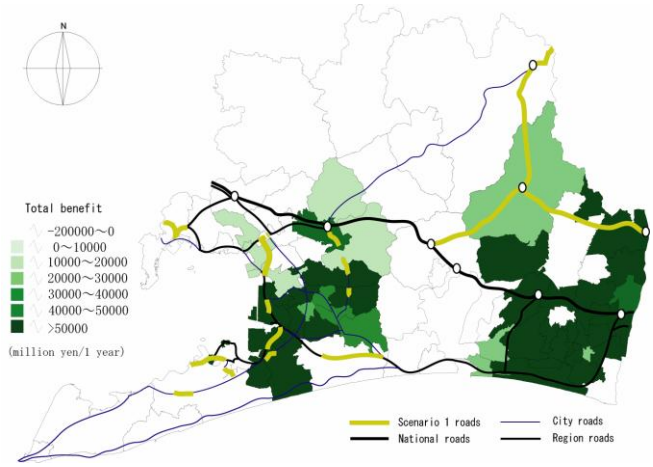

Figure 7. Economic Benefit in Scenario 1

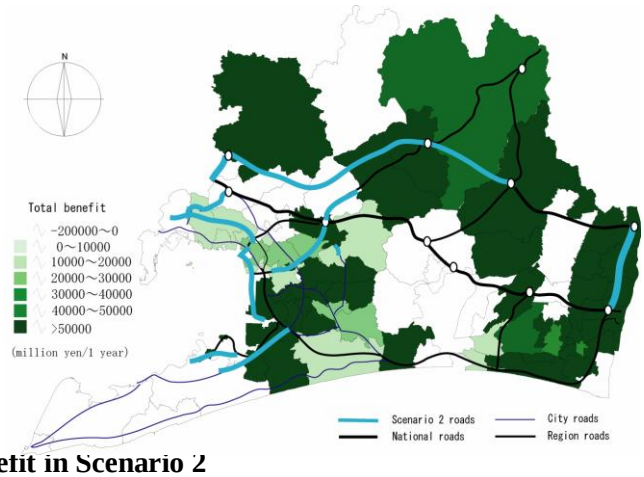

Figure 8. Economic Benefit in Scenario 2

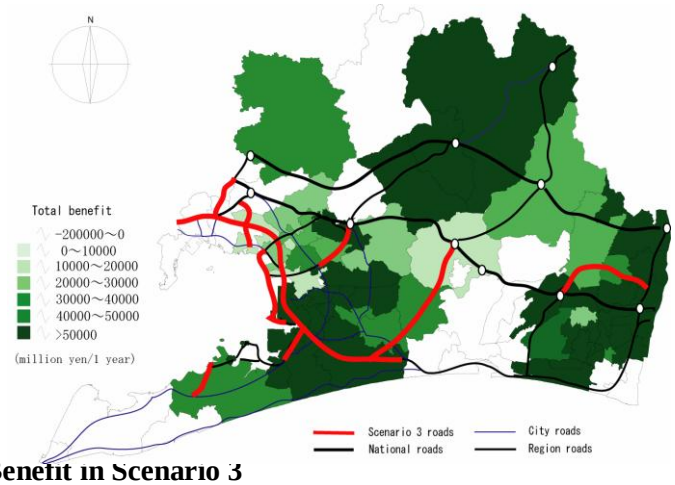

Figure 9. Economic Benefit in Scenario 3

5. Concluding Remarks

In this article, we have developed an integrated transportation and economic model for San-En region in Japan, and measured the economic impacts of road network improvement by zone based on the equivalent variation. From the evaluation results, even countryside in the study area has shown a possibility of future growth, if those zones would be linked to newly constructed roads.

Similar models have already been developed by other researchers, but the present model deals with much more complex road networks being appreciated as the first attempt for small zones' transportation, land use, and economy as far as the authors know. The evaluation method proposed in this study can be applied to the appraisal of new infrastructure development which has a great impact on the region. The advantage is that the benefit in each zone is estimated and the results can be referred to secure equality in decision making process. However the market under consideration is only land rental market excepting commodity and labor markets. Thus area worth examining in the future is to consider internalization of these markets.

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