ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia - Social and Behavioral Sciences 43 (2012) 384 – 398

Procedia
Social and Behavioral Sciences

8th International Conference on Traffic and Transportation Studies
Changsha, China, August 1–3, 2012

A Development of Dynamic Road Network Planning Model Considering Step-by-step Construction of Links and Facility on Nodes

Toshinari Kozasa[a,*], Makoto Tsukai[b], Akimasa Fujiwara[c]

[a] *Hiroshima University 5-1 Noborimachi Naka-ku Hiroshima city, Japan*
[b] *Hiroshima University 1-4-1 Kagamiyama Higashi-hiroshima city, Japan*
[c] *Hiroshima University 1-5-1 Kagamiyama Higashi-hiroshima city, Japan*

Abstract

In Japan, regional road network improvement project is evaluated by cost-benefit analysis. However, the conventional evaluation procedure would be inappropriate in case of step-by-step improvement in each link, due to its planning term over several decades. Moreover, some of facilities supposed to be trip destinations would be added or removed from the nodes during the planning term, which would influence on accessibilities of each node. This study proposes an integrated project evaluation model with improvement of links and facility-location on nodes. The proposed model enables a consistent evaluation to fulfill the accessibility requirement for the whole nodes, considering the order of each project.

Keywords: accessibility; dynamic programming; network externality

1. Introduction

In Japan, a guideline in “Cost-Benefit Analysis (CBA) Manual” or “Objective Evaluation Indicators” provided by the Ministry of Land, Infrastructure and Transport (MLIT; 1998, 2008) has officially been

* Corresponding author. Tel.: +81-82-502-8801 ; Fax: +81-82-502-8815 .
E-mail address: kozasa@fukuyamaconsul.co.jp

doi:10.1016/j.sbspro.2012.04.112

used to evaluate a transportation network improvement project. A standard shortcut procedure in CBA first calculates the increment of benefit between unimproved and fully improved network, then considers the cost of whole projects by subtracting from the benefit: a net benefit, or by dividing benefit with cost: a cost-benefit ratio (2003). The short cut method is useful in practical application, however, the project evaluation procedure based on economic approach has been improved in order to give more information of project benefit required in regional transportation planning.

Morisugi and Ohno (1995) proposed a benefit incidence table (BIT) which decomposes a whole benefit into item-wise benefit with each economic entity under the state of project completion. After BIT proposed, project evaluation standard in Japan has been developed, then the CBA manual by MILT is updated. Spatial Computable General Equilibrium (SCGE) is an approach in which can clarify the regions and sectors of benefit. Bröcker et al. (2010) evaluated the benefits in Trans-European Transport Network (TEN-T), based on SCGE. They concluded that most of the projects will not make net benefits over the cost allocated countries. While the application of economic evaluation increase, Jorgea, and de Rus (2004) claimed a problem of BIT when environmental impacts are assessed, from the viewpoint of difficulties in setting a system boundary. The boundary problem in SCGE also appears as the spatial and temporal ranges of project influence (Damart and Roy, 2009), and especially the temporal boundary such as long term project horizon and annual or step-by-step benefit flow during the project period cannot be dealt in conventional economic evaluation. Lakshmanann (2010) summarized these difficulties as following: spatial mobility and temporal changes in the factors (e.g. population or industry agglomeration) given in the model. Moreover, a cause-effect problem among the project between land use and agglomerations of economic activities or population would occur, since it takes several decades to finish all the transportation improvement projects on a target network.

A fundamental purpose in regional road network improvement is to increase regional accessibility to the facilities related to daily-life activities. There are two crucial factors to influence on accessibility: travel time and location of facility to be a trip destination. It is worth considering of facility location project used as the destination of trip within regional transportation network planning. Facility location model is developed in Operations Research (e.g., Drezner and Hamacher, 2001), and then it is applied for the location planning for public facilities used such as hospitals, school or municipal branch office. Starting from a simple set covering problem with fixed location cost and uncapacitated facility, the models has been mainly developed in Supply Chain Management (SCM) for applied problems as demand responded cost (Averbach *et al.*, 2007), stochastic demand in injured patient required “triage”(Syam, 2008), or freight delivery in supply chain with inventory (Hinojisa et al., 2008; Gebennini et. al, 2009). Arabani and Farahani (2012) summarized recent developments of facility location models employing the dynamic characteristics of design variables. They pointed out that long term dynamics or the integration of spatial network planning would become an important issue in this research field, instead of the short term dynamics appeared in SCM as one of conventional mainstreams. For example, the long term dynamism is discussed by Canel *et al.* (2001). They proposed a dynamic facility location model with multi-commodity which introduces the possibility of facility removal during design period.

Similar to the above discussions in facility location model, one of important but remaining issues in CBA is dynamic evaluation over the whole period of projects in actual space. Since the improvement of pieces of network will proceed in step-by-step, the order of improvements will significantly influence on accessibility of the neighbor. Such the effect is known as (physical) network externality. In terms of dynamic transportation network planning (without facility location) considering network externality, Peterson (2001, 2002) formulated the network improvement project under the dynamic programming problem (DP). He showed that the best project evaluated by conventional procedure assuming a static network condition does not coincide with the one under the dynamic condition. Also in Aoyama *et al.* (2002) and Matsunaka *et al.* (2005), a sensitivity analysis of a dynamic evaluation procedure taking account of the capital rent showed that the projects not adopted in step-by-step evaluation for each sub-project would be preferable. In summary, integration of regional road network planning with facility location problem would give a higher benefit to the users (inhabitants) of network. Corresponding to practical needs, a novel planning model which can deal with network externality caused by link and node interaction and their change in attributes should be formulated to enable dynamic project selection from multiple project candidates for the links and nodes.

This study attempts to propose an integrated model of dynamic link construction and facility location on the nodes of road network. The proposed model can consider the dynamic benefit generation not only from the decreasing the transportation cost (i.e. link improvement or construction) but from the improved potential or attractiveness of nodes (i.e. facility location). Since the integrated model is a dynamic integer problem, we adopt a genetic algorithm (GA) to find a feasible solution under the various constraints, which has advantages in terms of its flexible setting of constraints. Total budget of the projects and the minimal level of accessibility are subjected as the constraints to our model discussed in the rest of this paper.

Note that an idea to integrate traffic flow design with facility location planning was already proposed by Drezner and Wesolowsky (2003), but their problem setting is limited in tree shape network. Horner and Groves (2007) proposed a model about the park-and-ride facility location to maximize the catchment of traffic flow by facility location, following to daily-based demand. Within our reviews, an originality of our model is to integrate the network externality occurred in step-by-step link improvements with facility location in long term planning period, and simultaneously to design the project order (e.g. link improvement and facility location). In section 2 and 3, we formulate a dynamic road network planning model with GA solution procedure and make a simulation analysis in model performance.

2. Dynamic road network planning model

2.1. Objective function and constraints

In this study, we consider a dynamic network investment problem to increase regional accessibility. The investment targets are both of the links on road network and the facilities located at the nodes. Hereafter, the candidates of investment are called "project". Since the investment to each project requires time period to complete, net present value (NPV) of a set of executed projects would depend on the order of the project adoption. The objective function of the model is NPV of all the adopted projects with their order. As to maximize the objective function, the optimal sequence of project adoption is determined. Also, in our model, annual budget and the minimal level of accessibilities of each node at the end of whole project period are set as constraints.

$$\max_{\boldsymbol{\delta}} \ \mathrm{Y} = \sum_t \frac{1}{(1+r)^{t-1}} \left(B(\mathbf{X}_t) - C_t(\boldsymbol{\delta}) \right) \tag{1}$$

$$\text{s.t.} \ \ \boldsymbol{\delta} \in \{0,1\}, \ \forall t, \forall p \tag{2}$$

$$\sum_p \delta_p C_p \le C^* \tag{3}$$

$$C_t(\boldsymbol{\delta}) = \sum_p \delta_{pt} C_{pt} \le C_t^*, \ \ \forall t \tag{4}$$

$$\overline{T}_q^{te} = \frac{1}{N_q} \sum_{i \in M_q} (N_i T_{iq}^{te}) \le T_q^*, \forall q \tag{5a}$$

$$\overline{T}_h^{te} = \frac{1}{N_h} \sum_{i \in M_h} (N_i T_{ih}^{te}) \le T_h^*, \forall h \tag{5b}$$

where Y is a Net Present Value (NPV) of regional traffic. Subscript p and t are project type and its period, respectively. r is a social discount rate assumed to be 4%. δ_{pt} indicates a project adoption dummy for project p at period t, as adopted (=1) or not adopted (=0), and δ=(…, δ_{pt} ,…) is a vector of project adoptions (design variables). X=(…, X_a^t ,…) and $B(X_t)$ is the vector of link traffic at t : X_a^t , and annual benefit defined as a function of X_t , respectively. $C_t(\delta)$, C_p and C_{pt} are annual cost of the adopted projects, whole cost of each project, and annual cost for each project, respectively. Eq. (2) is integer constraints in design variables. Eq. (3) indicates total budget constraint denoted by C^*. Eq. (4) describes the annual budget constraint, denoted by C_t^*. Subscripts i and j indicate zones, and T_{ij}^{te} is travel time to the facilities between i and j at te, te is the initial year in service of last project, the project evaluation period that is set to be 50 years from the initial year in service of first project. Eqs. (5a) and (5b) are average accessibility constraints. In eq.(5a), q is a representative zone of local government q, M_q is a set of zones belong to local government q, $N_q=\sum_{i\in M_q} N_i$ is the population of local governments q. N_i is the population of zone i. $\overline{T}_q^{te}$ is a weighted average travel time of local government q by the zonal population at te, and T_q^* is the maximal constraint in local government access time. In eq.(5b), M_h is a set of zones within the Voronoi area from emergency hospital h, $N_h=\sum_{i\in M_h} N_i$ is the population of Voronoi area of h. $\overline{T}_h^{te}$ is a weighted average travel time of emergency hospital h by the zonal population N_i at te, and T_h^* is the maximal constraint in hospital access time.

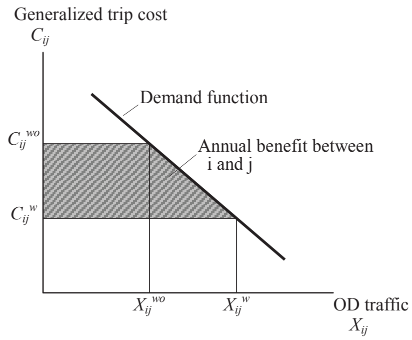

Fig.1. Consumer surplus setting in this study

2.2. Benefit, cost and projects

The annual benefit $B(X_t)$ is the consumer surplus in each year calculated by eqs. (6a) and (6b), as the approximated trapezoid area in Fig. 1.

$$B(\mathbf{X}_t) = B(\mathbf{X}_t^w) - B(\mathbf{X}_t^{wo}) \tag{6a}$$

$$= \sum_i \sum_j \left\{ \frac{1}{2} \left(\mathbf{X}_{ij}^{t,wo} + \mathbf{X}_{ij}^{t,w} \right) \left(C_{ij}^{t,wo} - C_{ij}^{t,w} \right) \right\}$$

$$C_{ij}^t = T_{ij}^t \cdot \omega \tag{6b}$$

$$X_{ij}^t = c \frac{G_i^t A_j^t}{T_{ij}^t} \tag{7}$$

where X_t^w and X_t^{wo} are a vector of link traffic with the adopted projects and that with no projects, respectively. C_{ij} is the generalized trip cost between OD i and j, and ω is a value of time parameter. OD traffic X_{ij}^t is a function of trip generation, attraction potentials and OD travel time T_{ij}^t. X_{ij}^t is calculated by

Eq. (7). Therefore, the annual benefit $B(X_t)$ is a function of OD traffic X_{ij}^t and generalized trip cost C_{ij}.

Trip generation and attraction potentials are modeled as in eqs. (8a) and (8b), respectively.

$$G_i^t = \sum_k \lambda_k V_{i,k}^t \tag{8a}$$

$$A_j^t = \sum_{k'} \gamma_{k'} W_{j,k'}^t \tag{8b}$$

where G_i^t and A_j^t are potentials of trip generation and attraction, in i and j at t, respectively. $V_{i,k}^t$ and $W_{i,k'}^t$ are k and k'th attribute variable of facility locations i and j at t, respectively. λ, γ and c are unknown parameters, respectively.

OD travel time T_{ij}^t is calculated by a sum of travel time of the links on its shortest path, therefore it is a function of link travel time vector t=(…, t_a ,…), as T_{ij}^t= $T_{ij}^t(t)$. Since the OD traffic x_{ij}^t is assigned to each link under the user equilibrium in our model, an improvement of link would potentially shorten the travel time of several ODs due to the shift of traffic from congested path to less congested one. The link performance function is in eq.(9). Note that time index t is dropped for simplicity.

$$t_a(x_a) = t_{a0} \cdot \left\{ 1 + \alpha \cdot \left(\frac{x_a}{c_a} \right)^{\beta} \right\} \tag{9}$$

where t_{a0}, x_a and c_a are free flow travel time, traffic volume, traffic capacity of link a, respectively, and α and β are parameters, respectively.

In proposed model, the adopted projects affect their attribute variables of related nodes: facility location, $V_{i,k}^t$ and/or $W_{j,k'}^t$ in eqs. (8a) and (8b). On the other hand, the projects related to link: road improvement projects influence on both t_{a0} and c_a, in eq.(9). For example, increase of regulated velocity by an improvement in longitudinal road shape will decrease t_{a0}, while the expansion of link width will increase c_a. By through these variables, the effect of investment will appear in NPV.

2.3. Annual project cost

In our model, we assumes that the total project cost C_p is constantly allocated during its investment period τ_p , and that τ_p is a nonlinear function of total project C_p , as shown in Eqs. (10) and (11), respectively.

$$\tau_p = \rho(\ln(C_p))^{\mu} \tag{10}$$

$$C_{pt} = C_p / \tau_p \tag{11}$$

where ρ and μ are positive parameters, respectively. Eq.(10) indicates that the marginal increase of project period will decrease to C_p.

2.4. Optimization procedure

The difficulty in DP is on its large and complex solution space due to huge number of project combinations, and of constraints in the real project evaluation. Such the optimization problem is called as NP-hard, that is, hard to solve in the polynomial evaluation period to the number of variables. In order to solve the problem, reformulation of the original problem with its solution space into the dual problem with real space, known as Lagrangean relaxation is often applied. Another approach for NP-hard problem is to find a feasible but approximated optimal solution, which is often applied due to its practical usefulness. In conventional DP, a genetic algorithm which can find a feasible but approximated optimal solution is often used due to its practical usefulness. Consequently we also adopt GA optimization to our model. The gene indicates the sequence of adoption order in all the roads and facilities.

All the individuals are evaluated by eq.(1), and all of them meet the constraints in eqs. (3), (4), (5a) and (5b). The genes to fulfill the constraints are built by following steps, referring to CBA cost allocation and to mimic an actual budget financing procedure. At first, the genes to fulfill total project budget in eq.(3) is generated with its launching order. Following the project order, annual cost of each project is summed up to the annual budget constraint in eq.(4). When the surplus of annual cost over the annual budget appears, it is carried over to the next year, and then the check in surplus is repeated for all the projects. This procedure meets the condition that the earlier launched project will always finish earlier than the late ones. Moreover in this procedure, multiple projects can be launched if each of annual project cost is less than annual budget, otherwise only one project is started in the year. The initial year in service of project is set to be the next year of its completion, basically. The exceptional treatment in initial year of service is made when the preceding project is not finished until the year of completion of following project (i.e., the following project is finished earlier than the preceding one), the initial service year of the following project is postponed until the completion of the preceding project.

Note that the initial year in service of project would be earlier if the annual cost allocation order is changed, while it requires further optimization for the dynamic knapsack problem of cost allocation. For simplicity, we apply the above procedure in cost allocation to our model. In this procedure, some of gene would include the project order that will not finished within the evaluation term, but such the genes will be dropped due to its low NPV over the evaluation period.

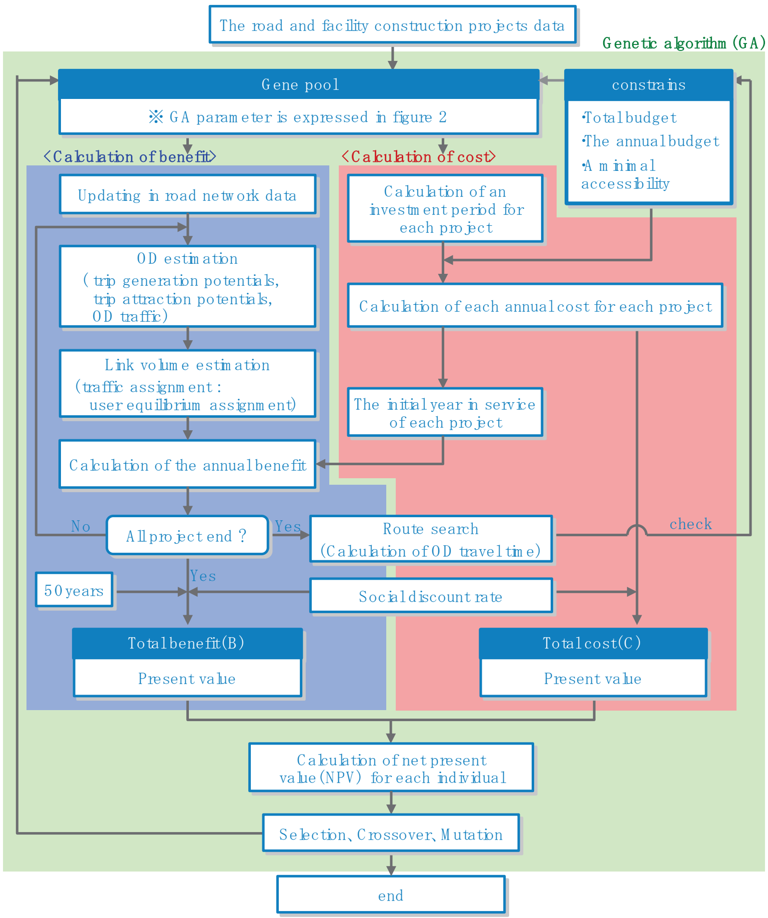

Fig. 2. Flowchart of genetic algorithm

Figure 2 shows a flowchart of genetic algorithm in this study. Fig. 3 shows the settings of gene in individual i. Where, the number of individuals (a set of construction order) is 10. Using the characteristics in traffic potentials which are a function of destination facilities, OD traffic is firstly calculated. Then the link traffic is calculated by assuming user equilibrium assignment theory under the link performance functions which parameters depends on the characteristics of link improvement. The traffic assignment procedure outputs the travel time in each OD, then NPV are calculated. After selecting individual genes which eliminates the lower evaluation index and/or the violation of the constraint in accessibility in eqs.(5a) and (5b), the individuals are multiplied to update the generation. When the N times of generation updating is finished, the individual that have the highest NPV is found to be an optimal solution for adopted projects with its construction order.

3. Simulation cases

We conduct a simulation analysis on a simplified network given in Fig. 4 is demonstrated as an empirical case in order to clarify the model performance.

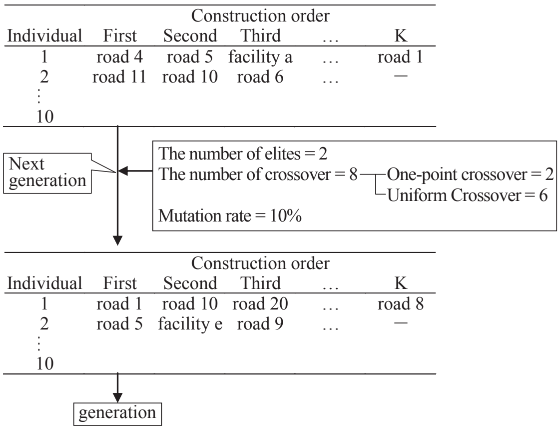

Fig. 3. Parameter setting in GA

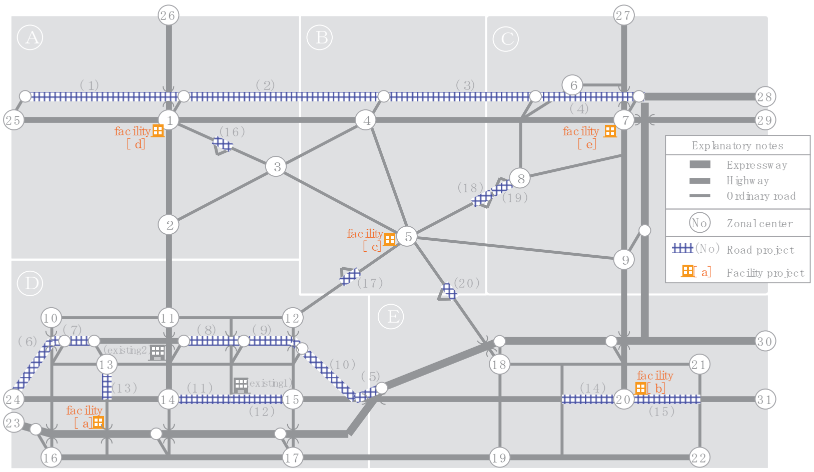

Fig. 4. Hypothetical network in a region

Table 1. Facility location projects

Facility	Project (p)	Hospital bed capacity (Vi、Wj)	Project cost (Cp)
General hospital	Existing 01	500 beds	-
	Existing 02	200 beds	-
	a	500 beds	5 billion yen
	b	500 beds	5 billion yen
	c	500 beds	5 billion yen
	d	500 beds	5 billion yen
	e	500 beds	5 billion yen

Table 2. Road improvement projects

Road	Project (p)	Length (km)	Construction summary				Project cost (billion yen) (Cp)
			Before construction		After construction		
			Regulation speed	The number of traffic lanes	Regulation speed	The number of traffic lanes	
Expressway	01	13.6	Non-construction	Non-construction	70	2	70
	02	17.2	-	-	70	2	90
	03	13.4	-	-	70	2	65
	04	8.4	-	-	70	2	40
(IC access)	05	1.4	-	-	50	2	5
Bypass	06	6.2	-	-	50	4	40
	07	4.5	-	-	50	4	25
	08	5.1	-	-	50	4	30
	09	5.2	-	-	50	4	30
	10	7.7	-	-	50	4	45
Widening	11	5.0	50	2	50	4	25
	12	5.0	50	2	50	4	25
	13	3.0	40	2	40	4	15
	14	5.0	50	2	50	4	25
	15	6.1	50	2	50	4	30
Linear improvement	16	1.7	30	1	40	2	5
	17	1.5	30	1	50	2	5
	18	1.8	40	2	50	2	5
	19	1.9	40	2	50	2	5
	20	2.5	30	1	40	2	10

3.1. Project and network settings on the hypothetical network

Candidates of projects are shown in Tables 1 and 2. The facility construction candidates are set to 5 nodes, supposed to be comprehensive hospitals. The hypothetical network consists of 124 links and 31 nodes, and the nodes from no.24 to 31 are representing the areas out of the cordons. Candidates of road construction. projects include various links, namely expressway, bypass, road width extension and longitudinal road shape improvement.

3.2. Outline of case setting

The following two cases are set. The former is to investigate the effectiveness in the proposed dynamic evaluation model. The latter is to examine the effectiveness in simultaneous optimization over the road and facility improvement.

Case 1: Comparison between dynamic and static evaluation

An evaluation procedure in a static network consists of two steps as follows: firstly, a set of projects to have positive NPV is selected. In scenario 1, the benefit on present network with a project and BAU are formulated B(Xtw) , B(Xtwo) in Eq. (5), respectively, while the benefit on fully constructed network and on almost fully constructed but lack in a project are formulated as B(Xtw) , B(Xtwo). Secondly, the construction order among the adopted projects follows to the descending order in NPV.

The purpose of case 1 is to compare three scenarios of the different combinations of evaluation network and project in the construction orders of the 20 designed road projects under the dynamic and the static network settings. Under the condition of the static network, two scenarios are compared such as the current network and fully constructed network (Table 3).

Table 3. Summary of case 1

Scenario No.	Evaluation network	Evaluation project
Scenario 1	Static network (present network)	Road construction
Scenario 2	Static network (fully constructed network)	-
Scenario 3	dynamic network	-

Table 4. Summary of case 2

Scenario No.	Evaluation network	Evaluation project
Scenario 4	dynamic network	Limited to road construction
Scenario 5	〃	Road and facility construction

Table 5. Models and its parameters

Model	Contents
Trip generation potentials model	(Traffic generation potentials)＝0.16×(Residence population) ＋5×(Hospital bed capacity) Where, residence population and hospital bed capacity are assumed to be constant for planning period.
Trip attraction potentials model	(Traffic attraction potentials)＝0.16×(Residence population) ＋5×(Hospital bed capacity) Conveniently, it is assumed to be same as trip generation potentials model. The constraints is the same, too.
Project cost model	(Construction period)=0.1×(ln(Construction cost))^2.4
Link performance function (BPR function)	(Movement time)=(Free trip time)× (1+0.48×((Traffic volume)/(Taraffic capacity))^2.82) Traffic capacity, Free trip time(=free spped) are set according to the road classification and the route situation and the number of the traffic lanes.

Case 2: Comparison in difference in candidate projects; limited to road construction and road and facility construction

Case 2 is calculated under the dynamic network assignment in order to compare the difference in candidate projects limited to road construction and those including road and facility construction (see table 4). The comparisons are made on terms of adopted projects, construction order, and NPV value.

3.3. Model parameter and constraints

Supposing the identical parameters for cases 1 and 2 as seen in Table 5, the constraints were also identically set as shown in Table 6.

As shown in Eqs.(5a) and (5b), the accessibility level is calculated by the average access time over all zones to a destination, that is, the target facility. An access time of each zone is determined after the traffic assignment estimation under the user equilibrium principle: it is estimated on the network corresponding to the gene information. Therefore, the constraint about the minimal level of accessibility is confirmed after gene setting and traffic assignment estimation (see Fig. 2). In order to decrease in lethal gene, we preliminarily check the access time under free flow situation.

Table 6. Constraints settings

Constraint	Case 1	Case 2
Total and annual budget (C*， Ct*)	600 billion yen or less (for all road projects), Plan period 20 years ⇒ 30 billion yen per year	350 billion yen or less, Plan period 20 years ⇒ About 18 billion yen per year
The minimal level of accessibility 1 (Tq*)	-	The maximal constraint in local government access time ⇒ 20 minutes
The minimal level of accessibility 2 (Th*)	-	The maximal constraint in hospital access time ⇒ 60 minutes

4. Results of simulations

4.1. Evaluation in dynamic and static network for road projects

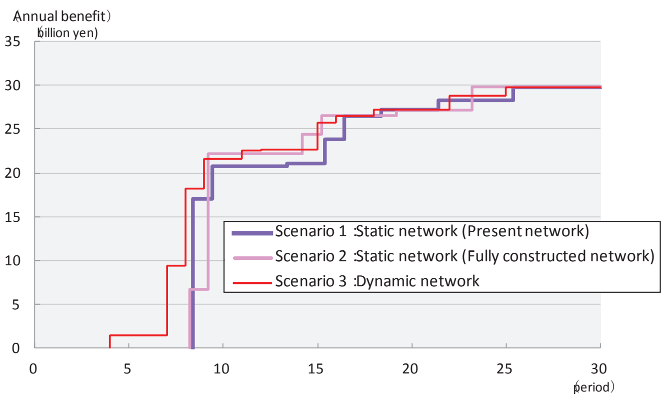

Fig. 5. Cumulative benefit in case 1

Table 7. Comparison in construction order and annual benefit

Construction order	Scenario 1：Static network (Present network)			Scenario 2：Static network (Fully constructed network)			Scenario 3：Dynamic network		
	Service year (period t)	Service project	Annual benefit (billion yen)	Service year (period t)	Service project	Annual benefit (billion yen)	Service year (period t)	Service project	Annual benefit (billion yen)
1	8	6	4.3	8	6	4.3	4	5	1.2
2	8	11	7.0	8	14	6.7	4	18	1.4
3	8	12	9.7	9	10	8.9	7	7	1.9
4	8	14	12.2	9	5	11.7	7	11	4.2
5	8	15	15.6	9	15	15.1	7	12	7.2
6	8	8	16.4	9	7	17.0	7	14	9.3
7	8	5	17.0	9	9	18.9	8	6	14.8
8	9	10	20.7	9	8	22.1	8	15	18.2
9	13	13	21.1	14	12	23.3	9	10	21.6
10	15	9	22.7	14	11	24.4	11	19	22.1
11	15	19	22.9	15	4	25.1	11	16	22.2
12	15	16	23.2	15	19	25.3	11	17	22.5
13	15	17	23.3	15	18	25.5	12	20	22.7
14	15	18	23.7	15	17	25.9	15	9	24.1
15	15	20	23.8	15	20	26.0	15	8	25.7
16	16	4	24.6	15	13	26.2	16	4	26.4
17	16	7	26.5	15	16	26.5	16	13	26.5
18	18	3	27.2	19	3	27.2	18	3	27.2
19	21	1	28.2	23	2	28.8	22	2	28.8
20	25	2	29.8	23	1	29.8	25	1	29.8
NPV （50years）			29.1			29.0			34.1
(present value)	（reference：B/C=1.07）			（reference：B/C=1.07）			（reference：B/C=1.09）		

Construction order, initial service year and annual benefit in different scenarios are listed in Table 7, respectively. The cumulative growth paths in annual benefit in the scenarios are shown in Fig. 5.

As shown in Table 7, the construction order is different among scenarios. In particularly, scenarios 1 and 2 calculated in static network show quite different project order in between the static present network and the static fully constructed network. Concerning the road width expansion projects in (11,12) and bypass projects in (8,9), which are located in parallel in each other, the scenario 1 on present network accepts bypass project after the road width expansion, while the scenario 2 of fully constructed network adopts them in vice versa. This result can be understood that the highest evaluation is given to road width expansion in scenario 1, since it is critical to increase the marginal benefit at present. While in scenario 2, the bypass project got the highest evaluation which can contribute to increase the marginal benefit in future. On the other hand, the scenario 3 also adopts the bypass project after the road width expansion. The major difference of the project order in comparison with scenario 1 and scenario 2 turns out that there are several projects in between these two projects. The project order in scenario 3 is influenced by the neighboring road network attributes around the project, and this result may imply a feature of dynamic project evaluation.

By starting the project to increase the benefit much earlier, NPV can be increased over a 50-year period, under the dynamic project adoption procedure. The results in NPV show that they are about 29 billion yen in scenarios 1 and 2, respectively, while it is about 34.1 billion yen in scenario 3, which is larger in amount of 5.1 billion yen than in scenarios 1 and 2.

In summary, as shown in the above simulations, an evaluation procedure in dynamic network expansion demonstrated in scenario 3 can give the project order in favor of earlier benefit appearance with consideration of neighbor road network condition around the project.

4.2. Integration of facility location projects

Table 8. Project adoption in Scenarios 4 and 5

Project		Project NO	Scenario 4：Limited to road construction	Scenario 5：Road and facility construction
Facility (Hospital)		a	×	×
		b	×	×
		c	×	×
		d	×	×
		e	×	●
		01	×	×
Road	Expressway	02	●	×
		03	×	●
		04	×	●
	（IC access)	05	●	●
	Bypass	06	●	●
		07	●	●
		08	×	●
		09	●	●
		10	●	●
	Widening	11	●	×
		12	●	×
		13	×	×
		14	●	●
		15	●	●
	Linear improvement	16	×	×
		17	×	×
		18	●	×
		19	●	×
		20	×	×
The number of projects			12 projects	11 projects
Total construction cost (billion yen)			350	340

Notes)●：Adoption、×：Non-adoption

The evaluation results of road construction order in scenarios 4 and 5 following the constraints in table 6 are shown in Table 8. In scenario 4, considering road construction projects, 12 projects requiring total cost with 350 billion yen are adopted. In scenario 5, considering road and facility construction, 11 projects requiring total cost with 340 billion yen are adopted. Comparing to scenario 4, one project and the cost in 10 billion yen were decreased. To see the detailed difference, scenario 5 adopts the facility e and adjacent road projects in 3 and 4. The feature of not-adopted projects is that the road projects in 18 and 19 is far from the facility, and the road projects in 11 and 12 is close to the facility but it is located prior to the planning period. Comparing scenario 4 with scenario 5, scenario 5 adopts the road projects to increase the benefit of adopted facility location.

The results of construction order, annual benefit and NPV are shown in Table 9. The cumulative growth paths in annual benefit in each case are in Fig. 6. Comparing the construction order with Scenarios 4 and 5, both of orders are almost similar, and the cumulative growths of their benefits also show similarity. However, the NPV in scenario 5 which considers facility construction is higher than scenario 4.

Consequently, the simultaneous planning of road and facility construction demonstrated in scenario 5 gives a desirable project adoption order with higher NPV, comparing the cases limited to road improvement project.

Table 9. Project adoption in scenarios 4 and 5

	Scenario 4： Limited to road construction			Scenario 5： Road and facility construction		
Construction order	Service year (period t)	Service project	Annual benefit (billion yen)	Service year (period t)	Service project	Annual benefit (billion yen)
1	4	5	1.2	4	5	0.9
2	7	14	3.5	4	e	2.1
3	7	11	6.3	7	14	4.4
4	8	15	9.7	8	15	7.8
5	8	6	13.7	8	6	11.9
6	13	12	16.2	10	10	15.7
7	14	7	17.9	15	7	17.5
8	14	18	18.2	16	8	19.1
9	15	9	18.7	16	9	22.6
10	16	10	23.1	17	4	23.2
11	17	19	23.5	24	3	24.4
12	24	2	24.2			
NPV （50years） (present value)	103.9 （reference：B/C=1.44）			108.3 （reference：B/C=1.46）		

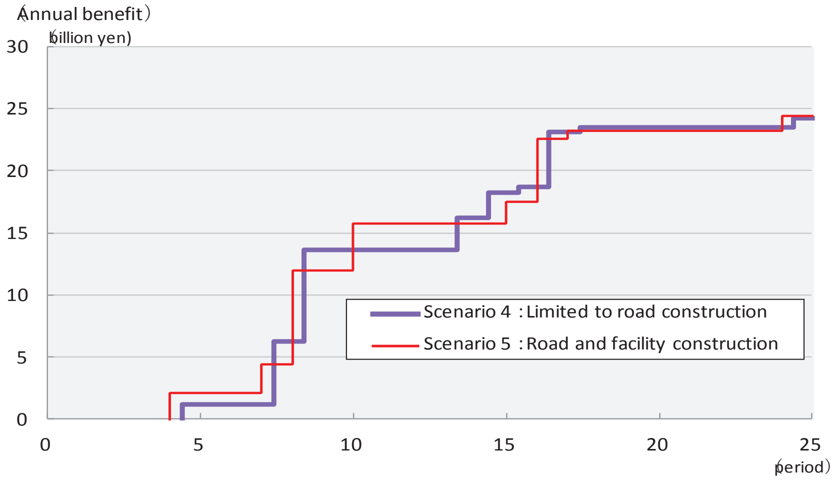

Fig. 6. Cumulative benefit in case 2

5. Conclusions

In the regional road network planning, accessibility improvement brought by the road section improvement and by facility location should be taken into account as well as the network externality caused by step-by-step completion of each project. This study proposed a dynamic project evaluation model which simultaneously determines the optimal project adoption order among the road and facility construction, considering step-by-step project completion. We demonstrated the model performance by following two comparisons: 1) dynamic against static evaluation, and 2) the projects limited to road against the projects including road and facilities. The numerical simulation showed that dynamic and integrated project adoption procedure gives more effective investment project sequence for regional road network planning. The existence of network externality, or an interaction on benefit between link improvement and facility location, suggests not only the importance of dynamic evaluation but the necessity of re-evaluation of project order when a project in link or node on the network is updated.

As the remaining issues, the proposed model should be expanded as to integrate the changes in land use and population distribution influenced by the construction of road and facilities. The constraint setting should be changed as to deal with more flexible, for example, environmental constraint.

References

Aoyama, Y., Matsunaka, R., Nomura, T. (2002). The optimization method of stage-wised construction process of large-scale expressway network and its application. *Transport Policy Studies*, Vol.5, pp. 2–13.

Arabani, A., Farahani, R. (2012). Facility location dynamics: An overview of classifications and applications, *Computers & Industrial Engineering*, Vol. 62, pp.408–420.

Averbakh, I., Berman, O., Drezner, Z., Wesolowsky, G. (2007). The uncapacitated facility location problem with demand-dependent setup and service costs and customer-choice allocation. *European Journal of Operational Research*, Vol. 179, pp.956–967.

Bröcker, J., Korzhenevych, A., Schürmann, C. (2010). Assessing spatial equity and efficiency impacts of transport infrastructure projects. *Transportation Research B*, Vol. 44, pp. 795–811

Canel, C., Khumawala, B., Law, J., Loh, A. (2001). An algorithm for the capacitated, multi-commodity, multi-period facility location problem. *Computers & Operations Research*, Vol. 28, pp. 411–427.

Committee of the guidance about the evaluation of the road investment (1998). The guidance about the evaluation of the road investment. (in Japanese)

Damart, S., Roy, B. (2009). The uses of cost–benefit analysis in public transportation decision-making in France. *Transport Policy*, Vol. 16, pp. 200–212.

Drezner, Z., Hamacher, H. (2001). Facility location, *Springer.*

Drezner, Z., Wesolowsky, G. (2003). Network design: selection and design of links and facility location. *Transportation Research A*, Vol. 37, pp. 241–256.

Gebennini, E., Gamberini, R., Manzini, R. (2009). An integrated production–distribution model for the dynamic location and allocation problem with safety stock optimization, *International Journal of Production Economics*, Vol.122, pp. 286–304.

Hinojosa, Y., Kalcsics, J., Nickel, S., Puertod, J., Veltene, S. (2008). Dynamic supply chain design with inventory. *Computers & Operations Research*, Vol. 35, pp. 373–391.

Horner, M., Groves, S. (2007). Network flow-based strategies for identifying rail park-and-ride facility locations. *Socio-Economic Planning Sciences*, Vol.41, pp. 255–268.

Jorgea, J., de Rus, G. (2004). Cost–benefit analysis of investments in airport infrastructure: a practical approach. *Journal of Air Transport Management*, Vol. 10, pp. 311–326.

Lakshmanan, T. (2011). The broader economic consequences of transport infrastructure investments, *Journal of Transport Geography*, Vol.19, pp. 1–12.

Matsunaka, R., Taniguchi, M., Masuoka, T. (2005). Study on the adoption possibilities of the not-adopted projects in plural decision criteria for phased construction process. *Journal of Infrastructure Planning in Japan*, Vol.22, pp. 667–674. (in Japanese)

Morisugi, H., Ohno, E. (1995). Proposal of a benefit incidence matrix for urban development projects. *Regional Science and Urban Economics*, Vol.25, pp. 461–481.

Peterson, E., Taylor, A. (2001). An investment planning model for a new North-Central railway in Brazil, *Transportation Research A*, Vol.35, pp. 847–862.

Peterson, E. (2002), A highway corridor planning model: QROAD. *Transportation Research A*, Vol.36, pp. 107–125.

Syam, S. (2008), A multiple server location–allocation model for service system design, *Computers & Operations Research*, Vol. 35, pp. 2248–2265.

The Ministry of Land, Infrastructure and Transport (MILT). (2003). Calculation method of the quantitative and evaluation indicators.

The Ministry of Land, Infrastructure and Transport (MILT). (2008). Cost-benefit analysis manual.