

EXPRESSWAY POLICY-SET ANALYSIS FROM MULTI-PERSPECTIVE VIEWPOINTS: MODEL, ALGORITHM AND APPLICATION

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Abstract: An obvious limitation of discussions concerning the expressway system is the subjectivity and one-sidedness. In line with this, there is a need for an objective, quantitative and comprehensive design methodology for an expressway system. Thus, this research developed a methodological tool (CESDA) for policy-set design from multi-perspective viewpoints that would be practical and applicable to real-world and large-scale problems. Initially, a comprehensive logical system of factors and variables on expressway system design, with consideration on the various viewpoints of different stakeholders in the system, were wholly constructed. A practically applicable mathematical model and system design analyzer was then developed using a tri-level model structure. An algorithm, which can deal with large-scale expressway policy-set design problems was proposed and verified. To verify its applicability, the expressway system of Japan was used as a case study. The optimal set of expressway expansion projects in the Construction Plan was obtained and discussed.

Key Words: Expressway, Policy-Set, Multi-Perspective, CESDA

1. INTRODUCTION

(1) Background

Various discussions concerning the expressway system and its design have recently cropped up especially in Japan. The arguments of privatization can be summarized into three core questions:

- To construct remaining expressways or not?
- What will be the relationship between new constructed expressways and existing expressways?
- How to deal with the existing corporations and links?

Such arguments are related to various stakeholders, their viewpoints, as well as various policies. A very obvious limitation of the arguments is the subjectivity and one-sidedness of the stakeholders. To give an example, users only consider several expressway links they often use; private investors consider maximizing their profits; while politicians would support short-term, high profile projects that would ensure them people's votes. This inevitably results in the difficulty of making objective and comprehensive decisions. Therefore, there is a need for an objective, quantitative and comprehensive design methodology for an expressway system. Although expressway system design has been thoroughly discussed, in reality, there is no scientific and quantitative basis for the design of comprehensive and large-scale network systems.

(2) Research Objective

This research is to develop a methodological tool for policy-set design that would be practical and applicable to real-world and large-scale problems, based on the concept of comprehensive expressway system design. The tool is called Comprehensive Expressway System Design Analyzer (abbreviated as CESDA), which is characterized by following 3 points .

- ① Multi-perspective viewpoints, i.e., various perspectives of various stakeholders, are considered wholly. The evaluation of expressway design is based on various perspectives systematically.
- ② Various policies can be designed together as a policy-set. Especially the very important issue of organizational design, which was seldom designed through quantitative analysis in a network system in previous researches, is considered.
- ③ The policy-set is designed based on scientific methods including both optimization and simulation. The policy-set is optimized based on the overall evaluation by the government. The financial indices of operators are interactive and changeable with policy-set changed; and user's route choice is also dependent on the policy-set.

2. SYSTEM DIAGRAM OF CESDA

As the system diagram shown in Figure 1, the main components of CESDA system include 5 kinds of stakeholders (the government, the government agency, public corporations, private companies and users), 4 policy variables (entity form, network division, toll regulation and expansion choice) and 3 main evaluation indices (economic efficiency, financial feasibility and fairness), which includes 7 sub-indices (user's cost ratio, supplier's cost ratio, financial feasibility of the government agency, financial feasibility of public corporations, financial feasibility of private companies, whole self-burden ability and whole poolability).

(1) Stakeholders

- ① Users will choose the shortest route of generalized cost, including travel time and toll, for their travels. Therefore, toll regulation and the network expansion have directly impact on user's route choice, and thereby decide the traffic volume of each road links.
- ② Government will decide the policy-set based on an overall evaluation of various indices concerned by all stakeholders. The solution with the highest comprehensive evaluation value is taken as the optimal solution.
- ③ Government agency is established mainly for: (i) constructing and operating non-toll expressways, and also operating all general highways; (ii) performing as a special entity, collecting charge (lease) from private operators and subsidizing public corporations using the charge and available budget from the government.
- ④ Public corporation is responsible for construction and operation of toll expressways with tight control by government and a certain amount of subsidy provided. The operation efficiency is lower than that of private company. One public corporation might operate several expressways sections, while the toll rate is uniform for each expressway section within one public corporation.
- ⑤ Private company undertakes construction and operation of toll expressways for the purpose of profit. The toll rate of expressway operated by private company is considered to be

set by the government. The private company has high operation efficiency, and operate the expressway in one-road-one-company form (each private company will operate just one expressway section) because the private company usually has rather low ability in financing and risk resistance (Gómez-Ibáñez. and Meyer, 1993).

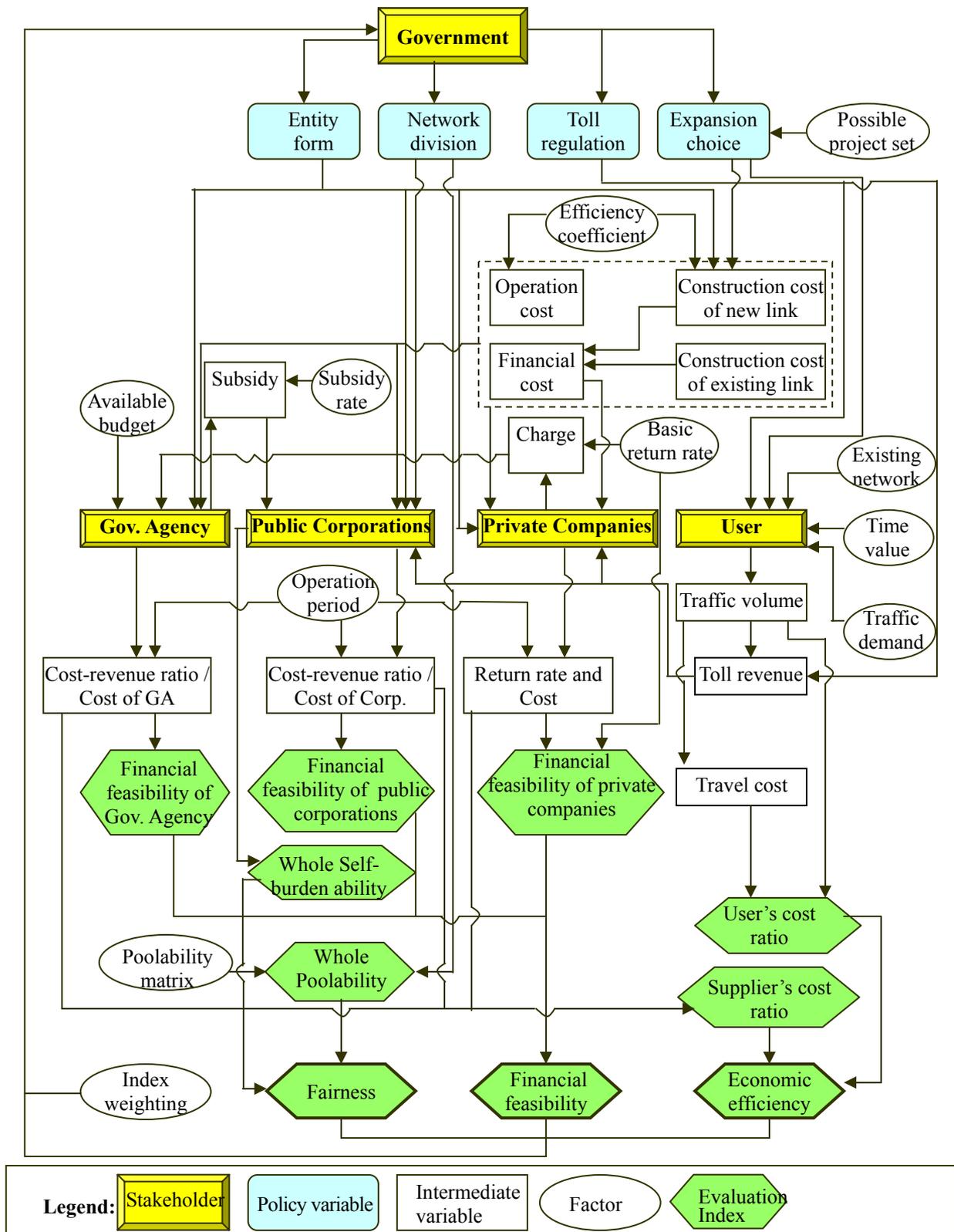


Figure 1. System Diagram of CESDA

(2) Police Variables

① Entity form is the form of the entity that constructs and operates expressways. In this research entity forms include government agency, public corporation and private company.

② Network division means how to divide the expressway networks into several parts, with each of which operated by a certain entity.

③ Toll regulation is defined as the toll-rate setting of each expressway.

④ Network expansion choice is defined as the choice between “to construct” and “not to construct” for each planned expressway section, i.e., which projects should be constructed among all the remained expressways in the given construction plan.

(3) Evaluation Indices

The evaluation indices are extracted from various stakeholders’ viewpoints based on extensive survey and review. The definition of each evaluation index of CESDA is shown in Table 1.

Several indices need to be explained since they are quite new concept in expressway policy-set design from multi-perspective viewpoints.

- **Self-burden rate:** Self-burden rate is the ratio of the revenue (toll plus subsidy) to its whole cost of each expressway. Accordingly there is an important index, acceptable self-burden rate (50% in Japan, Fujii, 1992), which is the lowest self-burden rate acceptable to the public if one expressway is pooled revenue with other expressways within one public corporation.

Table 1. Evaluation Indices of CESDA

Main Indices	Sub-Indices	Definition of Sub-Indices
Economic efficiency	User’s cost ratio	Basic user’s cost/User’s cost
	Supplier’s cost ratio	Basic supplier’s cost/Supplier’s cost
Fairness	Whole self-burden ability	The average of self-burden ability of each expressway operated by public corporation. The self-burden ability of each expressway is taken as the smaller value of 1 and the division of revenue by the product of cost and acceptable self-burden rate.
	Whole poolability	The average of poolability of all pairs of expressway, which is operated by the same public corporation. Poolability of a certain pair of expressways is taken from the poolability matrix as input factors.
Financial feasibility	Financial feasibility of Gov. Agency	The smaller value of 1 and cost-revenue ratio (the division of revenue by cost).
	Financial feasibility of public corporations	The average of the financial feasibility of each expressway operated by public corporation. The financial feasibility of each expressway operated by public corporation, is taken as the smaller value of 1 and cost-revenue ratio (the division of revenue by cost).
	Financial feasibility of private companies	The average of the financial feasibility of each expressway operated by private company. The financial feasibility of each expressway operated by private company, is taken as the smaller value of 1 and the division of cost-revenue ratio by the sum of 1 and basic return rate

- **Self-burden ability:** Expressways with enough self-burden ability can pool revenue with

other expressways within one public corporation. The expressway having self-burden rate higher than acceptable self-burden rate, has the self-burden ability of 1. Otherwise, its self-burden ability is taken as the ratio of self-burden rate to acceptable self-burden rate.

- Poolability (for detailed explanation, see Cheng, 2004): If the pooling system is large-scaled, users might argue why they should pay for the cost of other expressways since they might never use them. Poolability reflects the acceptability of expressway users to share the toll revenue between two different expressways. The value of poolability is mainly influenced by the distance between the expressways (since user's travel scope is usually limited).

3. MODEL FORMULATION

(1) Model Structure of CESDA

Based on the system diagram, a tri-level model is used for formulation of CESDA as shown in Figure 2. The policy variables are optimized in the upper two levels and the user's route choice is solved in the lowest level. Two additional measures are adopted to make the model workable to practical large-scale problems.

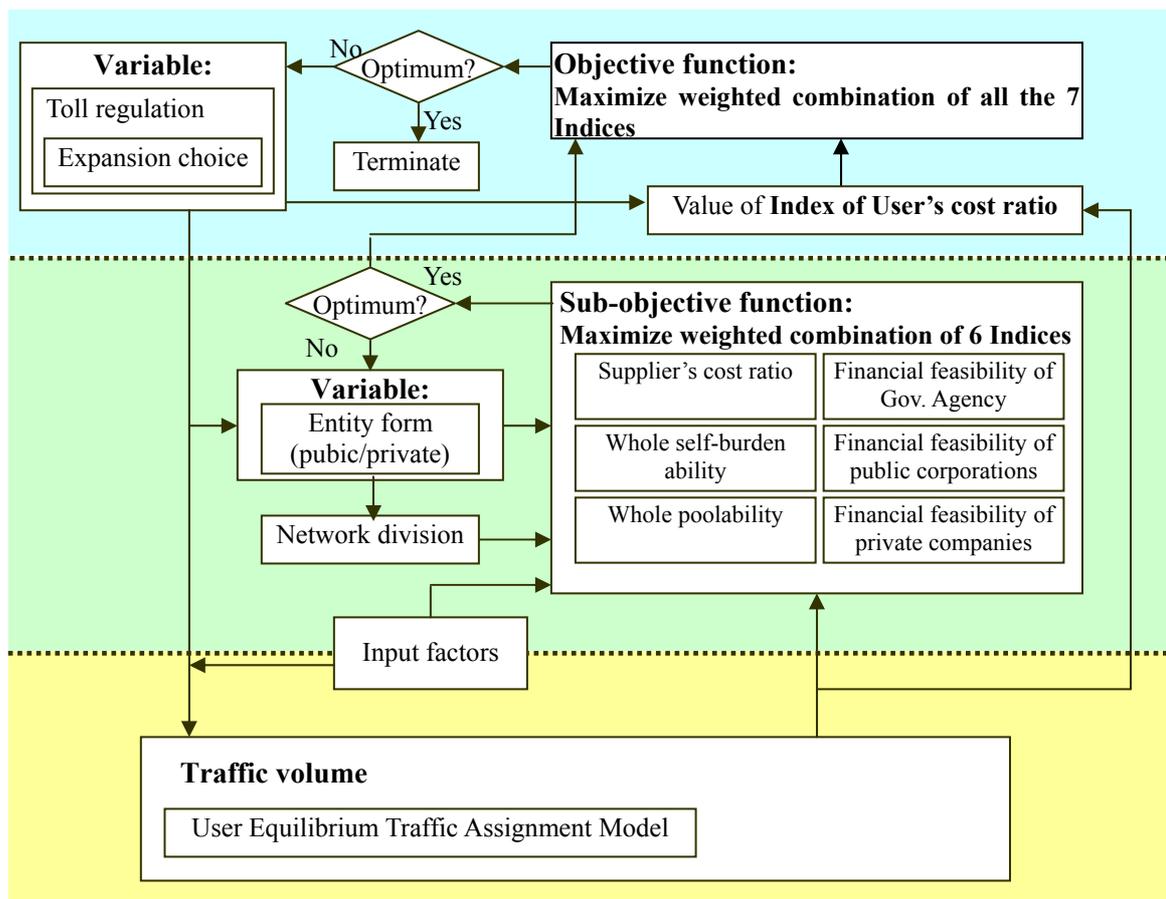


Figure 2. Model Structure of CESDA

①Toll rate to corporation correspondence assumption: It is assumed that each public corporation has different toll rate setting, in other words, there are not any two public corporations have the same toll rate setting. If the toll rate is given (suppose the toll rate >0), the network division will be decided simultaneously when the entity form is decided. That is,

if it is decided as private company, then it is a new established company according to the one-road-one-company assumption; if it is decided as a public corporation, automatically it is grouped to a certain public corporation based on its toll rate setting.

② Toll regulation comprising expansion choice: A special toll rate with very high value is taken as the “expansion choice” of “no to construct” to make users avoid using this expressway (the same effect as “not to construct”). In this way, the network can be fixed and need not have to be recoded under different expansion choice. It can, thereby, effectively reduce the calculation time of each traffic assignment.

(2) Mathematical Model of CESDA

$$\max_P y = \frac{w_1}{2} x_1(P, \{q_a\}) + \left[\frac{w_1}{2} x_2(E, P, \{q_a\}) + \sum_{i=3}^4 \frac{w_2}{2} x_i(E, P, \{q_a\}) + \sum_{i=5}^7 \frac{w_3}{3} x_i(E, P, \{q_a\}) \right] \quad (1)$$

where:

$$x_1 = TUC_0 / TUC \quad (2)$$

E is obtained by solving the following optimization problem:

$$\max_E y = \frac{w_1}{2} x_2(E, P, \{q_a\}) + \sum_{i=3}^4 \frac{w_2}{2} x_i(E, P, \{q_a\}) + \sum_{i=5}^7 \frac{w_3}{3} x_i(E, P, \{q_a\}) \quad (3)$$

where:

$$x_2 = TSC_0 / TSC \quad (4)$$

$$x_3 = \frac{\left\{ \sum_{a \in A^e} \lambda_a^1 (1 - \lambda_a^2) \mu_a + \sum_{a \in \bar{A}^e} \omega(p_a) \lambda_a^1 (1 - \lambda_a^2) \mu_a \right\}}{\left\{ \sum_{a \in A^e} \lambda_a^1 (1 - \lambda_a^2) + \sum_{a \in \bar{A}^e} \omega(p_a) \lambda_a^1 (1 - \lambda_a^2) \right\}} \quad (5)$$

$$x_4 = \frac{\sum_{m=1}^{m^{pub}} \sum_{a \in A^e \cup \bar{A}^e} \sum_{b \in A^e \cup \bar{A}^e} \omega(p_a) \omega(p_b) \delta(\lambda_a, p_a, m) \delta(\lambda_b, p_b, m) \alpha_{ab}}{\sum_{m=1}^{m^{pub}} \sum_{a \in A^e \cup \bar{A}^e} \sum_{b \in A^e \cup \bar{A}^e} \omega(p_a) \omega(p_b) \delta(\lambda_a, p_a, m) \delta(\lambda_b, p_b, m)} \quad (6)$$

$$x_5 = \min \left\{ \left[B + \sum_{A^e \cup \bar{A}^e} \omega(p_a) \lambda_a^2 u_a \right] / \left[\sum_{a \in A^e \cup \bar{A}^e} \omega(p_a) (1 - \lambda_a^1) (\eta^{con}(0, 0) c_{a0}^{con} (1 + r / 2) + \right. \right. \quad (7)$$

$$\left. \eta^{ope}(0, 0) (f_a^{ope} l_a z_a + v_a^{ope} l_a q_a(P, \Omega(P))) \right] + s \sum_{a \in A^e \cup \bar{A}^e} \omega(p_a) \lambda_a^1 (1 - \lambda_a^2) \eta^{con}(1, 0) c_{a0}^{con} \left. \right], 1 \left. \right\}$$

$$x_6 = \sum_{i=1}^{N^{pub}} F_i^{pub} / N^{pub} = \sum_{m=1}^{m^{pub}} F_m^{pub} / \sum_{m=1}^{m^{pub}} \left\{ \sum_{a \in A^e \cup \bar{A}^e} \omega(p_a) \delta(\lambda_a, p_a, m) \lambda_a^1 (1 - \lambda_a^2) \right\} \quad \forall m \in [1, M1] \quad (8)$$

$$x_7 = \sum_{i=1}^{N^{pri}} F_i^{pri} / N^{pri} = \sum_{a \in A^e \cup \bar{A}^e} \omega(p_a) \lambda_a^2 F_a^{pri} / \sum_{a \in A^e \cup \bar{A}^e} \omega(p_a) \lambda_a^2 \quad (9)$$

$$u_a = \omega(p_a) \lambda_a^2 \max \left\{ \left[p_a q_a(P, \Omega(P)) l_a \right] - (1 + r_b) \left[\eta^{con}(1, 1) c_{a0}^{con} (1 + r / 2) + \eta^{ope}(1, 1) (f_a^{ope} l_a z_a + v_a^{ope} l_a q_a(P, \Omega(P))) \right], 0 \right\} \quad (10)$$

where $\{q_a\}$ is obtained by solving the following model:

$$\min_{\{q_a\}} \sum_{a \in A^e \cup \bar{A}^e} \int_0^{q_a} t_a(q) l_a dq + \sum_{A^e \cup \bar{A}^e} \frac{1}{\theta} p_a l_a q_a + \sum_{a \in A^e} \int_0^{q_a} \omega(p_a) t_a(q) l_a dq + \sum_{a \in \bar{A}^e} \frac{1}{\theta} \omega(p_a) p_a l_a q_a \quad (11)$$

Subject to:

$$\sum_{r \in R_w} f_{rw} = d_w, \quad w \in W \quad (12)$$

$$q_a = \sum_{w \in W} \sum_{r \in R_w} f_{rw} \delta_{ar}^w, \quad a \in A \quad (13)$$

$$f_{rw} \geq 0, \quad r \in R_w, \quad w \in W \quad (14)$$

where,

w_i : weight of index i , w_1 -weight of economic efficiency, w_2 -weight of fairness and w_3 -weight of financial feasibility.

$E = [\lambda_a^1, \lambda_a^2]$: entity form

$\Delta = [\delta_{am}]$: network division

λ_a^1 : 1 if link a is tolled, and 0 otherwise (non-toll);

λ_a^2 : 1 if link a is operated by a private company, and 0 otherwise (by public corporation or government agency);

m : Entity m ;

δ_{am} : 1 if link a is operated by entity m , and 0 otherwise;

$P = [p_a]$: toll regulation, $a \in A^e \cup \bar{A}^e$

p_a : toll rate (toll per km) of link a , which is a discrete variable taken from a set of possible toll rates with the ceiling limit as \bar{p} , i.e., $p_a \leq \bar{p}$;

$\Omega = [\omega_a]$: network expansion choice, $a \in \bar{A}^e$, $\omega_a = \begin{cases} 1 & \text{if link } a \text{ will be constructed} \\ 0 & \text{if link } a \text{ will not be constructed} \end{cases}$

x_1 : index value of user's cost ratio;

TUC : Total User's Cost;

TUC_0 : constant, basic total user's cost in the case of all the remaining links being constructed and all highways being operated by the government agency, $P_0 = \{0, \dots, 0\}$, $\Omega_0 = \{1, \dots, 1\}$;

θ : time value of users;

$t_a(q_a)$: time-flow function of link a ;

q_a : traffic volume on link a ;

l_a : length of link a ;

x_2 : index value of supplier's cost ratio;

TSC : Total Supplier's Cost;

TSC_0 : constant, standard total supplier's cost in the case of all the remaining links being constructed and all highways being operated by the government agency, $P_0 = \{0, \dots, 0\}$,

$\Omega_0 = \{1, \dots, 1\}$, and all the cost financed by equity capital;

c_{a0}^{con} : basic construction cost of link a , the remaining cost for existing expressway or the total cost of remaining expressway to be constructed;

c_a^{con} : actual construction cost of link a , $c_a^{con}(\lambda_a^1, \lambda_a^2) = \eta^{con}(\lambda_a^1, \lambda_a^2)c_{a0}^{con}$

$c_a^{fin(n)}$: Financial cost function of link a , $c_a^{fin} = rc_a^{con} / 2$.

r : annual interest rate;

$c_a^{ope}(\lambda_a^1, \lambda_a^2, q_a)$: operation cost function, $c_a^{ope}(\lambda_a^1, \lambda_a^2, q_a) = \eta^{ope}(\lambda_a^1, \lambda_a^2) \{ f_a^{ope} l_a z_a + v_a^{ope} l_a q_a \}$;

f_a^{ope}, v_a^{ope} : parameters of fixed operation cost and variable operation cost;

z_a : lane-numbers of link a ;

x_3 : index value of whole self-burden ability;

s : subsidy rate;

μ_a : self-burden ability of expressway a ;

μ_0 : acceptable self-burden rate;

x_4 : index value of whole poolability;

α_{ab} : poolability between expressway a and expressway b ;

x_5 : index value of financial feasibility of government agency;

B : available budget;

u_a : charge from expressway a ;

x_6 : index value of financial feasibility of public corporations;

F_m^{pub} : financial feasibility of public corporation m ;

x_7 : index value of financial feasibility of private companies;

F_a^{pri} : financial feasibility of the private operating expressway a :

R_w : a set of all routes between OD pair $w \in W$;

d_w : OD traffic volume of OD pair w ;

f_{rw} : OD traffic volume of OD pair w , $w \in W$, which choose route r ;

δ_{ar}^w : 1 if link a is one link of route r between OD pair $w \in W$, and otherwise 0.

4. ALGORITHM OF CESDA

(1) Process of the Algorithm

The algorithm for CESDA, using Genetic Algorithm (abbreviated as GA, see Sakawa, H., et al, 1994) as basic algorithm, can be described as follow.

Step 1: Input factors including OD matrix, network information and other factors;

Step 2: Generate a vector of toll regulation P , which includes the solution of expansion choice: if the toll rate is equal to the special toll rate, the expressway will not be constructed, otherwise it will be constructed. The generated vector also includes part information of entity form: if the toll rate of one expressway is zero, the entity form of the expressway is government agency; if the toll rate is not zero, the entity form need to be decided in Step 5;

Step 3: Apply incremental assignment algorithm for traffic assignment;

Step 4: Calculate the value of evaluation index of user's cost ratio;

Step 5: Generate a vector of entity form for expressways with toll rate > 0 (based on the generated toll regulation in Step 2): if value of entity form is equal to 1, it is operated by the private company, otherwise by the public corporation. The network division is determined simultaneously: if the expressway is operated by private company, a new private company is added to the operator set according to the one-road-one-company assumption; otherwise, if the expressway is operated by public corporation, the network

- division (appointing the public corporation) will be decided based on its toll rate according to the toll rate to corporation correspondence assumption;
- Step 6: Calculate the fitness of the sub-objective function, weighted combination of 6 indices;
- Step 7: Judge if enough generations are calculated or not: if the calculated generations are not enough, go to step 8; else go back to step 9;
- Step 8: Generate new generation of E , through reproduction, crossover and mutation, go to step 6;
- Step 9: Calculate the fitness of the objective function, weighted combination of all the 7 indices;
- Step 10: Judge if enough generations are calculated or not: if the calculated generations are not enough, go to step 11; else go back to step 12;
- Step 11: Generate new generation of P , through reproduction, crossover and mutation, go to step 3;
- Step 12: Terminate calculation and output the solution and evaluation indices.

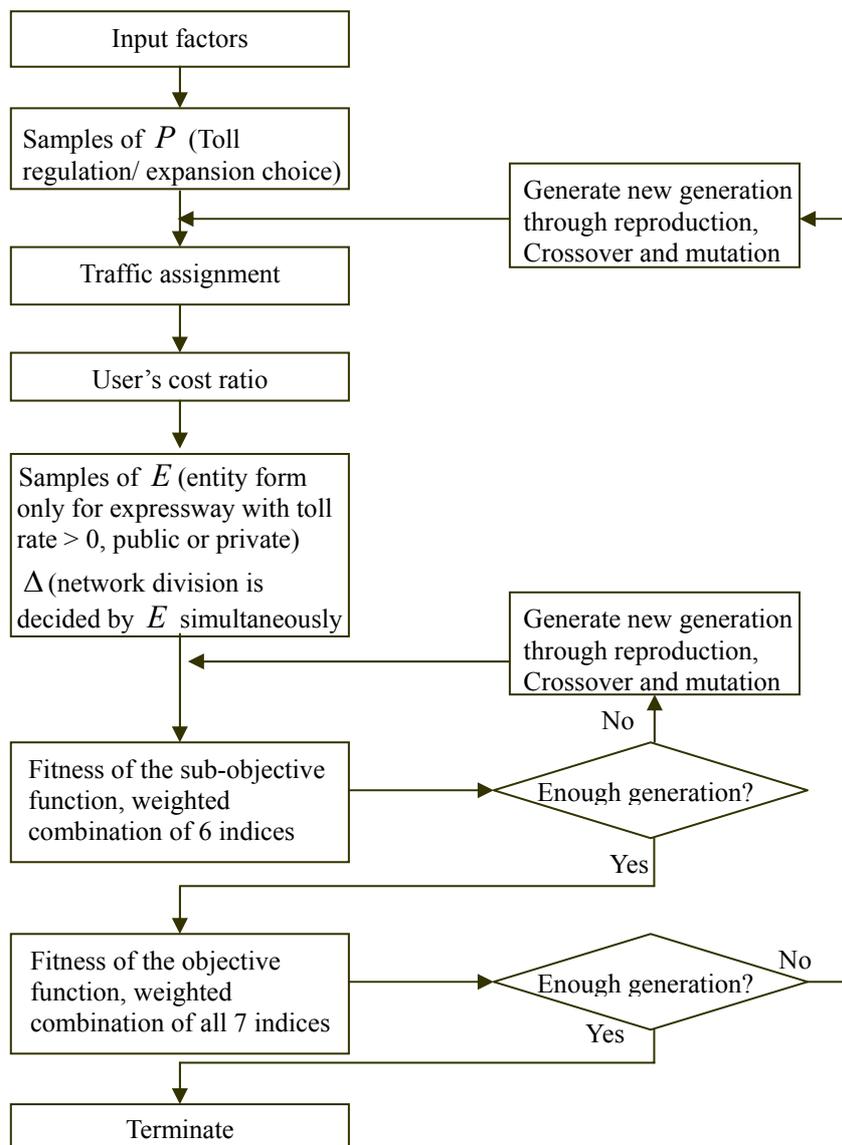


Figure 3. Flow Chart of Algorithm

For applying genetic algorithm, P is represented by a $m \times n$ -bit binary digit (in the case of m expressway projects and 2^n alternatives of toll regulation schemes), and E is represented

by a m -bit binary digit (in the case of m expressway projects which are tolled). The procedure of reproduction, crossover and mutation can be described as: First, randomly pick a pair of individual from the population pool and the individual with higher fitness will win with some probability (experimentally determined) and reproduced and transferred to mating pool; second, from the mating pool, a pair of individual will be randomly selected to “mate”. The offspring is formed by taking the bits after the random crossover point in the first parent string and combine it with the bits before the crossover point form the second parent string, and vice versa. This is repeated until the offspring filled new population set; third, the bits in each individual from new population undergo mutation (randomly change form 0 to 1 and 1 to 0) with some low probability.

(2) Workability of the Algorithm

The algorithm can effectively solve the policy-set design problem with acceptable computation time consumption. For an example of 84 expressway projects (see Cheng, 2004), it takes around 20 hours.

Table 2. Estimation of Calculating Time

Necessary Combinations of Entity form and Network Division ($A = 84^2$)	7056
Necessary Combination of Toll Regulation ($B = (4 \times 84)^2$)	112896
Necessary Samples ($C = A*B$)	796594176
Time Consumption Per Population (second, D)	8.8×10^{-5}
Total Time Consumption (hour, $C*D/3600$)	20

5. VERIFICATION

(1) Convergence

It's a weak point for GA-based algorithm that usually the convergence of algorithm cannot be proved strictly. This research verifies convergence through experiments, testing convergence in different sizes of network. The figures in Table 3 show the process of convergence.

For the genetic algorithm of this research, the best solution of each generation is always kept as a population sample for next generation; therefore, the fluctuation is displayed as jump. It can be found that with more generations calculated, the jump becomes smaller in general.

Although the genetic algorithm is considered as a practical and approximate optimization problem which can effectively avoid local optimization, the solution might still be local optimal under some special conditions. Fortunately, in this research the GA-based algorithm of CESDA can avoid local optimization problem, which is proved through experimenting on various examples.

(2) Rationality

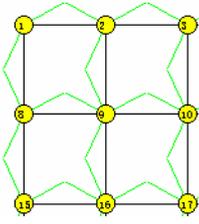
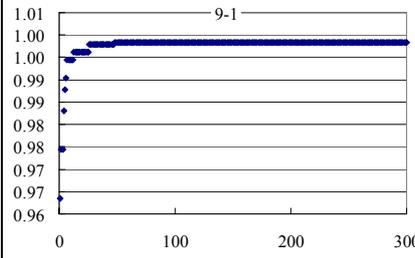
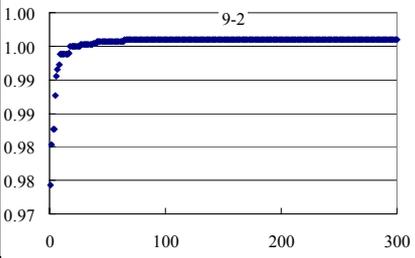
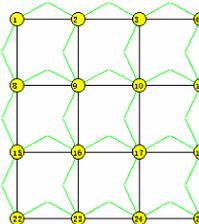
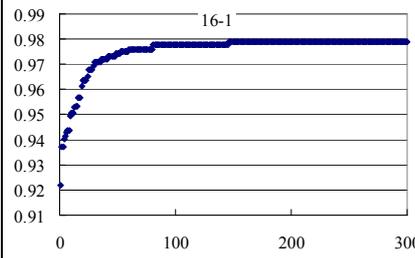
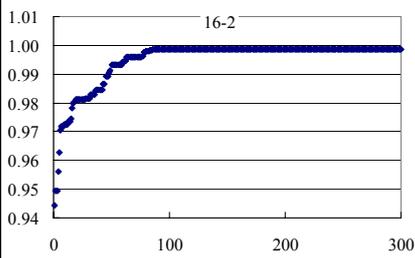
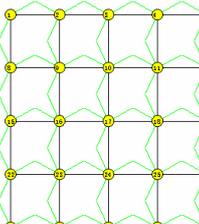
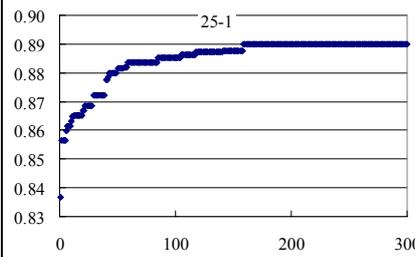
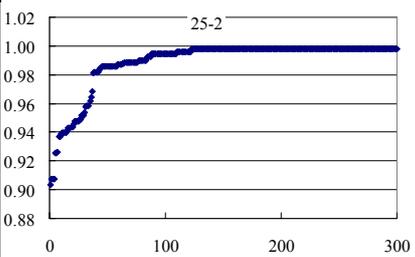
Two case studies were conducted for verifying the algorithm based on rationality judgment.

① Case study 1: Radial Symmetric System

As shown in Figure 4, a symmetric system including 9 zones, 12 expressways (in black line) and 24 general highways (in light green line), is assumed. The central zone is assumed having

much larger traffic attraction and production.

Table 3. Results of Experiment on Verifying Convergence

Testing network	Convergence of objective value of Test 1	Convergence of objective value of Test 2
		
		
		

The rationality can be judged based on two points: (i) Generally, policy-set design in a symmetric system should also have a symmetric solution accordingly; (ii) In this system the central expressways have high traffic volume and are profitable. The profitable expressways will attract private operators. The government then can charge the private operators to subsidize other expressways operated by public corporation with relatively low traffic volume. Such design can make the system economically efficient and financially feasible.

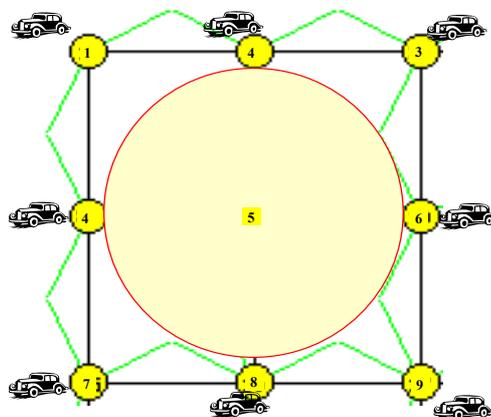


Figure 4. A Radial Symmetric System

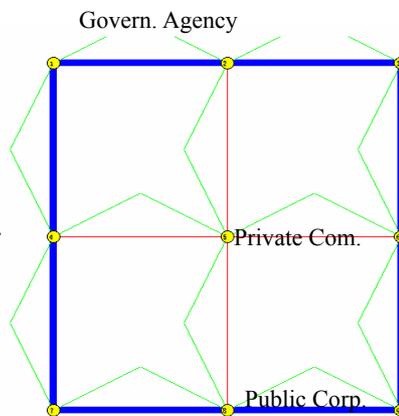


Figure 5. Solution of Organizational Design

② Case study 2: Best Policy for Unbalanced Traffic Demand in Symmetric Network

The assumed symmetric network includes 25 zones, 40 expressways (in black line) and 80 general highways (in light green line). The traffic demand is assumed as decreasing from the east to west, however, constant from north to south.

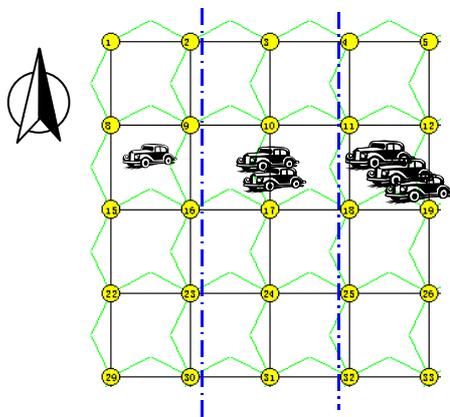


Figure 6. A Symmetric Network System with Unbalanced Traffic Demand

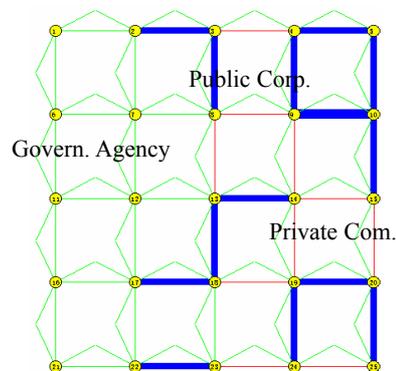


Figure 7. Solution of Organizational Design

The solution of organizational design is generally symmetric along the horizontal central axis. Similarly, the red line represents private company and the thick blue line represents public corporation, and the non-toll expressway operated by the government agency is represented by light green line.

The operator distribution fits to general sense that private companies and public corporations operate the expressway in the areas with relatively high demand, and the government agency provides free expressway for low demand areas.

6. APPLICATION

(1) Arguments on Network Expansion Choice

Till the end of 2003, there had been 7343km of expressway in operation in Japan. There is 1999 km of remaining expressway to be constructed in the near future according to the Construction Plan (see Figure 8). However, there is strong opposition for using the pooling system to finance them since the traffic volumes of these expressways are quite low.

CESDA was used to discuss this problem and the following questions would be answered:

- What is the best choice of network expansion? Namely, which projects should be constructed?
- What should be the corresponding organizational form?

(2) Preparation for Application

A very detailed OD data including 3381 zones (city, town and village) based on the census in 1999, is taken as the basic OD data. However, considering both the calculation time restriction and the accuracy requirement, the 3381 zones are combined to 207 zones in term of life activity area.

The highway network in this application includes all expressways constructed by 2004, other expressway planned to be constructed (1999 km) according the “Construction Plan”, most of the main national highways as well as some important subordinate highways in Japan. The highway network is composed of 485 nodes and 1882 directed links.

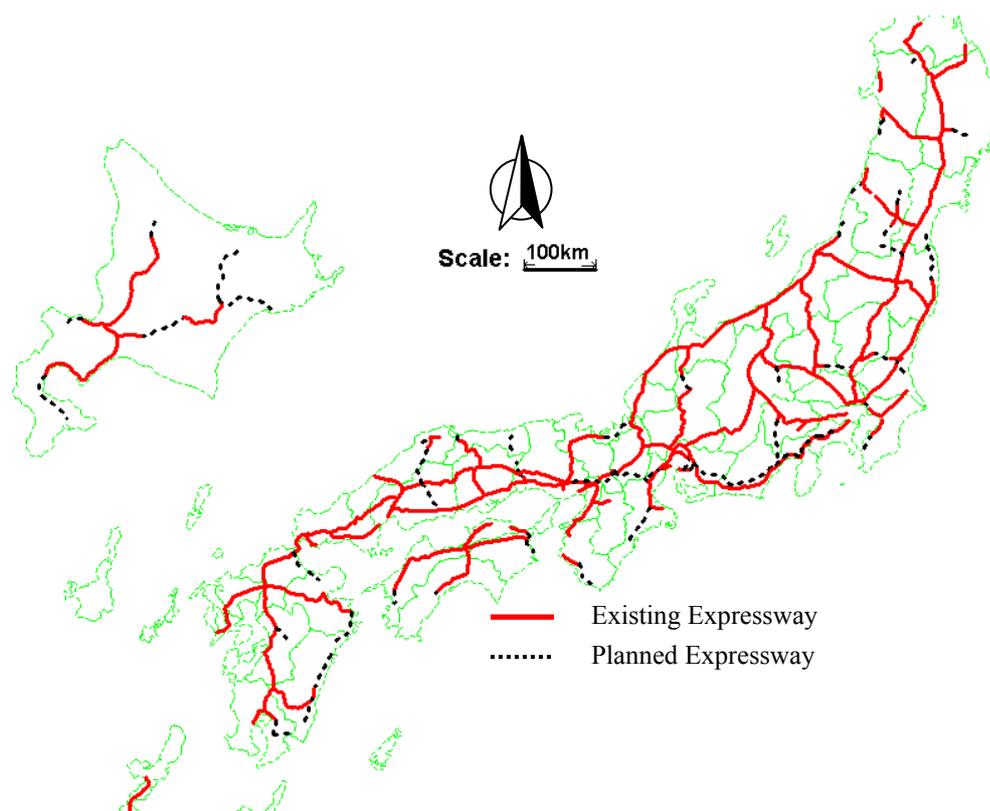


Figure 8. The Existing and Planned Expressways in Japan (by the end of 2003)

For analysis and comparison, a basic scheme of input factors is needed, which is determined based on various documents of the Japan Highway Corporation, the Japan Government, the World Bank, as well as various information from websites.

Table 4. Factors of Basic Scheme

Factor	Unit	Value
Operation Period /Repayment Period	Year	40
Basic Return Rate	%	10
Efficiency coefficient (Pri/Pub)		0.8
Subsidy rate	%	15
Parameter <i>b</i> of Poolability		1/1000

According to the parameter study (see Cheng, 2004), the weight-setting of three main indices, economic efficiency, fairness and financial feasibility are taken as 0.167, 0.167 and 0.667 correspondingly

(3) Solution of Network Expansion Design

According to the calculation of CESDA, 1059 km, around half of remaining expressways need to be constructed under the basic weight-setting scheme (shown in Figure 9).

Based on the analysis on expansion choice, traffic volume and per-km construction cost (see Figure 10), we can find there is an important principle to decide which expressways should be constructed. For those to be constructed, a certain condition should be satisfied: an input of 1 billion yen per-km construction cost should attract at least 3000 vehicle/km traffic volume.

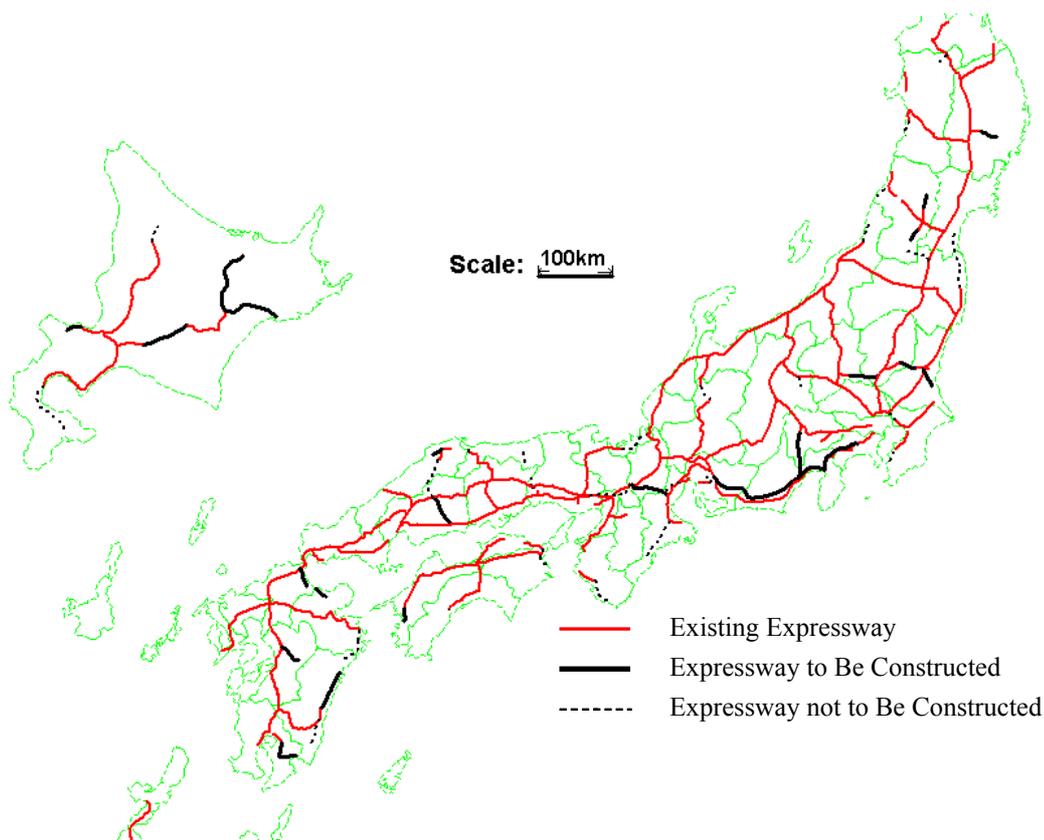


Figure 9. Solution of Network Expansion Choice

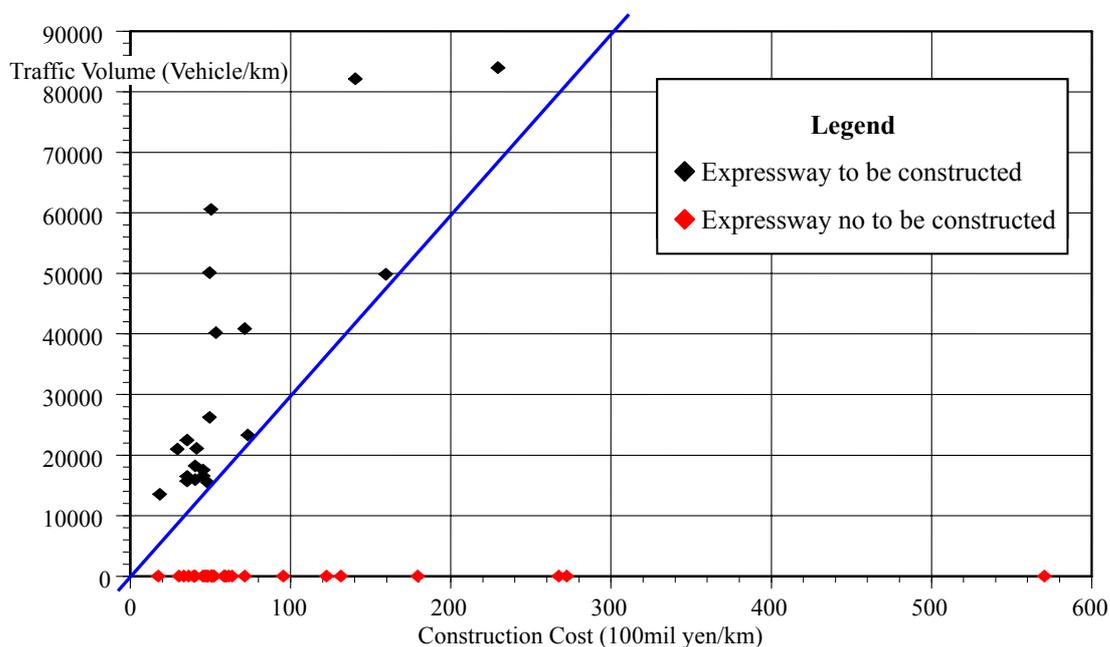


Figure 10. Relationship between Expansion Choice, Traffic Volume and Per-Km Construction Cost

(4) Solution of Organizational Design

The solution of the entity form and network division is shown in Figures 11. According to the calculation result, many new-constructed expressways should be operated by the government agency. The reason is that these expressways have relatively low traffic demand and cannot be financially viable if operated by public corporations or private companies. It reflects the critical financial feasibility of the planned expressways in general.

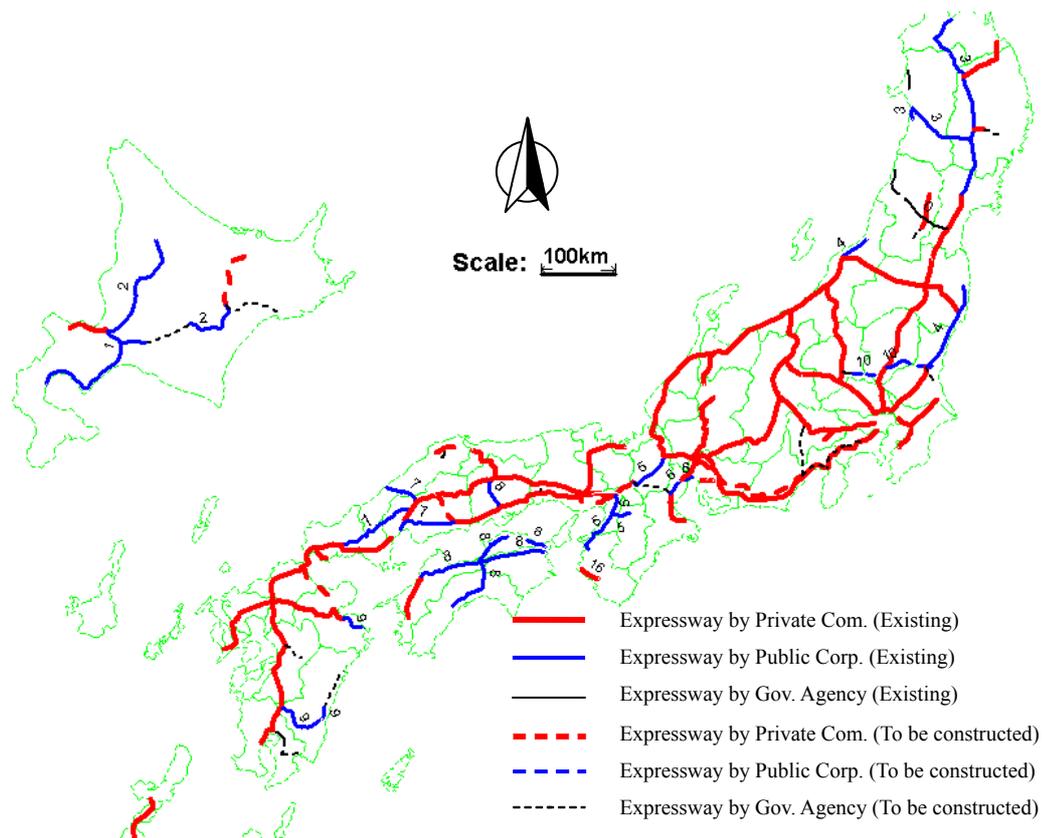


Figure 11. Solution of Organizational Design

(5) Suggestions on Policy-Set Design of JH Reform

About half of the planned expressways, should be constructed from multi-perspective viewpoints. Comparing to the plan in Four Acts on the Privatization of the Four Highway-Related Public Corporations enacted by Japan Government in March of 2004 where all the planned expressways will be constructed and JH will be divided into three public corporations, less expressways should be constructed, more entity form should be adopted, and more public corporations should be established. It was estimated that the proposed plan by CESDA can reduce total economic cost of 400 billion yen per year.

7. CONCLUSION

(1) Achievements

A logical system of stakeholders, policy variables, factors and evaluation indices on expressway system design was first constructed based on the concept of comprehensive expressway system design analyzer.

A mathematical methodology for comprehensive expressway system design, which can deal with large-scale network, was successfully developed. It's the first tool through which the decision-makers can analyze and design the practical expressway system comprehensively and quantitatively. Furthermore, the tool can be used for assessing landuse and multi modal transport options through reset stakeholders, policy variables, evaluation indices according to the needs in practice since the model structure of CESDA is quite flexible.

(2) Limitations

Considering only the fundamental issues and evaluation indices, and ignoring many issues

and evaluation indices might influence the reasonability of the designed policy-set. For example, it is unreasonable that according to the calculated network-division scheme some expressways are separated although they belong to the same public corporation. To make the designed scheme more reasonable, it is necessary to include the operation-related evaluation index, i.e., geographic interconnection in the future research. In addition, the externalities such as environmental effects, commercial and political risks, should be included in the tool. It is not difficult to include these factors as evaluation indices according to the model structure of CESDA. However, more efforts have to be made on how to quantify them.

The toll rate to corporation correspondence assumption, to make the design analyzer workable, inevitably decreases the accuracy of policy-set design. Meanwhile, the assumption of one-road-one-company form for private company might be released through introducing risk-management design in the future research.

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