Efficient Restoration Strategy against Seismic Damage to Highway Traffic Network in Tokyo Area

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SUMMARY: EFFICIENT METHOD TO ALLOCATE RESOURCES TO DAMAGE ON NETWORK
The study establishes a restoration strategy against damaged highway network. Solutions of the Set Covering Problem (SCP) and Dynamic Programming (DP) are applied into the strategy. Links that is likely to be candidate of malfunction are grouped into some subsets solved by SCP employing the Lagrangian relaxation method. DP then fixes an order of priority for those subsets and optimizes allocation of costs of recovery projects. The expected value of reliability for traffic to be resumed to normal under restoration projects is proposed for the optimization by DP. SCP and DP are calculated based on travelers' disutility estimated from the Stochastic User Equilibrium Traffic Network Flow Assignment Model with elastic demand. The paper shows a result of numerical analysis.

Keywords: restoration strategy, highway networks, drivers' utility, set-covering problem, dynamic programming

1. INTRODUCTION

The need of reliability management on infrastructures on and after an earthquake has been fully acknowledged since the 2011 off the Pacific coast of Tohoku Earthquake. On a purely road traffic matter, it goes without saying that drafting countermeasures against deterioration of traffic services is one of the most vital and urgent task for the regional disaster damage prevention plan.

From the safety-oriented point of view, there are firmly rooted practices to take countermeasures by seismic retrofitting works to meet the only damage against bridges. While on the occasion of catastrophic disaster, it needs a method to contribute for evaluating features of elasticity to withstand quake not to deteriorate performance of traffic service, owing to one of factors influencing the reliability to traffic service.

Tokyo Metropolitan Government has acted on the behalf of settling damage of serious impairment of dwellers' way of life; fixed the order of priority for reconstructing highway bridges; utilized for disaster relief; taken seismic retrofitting projects using its prioritized order (2004-2). However, it is not clear whether these projects have been carried out to make a commitment to maintaining the reliability of traffic service.

Social infrastructure must be defined as one of assets to make a profit and offer convenience to road users. Thus there exists a mention to be deserved that assets evaluation of network-type infrastructure such as transportation facilities should be taken spillover effects, external effects, and risk of loss from earthquake damage into consideration.

Tsukai et al. (2002-2) offered a model of production function simultaneously capable of measuring both direct and indirect spillover effects, then showed that highway infrastructure improvement projects in one region are able to contribute to increase productivity in other regions'. This study offered valuable knowledge to urge the fundamentals of measuring flow value within transportation facilities on/after quake damage. Ito and Wada (2002-1) also, estimated life-cycle cost of highway bridges, incorporating earthquake loss, therefore urged the importance of considering transportation network flow analysis. On the other hand, Nakamura and Hoshiya (2004-1) applied the discounted cash flow method to measure assets value of highway bridges, combining cost of seismic retrofitting projects estimated from risk of loss by quake damage as well as earthquake insurance cost.

As far as the authors can tell, however, there are any studies directly on analyzing restoration method based on users' disutility against damaged transportation facilities. On the other hands, some restoration measures are prone to focusing upon the extent of physical loss or repair costs and geographical positions.

Hence the study establishes a restoration method aiming at minimizing inefficiency in traffic flow, i.e., travelers' disutility. In order to minimize drivers' disutility, the study develops a procedure composed of 2 steps: grouping and prioritizing. A process, a kind of feedback loop, first classifies all the damaged links into some groups by depending upon disutility, next fixes an order of priority to these subgroups, and thereafter reiterates a chain of steps eliminating a top-priority subgroup as the restored one. The established method is presented in the following chapters.

2. THE SET COVERING PROBLEM FOR DAMAGED LINKS

2.1. General Formulation

The Set Covering Problem (hereinafter abbreviates as SCP) is one of fundamental combinational optimization problems with features to make itself practicable to solve many applied problems in logic analyses on big data such as the Vehicle Routing Problem, the Facilities Allocation Problem, and the Crew Scheduling Problem. It is also difficult to calculate the optimal solution on big data within feasible computational time, since the SCP is categorized in NP-hard problems.

The study employs the SCP in order to make the analysis facilitate by letting many damaged links aggregate into some subsets. The highway network in Tokyo central area consists of many thousands of streets. It is expected that many unserviceable and/or malfunctioned streets take place during resuscitation phase. Packing many damaged links by some rule is required in the first place to evaluate effectiveness on restoration strategies and practical retrofitting projects under budget and/or funds constraints.

Let all elements in a set being composed of damaged links and family of its subsets denote $i \in M = \{1, 2, \cdots, m\}$ and $S_j(\subseteq M)$, $j \in N = \{1, 2, \cdots, n\}$. If and only if subset $X\ (\subseteq N)$ satisfies $\bigcup_{j \in X} S_j = M$, family of subsets $\{S_j \,|\, j \in X\}$ covers M . As given cost c_j for $S_j,\ j \in N$, to minimize total cost of covering $X\,(\subseteq N\,)$ of M becomes the SCP. The SCP is formulated as 0-1 Integer Programming problem as :

$$
\begin{aligned}
& Min.\ z(\mathbf{x}) = \sum_{j=1}^{n} c_j x_j \\
& \qquad s.t.\quad \sum_{j=1}^{n} a_{ij} x_j \geq 1, \quad \forall\, i \in m \\
& \qquad\qquad\ \ x_j \in \{0, 1\}, \quad \forall\ j \in n\ ,
\end{aligned}
\tag{2.1}
$$

where matrix $a_{ij} = 1$ when $i \in S_j$, otherwise $a_{ij} = 0$.

2.2. The Lagrangian Relaxation Problem and the Subgradient Method

In order to design an efficient algorithm, a relaxation method is generally employed for the SCP. As relaxing by the Lagrangian Relaxation method, Eqn. 2.1 can be translated as represented in Eqn. 2.2.

$$\begin{aligned}
Min.\ z_{LR}(\mathbf{x}) &= \sum_{j=1}^{n} c_j x_j + \sum_{i=1}^{m} u_i \left(1 - \sum_{j=1}^{n} a_{ij} x_j\right) \\
&= \sum_{j=1}^{n} \tilde{c}_j(\mathbf{u}) x_j + \sum_{i=1}^{m} u_i \qquad (2.2) \\
s.t. \quad & x_j \in \{0,1\}, \quad \forall\ j \in n,
\end{aligned}$$

where $\mathbf{u} \geq 0$, is Lagrangian multiplier, implicates coefficient of weight for relaxed constraint. One of feasible Lagrangian relaxation solutions is determined when $\mathbf{u}$ is fixed. Since functional relation between the dual costs $\tilde{c}_j(\mathbf{u})$ and the optimal Lagrangian solutions is formulated as :

$$\tilde{x}_j(\mathbf{u}) = \begin{cases} 1, & \tilde{c}_j(\mathbf{u}) < 0 \\ \{0,1\}, & \tilde{c}_j(\mathbf{u}) = 0 \\ 0, & \tilde{c}_j(\mathbf{u}) > 0 \end{cases}, \qquad (2.3)$$

Lagrangian optimal solution can straightforwardly be yielded. The objective of Lagrangian relaxation problem $z_{LR}(\mathbf{u})$ gives lower bound of original problem $z(\mathbf{x})$. In order to find the ideal lower bound $\mathbf{u}$, the study uses the subgradient method formulated as :

$$\begin{aligned}
& s_i(\mathbf{u}) = 1 - \sum_{j=1}^{n} a_{ij} \tilde{x}_j(\mathbf{u}), \quad \forall\ i \in m \\
& where \quad u_i^{(l+1)} = \max\left\{ u_i^{(l)} + \lambda \frac{z_{UB} - z_{LR}\left(\mathbf{u}^{(l)}\right)}{\left\| \mathbf{s}\left(\mathbf{u}^{(l)}\right) \right\|^2} s_i\left(\mathbf{u}^{(l)}\right),\ 0 \right\}, \quad \forall\ i \in m,
\end{aligned} \qquad (2.4)$$

here $\mathbf{s}(\mathbf{u})$ is subgradient vector and z_{UB} is upper bound of original problem $z(\mathbf{x})$. l is iteration number. The study calculates upper bound by employing the Greedy algorithm.

3. DYNAMIC PROGRAMMING FOR RESOURCES ALLOCATION

3.1. Resources Allocation Strategy

Resource allocation plan is the most vital strategy against the event of outbreak of catastrophic damage. Rebuilding damaged road bridges, for example, costs government many periods of time and extra expenses. It can readily be imagined with the prospects of economy that national and/or local government is, owing to budgetary deficit, adequately not able to adjust the budget for earthquake restoration projects. Reasonable and efficient handling of extraordinary disbursements from limited budget is indispensable. The study defines costs of reconstruction and investment schedule as resources. The paper shows a management method to optimize these resources. Dynamic Programming (hereinafter abbreviates as DP) can optimise an allocation of restricted resources in order to maximize effectiveness of spending restoration costs considering schedule costs.

Here let damage loss on each link and a set of damaged links be given. Also let damaged links be malfunctioned caused by damaged bridges. DP applied in the study is formulated as :

$$Max.\ A(\mathbf{b},\mathbf{t}) = \sum_{t\in T}\sum_{i\in I} r_i^t\left(y_i^t,\ l_i\right), \quad \forall\, t\in T, i\in I \tag{3.1}$$

$$r_i^t\left(y_i^t, l_i\right) = -l_i \cdot \frac{n_i^c}{n_i} \cdot \left[x\left(y_i^t\right) \cdot \int_{-\infty}^{x\left(y_i^t\right)} \omega\,(x)\, dx \right] \tag{3.2}$$

$$x\left(y_i^t\right) = 1.98\left(y_i^t\right)^{1.33} \tag{3.3}$$

$$y_i^t = \frac{b_i^t \cdot t^{-1} \cdot (1+d)^{-t}}{n_i} \tag{3.4}$$

$$s.t. \quad B = \sum_{t\in T} b_i^t, \quad \forall\, t\in T \tag{3.5}$$

$$1.0 \le y_i^t \le 2.5\,, \tag{3.6}$$

where $r_i^t(\cdot)$ represents effectiveness to invest costs of restoration against a set i of damaged links at time t such as profit or gain function. y_i^t is average investment costs by budget b_i^t with discount rate d substituting for the present value at time $t=0$. n_i and n_i^c is the number of all elements in a set i and the number of feasible elements restored with b_i^t. l_i is loss and/or disutility caused by damage on a set i. $x(\cdot)$ is, correlation function between the investment costs and the design response acceleration of bridges, derived from knowledge of the Hanshin-Awaji Great Earthquake Damage of January 17, 1995. $\omega(x)$ is Weibull distribution function. Hence, Eqn. 3.2 indicates an expected value of a reliability for traffic to be resumed to normal weighted by l_i. DP can produce the series of $\mathbf{b}$ by the principle of optimality along with t for i.

4. NETWORK TRAFFIC FLOW MODEL

4.1. Flow Estimation Model

The study defines that source demand (Origin) is given. Thus network traffic flow estimation model is one-sided constrained stochastic user equilibrium traffic assignment with elastic demand model, which is mathematically incorporating assignment estimation with OD trip distribution estimation into integrated model based on the Multinomial Nested Logit model.

Let a trip maker's origin, destination and chosen path denote r, s and k, respectively, and let conditional utility on k with given rs pair, combinational utility on rsk and utility being independent of choosing k denote $U(rs,k)$, $U(rsk)$ and $U(rs)$, respectively. Conditional utilities are shown as :

$$U(rs,k) = U(rs) + U(rsk), \quad \forall\, k\in K_{rs}, r\in R, s\in S \tag{4.1}$$

$$U(rs) = -C_{rs} + \xi_{rs}, \quad \forall\, r\in R, s\in S \tag{4.2}$$

$$U(rsk) = -c_k^{rs} + \varepsilon_k^{rs}, \quad \forall\, k\in K_{rs}, r\in R, s\in S\,, \tag{4.3}$$

where k_{rs}, R and S represents the set of path with given r and s, the set of origin and the set of destination, respectively. C_{rs} is a fixed cost being independent of path between the OD pair and c_k^{rs} is a travel cost on path k between the rs OD pair. ξ_{rs} and ε_k^{rs} are random error, giving analysts traveler's cognitive bias of path and destination choice behavior, independently ruled by Gumbel distribution with respective parameters. Usually, every ξ_{rs} and ε_k^{rs} is ruled by independent Gumbel distribution with its location parameter η and positive scale parameter μ, i.e., $G[\eta,\mu]$.

This study assumes an error $G[0, \theta]$.

The study postulates travelers' behavioral norm to be the state in which no user is firmly persuaded of one circumstance to economize their own destination and/or path choice cost by altering their own destination as well as path. Assuming that the above-mentioned criterion is adequate, user's travel choice behavior can formulate on the basis of Multinomial Nested-Logit model as destination choice to be the prior problem and path choice to be subordinate one. Giving numerical expression $P[k \mid rs]$ and $P[s \mid r]$ as a conditional probability of path choice between the rs pair and that of destination choice with origin r,

$$P[k|rs] = \frac{\exp\left(-\theta_1 c_k^{rs}\right)}{\sum_{k \in K_{rs}} \exp\left(-\theta_1 c_k^{rs}\right)}, \quad \forall\, k \in K_{rs}, r \in R, s \in S \tag{4.4}$$

$$P[s|r] = \frac{\exp[-\theta_2 (C_{rs} + S_{rs})]}{\sum_{s \in S} \exp[-\theta_2 (C_{rs} + S_{rs})]}, \quad \forall\, r \in R, s \in S\ , \tag{4.5}$$

where θ_1 and θ_2 is dispersion parameter ruling path choice probability and destination choice probability. S_{rs} is log-sum variable representing expected minimum cost of path choice between the ODs based on expected utility maximizing theorem :

$$S_{rs} = -\frac{1}{\theta_1} \ln\left[\sum_{k \in K_{rs}} \exp\left(-\theta_1 c_k^{rs}\right) \right] \tag{4.6}$$

According to stochastic formulas as shown in Eqn. 4.4 and Eqn. 4.5, the k-th path flow volume between the rs pair f_k^{rs} and the OD volume q_{rs} is formulated from given origin demand as Eqn. 4.7 and Eqn. 4.8 ;

$$f_k^{rs} = q_{rs}\ P[k|rs], \quad \forall\, k \in K_{rs}, r \in R, s \in S \tag{4.7}$$

$$q_{rs} = O_r\ P[r|s], \quad \forall\, r \in R, s \in S \tag{4.8}$$

The network flow satisfying Eqn. 4.4 - Eqn. 4.6 as well as flow conservation conditions Eqn. 4.7 and Eqn. 4.8 prove to be an equivalent mathematical nonlinear optimization problem as :

$$\begin{aligned} Min.\ Z(x(f), q) = & \sum_{a \in A} \int_0^{x_a} t_a(\omega)\, d\omega + \frac{1}{\theta_1} \sum_{r \in R} \sum_{s \in S} \sum_{k \in K_{rs}} f_k^{rs} \ln\left(\frac{f_k^{rs}}{q_{rs}} \right) \\ & + \frac{1}{\theta_2} \sum_{r \in R} \sum_{s \in S} q_{rs} \ln\left(\frac{q_{rs}}{O_r} \right) + \sum_{r \in R} \sum_{s \in S} q_{rs} C_{rs} \end{aligned} \tag{4.9}$$

$$s.t. \quad \sum_{s \in S} q_{rs} = O_r, \quad \forall\, r \in R \tag{4.10}$$

$$\sum_{k \in K_{rs}} f_k^{rs} = q_{rs}, \quad \forall\, r \in R, s \in S \tag{4.11}$$

$$f_k^{rs} \geq 0, \quad \forall\, k \in K_{rs}, r \in R, s \in S \tag{4.12}$$

$$q_{rs} \geq 0, \quad \forall\, r \in R, s \in S \tag{4.13}$$

Partial Linearization Algorithm (hereinafter abbreviates as PLA) can solve the mathematical formulas

Eqn. 4.9 - Eqn. 4.13. Transforming path flow variable of the 2nd term expressed by entropy in right hand of Eqn. 4.9 into link flow volume variable every origin nodes, and then applying the Dial algorithm in order to avoid enumerating a large number of paths, finally carrying out uni-dimensional search by the Frank-Wolf method, the mathematical problem can be equivalently solved.

5. TRAVELERS' DISUTILITY

5.1. Generalized Cost

User's profit assessed upon effects of highway maintenance, improvement and/or retrofitting projects is, based on the relation between the performance of traffic service and traffic demand, defined as consumer (user) surplus. It is assumed to be produced from having users' total bearing financial and schedule cost reduced. It is generally called generalized cost, meaning all of cost to be saved. The study, contrarily, treats increased generalized cost as user's loss occurred by mainly wasting of time.

Let traveler's disutility on OD volume, disutility on link volume, generalized cost with, and without seismic damage denotes D, d_{ij}, P^{with}, and $P^{without}$, respectively and let OD pair demand volumes with and without damage denote $Q^{without}$ and Q^{with}. The amount of disutility on OD volume and link volume is formulated as :

$$D = \frac{1}{2} \sum_{r \in R} \sum_{s \in S} \left(P_{r,s}{}^{with} - P_{r,s}{}^{without} \right) \cdot \left(Q_{r,s}{}^{with} + Q_{r,s}{}^{without} \right) \tag{5.1}$$

$$d_{ij} = \frac{1}{2} \sum_{r \in R} \sum_{s \in S} \left\{ t_{ij}\left({}^{with}x_{ij}^{r,s} \right) - t_{ij}\left({}^{without}x_{ij}^{r,s} \right) \right\} \cdot \left\{ {}^{with}x_{ij}^{r,s} + {}^{without}x_{ij}^{r,s} \right\} \tag{5.2}$$

Here, there are three types of generalized cost achieved from the stochastic user equilibrium model; minimum cost, expected minimum cost and average cost. The average cost is easily produced by PLA method employed in the study. The average cost (generalized cost) between the origin r and destination s, P_{rs}, is formulated with denoting k for any path,

$$P_{rs} = \frac{1}{Q_{rs}} \sum_{k \in K_{rs}} f_k^{rs} \cdot c_k^{rs} = \frac{1}{Q_{rs}} \sum_{ij \in L} x_{ij}^{rs} \cdot t_{ij}\left(x_{ij} \right) \tag{5.3}$$

Since PLA method is not needed to enumerate path volumes between the ODs, as seen in the 3rd term of Eqn. 5.3, only link volumes from every origin and destination can produce average cost.

6. MATHEMATICAL ANALYSIS

6.1. Network Topology, Damage and Its Constitution

The purpose of the study is to establish and verify an evaluation system for effectiveness on restoration strategy and practical retrofitting projects under network flow performance and travel time of travelers' disutility with and without damage. Thus the network being investigated is on Tokyo metropolitan central area but abstracted only major highways from actual network. Let assume network damage be occurred against road bridges (includes overpass). Let its topology of the network and locations of highway bridges be real while characteristics of every link (for instance, link capacity, free flow speed, the number of lanes and so on) be minimally modified. The network is composed of 533 nodes (including centroids, i.e. source/sink points), 1802 directed links (including dummy links) and 84 OD pairs. The 274 links with 300 bridges are configured to be damaged in the analysis.

6.2. Model Parameters Arrangements

The details of parameters for the network flow model mentioned above are shown in **Table 6.1**. Every OD pair volume will change in searching process for the optimal equilibrium point, since feasible solution of those are elastically estimated in accordance with network flow performance in the operational process. However, the initial OD pair volumes employ a traffic census data; approximately 4 million vehicles per day in control total. Every average travel time between the OD pairs, observed by field survey, substitutes for the fixed trip cost. Hourly capacity of every directed link is at first commensurately calculated to the number of lane with the postulation that link hourly capacity per lane = 1,800 vehicles/hr./lane. Next, an entire day capacity of every directed link is calculated by conversion rate for entire day capacity, γ_a, as 17.9325 (1989), since the analysis operates in units of 24 hours. Directed link performance function uses modified BPR function (developed by US Bureau of Public Road) and its exogenous parameters are equals in every link (2003). Free travel time of links, $t_a(0)$, is reckoned by its distance and speed of 48, 60 and 72 km/hr, respectively, in proportion of the number of lanes on one side of street.

Probability distribution of destination and path choice generally gets decreased as variance factor $\theta \to +\infty$, i.e., control variable for distribution θ_1 and θ_2. Although parameter θ_1, out of the range of $[0.1, 1.0]$, especially has more effect on estimating directed link volumes (2004-2), an elastic demand type model, however, cannot be solved straightforwardly, since θ_1 and θ_2 affects each other in estimating process. Upon this, both control variable of destination choice probability and path choice one, as shown in **Table 6.1.**, are calibrated so as to increase variance.

Table 6.1. Exogenous Model Parameters Arrangements

Parameters/Control Variables	Specification	Notes
OD Pairs	84×84=7,056	Not included inner volumes
Initial OD Volumes	$\cong$ 4 million veh./day	Control total of Census
Links	1,802	Both sides
Nodes	533	Includes source/sink points
Link Capacity C_a	1,800 veh./hr./l.	Identical in links
Lanes	1, 2, or 3 on one side	-
Conversion Rate for Entire Day γ_a	17.9325	Identical in links
Free Flow Speed $t_a(0)$	40, 60, 72 km/hr.	-
BPR's Parameter α	2.62	Identical in links
BPR's Parameter β	5.2	Identical in links
Control Variable for Destination choice θ_2	Elastic:0.01068	-
Control Variable for Path Choice θ_1	Fixed:0.128, Elastic:0.01068	-
Fixed Cost C_{rs}	Substitute Observed Average Trip Time	

6.4. Estimated Travelers' Disutility

The amount of travel disutility of all drivers is estimated as shown in **Table 6.2.** It is calculated on the supposition that all of 274 bridges are damaged and capacity of each link with bridge is reduced to 99.0 percent. **Figure 6.1.** and **Figure 6.2.** respectively illustrates the outcome of estimated network flow of one-way direction with and without damage.

Table 6.2. Estimated Disutility of Users (OD base)

Δ OD vol. time	ΔQ_{rs}	ΔP_{rs}	Loss (Negative Surplus)
(veh.hr.)	(veh./hr.)	(hr.)	(veh.hr.)
-1,049,598.1	7,502.3	-2,700.9	-1,299,885.6

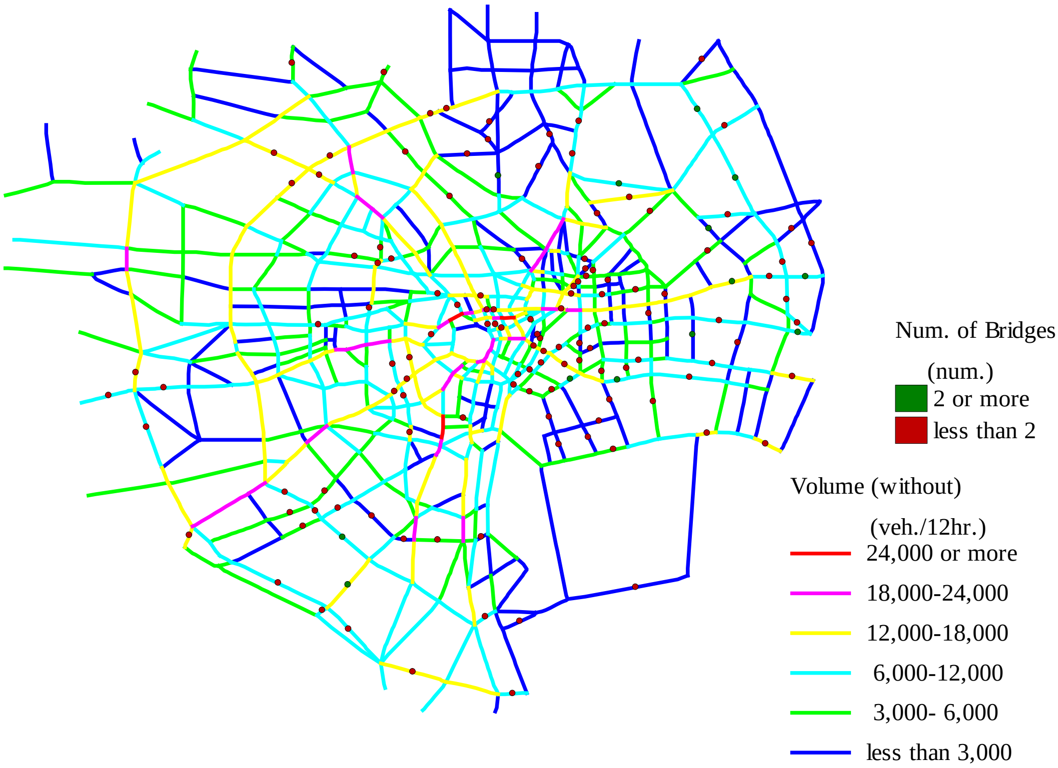

Figure 6.1. Estimated Network Flow of One-way Direction (without Damage; Fixed Demand)

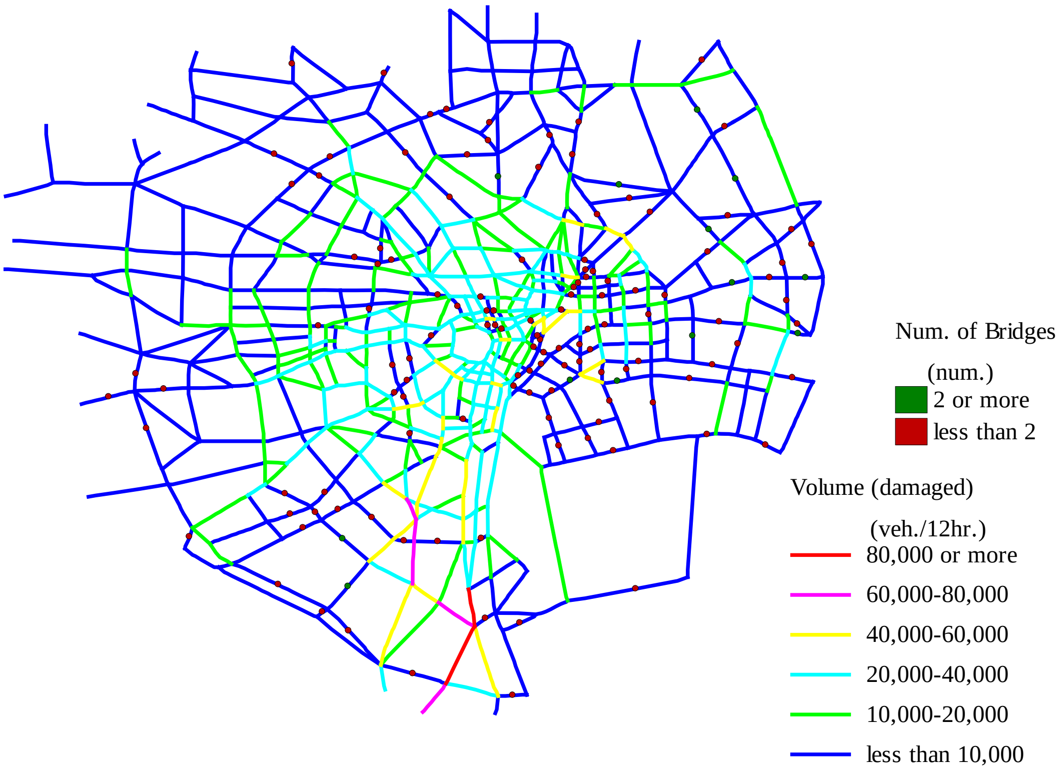

Figure 6.2. Estimated Network Flow of One-way Direction (with Damage; Elastic Demand)

6.5. Numerical Analysis by the SCP and DP

6.5.1.The SCP

Once each of travelers' disutility on links is estimated by Eqn. 4.9 - 4.13 and Eqn. 5.2, the optimal solution of the SCP can be easily worked out.

The optimal problem requires the set of damaged links, cost of elements within the set, and a combination of the elements as the subjects. The study obtained 5 benchmark problems belonging to moderate-to-solve class from the OR Library. The number of the elements of a set in a benchmarks' is, equal to the analysis, 300. Each cost of element is yielded from the network flow. The number of a combination of elements equals 3,000. Since solutions of the benchmark problems are previously confirmed, the study, in advance, could verify whether a self-written program is correct or not.

As the result of computes, the elements of a set, to be damaged 300 links, are grouped into 67 subsets on the case of the minimal objective. The results are shown in **Table 6.3**.

Table 6.3. Results of the SCP with Benchmarks

	Case-1	Case-2	Case-3	Case-4	Case-5
Number of covers	66	67	68	71	71
Objective (negative surplus)	611756.9	586338.5	591920.3	603705.2	614108.9

6.5.2. DP

As information about the optimal solution of set cover and travelers' disutility are yielded, DP can optimize resources allocation. Let analysis time, i.e. restoration periods of time in a restoration cycle, be 12 months. Discount rate substitutive of present time $d = 5.0\,\%$. Total reconstruction costs $B = 36.0$ unit within a cycle. Weibull distribution is calculated with letting Weibull modulus m be 1.0 and scale parameter η be 2.4. The other family of sets of links to be damaged is prepared for the subject of comparison with the proposing method. This is composed of 6 sets established by depending on geographical position. The optimal solutions of DP for two cases are illustrated as **Figure 6.3.** and **Figure 6.4.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1																															2			
2						1		1		1			1			1							1					1						
3		1															1		1															
4							1							1								1			1	1			1				1	
5					1				1		1													1								1		
6	1		1	1								1						1		1	1						1			1				1
7															1																			

	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	**Obj.**
1																								10										**330**
2			1											1								1					1					1		**1320**
3		1				1			1						1			1	1							1		1			1			**743**
4								1		1		1								1													1	**535**
5				1			1				1										1		1		1				1					**367**
6	1												1																					**212**
7					1											1	1													1				**41**

Figure 6.3. The optimal solution of DP for Subsets yielded by the SCP

	1	2	3	4	5	6	**Obj.**
1	6		3	3			**120**
2		2			2	2	**196**

Figure 6.4. The optimal solution of DP for Comparison

The row indicates resource allocation cycle of restoration work, and the column shows the subsets' number. A numerical value in one cell represents an assigned cost of investment unit. The end of column indicates optimal objective of DP. As shown in **Figure 6.3.** and **Figure 6.4.**, the proposing method incorporating with the SCP is promising, since the expected values of reliability for traffic to be resumed to normal, equals to calculated objective of DP, is estimated at high compared with no implementation with the SCP. It is inducible that to allocate poor and/or restricted resources randomly to many damaged infrastructures at one time has little effect. Rather than restoring many damaged infrastructures all at once, allocating a small quantity of costs for reasonably selected damaged infrastructures and then carrying out the restoration projects in some periods of time is beneficial.

7. CONCLUTION

The paper proposed a method of allocating resources for restoration strategy and showed its effectiveness. The results are summarized as :

(1) SCP is effectual method to sort out many damaged links based on drivers' disutility.
(2) Proposed function to estimate expected value of reliability for traffic to be resumed to normal under restoration projects which is applicable for DP is convincing to use.
(3) DP is useful in allocating restricted resources for damaged infrastructures.
(4) To estimate network traffic flow by static model becomes practicable, but dynamic model is required.

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