Evaluation and Analysis of Disaster Resilience in Relation to the Scheduling of Road Network Restoration

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Introduction

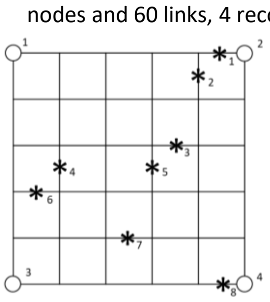
- The term resilience refers to the capability to regain functioning after the damage caused by a disturbance. Quantitative evaluation is used to address questions related to resilience in engineering contexts.
- This study proposes a method of evaluation and analysis to schedule the restoration of road networks in devastated areas after an earthquake.
- We formulate the scheduling of the restoration of a road network as a combination of problems of optimization. The proposed method simulates the restoration of road networks and optimizes task allocation and the scheduling of recovery teams. The optimization method called genetic algorithms is used to find the optimal restoration scheduling.
- The proposed method applies resilience-triangle-based evaluation to objectively evaluate restoration scheduling. This approach leads to the ability to evaluate, compare, and analyze various restoration strategies from the viewpoint of resilience.

Methods

- The proposed method determines which recovery team should work on which affected site and in what order affected sites must be recovered.
- This study combines and formulates the appropriate assignment of recovery teams and proper work orders as an optimization problem to determine a recovery plan. Genetic Algorithms (GAs) (a random searching algorithm) is used to determine the recovery plan.
- The proposed method expresses the order of road recovery and the appropriate assignment as genes in GAs and evaluates the appropriate recovery plan via recovery simulation.

An example of analysis model

- Road networks consist of nodes and links. Recovery simulations assume that road recovery work will begin immediately after great damage is caused by an earthquake.
- Road recovery teams and road damage conditions for determining a recovery plan is set on nodes and links, respectively. We set two analysis conditions: a) position and capability values of construction workers and b) position and amount of road damage.
- The best combination of road recovery teams' arrangement and construction order is retrieved using GAs to determine a plan to complete recovery early.
- Below figure and tables shows an example of an analysis model. The network comprise 36 nodes and 60 links, 4 recovery teams (shown with ○), and 8 damaged roads (shown with *).



An example of networks.

Damaged roads (shown with *).

No	Value	Priority
1	10	1
2	10	1
3	20	5
4	5	3
5	15	3
6	13	2
7	20	1
8	3	4

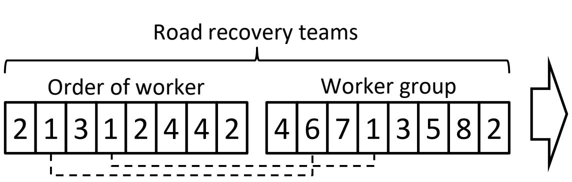
Recovery teams (shown with ○).

No	Ability
1	3
2	5
3	4
4	2

A road recovery team is set on the nodes. The recovery ability means the debris processing capability in an hour [m^3/h]. A Road damage is set on the links. It means the debris amount[m^3].

Coding rule of GAs

- Coding rules are comprised of service orders and teams for each task.



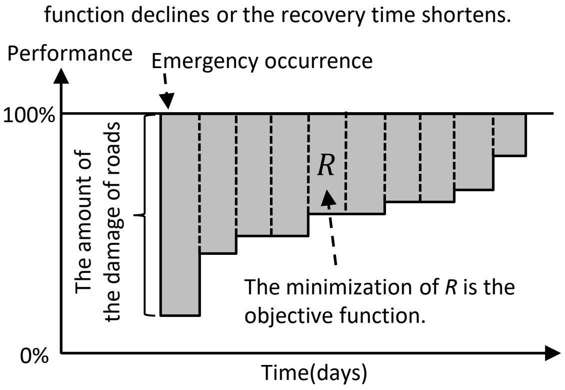
a) Genotype

Worker group	Order of worker
Team 1	6 → 1
Team 2	4 → 3→ 2
Team 3	7
Team 4	3 → 5

b) Phenotype

Objective function of GAs

- The objective function evaluates the recovery plan determined by GAs. The proposed method uses the minimization of the size of the area of the resilience triangle.
- The resilience triangle (Bruneau et, al. 2003), a means of evaluating resilience, provides a measure of both the loss of functionality of a system following a disaster and the amount of time required before the system can return to normal performance levels.
- The resilience triangle can be visualized as a shaded area in below figure. The vertical axis represents the loss of function, and the horizontal axis represents time. The resilience triangle evaluates the size of the area from the state of functional deterioration to that of recovery. Smaller areas represent greater resilience. The size of the triangle shrinks when the loss of function declines or the recovery time shortens.



$$R = \sum_{d=1}^{D} (1 - road(d))$$

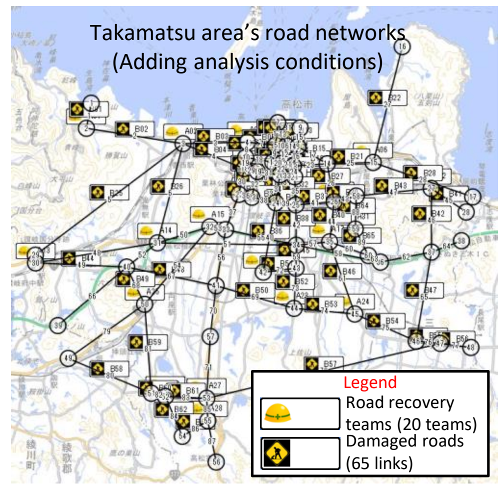
$$road(d) = \frac{\sum_{i \in J^d} rd_i \times w_i}{\sum_{i \in J^0} rd_i \times w_i}$$

D : dates for completing recovery *road(d)*, until the end of the plan.
J_0 : the group of numbers of affected roads
J_d : the group of numbers of roads that become passable by day *d*.
rd_i : the *i*th road damage amount is expressed by the product of damage amount.
w_i : road importance.

Results

Analysis Conditions

- This study presents an case analysis of road networks in Takamatsu city in Japan.
- The following four cases with different clearing priorities were created. The difference in priority roads in each case was considered by changing the road importance value w_i = [1, 3, 5] in the objective function of GAs.



The road network comprise 60 nodes and 87 links.

Road recovery team	In the Takamatsu city model, 20 teams and capability values of 214-1007[m^3/h] (mean 481, standard deviation 238) were set. Work time per day was 12 hours (including preparation time of 2 hours and travel time calculated based on the distance to the work site). Traveling speed was set at 15[km/h].
Road damage	Debris damage [m^3] that blocks roads on links in road networks is set. In the Takamatsu city model, 65 points and damage amounts of 560-34328 [m^3] (mean 7424, standard deviation 7444) were set.

Case	Name	Description
Case 0	No Priority	Ignored the priority of road recovery by using the same road importance value
Case 1	Compliant with guideline	The first, second and third priority roads are determined based on the publicity guideline.
Case 2	Medical facilities prioritized	Roads near the medical facilities are set the highest priority.
Case 3	Lifeline facilities prioritized	Roads near the lifeline facilities are set the highest priority.

Analysis Results and Discussions

- In four cases, roads are recovered most promptly in eight days: Case studies 0 and 1, as shown in Fig. 1. This is followed by Case study 2 in 9 days, and Case study 3 in 10 days.
- The recovery rate increased most rapidly in "Case 1: compliant with guideline." This seems to be because of effective recovery through the concentrated recovery of the central area with many first priority routes.
- In Case 3, where lifeline facilities were prioritized, road recovery was not effective because the routes to lifeline facilities were distributed over a broad area.
- These results showed that road recovery proceeded most rapidly in "Case 1: compliant with guideline," and there was little difference, suggesting the effectiveness of road recovery planning according to guidelines.

- We also analyzed the effect of medical facilities in each case. Fig. 2 shows the number of available facilities.
- All medical facilities became available most rapidly in "Case 1: compliant with guideline," while the number recovered was largest in "Case 2: medical facilities prioritized" in the first stage of recovery. Therefore, the entire district recovered most rapidly in Case 1, whereas Case 2 could be chosen when medical facilities must be recovered quickly.
- Case 2 reduced the recovery time of routes to medical facilities and indicated the importance of recovery purpose clarification. In particular, in the road network of Takamatsu city, clarifying the recovery purpose effectively led to the prompt recovery of the entire district.

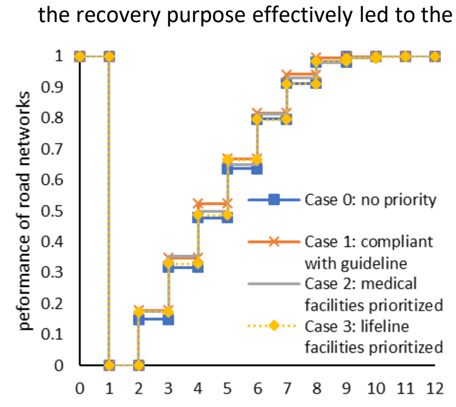


Fig. 1 Road recovery rate in the four cases.

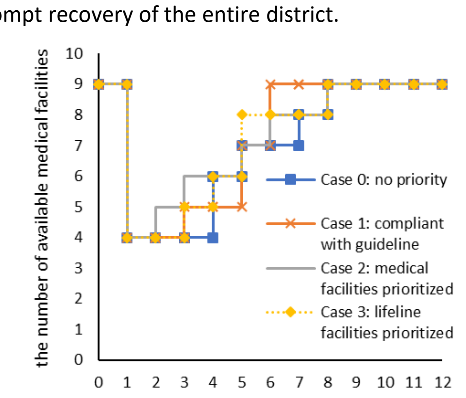


Fig. 2 The number of medical facilities available.

Conclusions

- This study presented several examples of scheduling of restoration for road networks are presented to demonstrate how resilience evaluation can be implemented.
- When the proposed method is introduced to evaluate restoration scheduling, disaster response effects could then be quantified in relation to increases in disaster resilience, and the effects of disaster reduction and resilience can be provided as an objective index.

Acknowledgements

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