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Optimal Restoration Scheduling of Damaged Networks Under Uncertain Environment by Using Improved Genetic Algorithm

Hitoshi FURUTA[1,**], Ken ISHIBASHI[2], Koichiro NAKATSU[1], Shun HOTTA[2]

1. Department of Informatics, Kansai University, Takatsuki, Osaka 569-1095, Japan;
2. Graduate School of Informatics, Kansai University, Takatsuki, Osaka 569-1095, Japan

Abstract: The purpose of this research is to propose an early restoration for lifeline systems after earthquake disasters. The previous researches show that the optimization of the restoration schedule by using genetic algorithm (GA) is powerful. However, those are not considering the uncertain environment after earthquake disasters. The circumstances of the damage at devastated areas are very changeable due to the aftershock, fire disaster and bad weather. In addition, the restoring works may delay by unexpected accidents. Therefore, it is necessary to obtain the restoration schedule which has robustness, because the actual restoring works could not progress smoothly under the uncertain environment. GA considering uncertainty (GACU) can treat various uncertainties involved, but it is difficult to obtain the robust schedule. In this study, an attempt is made to develop a decision support system of the optimal restoration scheduling by using the improved GACU.

Key words: restoration schedule; genetic algorithm; uncertainty; delay of schedule

Introduction

In recent years, serious earthquakes have frequently occurred in Japan. In the near future, there is the fear that large earthquakes occur. Therefore, it is necessary to minimize damages caused by such earthquake disasters.

Nowadays, our life is based upon various lifeline systems. If these lifeline systems are not workable properly with earthquake disasters, our life suffers from serious damages. Therefore, it is necessary to develop a synthetic disaster prevention program based on the recognition that lifeline systems may unavoidably suffer from damages when big earthquakes occur.

The main purpose of this research is the early restoration of lifeline systems after earthquake disaster. Here, two issues are focused on, the first of which is such an allocation problem that which groups will restore which disaster places, and the second is such a scheduling problem what order is the best for the restoration. In order to solve the two problems simultaneously, genetic algorithm (GA) is applied, because it has been proven to be very powerful in solving combinatorial problems. However, road networks after earthquake disasters have an uncertain environment, that is, the restoring works are not progressing on schedule. The actual restoring process should be performed by considering various uncertainties. GA considering uncertainty (GACU)[1] can treat various uncertainties involved, but it is difficult to obtain a schedule which has robustness. In this study, an attempt is made to develop a decision support system of the optimal restoration scheduling by using the improved GACU.

The environment after earthquake disasters has various uncertainties. When a restoration team arrives at the site, the disaster circumstances may be different from those predicted, because devastated situations are constantly changing by the aftershock, fire disaster and bad whether, which are likely to make damage worse. Such a change of devastated area affects the scheduling

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** To whom correspondence should be addressed.
E-mail: furuta@res.kutc.kansai-u.ac.jp

process, because it takes more days than those scheduled, and furthermore it may be impossible to restore unless the restoration teams have enough ability. In addition, restoration works may delay by unexpected accidents like the shortage of materials. In this study, the uncertain factors of the restoration works are defined as the change of damages and the delay of restoring days. The restoration scheduling problem is formulated as an optimization problem with uncertainties.

1 Road Network

Here, it is assumed that a road network is damaged, in which multiple portions suffer from damage so that it can not function well. The objective of this study is the realization of quick restoration of the road network. It is intended to determine the optimal allocation of restoring teams and scheduling of restoring process.

Then, the following conditions should be taken into account.

(1) The optimal allocation and scheduling must be determined simultaneously.

(2) A portion of the link suffers from several kinds of damages with a hierarchical relation in time.

1.1 Existing road network

As an example of restoration, an existing road network in Kobe, Japan is considered, which has 164 nodes and 228 links as shown in Fig. 1[2,3].

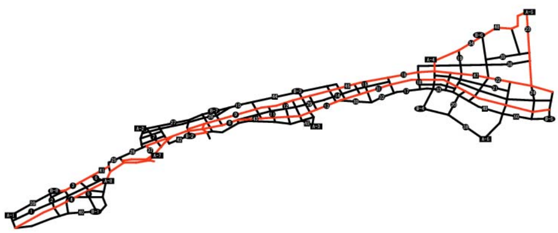

Fig. 1 Example of road network

For this road network, the following restoration works are necessary to recover the function.

(1) Work to clear the interrupted things: 38 sites;

(2) Work to repair the roads: 50 sites.

Each restoration work sets the amount of damage and the importance degree of the link. The importance degree of the devastated link indicates how it is important on the road network by three categories i.e. level 1 (less important), level 2 (important), and level 3 (most important). In this study, the importance degree can be considered to be constant through the restoration process, because the importance degree is determined based on the normal condition.

In this study, it is assumed that there are eight restoration teams for each category of work. The abilities of all teams are not equivalent because each team has different equipments and works.

1.2 Calculation of restoration rate

A calculation method of restoration rate was proposed by Sugimoto[4]. Weighting factors are prescribed for the links with damage, which are denoted by $W_i (i = 1 - n_L)$, where n_L is the total number of damage links. Then, the restoring rate after q days, R^q, is expressed as

$$R^{(q)} = \frac{\sum_{i \in J^q} W_i \times l_i}{\sum_{i \in J^0} W_i \times l_i} \quad (1)$$

where l_i is the distance of the *i*-th link, J^0 is the set of damaged links, J^q is the number of restored links until q days after the disaster, and W_i is the weighting factor of the *i*-th link.

Then, the objective function can be calculated by using the restoring days and the restoring rate. The relation between restoring day and restoring rate is shown in Fig. 2. The area of the colored portion should be minimized to obtain the optimal solution, which enables not only to shorten the restoring days but also to restore the important links fast.

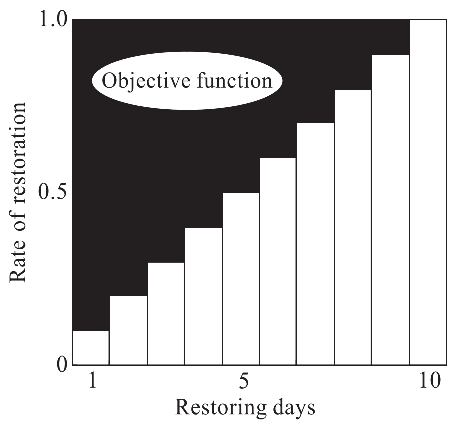

Fig. 2 Relation between restoring day and restoring rate

Restoring days are calculated for each restoring work, and the minimum days necessary for each work is given as

$$d = h / t_1 \tag{2}$$

where h is the restoration time required to complete the restoration work. In this study, the restoration time is calculated by using the restoration rate for each work and the capability value. The relation between the restoration rate for each work and the capability of the team are shown in Fig. 3.

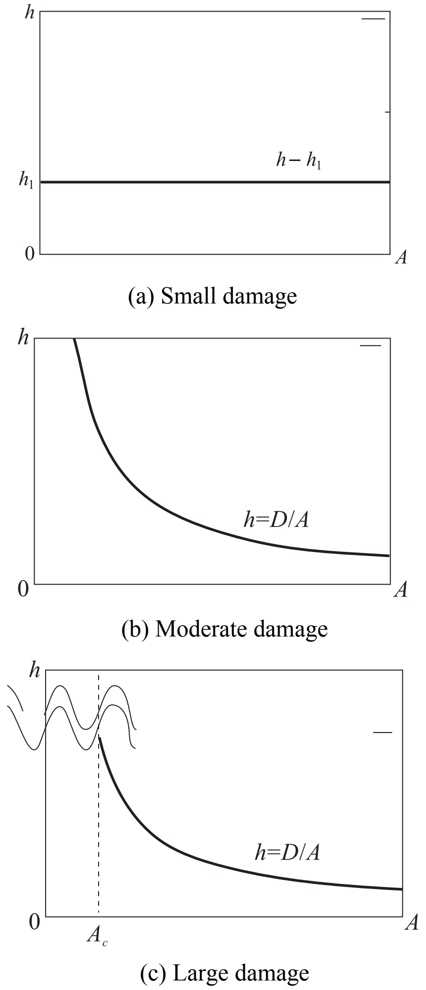

Fig. 3 Relation between restoration rate for each work and capability of the teams

The restoration rate is given as follows:

(1) Small damage: In the small damage, there is no difference in capability among each team. The restoration will be completed during a fixed time. Here, 4 hours are assumed.

$$h = h_t \tag{3}$$

(2) Moderate damage: In the moderate damage, there is some difference in capability among every team, however, every team can restore the damage.

$$h = D / A \tag{4}$$

where D is the amount of damage and A is the capability of the team, that is, the restoring amount per hour.

(3) Large damage: In the large damage, only some teams can restore, because other teams have no restoring equipment and facility necessary for the large damage.

$$h = \begin{cases} \infty & (A < A_c) \\ D / A & (A \geqslant A_c) \end{cases} \tag{5}$$

The working hours per day of a restoration team is calculated by Eq. (6), where t_m is the arriving time at a site.

$$t_1 = t_0 - 2t_m - h_c \tag{6}$$

The shortest distance from the waiting place of the restoration team to the site is expressed as L (km), and the moving speed of the team is set to be v (km), and h_c is the preparation time necessary for every works.

$$t_m = L / v \tag{7}$$

1.3 Influence of uncertainty in restoring works

At a devastated area after earthquake disaster, the circumstances are changing with aftershock, fire and bad weather. The devastated area may not be constant and may make the damage. In addition, restoration works may delay due to unexpected accidents like the shortage of materials. This is due to the uncertainties which occur from the followings:

(1) Delay;

(2) Impossibility to restore.

Delay induces the increase of restoring days of a work. Delay of the work influences the whole restoring schedule. Delay caused by changes of the degree of damages can be minimized by allocating the large damage work to the restoration team which has the high ability of restoration. However, the delay which not occurred by changes of the degree of damages but unexpected accidents can not be contained. Impossibility to restore is the situation that a team without sufficient restoring equipment and facility is assigned to large damage work. Such teams are not possible to restore the large damage work. Impossibility to restore a work causes failure of restoring schedule.

In this study, the following uncertain factors are considered for works selected randomly:

(1) Increase of damage;

(2) Delay of restoring days.

The change of the devastated area is assumed as that some amounts of the damages are increased. The increase of damage is given by random numbers generated by Gaussian distribution with the average of 0.3 and the standard deviation of 0.1. The delay which occurred due to unexpected accidents is assumed the delay of restoring days. The delay of restoring days is given by random numbers generated by Gaussian distribution with the average of 0.0 and the standard deviation of 3.0. Each uncertain factor occurs with the probability of 0.3. In this study, the value of these uncertain factors is more than 0.0.

2 Restoration of Road Network Using GACU

When there are two kinds of repair work, coding of genes is carried out as shown in Fig. 4. The numbers in the row of team mean the identifying numbers of teams. They correspond to the left numbers of repair work. Using the coding, it is possible to determine the allocation and scheduling simultaneously.

Restoration work A									
Schedule					Team				
1	3	4	5	2	0 1	0 0	0 0	0 0	0 1

Restoration work B									
Schedule					Team				
5	2	3	4	1	0 1	1 1	1 0	0 0	1 1

(a) Gtype

Restoration work A									
Schedule					Team				
1	3	4	5	2	1	0	0	0	1

Restoration work B									
Schedule					Team				
5	2	3	4	1	1	3	2	0	3

(b) Ptype

Fig. 4 Coding

2.1 Genetic algorithm considering usncertainty

In order to obtain an optimal schedule considering uncertainties, an attempt is made to use GA considering uncertainty (GACU) which was proposed by Tamaki[1]. GACU estimates the expected value of candidates of optimal schedule, by implementing the search process with sampling. This sampling is performed by considering the evolution mechanism of inheritance. The procedure of GACU is given as follows:

(1) Generation of initial population;
(2) Re-evaluation and adding age;
(3) Selection of parents;
(4) Crossover and mutation: generation of new individuals;
(5) Evaluation: evaluation of new individuals;
(6) Natural selection;
(7) Steps 2 to 6 are repeated until the convergence is achieved.

GACU is applied to obtain the optimal robust restoration schedule. Table 1 presents the parameters of GACU used here. The optimal robust scheduling plan is presented in Fig. 5. Figure 5 presents the timetable that satisfies the constraints of completing date for each work and hierarchical relation in time.

Table 1 Parameters of GACU

Parameters	Values
Population	1000
Generation	500
Probability of crossover	0.6
Probability of mutation	0.005

The portion colored by gray means the waiting time without doing any work, and the team which has no restoring equipment and facility necessary for the large damage is colored. Light gray works show large damage works, and black works show medium damage works which are changeable to the large damage state. Table 2 presents the result by 1000 times simulation, which can check the robustness of restoration schedule given in Fig. 5. The simulation has uncertainties of damage and delay. In Table 2, "Impossibility number" means the number of occurrence of impossible restoration.

Table 2 Result by 1000 simulations

Items	Values
Average of evaluation	13.21
Standard deviation	1.250
Impossibility number	26/1000

In Fig. 5, it is seen that the medium damage work which has high possibilities of changing to large

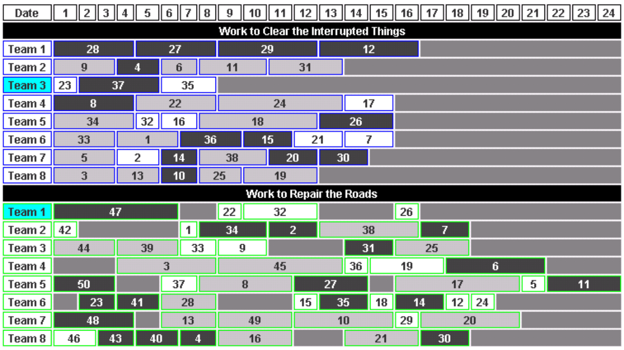

Fig. 5 Result by GACU

damage state is allocated to the team which has no restoring equipment. The robust scheduling plan may be obtained by this method, but the frequency of obtaining robust solutions is low. Therefore, this method has no practicality. In addition, the frequency of obtaining robust solutions is higher than GACU's.

GACU can search for local solutions effectively with its sampling. However, this method is more likely to go into the initial convergence because the ability of searching for local solutions is more powerful than the ability of searching for global solutions.

3 Restoration of Road Network Using Improved GACU

Improved GACU (IGACU) is improved to search local and global solutions effectively. IGACU uses the maintenance of diverseness with the density of individuals. This method can maintain the diverseness of individuals which have equal evaluations. The procedure of IGACU is given as follows.

(1) Generation of initial population;

(2) Re-evaluation and adding age;

(3) Selection of parents: prior selection of elder individuals partially;

(4) Crossover and mutation: generation of new individuals;

(5) Evaluation: evaluation of new individuals;

(6) Natural selection: selection considering the diverseness of individuals;

(7) Steps 2 to 6 are repeated until the convergence is achieved.

IGACU is applied to obtain the optimal robust restoration schedule. The parameters of IGACU are the same as GACU's. In step 3, IGACU selects preferably 30 percents of elder individuals. The optimal robust scheduling plan is presented in Fig. 6. The result by 1000 simulations is shown in Table 3.

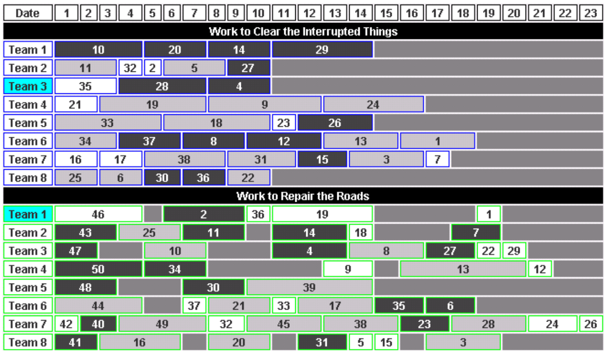

Fig. 6 Result by IGACU

Table 3 Result by 1000 simulations

Items	Values
Average of evaluation	13.51
Standard deviation	0.879
Impossibility number	0/1000

In Fig. 6, it is seen that the medium damage works which are changeable to large damage state is allocated to the team which has no restoring equipment. However, the impossible restoration does not occur in the simulation. The medium damage work which is very changeable to the large damage state is not allocated to the team which has no restoring equipment, then that probability is very low. Therefore, this scheduling plan has the robustness to uncertainties of the increase of damage and the delay of restoring days.

In this study, assuming that a restoration work of road network has uncertain damage and delay, it is intended to obtain the optimal restoring schedule considering uncertainties. From these results, it is concluded that the proposed method using IGACU is useful for obtaining the optimal restoring schedule with robustness to uncertainties of damage and delay.

4 Conclusions

In this study, an attempt was made to develop a new method to obtain a robust restoring plan considering the uncertain circumstance after earthquakes.

Through the numerical example, the following conclusions were derived.

(1) GACU is the method which can treat various uncertainties involved. However, it was difficult to

obtain the scheduling plan considering the uncertainties of damage and delay by using GACU. GACU is more likely to go into the initial convergence because the ability of searching for local solutions is more powerful than the ability of searching for global solutions.

(2) GACU can obtain the robust scheduling plan, but the frequency of obtaining robust solutions is low. The frequency of obtaining robust solutions is important in the optimization with considering uncertainty, because the characteristics of the robust solution are not identified generically.

(3) Applying IGACU, it is possible to obtain a restoration schedule which has robustness to the uncertainties of damage and delay. In addition, the frequency of obtaining robust solutions is higher than GACU's.

(4) In this study, one restoring work is allocated to a single group. However, the actual restoring works are performed by multiple groups in some cases. The restoring work performed by multiple groups is expected to be effective to the large damage works and the optimization considering uncertainties. Therefore, it is necessary to study the restoration considering the restoring works performed by multiple groups.

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