A Fuzzy Multi-objective Model for Reconstructing the Post-quake Road-network by Genetic Algorithm

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Abstract

Earthquakes have often led to many damage points throughout the road-network in Japan and America. Therefore, mass travelers can't be efficiently conducted via the post-quake road-network. Since the road-network is important to maintain the basic life and daily transit after disaster, it is very necessary to develop available reconstruction strategies for the broken road-network. To aid the reconstruction decision for a post-quake road-network, the fuzzy multi-objective model is established as a simulation model of reconstruction scheduling with many work-troops. Furthermore, a technique of asymmetric traffic assignment is also employed as to measure the effectiveness of a reconstruction schedule. Study results show that a satisfying solution can be efficiently derived by our modified genetic algorithm. This solution not only can instruct the reconstruction order, but also can assign the appropriate reconstruction work to relevant work-troops. Nevertheless, this research can be a guideline for the pre-quake exercise.

Keywords: earthquake, fuzzy, network, traffic assignment, genetic algorithm.

1. Introduction

Taiwan as well as Japan and America are all located in the unstable earthquake region, where a big quake is possible to occur. According to the seismic experiences of Japan and America, earthquakes have often led to many damage points throughout the post-quake road-network, hampering the post-quake transit for basic life and economical activities. To promote the post-quake transportation effectiveness, a well considered reconstruction plan for the post-quake road-network has become a must [31,32]. Thus, an appropriate reconstruction plan of the seismic road-network is considerably designed.

First of all, the damage characteristics of seismic road-network are taken into consideration. In the case of Northridge earthquake in America, there are many damage points scattered throughout the post-quake road-network– this situation is shown in Figure 1 [5]. The black spot denotes the scale of the earthquake measured by a local earthquake-meter, and the gray spot indicates the slump area. Therefore, the reconstruction task for each damage point should be reasonably assigned to each work-troop on duty so as to maximize the reconstruction effectiveness. The effectiveness of reconstruction can be maximized by: (a) minimizing the total reconstruction time; (b) maximizing the convenience for travelers in a road-network during reconstruction; (c) minimizing the idle time between any two work-troops (equity index of workload).

Secondly, the schedule model for reconstruction is a combinatorial optimization problem. In actuality, the schedule model is the expansion of work assignment model to incorporate the desired objectives, e.g., minimizing the total working time [13,34]. Relative researches by many authors could be easily found, for example, the scheduling problem solved by branch and bound method [4,29], by genetic approach [7,9,10,31,32], by multi-objective approach [11,17,21,22], etc.

Thirdly, this study is far different from aforementioned traditional models in many aspects: the traffic volume in the road-network will be dynamically updated as the reconstruction order varies; thus, our problem is somewhat similar to the network design problem (NDP). A NDP is often formulated with a bi-level model; thus, our formulation in this study also follows the similar concept [12,33]. The upper level of our model is finding the optimal work schedule by many work-troops, and the lower level is the asymmetric traffic

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assignment model [18,19,20,27,28]. An asymmetric traffic assignment is proved to be more appropriate for the congested traffic [1,2,3], which will obviously happen on a broken road-network after a large earthquake. Furthermore, although our model is somewhat similar to the NDP, but is more complicated than the traditional NDP [12]. Our task assignment model in the upper level is eventually a network scheduling problem, which combines the vehicle routing problem (VRP) and the scheduling problem in a road-network [37,38]. Moreover, the VRP with optimal scheduling is a well-known NP-hard problem. In view of the aforementioned resolution complexity, the concept of genetic algorithm (GA) is applied in this study as to obtain a heuristic solution [6,16] Although our problem is a well-known combinatorial optimization problem, but a satisfying heuristic solution can be more easily and efficiently derived by the recent-developed GA. [15,25,26].

Finally, the bi-level reconstruction model is established, and a GA with modified genes will be discussed in detail. Moreover, a simple road-network will be illustrated as a numerical example to validate our model. Study results show that a satisfying solution can be efficiently derived by our modified GA. Thus, this study can be a powerful basis for pre-quake simulation.

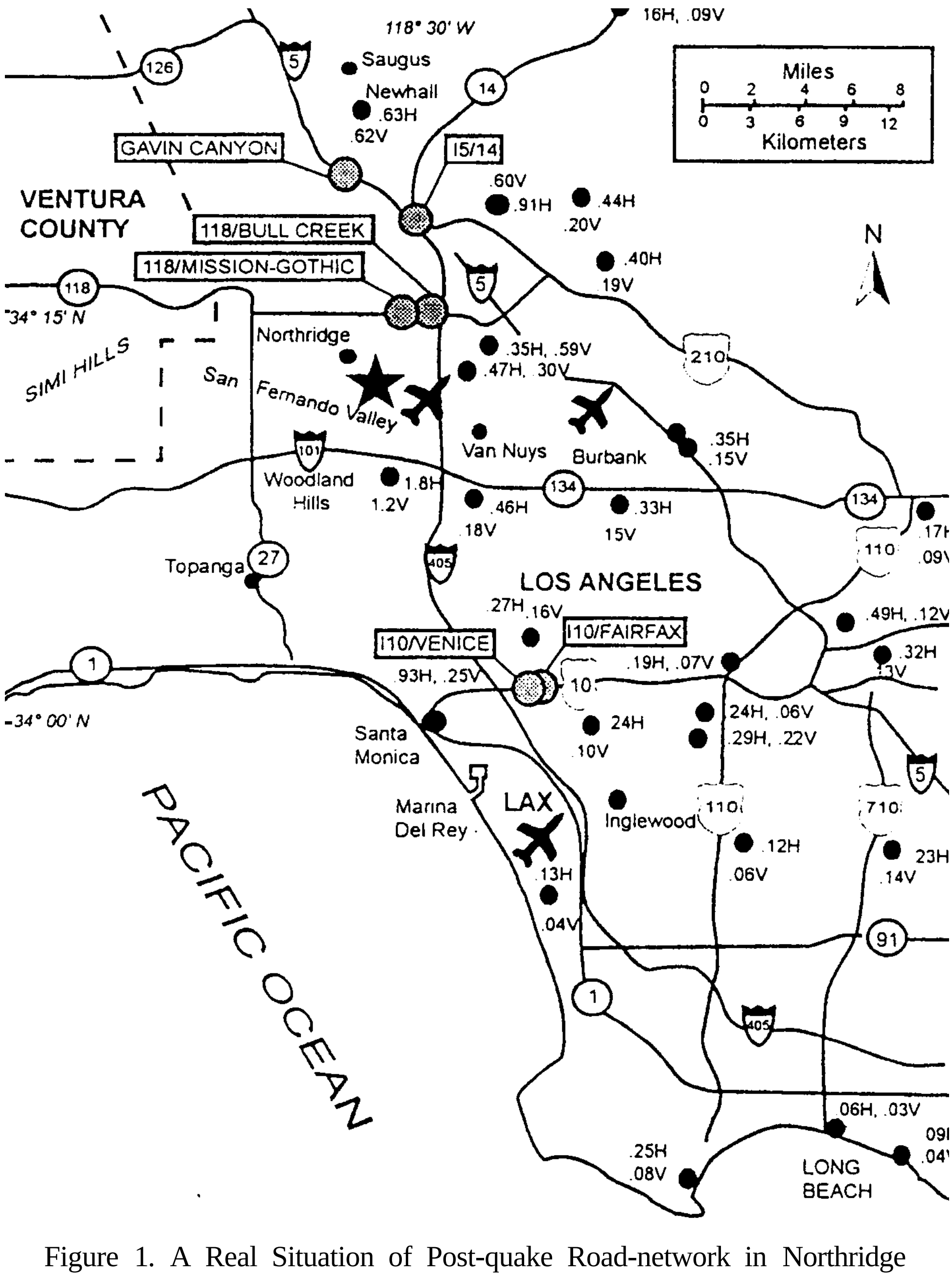
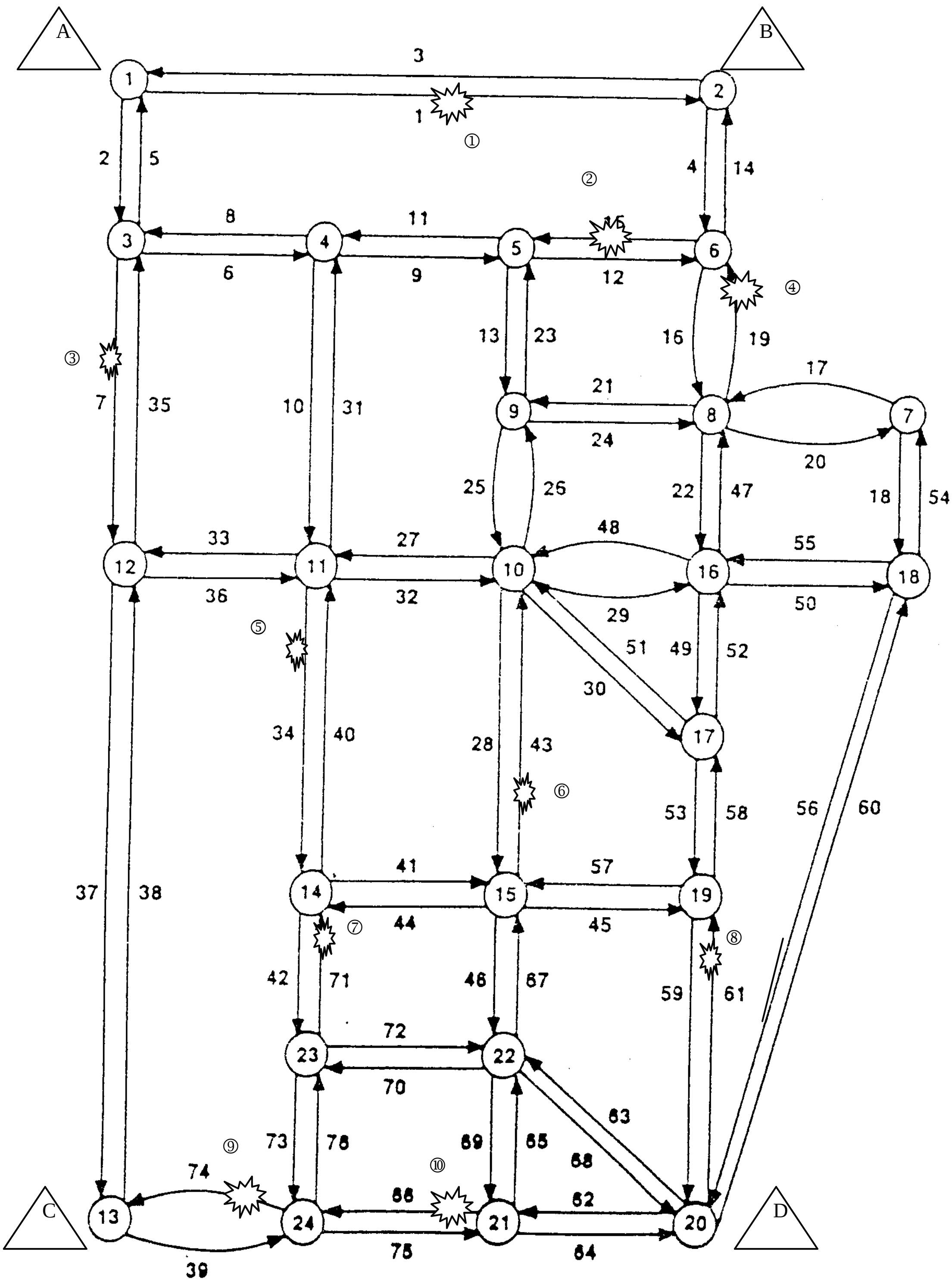


Figure 1. A Real Situation of Post-quake Road-network in Northridge



△ : Work-troop for Reconstructing Damage Points

○ : City

✸ : Damage Point

Figure 2. An Abstracted Situation of Post-quake Road-network

Source: Modified from the Original Network of Suwansirikul's [30]

This paper is organized as follows: in this section, the background, the purpose, the literature reviews and the method for solving our problems are briefly discussed. In Section 2, the problem characteristics are described and the mathematical model is constructed. In Section 3, the concept of fuzzy multi-objective optimization and a revised GA are proposed and explained. In Section 4, the numerical example is presented so as to validate our formulation and resolution method. Finally, conclusions and recommendations are included in Section 5.

2. Problem Description and Model Construction

According to the seismic experiences of Japan and America, the earthquake situation varying with time can be simply divided into three periods: the first period can be defined as the chaos period, which begins when earthquakes occur unexpectedly. In the mean time, the life-lines, e.g., the computer-networks, transportation-networks, electric power lines, telephone lines, etc., will be seriously destroyed. This chaos period ends as the instant rescue activities are proposed. After the chaos period, comes the rescue period, which allows fire-extinguishing, emergency rescue for lives, etc., to be carried out according to the damage report. Finally, the third period can be defined as a restoration period, which begins after the necessary rescue operations are adequately provided. In this period, a long-term reconstruction plan should be drawn up and executed. This study attempts to establish a simulation model for road-network reconstruction during the restoration period. Moreover, our model can be installed on a portable computer functioning as a radioactive command center.

After a large-scale earthquake, there might be many damage points scattered throughout a road-network (see Figure 1), this situation is abstracted in Figure 2 to clarify our formulation concept of such a problem. Meanwhile, supposing that there are also a few available work-troops for reconstructing the damage points (see Figure 2). A work-troop is defined as the work group holding the restoring resources and is responsible for reconstructing broken road-network. Each work-troop is permitted to move bi-directionally along a well link in order to save its travel time during reconstruction.

To ensure the reconstruction efficiency of each work-troop, which is normally constrained in resources, the reconstruction guideline for each work-troop must be arranged appropriately so as to minimize total reconstruction time, travel-time for travelers and the idle time between any two work-troops. The reconstruction guideline not only can instruct each work-troop how many damage points should be tackled, but also in what order these damage points are to be reconstructed.

The first objective of our model is used to reflect the convenience of traveling, and is defined as minimizing the total travel-time for travelers in a road-network during reconstruction (Z_1). This measurement is done by summing up the product of the traffic volume and travel-time for all links during reconstruction. Furthermore, minimizing the individual reconstruction time of any work-troop is used for the second objective (Z_2). This second objective will result in globally minimizing the total reconstruction time. Finally, minimizing the idle time between work-troops is the third objective (Z_3). The idle time is defined as the variance of the maximal and minimal working time between any two work-troops in a reconstruction plan.

Furthermore, assuming that a work-troop is continuously reconstructing a assigned damage point till this point is well-reconstructed; therefore, in terms of bi-level programming, our multi-objective model in this study can be shown as in Equations (1) - (13):

The Upper Level

This Level achieves to minimize the travel-time of travelers, total working time and idle time between work-troops by the following objectives and constraints:

$$\left.\begin{aligned} Min \quad Z_1 &= \sum_{i\in o}\sum_{j=1}^{n}\sum_{k=1}^{h}\sum_{l=1}^{nl} Q_k^l(x_{ijk})\times t_k^l(x_{ijk}) \\ Min \quad Z_2 &= \underset{j}{Max}\{RT_j\} \\ Min \quad Z_3 &= \underset{j}{Max}\{RT_j\} - \underset{j}{Min}\{RT_j\} \end{aligned}\right\} \quad (1)$$

s.t

$$\text{if } \; x_{ijk} \neq 0, \text{ then} \sum_{j=1}^{n} x_{ijk} = 1, \quad \forall\, i, \;\; \forall\, k \qquad (2)$$

$$\sum_{k=1}^{h}\sum_{i\in o} x_{ijk} \geq WT_i^j, \quad \forall\, j \qquad (3)$$

$$\sum_{\substack{k\in u,\\ i\in o}} x_{ijk} = WT_i^{\,j} \ ,\forall j \tag{4}$$

$$\sum_{k=1}^{h}\sum_{i\in o}\sum_{j=1}^{n} x_{ijk} = \sum_{i\in o}\sum_{j=1}^{n} WT_i^{\,j} \tag{5}$$

$$\sum_{k=1}^{h}\sum_{i\in o}\sum_{j=1}^{n} y_{ijk} = \sum_{\substack{i,s\in o\\ i\neq s}}\sum_{j=1}^{n} TT_{is}^{j}, \tag{6}$$

o ={i| the damage point i is assigned to work-troop j}

u ={k| the damage point i is continuously reconstructed by the work-troop j in interval k}

$x_{ijk} \in \{0,1\}$; $y_{ijk} = 1 - x_{ijk}$, $\forall i$, $\forall j$, $\forall k$

if l is a damage link including damage point i, then for each damage point i at any given time-interval k, the traffic volume subject to:

$$Q_k^l(x_{ijk}) = \begin{cases} 0, if \sum_{\tau=1}^{k}(x_{ij\tau} + y_{ij\tau}) \le \sum_{\substack{i,s\in 0\\ i\neq s}} WT_i^{j} + TT_{is}^{j}, \ \forall i,j,k \\ Q_k^{l*}, otherwise \end{cases} \tag{7}$$

but if l is not a damage link, then the traffic volume subject to:

$$Q_k^l(x_{ijk}) = Q_k^{l*}, \qquad \forall k \tag{8}$$

and the varying travel-time in a well link l in each time-interval k, subject to:

$$t_k^l(x_{ijk}) = b_{\,l}\, L_{\,l}\, Q_{\,k}^{\,l}\,(x_{ijk})\,, \forall l, \quad \forall k \tag{9}$$

and for each work-troop j, the total working time subject to:

$$RT_j = \sum_{i\in o}\sum_{k=1}^{h}(x_{ijk} + y_{ijk}), \qquad \forall j \tag{10}$$

The Lower Level

This Level achieves to obtain a convergent link flows under the reconstruction states of road-network from the upper level. Thus, A variational inequality problem (VIP) is solved as follows:

Find $f^* \in \Omega$, such that:

$$\sum_a C_a(f^*)(f_a - f_a^*) \ge 0, \qquad \forall f \in \Omega \tag{11}$$

$$\Omega = \{ f : f_a - \sum_a \delta_{ar} h_r = 0, \forall r; \sum_r h_r - T_{xy} = 0, \ \forall x,y; h_r \ge 0, \forall r\} \tag{12}$$

if $f_a^* \in l$ then Q_k^{l*} is subject to:

$$Q_k^{l*} = \sum_a f_a^*, \tag{13}$$

where:

i : damage points, i =1,2,…,m;

j : available work-troops for reconstruction, j =1,2,3,…n;

k : time-interval, k =1,2,…,h;

l : all physical links in a post-quake road-network, l = 1,2,…,nl;

x_{ijk} : the decision variable, if damage point i is reconstructed by work-troop j at time interval k, then its value is 1, otherwise is 0;

y_{ijk} : the dummy variable, if x_{ijk} = 1, this value equals 0, otherwise is 1;

$WT_i^{\,j}$: the time needed for work-troop j to reconstruct completely damage point i ;

TT_{is}^{j} : the travel time for work-troop j to move from a well-reconstructed point i to another damage point s;

$t_k^l(x_{ijk})$: the travel-time function of link l at time-interval k, this function is related to the reconstruction state of any damage point i;

$Q_k^l(x_{ijk})$: the traffic volume function of link l at time-interval k, this function is also related to the reconstruction state of any damage point i;

L_l : the length of link l;

Q_k^{l*}: the traffic volume of a well link l at time interval k, this volume is recomputed by asymmetric assignment when a damage point is completely reconstructed;

b_l : the translation coefficient between traveling-speed and traffic-volume of a well link l, where $L_l\ Q_k^{l*}/t_k^l$ =1/ b_l, b_l is set to be 0.0001 for all physical links in this study;

RT_j : the total reconstruction time for work-troop j;

f_a: the flow in link a of the detailed network during asymmetric traffic assignment, and f_a^*

represents the convergent flow in link a, f^* represents the convergent flow vector in network;

C_a : the travel-cost of link a in the detailed network during asymmetric traffic assignment;

h_r: the traffic volume of route r in a detailed network during traffic assignment;

d_{ar}: the dummy variable, if route r is used and link a is passed, then d_{ar} = 1; otherwise d_{ar} = 0;

T_{xy}: the traffic demand between node x and y in a physical network.

The aforementioned bi-level model essentially integrates the work scheduling and assignment for reconstruction in the upper level. Furthermore, the lower level is expressed in a variational inequality problem (VIP) [2,20] for asymmetric traffic assignment. Meaning of equations are explained as follows:

Equation (2): any damage point is exactly reconstructed by only one work-troop;

Equation (3): any work-troop should at least reconstruct one damage point;

Equation (4): any damage point should be continuously reconstructed;

Equations (5)-(6): total damage points should all be tackled during reconstruction;

Equations (7)-(8): a test rule established so as to take the well-reconstructed links into the first objective's measurement;

Equation (9): a function established based on traffic-flow theory in order to compute the travel-time in the first objective;

Equation (10): a function established to compute the total reconstruction time of each work-troop;

Equations (11)-(12): a variational inequality form of asymmetric traffic assignment;

Equation (13): summing the flows in the detailed network as to form the physical link flow after asymmetric traffic assignment.

After available data are input (e.g., origin/destination (OD) pattern of traffic demand for a pre-quake road-network, and the locations of work-troops and damage points, etc.), this model will output a schedule in order to assign the reconstruction task to each work-troop. Furthermore, because the network recovery status varies with time, Equations (11)-(13) are continuously resolved by the diagonalization method [1,2,3,23] to obtain the assigned traffic in Figure 2. The assigned traffic in each reconstruction period is used as a performance index by Z_1 for evaluating the reconstruction effectiveness.

In the next section, we will illustrate how we resolve the schedule problem of Equations (1)-(13) by fuzzy multi-objective approach and GA.

3. Fuzzy Multi-objective Model Resolved by Genetic Algorithm

A fuzzy multi-objective GA is employed for the following reasons: First, three objectives in Equationa (1)-(3) should be simutaneously optimized; thus, the techniques for optimizing only one single objective will not be suited for such a problem [35,36]. Moreover, our model is a combinatorial optimization problem, and the fuzzy multi-objective GA is more effective when compared with other traditional optimization methods [24,26].

3.1 Fuzzy Multi-objective Optimization Model

A fuzzy multi-objective approach is applied because that the exact solution for Equations (1)-(13) is very hard to find; thus, our model is heuristically resolved for the maximal satisfaction of a decision maker instead of finding the global optimum with intolerable computation time. Coincidentally, the basic concept of fuzzy multi-objective optimization is to find the maximal satisfying degree (or achievement level) among constraints of conflicting objectives [25]. Using Equations (1)-(3) as an example, and assuming that the optimistic value of kth (k=1,2,3) objective is Z_k^+, while the pessimistic value is Z_k^-, the achievement level is expressed as in Figure 3 [8].

The $m_k(Z_k)$ represents the fuzzy membership function of Z_k, which also reveals the achievement level of Z_k. By using the l transformation [8], and $l = \underset{k}{Min}\, l$, Equations (1)-(13) can be rewritten in Equation (14).

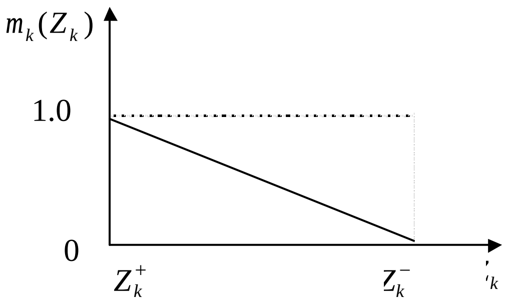


Figure 3 The Achievement Level for Fuzzy Objectives (k=1,2,3)

$$\begin{aligned} &\underset{k}{Max}\ l \\ &st \\ &l \le \frac{Z_k - Z_k^-}{Z_k^+ - Z_k^-} \quad , k = 1,2,3 \end{aligned} \tag{14}$$

and Equations (2)-(13).

3.2 Model Resolved by Genetic Algorithm

To solve the mathematical model in Equation (14), the concept for optimizing a bi-level model is necessary [12,33]. The upper level in Equations (1)-(10) will first output a reconstruction plan, which will instruct the work-troops how to share the reconstruction tasks of damage points. Secondly, the reconstruction plan from the upper level will be an input to the lower level in Equations (11)-(13). The lower level uses this input to find the convergent link flows by asymmetric traffic assignment. The convergent link flows will be feedback to the Z_1 of the upper level so as to evaluate the effectiveness of a reconstruction plan.

A GA is applied in this study because: (a) the concept of GA is easy to understand; (b) the GA is full of transferability; and (c) the GA is proved to be effective in solving such a NP-hard problem [25]. Considering the characteristics of our model, the gene type, crossover, and mutation are re-defined as follows:

(1) Gene type

A: 1-3-③-11-4-5-②-6-④-8
B: 2-①-1-3-4-11-⑤-14-⑦-23
C: 13-⑨-24-⑩-21
D: 20-⑧-19-15-⑥-10

Figure 3. The Gene of Reconstruction Plan

The gene is the basic unit used to evaluate the performance of reconstruction plan by three objectives (Z_1, Z_2 and Z_3). See Figure 2 for example, assuming there are 10 damage points, e.g., ①,②,…, ⑩, and four available work-troops, e.g., A, B, C and D in a road-network, which has 24 nodes, e.g., 1, 2,…, 24. Thus, a feasible solution expressed in Fig. 3 defines a gene (reconstruction plan) in our model.

The gene in Figure 3 can be analyzed as follows: the work-troop A arrives at the damage point 3 (③) by traveling from the node 1, and then through the node 3. After work-troop A has reconstructed completely the damage point 3, it then reaches the damage point 2 (②) from the node 12 by passing nodes 11, 4 and 5. After the damage point 2 completely reconstructed, the work-troop A is at the node 6; thus, the damage point 4 (④) will be repaired next. The work plan for troop B and troop C can also be recognized in a similar way. The reconstruction plan of each work-troop is defined as a sub-gene in our study. Ten initial genes are available in a database (population) for the following crossover, mutation and rank selection in GA.

(2) Crossover

The crossover is defined as follows: First, we randomly choose two sub-genes from a gene, which is randomly selected in a gene population. One of these sub-genes is defined as the father gene, e.g., the work plan of troop A in Figure 3; the other gene is defined as the mother gene, e.g., the work plan of troop B in Figure 3. Secondly, we check if there are the same or compatible access points between the father gene and mother gene. For example, the work plans of troop A and troop B both pass the node 11; thus, the node 11 is used as a cut-point. Finally, we swap the content after the same (or compatible) access points between father gene and mother gene, and the overlapping route in each gene will be reduced. This crossover is shown in Figure 4.

A: 1-3-③-11-4-5-②-6-④-8
B: 2-①-1-3-4-11-⑤-14-⑦-23

↓

A: 1-3-③-11-⑤-14-⑦-23
B: 2-①-1-3-4-5-②-6-④-8

Figure 4. The Crossover of Reconstruction Plan

(3) Mutation

The mutation is designed as follows: First, two sub-genes are randomly chosen from a gene, which is randomly selected from the gene population. Secondly, the work plans are swapped between these two work-troops. This mutation of work plan for troop A and troop C can be illustrated as in Figure 5.

A: 1-3-③-11-4-5-②-6-④-8
C: 13-⑨-24-⑩-21

↓

A: 1-3-12-13-⑨-24-⑩-21
C: 13-12-③-11-4-5-②-6-④-8

Figure 5. The Mutation of Reconstruction Plan

The aforementioned GA for work scheduling and assignment in this study will derive satisfying solutions through 30 generations after 20 runs. A generation is defined as a process to make gene population undergo the rank selection once, crossover once and mutation once. A run is defined as a re-starting process with a different random seed to iterate GA for 30 generations. This special optimization steps of our model is illustrated as follows:

Step 1

Input the required data for Equations (1)-(13). For example, the OD traffic demand of a pre-quake road-network, damage points need to be reconstructed, available work-troops, and so on.

Step 2

Encode the reconstruction order by the aforementioned GA and expanding the initial gene population by GA with 10 runs to heuristically compute the optimistic value (Z_k^+), the pessimistic value (Z_k^-) of the objectives (k=1,2,3). Furthermore, the initial gene population is set to ten genes.

Step 3

Use the relevant crossover, mutation to extend the offspring genes. The achievement level of each gene will be evaluated by Equation (14) for k =1,2 and 3. The evaluation index (EI) for any gene in the population is presented as follows:

$$\mathrm{EI}_g = \underset{g}{Max}\, l_g \tag{15}$$

where :

g: the g-th gene in population, g=1,2,…,10;

EI_g: the evaluation index of the g-th gene in population;

l_g : the minimal value of l ($\underset{k}{Min}\, l$, k=1,2,3) for the g-th gene from Equation (14).

The gene with higher value of EI_g is more preferred and highly ranked. The best ten genes will be kept by rank-selection after *Step* 3 terminated.

Step 4

Iterate *Step* 3 for 20 runs. The values of Z_k^+ and EI_g will be dynamically replaced in each run if better objective values are found.

Step 5

Use the final (latest) EI_g to evaluate the genes remaining in the final population. Thus, the heuristic reconstruction plan is obtained.

Using our GA and the aforementioned five steps, a heuristic solution can be easily derived. A numerical example is used to validate our model and optimizing process in Section 4.

4. Numerical Example and Discussions

An assumed post-quake road-network in Figure 2 is used to validate our model and GA. The reconstruction time for a damage point depends on the ability of each work-troop and is estimated about from 30 to 80 time-intervals for a single damage point by experienced civil engineers. Moreover, the travel time and the shortest path for any work-troop to reach any damage point will be recognized. To reflect the traffic dynamics in different restoration states of this network, the traffic volume in each link will be re-assigned if a damage point is fully recovered. The pre-quake traffic demand of Figure 2 is expressed in an OD matrix, which is shown in Table 1. The detailed network and the detailed link costs are individually established by a similar concept of Nagurney's [18].

Table 1. The Assumed Traffic Demand of a Pre-quake Road-network in Figure 2

From\To	10	11	14	15
1	470	480	450	400
2	480	455	470	450
13	465	440	400	500
20	470	450	460	450

After all desired parameters of Equation (14) are input, the traffic demand from Table 1 is loaded. We apply five steps in Section 3; therefore, a heuristic reconstruction schedule is finally obtained, this schedule is shown in Figure 6. The heuristic objective values are, Z_1= 3,256,547 (traffic volume × time-intervals), Z_2= 105 (time-intervals),

Z_3 = 23 (time-intervals). The global achievement level with l = 0.63.

$$\begin{cases} \text{A: 1-①-1-3-③-11-10-17-19-⑧-20} \\ \text{B: 2-6-8-16-17-19-20-21-⑩-24-⑨-13} \\ \text{C: 13-24-23-14-⑤-10-9-5-②-6} \\ \text{D: 20-22-23-⑦-15-⑥-9-8-④-6} \end{cases}$$

Figure 6. A Heuristic Reconstruction Schedule for Each Work-troop

Figure 6 can be interpreted as follows: the work-troop A starts its reconstruction trip form repairing the damage point 1 (①). After the damage point 1 completely reconstructed, the work-troop A arrives at the node 2 and continues to pass the nodes 1 and 3 for reconstructing the damage point 3 (③). And after the damage point 3 recovered, the work-troop A arrives at the node 12 and orderly travels through nodes 11, 10, 17 and 9 for reconstructing the damage point 8 (⑧). The work-troops B, C and D can also be explained in a similar way. Figure 6 is available for relevant authorities when simulating a reconstruction plan to reduce the negative impacts of a post-quake road-network. Since this study is constructed based on the mathematical optimization, with more precise data input to our model, a heuristic reconstruction schedule can be scientifically made instead of the messy decision being made after a large-scale earthquake.

Furthermore, since this reconstruction schedule is powerful and effective, it not only can be a reaction plan for pre-quake exercise, but also be available to be installed on a portable computer for the real-time restoration decision by a radioactive command.

5. Conclusions and Recommendations

This study successfully uses the concept of a network restoration problem (NRP) to formulate the complicated process of road-network restoration. To catch the traffic variation in a post-quake road-network during reconstruction, the technique of asymmetric traffic assignment is applied. Since the asymmetric traffic assignment is proven to be more appropriate in congested traffic [20], this assignment technique is reasonable to explain the traffic variation affected by any different reconstruction plan during reconstruction.

Simulating an efficient reconstruction plan for the NRP can bring much benefit. First, it can shorten the total time needed for reconstruction, minimize the inconvenience of travelers during reconstruction and minimize the idle time between work-troops. Since many economic activities are supported by the road transportation, the post-quake economic productivity can be recovered as soon as possible. Secondly, a considerable reconstruction plan can efficiently command the scarce work-troops and prevent resource wasting. Thirdly, an appropriate reconstruction plan can scientifically and systematically command the work-troops instead of messy decisions after a large quake; therefore, the reputation of the government can be promoted. According to these reasons above, this study tries to establish a fuzzy multi-objective model to optimally reconstruct the post-quake road-network. Since our model is essentially a combinatorial optimization problem with NP-hard complexity; thus, our modified GA with sub-genes in a string type is developed and applied to show its resolution power in this study. The valuable results derived from this study can assist relevant authorities to predetermine and stimulate an effective reaction plan for their own needs.

With more precise data for our NRP in the near future, this study can be developed as a disaster decision support system (DDSS) on a geographic information system (GIS) for simulating more practical and optimal reconstruction plans. Furthermore, more factors can be considered in order to greater reflect reality, such as, combining the fuzzy traffic assignment [39], fuzzy time window, fuzzy working time and forecast the post-quake situation by fuzzy techniques, etc. Of course, an effective resolution approach for the NRP is also urgently needed and should be continuously developed.

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