A GIS-BASED MODEL FOR POST-EARTHQUAKE PERSONALIZED ROUTE PLANNING USING THE INTEGRATION OF EVOLUTIONARY ALGORITHM AND OWA

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ABSTRACT:

Being one of the natural disasters, earthquake can seriously damage buildings, urban facilities and cause road blockage. Post-earthquake route planning is problem that has been addressed in frequent researches. The main aim of this research is to present a route planning model for after earthquake. It is assumed in this research that no damage data is available. The presented model tries to find the optimum route based on a number of contributing factors which mainly indicate the length, width and safety of the road. The safety of the road is represented by a number of criteria such as distance to faults, percentage of non-standard buildings and percentage of high buildings around the route. An integration of genetic algorithm and ordered weighted averaging operator is employed in the model. The former searches the problem space among all alternatives, while the latter aggregates the scores of road segments to compute an overall score for each alternative. Ordered weighted averaging operator enables the users of the system to evaluate the alternative routes based on their decision strategy. Based on the proposed model, an optimistic user tries to find the shortest path between the two points, whereas a pessimistic user tends to pay more attention to safety parameters even if it enforces a longer route. The results depicts that decision strategy can considerably alter the optimum route. Moreover, post-earthquake route planning is a function of not only the length of the route but also the probability of the road blockage.

1. INTRODUCTION

The problem of finding the optimum path which can be the shortest path could be regarded as one of the most controversial problems in network analysis (Pahlavani & Delavar, 2014). This problem is in the focus of other researches such as finding the service area and vehicle routing problem (Pourrahmani, Delavar, Pahlavani, & Mostafavi, 2015). The important issue is that the shortest path is not the optimum path necessarily. Sometimes a number of criteria should be considered in a way finding problem. For example, the length of the route, the number of traffic lights and the travel time all can be important criteria in a path finding problem (Karimi, Zhang, & Benner, 2014; Nadi & Delavar, 2011). Therefore, route planning can regarded as a multi-criteria evaluation problem and multi-criteria decision making methods can be used to address this problem (Nadi & Delavar, 2011). Frequent researches have been undertaken on designing and developing a spatial decision support system for route planning problem (Jankowski & Richard, 1994; Niaraki & Kim, 2009; Papinski, Scott, & Doherty, 2009; Torrens, 2014; Xie, Li, Wan, & Li, 2014; Yao, Loo, & Yang, 2015).

A personalized route is a proper route with respect to the combination of the preferences of a decision maker. Criteria such as travel distance, travel time, width of the route, scenery, number of high rises around the route and the number of traffic lights could be considered in a personalized route planning system. For example, a tourist may have a tendency to visit more landscapes, even if it takes longer hours (Nadi & Delavar, 2011). In after earthquake route planning, road segments which are wider and have lower number of high rises are more preferred (Peiman & Clarke, 2014; Pourrahmani et al., 2015).

Nadi and Delavar (2011) proposed a spatial decision support system for personalized route planning. They designed and developed a web-based GIS which is able to input user preferences for each criterion. The system is able to find the optimum path with respect to user preferences using ordered weighted averaging operator. Jankowski and Richard (1994) was one of the first researchers that worked on the integration of GIS and decision making methods for implementing spatial decision support systems. In (Jankowski & Richard, 1994) they proposed an SDSS for route planning according to some decision rules stated by the user of the system. Pahlavani and Delavar (2014) proposed a route planning model based on invasive weeds optimizations which can search the problem space by simulating the colonizing of weeds. The superiority of the model is that it is very fast in comparison to other optimization methods. The problem of post-earthquake route planning is addressed in work carried out by Pourrahmani et al. (2015). They proposed a route planning algorithm from local shelters to regional ones for long term safety. They proposed a route finding algorithm based on simulated annealing which is able to manage the traffic demand dynamically.

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In this research a GIS-based model is proposed for personalized route planning. The model consists of two main parts. The first part searches the problem space for the optimum path, while the second part tries to find an overall score based on the scores of the route in different criteria. In other words, a multi-criteria decision making method is employed to calculate the degree to which a route is preferred (objective function of the optimization method). In this paper, OWA algorithm is used to find an aggregated score for each route based on a number of criteria associated with earthquake. Then, GA is employed to find the optimum route with respect to the predefined objective function. In other words, the fitness function of the GA algorithm is the aggregation function of OWA. The criteria of route planning are defined based on vulnerability against earthquake. Vulnerability of a route is the probability of blockage after a large earthquake. Thus, the proposed route planning model tries to make a balance between the length of a route and the probability of the blockage of road segments. Obviously, in this paper, it is assumed that there is no real damage data available and the system tries to avoid vulnerable roads and very long ones simultaneously based on the optimism degree of users.

2. METHODOLOGY

2.1 OWA operator

The OWA operator which was introduced by Yager (1993) is an aggregating operator from a class of mean-like operators. The aggregation operator of ordered weighted averaging method is as follows (Yager, 1993):

$$F(a_1,...,a_n) = \sum_{i=1}^{n} w_i * b_i = w_1 b_1 + w_2 b_2 + ... + w_n b_n \tag{1}$$

where w_i = the weight associated to *i*th criteria
b_i = the *i*th attribute value.

The OWA operator is able to provide a wide range of answers from the most optimistic to the least optimistic solution. In fact, weight vector (w) is a key element for describing the characteristics of the operator (Milad Moradi, Delavar, & Moshiri, 2015). Frequent methods have been proposed in order to calculate the optimum set of weights for OWA. The most famous one is based on employing linguistic quantifiers (Zarghami, Szidarovszky, & Ardakanian, 2008). Linguistic quantifiers are expressions from natural language which indicates the preferences of user on each criterion. Furthermore, linguistic quantifiers imply the degree to which the decision maker is optimistic or pessimistic (Yager, 1992). The level of optimism can be determined using a linguistic quantifier. Let Q be a linguistic quantifier, the corresponding weight vector could be calculated as (Yager, 1992):

$$W_i = Q_{RIM}\left(\frac{i}{n}\right) - Q_{RIM}\left(\frac{i-1}{n}\right), \quad i = 1,2,...,n \tag{2}$$

where w_i = the weight of *i*th criterion
Q = the linguistic quantifier.

The quantifier can be expressions such as All, Most, Half, Few and At least one. Half means that satisfaction (great score) of half of the criteria is enough for an acceptable result, while most means that satisfaction of most of criteria is obligatory for an acceptable alternative (Malczewski & Liu, 2014; M Moradi, Delavar, & Moshiri, 2013). OWA weights do not represent importance of criteria. They indicate order weights which represent the degree to which the decision maker is optimistic (Jelokhani-Niaraki & Malczewski, 2015). When the relative weight of the criteria is important, the weight vector is obtained using Eq. 3 (Malczewski & Rinner, 2015):

$$w_j = \left(\frac{\sum_{k=1}^{j} v_k}{\sum_{k=1}^{n} v_k}\right)^{\alpha} - \left(\frac{\sum_{k=1}^{j-1} v_k}{\sum_{k=1}^{n} v_k}\right)^{\alpha} \tag{3}$$

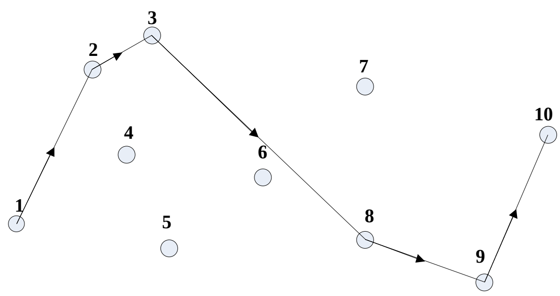
where V_k = the relative importance of the *k*th criteria.

2.2 Genetic Algorithm

Genetic algorithm is a search algorithm in artificial intelligence which simulates the process of natural selection. This algorithm could be used in shortest path problems because it is able to simulate each route as a chromosome according to which the algorithm can analyse different possible solutions and find the optimum path. Each route is represented by a chromosome (see Figure 1). The problem of route finding is simulated by a weighted digraph $G = (\mathrm{N}, \mathrm{E})$ where $N = \{1, 2, ..., n\}$ indicating nodes of the network and $E = \{e_1, e_2, ..., e_n\}$ indicating communication links between them (Abbaspour & Samadzadegan, 2011). Then, a path *P* is the shortest path if the bandwidth of it is minimum value (Zhang, Wu, Wei, & Wang, 2011):

$$Band(P) = \min(Band(e), \quad e \in E_p) \tag{4}$$

Thus, the problem of finding the shortest path is equal to the problem of finding the path with minimum bandwidth.



Chromosome	1	2	3	8	9	10

Figure 1. Representation of a route as a chromosome

2.3 Crossover

In order to find the best solution, genetic algorithm make new generation based on the past ones. In other words, the best members of the current generation are selected and the next generation is produced from crossover operation between them

(Vidal, Crainic, Gendreau, & Prins, 2013). Crossover operation represents the natural selection in which the more strong parents produce the next generation. For route finding, crossover is similar to Figure 2.

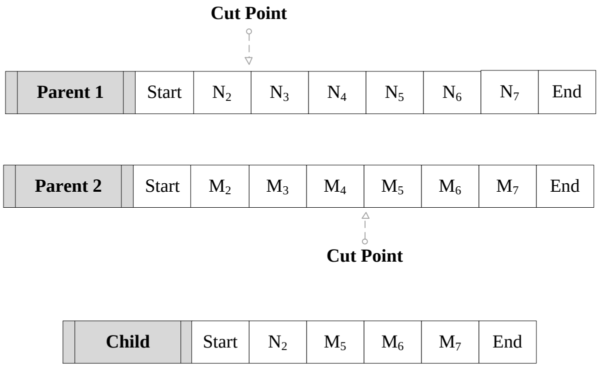


Figure 2. The procedure of crossover

It means that two valid paths between the start and end points are combined to produce a new valid path between them. In a simple way crossover can be done by fragment of two parent chromosomes and reunion of them. The very important point is that the new path should be valid. In implementation, invalid paths are removed from the set of parents who produce the next generation (Heidari & Abbaspour, 2014).

2.4 Mutation

Mutation is a genetic process which aims to provide the population with diversity (Vidal et al., 2013). Mutation alters a number of genes in a chromosome and produces a new one. In fact, mutation facilitates global search by producing random valid members in each generation. In route finding one or two nodes are changed in a chromosome and a new route will be produced which may not necessarily be valid according to the connection matrix of the problem. Figure 3 illustrates a sample mutation process.

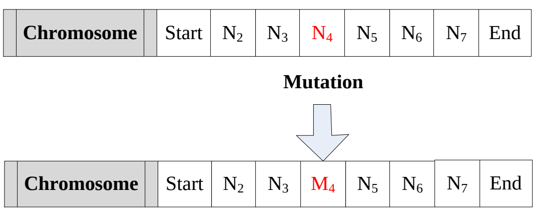


Figure 3. The procedure of mutation

Mutation cause relatively smaller changes in the parent routes in comparison to crossover. Crossover makes substantial changes in the length and characteristics of a route. For example, crossover can cause a route to pass from a road with high percentage of vulnerable building which considerably reduces the preferably of that route for this problem. However, mutation only changes one node and two edges (road segments). Thus, the overall score of the route does not alter dramatically (Rajabi-Bahaabadi, Shariat-Mohaymany, Babaei, & Ahn, 2015).

3. IMPLEMENTATION

3.1 Study Area

This study is undertaken in Tehran metropolitan area where the infrastructure is in a very poor condition due to the rapid urban growth which resulted in urban sprawl (M Moradi, Delavar, & Moshiri). The width of many streets is insufficient and can cause blockage in a natural disaster like earthquake.

3.2 Contributing Criteria

Although the proposed model is a general model for route planning, a case study of after earthquake route planning has been undertaken in this paper. Figure 4 illustrates a number of contributing factors which were employed in previous researches. In this research only 4 criteria are used including length of route, width of road, percentage of high rises around the road and percentage of non-standard buildings around the road. Considering the fact that in this research it is assumed that there is no real damage data, the data layers which indicates the probability of road blockage are employed. The higher percentage of non-standard building and high rises decrease the suitability of this road.

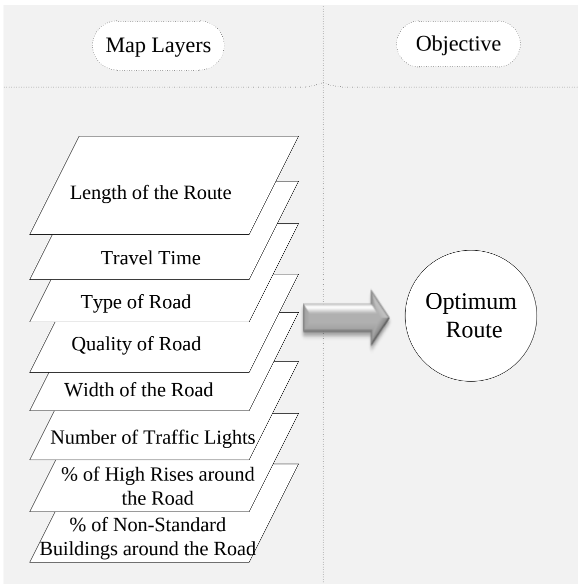


Figure 4. Contributing factors used in this paper

The steps of the proposed model are shown in Figure 5. Firstly, the contributing criteria are determined. Then, relative weights are determined by the expert. These weights indicate the relative importance of criteria in comparison to each other. Following that, genetic algorithm is employed to find the best route from the set of alternative routes. A chromosome is made for each possible route using the nodes and edges. Next, the fitness function of these routes is calculated using the aggregation function of OWA operator. In this step, an overall score in calculated for each route based on the four contributing criteria. After that, crossover and mutation search all the alternative routes and find the best one through an iterative process. The impact of optimism degree is on combination of scores where an overall score for the fitness function is calculated with respect to optimism degree.

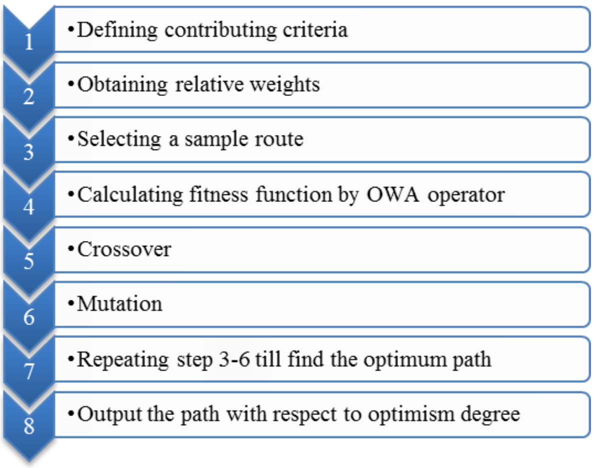


Figure 5. Steps that are done in this research

Figure 6 illustrates the pseudo code of the proposed evolutionary model for route planning. In fact, evolutionary algorithm is employed in research as it is used in finding the shortest path. However, the fitness function is not the length of the route. The fitness function of this model is calculated by OWA which can take into account the optimism degree of expert.

Algorithm

Inputs: Initial_size; Connection_matrix; Max_Iteration; P_m; P_c; n_0

```
1- Start
2- Generate initial population
3- g=1
4- While (g <= Max_iteration)
5- p=1
6- While (p < Initial_size)
   7- Choose 2 parents
   8- Do crossover based on Pc
   9- Do mutation based on Pm
   10- Compute fitness function (Eq. 4)
   11- IF child is Not valid based on
           Connection_ Matrix delete it
   12- IF fitness > B save the child as valid
   13- p = p + 1
   14- End
15- Output the best member of pupolation
16- End
```

Figure 6. Pseudo code of the proposed model

One of the main differences of the shortest path problem and route finding problem is that in route planning the shortest path is not the most preferable one necessarily. In this research, the objective is to develop a model for post-earthquake route planning. Hence, the user wants to avoid routes which are surrounded with non-standard buildings and the roads which are near the faults because they are more likely to become blocked. On the other hand, the user does not want to select a route which is considerably long. Therefore, there should be a trade-off between the length of the path and the suitability of it with respecting the earthquake vulnerability criteria. Two main problems are combined here, the first one is th problem of finding the best route between a number of alternative and the second problem is to find a good fitness function that indicates the degree to which a route is preferable based on user's opinion. The former problem is addressed using genetic algorithm, while the latter is addressed by OWA operator.

3.3 Results and Discussion

In order to evaluate the proposed personalized route planning model, the preferences of one user is asked over contributing criteria. The user assigned normalized weights to the 4 criteria which are as follows:
The length of route: 0.5
The width of road: 0.2
The percentage of high rises around the road: 0.1
The percentage of non-standard buildings around the road: 0.2

The weights are included into Equation (3) and the order weights are calculated. The order weights then are used to run the model. Following that, the optimum route based on the preferences of the user is selected for three different optimism degrees. Figure 8 illustrates the three different routes. The optimistic route is more similar to the shortest path because the user wants to take the risk and go through the shortest path available. On the other hand, the route selected based on the pessimistic strategy tends to select road segments which are high ways because the user tends to avoid narrow roads which are surrounded by non-standard buildings. Therefore, the length of the route increases. Quantifier-guided OWA can make a trade-off between the length of the route and other factors.

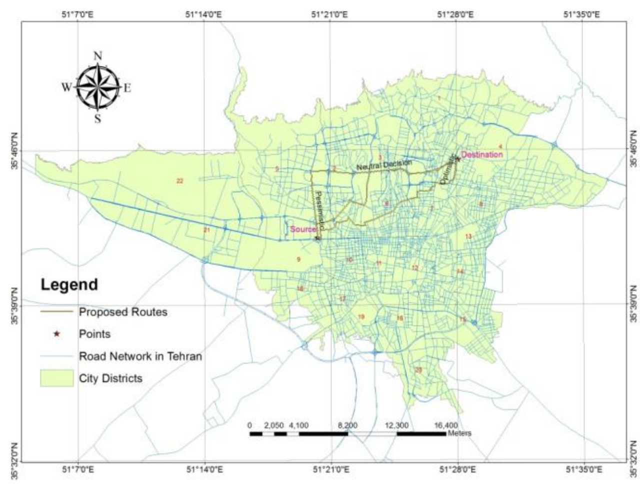


Figure 7. Routes based on optimistic and pessimistic views

Figure 8 indicates 3 different routes for after earthquake based on different point of views. An optimistic decision maker pays no attention to the risk of road blockage and selects the shortest path, whereas a pessimistic one selects the route that is away from those non-standard buildings even if this route is longer (pessimistic users select the safest route).

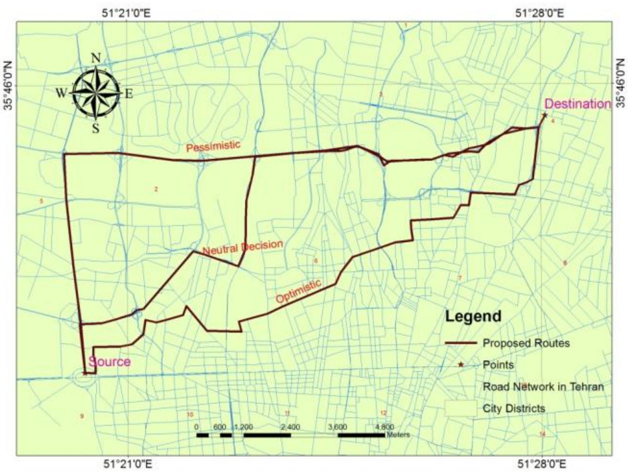


Figure 8. The influence of optimism degree on route finding

Although the proposed route planning model is efficient, due to the computational complexity of the model it is not suitable for large number of road segments. In that case, other network analysis techniques may be used to reduce the complexity of the model.

4. CONCLUSION

This paper proposes a novel personalized route planning model for after earthquake based on the integration of evolutionary algorithm and ordered weighted averaging. The issue of personalization is addressed in this paper. Previous route finding models tend to find the shortest path, while this model tends to find a route based on not only the length of the path but also the safety measures. Furthermore, this model makes a trade-off between the length of the route and other factors such as the width of it. Thus, the output of this model is not a shortest path but also the optimum path with respect the user's preferences. OWA operator, which is employed to calculate the fitness of each route, enables users to include a wide range of decision strategies instead of only neutral decision making. This model can be used in other route finding problems with minor modifications.

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