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An optimization design for evacuation planning based on fuzzy credibility theory and genetic algorithm

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Abstract: Evacuation planning is an important activity in disaster management. It has to be planned in advance due to the unpredictable occurrence of disasters. It is necessary that the evacuation plans are as close as possible to the real evacuation work. However, the evacuation plan is extremely challenging because of the inherent uncertainty of the required information. There is a kind of vehicle routing problem based on the public traffic evacuation. In this paper, the demand for each evacuation set point is a fuzzy number, and each routing selection of the point is based on the fuzzy credibility preference index. This paper proposes an approximate optimal solution for this problem by the genetic algorithm based on the fuzzy reliability theory. Finally, the algorithm is applied to an optimization model, and the experiment result shows that the algorithm is effective.

1 Introduction

Recently natural disasters may occur such as earthquakes, floods, etc. In the urban areas of hurricanes, chemical spills, and the importance of nuclear accidents. Emergency management and planning is very important. Although the probability of disaster may be relatively low, it still has to execute the emergency evacuation planning to avoid the tragic accident before the disaster occur.

Evacuation is an important emergency strategy to transfer the people from the dangerous area to the safe area[1]. During the evacuation, part of the crowd choose the self-driving cars to evacuate, but the others which do not have or can not use private cars, including the senior citizens, the sick people, wounded travelers, and people with low incomes, may choose public transportation as their evacuation tools[2].

Public transportation is a very effective way of emergency evacuation[3]. On the one hand, the number of people can be increased, on the other hand, it has minimal influence on the traffic road. The empirical studies have proved that if using the majority of the public transport as evacuation tools, it can be a good improvement of the evacuation space, and increasing the clearance time of the evacuation in dangerous areas.

Evacuation planning is a challenging and complex problem, because the information which help the decision-making is uncertain to the emergency evacuation point. In the public transportation evacuation, the information of the victims and their location, evacuation tools, evacuation networks are uncertain and incomplete. Meanwhile, they are also uncertain including the number of vehicles, the ability of victims reception and their original location. In the traffic network, the uncertainty may be in the
limited link capacity and the limited link traffic time. In addition, the unpredictable time of disaster occurrence and the extent of its destruction are also uncertainty factors on the evacuation planning.

At present, most of the researches in evacuation planning have ignored the uncertainty of informat. However, the actual evacuation flow is not likely to be consistent with the intended direction. Therefore, the uncertainty of optimization should be considered as far as possible on the evacuation planning, which can lead to the real evacuation rate closer to the planning[4].

In this paper, we mainly consider the people on evacuation which uses public transport in urban areas when they are in danger. And we also consider the uncertainty of evacuation demand. In this evacuation plan, the number of the evacuation crowd is fuzzy variables in the evacuation centers, and we use the triangular fuzzy number to represent the number of evacuation crowd. Finally, this paper make the most optimized solution to the evacuation model by using the Fuzzy credibility theory and genetic algorithm.

2 Literature Review

2.1 Theory of Fuzzy Set

Fuzzy set theory can be a good representation of the uncertainty of the problem variables. On the one hand, it is easy to find the uncertain factors with the fuzzy theory, which based on expert judgment, experience value and historical information. So that it will decelerate the speed of the optimization process. In addition, using the fuzzy sets to construct uncertain data is relatively simple, and it does not increase the complexity of the problem. It can be more realistic to reflect some of the data in the objective world, especially the description of the subjective valuation. Generally speaking, scientific research can accept this kind of fuzzy set data within the range of tolerated space. In addition, comparing to the stochastic programming problem, the fuzzy set theory does not require the exact information to define the difference in various disaster scenarios.

Copy old text onto new fiFuzzy credibility theory: possibility, necessity and credibility are as follows.

**Definition 1:** measure of possibility

Assume that \( \theta \) is not an empty set, then \( P(\theta) \) is a power of it, element in \( P(\theta) \) is called an event.

Assume that \( A \in P(\theta) \), and it is non negative number. \( pos(\theta) \) is a probability that can indicates the possibility of occurrence of \( A \). Thus, \( pos(\varnothing) \) represents a possibility strategy, in which:

\[
pos(\varnothing) = 0 \quad ; \quad pos(\theta) = 1\
\]

\[
pos(A_1, A_2) = \max\{pos(A_k) \} \quad \forall \{A_k\} \in P(\theta) \quad (1)
\]

**Definition 2:** measure of necessity

\( \{\theta, P(\theta), pos(\theta)\} \) is a possibility space, \( A \in P(\theta) \), \( pos(\theta) \) is the strategy set of feasibility about A. If \( \bar{A} \) is the complement of \( A \), then the necessity measure can be defined as:

\[
nec\{A\} = 1 - pos(A) \quad (2)
\]

**Definition 3:** measure of credibility

If \( \{\theta, P(\theta), pos(\theta)\} \) is a possibility space, \( A \in P(\theta) \) then the credibility can be defined as:

\[
Cr\{A\} = \frac{1}{2}(pos(A) + nec\{A\}) \quad (3)
\]

**Definition 4:**

Assume that \( \mu(x) \) is a membership function of fuzzy variables \( \xi \), then the possibility, the necessity and the credibility of the fuzzy variables can be calculated as follows:

\[
pos(\xi \geq r) = \sup_{x \in r} \mu(x) \quad (4)
\]
From this, we can know that the reliability is the average of the possibility and necessity in fuzzy events. If the reliability of fuzzy events is 1, it means that it must be held, otherwise it is 0, it will disappear.

The optimization approaches discussed in the last section have some limitations in the terms of computation time, complexity and initial information. These limitations may decrease their applicability to real-world scenarios.

The theory of fuzzy set is successful in modeling problems that contain an element of uncertainty related to subjectivity, ambiguity and vagueness. This theory involves with fuzzy sets, the elements of which have degrees of membership. Fuzzy set theory permits the gradual assessment of the membership of elements in a set.

Using fuzzy theory, one can easily estimate the uncertain element based on expert judgment, experience or historical information. Therefore, it does not slow down the optimization process by any iterative approaches. Besides, it is relatively simple to model uncertain data using fuzzy sets and it does not increase the complexity of problem. This is particularly true about cosmological data (e.g. maximum capacities of water intakes, water pollution induces, and demands), due to high subjectivity in the estimation. The experts accepted expressing this data in the terms of tolerance intervals with a most-possible value and decreasing.

However, there are some other studies that use this theory for generating evaluate scenarios or presenting the relation between evacuation population and places (e.g. [9,39,29]). To the best of the author’s knowledge, none of these studies considered the assignment of uncertain demand to public vehicle routes for an evacuation operation. However, in most real-world cases precise information about evacuation demands and vehicles’ capacity are not available.

2.2 Genetic Algorithm

Genetic Algorithm is a kind of evolution process calculation model which simulate Darwin’s biological evolution theory of natural selection and genetic mechanism, and it is also the best approaches by simulating the natural evolution process. Genetic algorithm is from beginning of a population which represent a potential solution set for the problem. And one population is made up of a certain number of individuals which are encoded by a gene. Each individual is actually a chromosome with characteristics of the entity.

Chromosome, as the main carrier of genetic material, is a collection of multiple genes, and their internal performance is a kind of gene combination. It determines the external performance of the shape of the individual. For example, the characteristics of the black hair is controlled by the combination of certain genes which determine the characteristics on the chromosome. Therefore, when we start the encoding work, which need to realize the gene mapping from the phenotype to the Linotype, we usually tend to simplify it, such as binary coding, due to the complexity of simulation. When the original population is generated, generational evolution can produce better approximate solution according to the principle of survival of the fittest and the evolution. In each generation, we select the individual in problem domain size according to the fitness size. And by means of natural genetics and genetic operators, we produce the population on behalf of the new solution set combined crossover and mutation.

This paper presents an evacuation vehicle routing problem (EVRP) using public vehicles in urban areas. The source of uncertainty in this problem is the evacuation demand. In the proposed methodology, demand (number of evacuees) at each evacuation pick-up point is introduced as a fuzzy variable. Fuzzy credibility theory is used to deal with this uncertainty.
and a genetic algorithm (GA) based on this theory is designed to solve the stated problem. To evaluate the obtained solutions, a stochastic simulation method is employed. As far as the authors know, this is the first work in the literature of the evacuation planning which uses fuzzy credibility theory to model the assignment of uncertain demands to the vehicle routes.

3 Model

3.1 Model

In this paper, we consider the use of public transport evacuation strategy in urban areas. People are waiting for public transport to evacuate at the concentration point (pick-up points). The usual bus stop is thought to be a collection point, and then the victims are evacuated to the nearest shelter. It is assumed that the number of public transport can be sufficient to satisfy the evacuation of such personnel. Build Model base on VRP of evacuation, usually considering the objective function is a set of lines, the line starts a point to leave after a series of points and then back to a point, as shown in Fig. 2. The path usually chosen by the minimum cost method, the minimum cost is the minimum total distance or the total computation time in Euclidean space.

In this paper, VRP is extended to EVRP. Each vehicle in EVRP starts from a point and through some pick point to receive the victims. And then the victims are transferred to the nearest refuge. Pick points should be arranged in the smallest point of total evacuation time in the entire evacuation routes. It leads to a reduction in the evacuation time. The total travel time is calculated by the traffic network model.

In EVRP, it is assumed that the initial capacity of the buses is the same, and they are empty when they start their journey.

EVRP problem is described that E is a node, N is the edge, G is a graph. Node contains that starting point, picking point and refuge. Edge represents the shortest connection between two points in a traffic network. The subset of points is used in the next mathematical notation. In order to facilitate the demonstration of the model which using symbols instead, as shown below:

$$N_{wp} : \text{Set of depot points.}$$

$$N_{sp} : \text{Set of shelters points.}$$

$$N_{pp} : \text{Set of pick-up points.}$$

$$w : \text{Depot.}$$

$$VK : \text{Set of vehicles.}$$

$$i, j : \text{Node index.}$$

$$k : \text{Vehicle index.}$$

$$C : \text{Initial vehicle capacity.}$$

$$t_{ij} : \text{Travel time between node } i \text{ and } j.$$ 

$$N : \text{Number of pick-up points.}$$

$$E_i : \text{Number of evacuees boarded on vehicle } k.$$ 

$$E_i : \text{Number of evacuees at pick-up } i.$$ 

$$u_k : \text{Free variable used in the elimination constraint.}$$

$$X_{ij}^k : \text{Decision variable: 1, if vehicle } k : \text{passed from node } i \text{ and } j, \text{ then variable}=1. \text{Otherwise variable}=0.$$ 

$$\min(F = \sum_{i \in N_{pp}} \sum_{j \in N_{sp}} \sum_{k \in VK} t_{ij} \cdot X_{ij}^k) \quad (7)$$
The formula (7) represents the objective function. The objective function is the minimum of the total travel time, and through all the buses from one point to the picking point. Formula (8) describe the flow conservation bound for each pickup point, the vehicle entering the pick must leave it eventually. Formula (9) is used to eliminate the subtour in the VRP. Formula (10) shows that the vehicle capacity constraints. In this formula, the capacity available is defined based on this constraint. Formula (11) ensures that each bus is used up to one time during the whole evacuation period. In other words, in the whole evacuation process, each bus must choose a route from the point of the pick point as the starting point to the shelter as the end point. Formula (12) and (13) ensure that each pickup point can be accessed by a car. In addition, each of the victims should not be picked up by more than one car. The formula (14) describes the domain values of the two-dimensional decision variables.

3.2 Uncertainty of Fuzzy Demand

When we discuss the problem of uncertain evacuation demand, triangular fuzzy number $E = (e_1, e_2, e_3)$ can be considered as describing the number of pickup point for victims. For such a problem, disaster managers, planners and analysts have their solution usually by competent estimates, his experience, intuition and the historical data. The number of victims is not less than $e_1$, not more than $e_3$.

Whether a car can pick up passengers from the next pick point depends on its ability and the number of victims at the pick point. If the capacity of the vehicle is equal to or greater than the number of the next pick point, it can be on the way to the point of the road to receive more victims. Otherwise it should leave the pickup point to move to the nearest safe place. (The first step, give a path to the vehicles. The second step, determine the vehicles for each pickup point whether it can accept the victims.) When the number of victims is accurate, it is easy to choose the way whether the vehicle is to accept the victims or continue to move forward. However, when the number of victims be described by triangular fuzzy number, this decision is more complex. The greater the difference between the vehicle capacity and the number of victims of the next pickup point, the vehicle has the more opportunity to go to the pickup point.

3.3 Base on Fuzzy genetic algorithm

The VRP problem of fuzzy variables is a NP hard problem, which can not be solved by polynomial method. So intelligent heuristic algorithm can be applied in the field. At the same time, the EVRP problem contains the fuzzy demand, so the heuristic is an effective way to solve the problem.
GA is a well-known heuristic algorithm on the path problem, it can successfully solve the VRP problem of fuzzy variables. In the text, the contribution of GA is to construct the solution using the fuzzy credibility theory. According to this point, taking into account the fuzziness of the evacuation demand and the available capacity of the vehicle, we distribute the extraction point $Cr^*$ according to a value of the vehicle path.

1. Representation of solutions

In this algorithm, each of the complete solution is consisted with a series of digital coding. Each encoding represents the point of the ride. Virtual 0 is inserted in a sequence that represents a different vehicle path.

2. Using the result of the roulette wheel selection strategy for future generations.

3. Cross

In the original location of the solution, it achieves the unified and sequential cross method for this purpose based on the cross (or roulette). In this method, at first, a random binary string is generated, and the same length of the parents are generated. The first generation solutions can retain these ride points, where the binary string is "1" but on its 2 location. The offspring is also filled with elements of 2 from the parent, but their appearance indicates a uniform ordered crossover strategy.

4. Variation

A two point crossover method is applied to the mutation. Similar to crossover, mutation is the solution to the original location about the mutation rate. The double pick points are randomly selected and exchanged from the solution and their locations.

5. Determination of $Cr^*$

The value of $Cr$ among the [0,1] indicates the strategy of bringing the vehicle to the next pick point. When $Cr = 1$, it means that the vehicle should reach the next pick point. When $Cr = 0$, it means that the vehicle should not enter the next pick point, and it should go directly to the nearest shelter.

In order to make decisions based on $Cr$, a threshold index $Cr^*$ can range from 0 to 1. If $Cr < Cr^*$, the vehicle enters a pickup point, otherwise, the vehicle leave the pickup point to the nearest evacuation shelter. Lower values represent the ability to use vehicles as much as possible. However, when the value of $Cr^*$ is low, it is more likely to be that the vehicle has entered the next pick point, but it can not take away the victims we planned because of the small volume. On the other hand, the higher values of $Cr^*$ decrease the possible proportion of failures, and increase the number of paths added dramatically.

4 Simulation Experiment

This example assumes that the 60 points are used as evacuation points, 3 shelters are determined in the open and outside region. And a suburban public transport terminal is designed. It also assumes that there are sufficient vehicles provided for the evacuation crowd. The number of people to evacuate is a triangular fuzzy number. And managers or planners will decide the three values, which from their experience or historical data. In order to carry out the fuzzy GA optimization algorithm, the $Cr^*$ need to be determined.

4.1 Electronic Determination of $Cr^*$

In this paper, we use the simulation experiment method and get the value of $Cr^*$ in the range of [0,1]. Every other 0.1, we put each different result as each demand for the car, and predict the total number of people in different time periods. Compared with the real total evacuation number, the most proximate number will be the value of $Cr^*$ and be the ideal feasibility threshold. Specific simulation results are shown in Fig.1:
Fig 1. The influence of different fuzzy thresholds on the prediction of the number of evacuation

According to the above figure, it can be seen that $Cr^r=0.4$ is more reasonable, when the credibility of the next pick-up point $Cr^r \geq 0.4$, it should into the feasible path sequence. According to the second part of the mathematical model and the third part of the fuzzy genetic algorithm, we can solve the model optimization solution and calculate the change of people number with time in every security point.

Fig 2. The number of crowd with the change of time in three evacuation settlements

5 Conclusions

The high occurrence of disaster clearly indicates the necessity of early warning planning, and evacuation is an important and active function of emergency management, including more uncertainty of resources. Therefore, it is important to plan the evacuation in advance. In order to avoid the difficulties in the process of evacuation, the uncertain factors should be involved in the planning. One of the uncertainties in the evacuation is the uncertainty of demand.

In this paper, we optimize the evacuation route planning with urban public transportation. EVRP, as a planning model, based on this kind of process of evacuation. The evacuation car starts from the garage, save the crowd in the pick-up point which designed in advance, send them to the nearest shelter. Due to the uncertainty of evacuation demand, the crowd at a point of arrival is considered to be a triangular fuzzy number. Then, a fuzzy based genetic algorithm is proposed to solve the evacuation problem, as the goal to obtain the minimum total travel time. In order to analyze the reliability index, a stochastic simulation is used to simulate the number of crowd demand for each pick-up point. The method in this paper can be used in the performance of the emergency evacuation phase algorithm.
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