Research on Flood Rescue Route Modeling Considering the Priority of Trapped People

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Abstract: In flood rescue work, due to the complexity of the disaster and the wide distribution of people, how to efficiently and timely rescue has become the top priority of rescue operations. In the short time after the disaster, the flood spreads rapidly, ground transportation is often seriously affected, and the survival status of trapped people, injuries and other information is incomplete or lagging behind, resulting in a great challenge to the rescue command. Therefore, how to rationally deploy resources, optimize rescue routes, enhance rescue efficiency, and ensure that the most urgent trapped people are rescued in a timely manner is an important topic in current research and practice. In this context, this paper proposes a flood rescue route model based on the priority of trapped people, aiming to optimize the rescue routes through the scientific ranking of trapped people's priority and combining with the data of road conditions in the disaster area, so as to improve the rescue efficiency.

Keywords: Flooding; Prioritization; Rescue; Mathematical modeling.

1. Introduction

Floods, as one of the frequent natural disasters around the world, pose a great threat to the safety of people's lives and property, social stability and economic development. After a flood, rapid and efficient rescue operations are crucial, especially when there are many trapped people, how to scientifically dispatch rescue resources and optimize rescue routes becomes the key to improve rescue efficiency. However, most of the existing rescue route planning methods ignore the priority of trapped people and fail to fully consider the severity of the disaster and the urgency of trapped people in different affected areas, thus affecting the overall rescue effect.

In the event of a flood, the life and death of trapped people are closely related to the timeliness of rescue. Trapped people in different regions may face different rescue needs and time windows when it is a matter of life and death. Therefore, how to rationally plan rescue routes according to the priority of trapped people has become an important research topic to enhance the efficiency and effectiveness of rescue.

The aim of this paper is to optimize the route selection by considering the differences in the priorities of trapped people, combined with the limited nature of rescue resources. Based on the consideration of different priority levels of trapped people, this study constructs a mathematical optimization model to guide rescuers to develop optimal rescue routes in complex flooding environments in order to save more lives in the shortest time.

2. Literature Review

In accordance with the main research content of this paper, the following is a categorized review and commentary of domestic and international literature on emergency route planning research under emergencies and flood emergency route planning research.

2.1. Research On Emergency Route Planning Under Emergencies

An emergency is an emergency or disaster that occurs suddenly in a certain region, is large in scale and has a broad negative impact on society, such as various natural disasters and public health events. Such situations can lead to the interruption of people's normal lives and the destruction of resources necessary for their survival. Therefore, at the location of the event, people need to be rescued and relocated to a safe place within a short period of time. Reasonable and timely planning of emergency rescue routes can largely improve the rescue efficiency, alleviate the disaster situation, and protect the lives and properties of the people. Therefore, the study of emergency rescue route planning is of great practical significance. This not only helps to improve the efficiency of rescue operations, but also effectively respond to the various challenges that may be brought about by emergencies, to ensure the safety and stability of the people.

A number of related studies have been conducted at home and abroad on emergency route planning under emergencies. Yang et al [1] developed an optimization model that, given real-time traffic information, can help emergency response vehicle dispatchers to assign multiple emergency response vehicles and determine routes to avoid congested points in the traffic network. In the aftermath of a large-scale disaster, optimal helicopter rescue task assignment as well is critical to save many lives. Andreeva-Mori et al [2] proposed a model that can reflect the various characteristics of helicopters as well as evacuation task characteristics. Fereiduni et al [3] proposed a single-objective optimization model that addresses the response phase of disaster management. The model will help decision makers to make optimal choices in terms of localization, distribution and evacuation at the same time. Tao Zhang et al [4] argued that the route planning problem after an earthquake is different from the traditional shortest-circuit problem and vehicle route planning problem, where timeliness and safety become the most important constraints; it also needs to consider the changes in road conditions caused by the earthquake and the update of weights. Ki-Wen Ahn et al [5] described the rescue and evacuation route planning problem by defining the emergency demand-oriented transportation network, the access cost of the transportation routes and the passability of the transportation routes, etc. In the case of natural disasters,

a reasonable evacuation plan can save the lives of human beings. In order to develop an effective emergency evacuation plan, Dulebenets et al (6) proposed a mixed-integer planning model that assigns individuals, including vulnerable groups, to emergency shelters via evacuation routes within the available time period. Determining safe and fast routes for first responders is an important issue in disaster response. After a disaster, a fast response time is required and the responders should reach the disaster site to provide emergency services as fast as possible and even through certain obstacles.Wang and Zlatanova (7) studied route planning through moving obstacles, considering the effect of obstacles on the road network conditions and the speed of rescue vehicles. Considering that emergencies can have a large impact on the road network, Xing Zhao et al (8) used route travel time based on BPR (FHWA) road resistance function with reliability based on a large amount of historical traffic data as the optimization objective for route planning. Zhong et al (9) developed a bi-objective model for the disaster relief location routing problem (LRP) with stochastic demand. Liu et al (10) considered rescue process and other important factors, such as the number of people affected and the extent of building damage, to solve the rescue route problem by maximizing the efficiency of arc-based rescue. Based on the objective analysis of multi-objective emergency rescue dispatching and optimal route selection, Yao et al (11) proposed an integrated optimization model for two-layer planning considering different types of emergency vehicle dispatching and optimal route selection. Dispatching rescue vehicles to the scene of a fatal accident or fire as soon as possible is crucial to save lives; however, how to minimize the time for rescue vehicles to arrive at the rescue site remains an open challenge. Nguyen et al (12) proposed a route planning and traffic diversion scheduling scheme to minimize the travel time of electric vehicles in the context of vehicular connectivity. A cooperative optimization method for ambulance vehicle routes was proposed in the context of the New Crown epidemic, taking into account the uncertainty of the traffic environment under the time-varying urban road network.

Most of the aforementioned studies on emergency route planning under emergencies look at the broader context of disaster emergency management and explore emergency route planning strategies that are applicable in many different disaster situations. Some of the studies focus on specific types of disasters, such as earthquakes, because the destructive and unpredictable nature of earthquake disasters requires special emergency response strategies. Relatively few studies have been conducted in the context of floods, but flood hazards also require specialized emergency route planning studies due to their unique challenges, such as rapidly changing hydrological conditions and damage to infrastructure.

2.2. Flood Emergency Route Planning Study

The characteristics of floods such as suddenness, urgency and destructiveness lead to the characteristics of flood relief such as uncertainty, urgency and danger. These characteristics have led to some important research contents of flood emergency route planning. Aiming at the problem of post-disaster search and rescue in the storm surge assisted decision-making system for the affected area, Huang Dongmei et al (13) proposed how to carry out search and rescue route determination in the special case of extending the search and rescue team into two. For the search and rescue of trapped people in floods, Li Shouying et al (14) established an optimization model for the locating-route problem with fuzzy search and rescue time and with time windows, and proposed a hybrid genetic algorithm with heuristic rules. Cong Zhang et al (15) compared the experimental results, the dynamic ant colony algorithm has higher accuracy in solving the shortest route and provides an efficient and practical reference method for future flood search and rescue problems.Gama et al (16) proposed a multi-period location allocation method, which determines when and where to open a predefined number of shelters, when to send evacuation orders and how to assign the evacuees to the evacuees over time. of time evacuees are assigned to shelters. In a flood scenario, Mollah et al (17) addressed the problems of evacuating people, reassigning them to relative safety, and distributing relief supplies by developing a cost optimization model.Zhu (18) constructed two differentiated models based on the same and different levels of damage, in which relative deprivation cost was proposed as one of the decision objectives, emphasizing fairness, and the tolerable pain in transportation duration as a time window constraint to highlight the rescue priority.

Under the characteristics of flood rescue, existing researches have fully considered the key uncertainties such as search and rescue time and the number of trapped people, and designed corresponding solution algorithms for the rescue route planning model. These studies usually include key indicators such as rescue time and rescue cost in the objective function to realize the optimal allocation of rescue resources. However, relatively few studies focus specifically on the rescue priority of trapped people, which is important for improving rescue efficiency and guaranteeing rescue quality in actual rescue operations.

3. Mathematical Model

3.1. Description of the problem

In the event of a flood, infrastructure such as roads, bridges, and communications in the affected area are usually severely damaged, making rescue operations complex and challenging. The assault boat has the ability to be highly maneuverable, shallow water adaptable, and highly loaded, so trucks are used to carry the boat to the vicinity of the water, and the boat enters the water to rescue the trapped people. The first task after a flood is to carry out rapid and effective rescue of trapped people, and in large-scale disasters, rescue resources are usually limited, and resources must be reasonably scheduled to ensure that the rescue work is carried out efficiently. At this time, how to maximize the rescue efficiency through scientific route planning, especially how to rationally arrange the rescue order and route according to the priority difference of the trapped people, has become a key issue in post-disaster rescue. In summary, the problem is to plan the rescue route path of the truck-surge boat to minimize the product of the weight of the trapped person and the rescue time based on the existence of rescue priority difference of the trapped person?

To clarify the scope of application of the thesis, the following assumptions are made:

1) The locations and distances of the rescue operation center, the truck stop, and the node where the assault boat goes to rescue are known.

2) The same type of trucks and assault boats are used. The same type of carrier has the same load capacity and speed.

3) Each truck carries only one assault boat and the power of the assault boat is not considered.

3.2. Model Construction

3.2.1. Symbols and variables

(1) Sets

I_1 denotes the set of truck docking nodes. I_2 denotes the set of nodes where the assault boats went to the rescue. I denotes the set of nodes, $I = I_1 \cup I_2$, $i, j, f \in I$. o denotes the center of the rescue operation. E denotes the set of all nodes, $E = o \cup I$. K denotes the set of rescue trucks, $k \in K$. C denotes the set of assault boats, $c \in C$. B denotes the set of all trapped persons, $b \in B$. N denotes the collection of times each punch boat carried by the rescue truck departed from the shore to the rescue, $n \in N$.

(2) Parameters

w_b denotes the weight corresponding to the trapped person b. ω_c denotes the maximum load of the assault boat c. t_c^{per} denotes the single rescue time of the assault boat c. t_c^{take} denotes the time for a single shore reception of a trapped person in an assault boat c. t_c^{out} denotes the preparation time of the assault boat c. t_c^{in} denotes the receiving time of the assault boat c. t_{ijk}^{tra} denotes the time for the rescue truck k to travel from the node i to the node j. t_{ijkc}^{tra} denotes the time the rescue truck k with the assault boat c traveled from the node i to the node j. M denotes a large constant.

(3) Intermediate variables

a_{ik} denotes the time when the rescue truck k arrives at the node i, $i \in I_1$. g_{ik} denotes the time when the rescue truck k leaves the node i, $i \in I_1$. a_{ikc}^n denotes the time of the Nth return to the shore node i of the assault boat c carried by the rescue truck k, $i \in I_1$. g_{ikc}^n denotes the time of the Nth departure of the assault boat c carried by the rescue truck k from the shore node i, $i \in I_1$. $a_{i,jkc}^n$ denotes the time when the rescue truck k carrying the assault boat c departs from the shore node i to the water rescue for the Nth time and arrives at the pending rescue node j in the water, $i \in I_1, j \in I_2$. $g_{i,jkc}^n$ denotes the time at which the rescue truck k carrying the assault boat c departs from the shore node i for the Nth time to rescue in the water and leaves after rescuing node j, $i \in I_1, j \in I_2$. t_{ikc}^{pro} denotes the time taken by the assault

boat c carried by the rescue truck k to complete the rescue mission corresponding to the waters near node i, $i \in I_1$. t_{ik}^{pro} denotes the time taken by the rescue truck k to complete the rescue mission in the water near the node i, $i \in I_1$. t_b denotes the extrication time of the trapped person b.

(4) Decision variables

α_{ik} denotes a 0-1 variable that takes the value of 1 when rescue truck k stops at node i and uses its mounted assault boat to perform a rescue of a node in the water in its vicinity; otherwise, it takes the value of 0. $\beta_{i,jkc}^n$ denotes a 0-1 variable that takes the value of 1 when the rescue truck k carries an assault boat c that departs from the shore node i for the Nth time to rescue the water and performs a rescue of node j in the water; otherwise, it takes the value 0. x_{ijk} denotes a 0-1 variable that takes the value of 1 when rescue truck k moves from node i to node j; otherwise, it is 0. $y_{i,jfkc}^n$ denotes a 0-1 variable that takes the value of 1 when the rescue truck k carries the assault boat c for the Nth time for rescue from the shore node i, moving from node j to node f; otherwise, it is 0. $\rho_{i,jkc,b}^n$ denotes a 0-1 variable that takes the value 1 when the rescue truck k carrying the assault boat c departs from the shore node i for the Nth time for a rescue in the water, and rescues the trapped person b at node j; otherwise, it takes the value 0.

Model construction

The model is built as follows:

$$min \sum_{b \in B} w_b t_b \tag{1}$$

$$\sum_{i \in I_1} x_{oik} = 1, \forall k \in K \tag{2}$$

$$\sum_{i \in o \cup I_1} x_{ijk} = \sum_{f \in I_1} x_{jfk}, \forall j \in I_1, k \in K \tag{3}$$

$$\sum_{i \in I_1} \sum_{j \in I_1 \cup I_2} y_{i,jfkc}^n = \sum_{i \in I_1} \sum_{e \in I_1 \cup I_2} y_{i,fekc}^n, \forall f \in I_1 \cup I_2, k \in K, c \in C, n \in N \tag{4}$$

$$\sum_{k \in K} \alpha_{ik} = 1, i \in I_1 \tag{5}$$

$$\sum_{b \in B} \sum_{i \in I_1} \sum_{j \in I_2} \sum_{k \in K} \rho_{i,jkc,b}^n \beta_{i,jkc}^n \leq \omega_c, \forall c \in C, n \in N \tag{6}$$

$$a_{jk} \geq g_{ik} + t_{ijk}^{tra} - M(1 - x_{ijk}), \forall i \in o \cup I_1, j \in I_1, k \in K \tag{7}$$

$$g_{ik} \geq a_{ik} + t_{ik}^{pro} - M(1 - \alpha_{ik}), \forall i \in I_1, k \in K \tag{8}$$

$$a_{i,jkc}^n \geq g_{ikc}^n + t_{ijkc}^{tra} - M(1 - y_{i,ijkc}^n), \forall i \in I_1, j \in I_2, k \in K, c \in C, n \in N \tag{9}$$

$$a_{ikc}^n \geq g_{i,jikc}^n + t_{jikc}^{tra} - M(1 - y_{i,jikc}^n), \forall i \in I_1, j \in I_2, k \in K, c \in C, n \in N \tag{10}$$

$$g_{ikc}^1 = a_{ik} + t_c^{out}, \forall i \in I_1, k \in K, c \in C \tag{11}$$

$$g_{ikc}^n = a_{ikc}^{n-1} + t_c^{take}, n = 2,3,\ldots,N, \forall i \in I_1, k \in K, c \in C$$

$$(12)$$

$$a_{i,fkc}^n \geq g_{i,jkc}^n + t_{jfkc}^{tra} - M(1 - y_{i,jfkc}^n), \forall i \in I_1, j, f \in I_2, k \in K, c \in C, n \in N \qquad (13)$$

$$g_{i,jkc}^n \geq a_{i,jkc}^n + t_c^{per}(1 + \delta)^{n-1} - M(1 - \beta_{i,jkc}^n), \forall i \in I_1, j \in I_2, k \in K, c \in C, n \in N \qquad (14)$$

$$t_{ikc}^{pro} = \sum_{k \in K} \sum_{j \in I_1} \sum_{n=1}^N a_{ikc}^n + t_c^{take} + t_c^{in}, \forall i, j \in I_1, k \in K, c \in C \qquad (15)$$

$$t_{ik}^{pro} = max\{t_{ikc}^{pro}, \forall i \in I_1, k \in K, c \in C\} \qquad (16)$$

$$t_b = \sum_{n \in N} \sum_{c \in C} \sum_{k \in K} \sum_{j \in I_2} \sum_{i \in I_1} (a_{ikc}^n + t_c^{take}) \beta_{i,jkc}^n \rho_{i,jkc,b}^n + \sum_{n \in N} \sum_{h \in H} \sum_{f \in I_3} (a_{oh}^n + t_c^{take}) \gamma_{o,fh}^n \sigma_{o,fh,b}^n, \forall b \in B \qquad (17)$$

$$\sum_{n \in N} \sum_{c \in C} \sum_{k \in K} \sum_{j \in I_2} \sum_{i \in I_1} \rho_{i,jkc,b}^n + \sum_{n \in N} \sum_{h \in H} \sum_{f \in I_3} \sigma_{o,fh,b}^n = 1, \forall b \in B \qquad (18)$$

$$\alpha_{ik}, \beta_{i,jkc}^n, x_{ijk}, y_{i,jfkc}^n, \rho_{i,jkc,b}^n \in \{0,1\}, \forall i, j, f \in E, k \in K, c \in K, n \in N \qquad (19)$$

In the model, Eq. (1) represents the objective function, where the objective is to minimize the product of the weight corresponding to the trapped person b and the extrication time of the trapped person b. Constraint (2) indicates that the rescue truck can only depart from the rescue operation center once. Constraint (3) denotes that the rescue truck reaches a certain node and must leave from that node. Constraint (4) means that a rush boat arrives at a node and must depart from that node. Constraint (5) indicates that each I_1 node can only be traveled to by one rescue truck. Constraint (6) means that the boat cannot carry more than its maximum load of trapped people per departure. Constraint (7) means that the arrival time of a rescue truck at a node is not less than the sum of the departure time from the previous node and the traveling time between the two nodes. Constraint (8) indicates that the time for the rescue truck to leave a node is not less than the sum of the time to arrive at the node and the time to complete the rescue mission in the waters near the node, and the resting time of the rescue personnel. Constraint (9) denotes the relationship between the time of the Nth departure time of a rescue truck k carrying an assault boat c from the shore node i to the nearby water for rescue and the time of arrival time at any of the nodes to be rescued in the water. Constraint (10) denotes the relationship between the time of the Nth return of the assault boat c carried by the rescue truck k to the shore node i and the time of its departure from any of the pending rescue nodes in the watershed. Constraint (11) represents the relationship between the time of the rescue truck k carrying an assault boat c 1st departure from the shore node i to the nearby waters for rescue equal to the sum of the time of the rescue truck's arrival at the node i and the time of the assault boat's departure readiness. Constraint (12) denotes that the time for the Nth departure of the assault boat c carried by the rescue truck k from the shore node i to the nearby water for rescue is equal to the sum of the time for the $(N-1)th$ return to the shore node i and the time for the single reception of the trapped person carried by the assault boat. Constraint (13) denotes that the Nth departure of the assault boat c carried by the rescue truck k from the shore node i to the nearby water for rescue

takes no less time to reach a pending rescue node in the water than the sum of the time of leaving the previous rescue node and the traveling time between the two nodes. Constraint (14) denotes that the rescue truck k carrying the assault boat c departs from the shore node i for the Nth time to the nearby water for rescue, and the time to leave a node to be rescued within the water is not less than the sum of the time to arrive at the node and the time to rescue at that node. Constraint (15) denotes the time spent by the assault boat carried by the rescue truck k to complete the rescue task corresponding to the water in the vicinity of node i. Constraint (16) denotes the time consumed by the rescue truck k to complete the rescue mission in the water near node i. Constraint (17) denotes the extrication time of the trapped person b. Constraint (18) indicates that each trapped person must be rescued. Constraint (19) is a decision variable constraint.

4. Summary

The flood rescue route model based on the priority of trapped people proposed in this paper aims to improve the efficiency of flood rescue and ensure the maximization of life-saving in the case of limited resources. By comprehensively considering the life status of trapped people, geographic location, rescue needs and changes in the disaster area environment, the model realizes optimal scheduling of rescue resources and route planning, which can effectively improve the accuracy and timeliness of rescue work.

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