The optimal allocation of emergency materials for multiple points on water based on genetic algorithm

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Abstract: In order to study the shortest time of emergency supplies allocation, the supply chain of rescue materials is divided into three levels that is supply areas, shore rescue points and multiple accident points. Taking the limited period of emergency supplies as a prerequisite, a material distribution model is built for studying the shortest time of material distribution from rescue base to accident site; considering the sustainability of rescue base supplies, a land material distribution model is built for studying the minimum cost of transportation problem. According to the dispatching priority of emergency supplies at each accident site, a genetic algorithm is designed to solve it, and a approximate optimal rescue material distribution plan is obtained.

1. INTRODUCTION
Because of the increasing frequency of human maritime activities, the risk sources of maritime accidents are increasing everyday. Large ship accidents may require multiple rescue efforts at the same time. Due to the strong timeliness of handling maritime accidents \cite{1}, the efficient deployment of emergency materials has become the key to the success of large-scale maritime rescue activities.

At present, remarkable achievements have been made in the research on the deployment of emergency supplies. The output of representative results is often targeted at the minimum transportation cost \cite{2,3}, the shortest response time \cite{4} and the most reliable transportation path \cite{5,6}. Chen jinjing \cite{7} constructed the material scheduling model with the shortest transportation time while the transportation capacity of the emergency response base was limited and the materials could not be transported to the accident point at one time. It is on the premise of meeting the emergency limitation period of all kinds of materials. Literature \cite{8-9} considered the problem of ensuring the effective allocation of materials in the emergency response period with limited transport capacity. It established a two-stage multi-objective dynamic scheduling model based on demand chain. Zhang Mei \cite{10} optimized the distribution path of maritime emergency supplies by adopting ant colony algorithm, which improved the distribution efficiency of relief supplies.

These studies on the allocation of emergency materials for maritime accidents were based on the distribution of materials for single accidents. However, it did not consider the problem of the distribution of materials for more than one maritime accident at the same time within the influence range of a weather system due to the particularity of the environment. This article established the land material supplier, the bank rescue points, many accidents of emergency supplies and preparation of three layer structure model with the goal of the shortest water allocate time, the minimum land transport cost, when the shore base capacity is limited, the resources reserve is insufficient. It met the demand of accidents continue to
supply the material problems. Moreover, according to the accident spot for scheduling priority of different relief supplies, designed a genetic algorithm for solving, the article obtained the approximate optimal relief supplies allocation.

2. PROBLEM DESCRIPTION
The "accident prone place" in the road traffic system is generally only related to the local topography and road conditions. The frequency of accidents in the water traffic system is not only related to the hydrological characteristics of a certain region, but also may be affected by a certain weather system in a certain time, such as squall lines. It can be seen that in the water transportation system, it is not uncommon for multiple maritime accidents to occur simultaneously in a certain sea area within a certain short period of time. Due to aid distribution order, the impact on the rescue process and the role played by the different accident rescue is different, so in the process of water accident rescue has different scheduling priority, accident more relief, compared to the single accident point is to consider the accident point to of all kinds of aid distribution scheduling priority, and when accident more disasters occur, each bank rescue base need to juggle all accident point of material transportation, maximum utilization of capacity. As a result, the bank rescue base, make rescue response time the shortest.

When multiple accidents occur, it is difficult to meet the material demand of the accident site simply by relying on a limited number of shore-based rescue forces. In order to improve the sustained supply capacity of relief materials, it is necessary to trigger the rapid and effective accumulation of materials in the land supply area and timely delivery of materials to the shore-based rescue base. As shown in Figure 1, the material supply layer represents the onshore supply base belonging to the shore rescue base in the assembly layer. When the material storage in the assembly layer is insufficient, the supply layer will carry out distribution. Finally, the assembly layer will be transported to the accident layer after optimizing deployment.

Due to the limited shipping capacity of the rescue base, it is not possible to transport all the supplies to the accident points at the same time. So it may be necessary to transport the rescue ships for multiple times. Therefore, according to the priority of dispatch under the condition of limited capacity of the shore rescue base, the main problem to be considered is how to load and transport the materials to each accident point in the shortest time. In this situation, this paper make an optimal allocation, that the optimized scheme is divided into two parts. The first part is to determine the number of rescue ship and rescue ship on the shore to each accident rescue base point and the number of times, transportation between the demand for emergency supplies always make sure that the accident through a reasonable distribution of rescue ships, which on the basis of response rescue the shortest time and participate in
the rescue ship quantity at least. The second part minimizes the cost of overland transportation on the premise of meeting the time requirements of rescue materials for each accident point.

3. MATHEMATICAL MODEL

3.1 Model assumptions
(1) Sum category of emergency supplies are known.
(2) The optimal route for land transportation is known. Land transport vehicles use only one mode without capacity limits.
(3) The drift of each accident point is not considered.
(4) The transportation process does not consider the weather, road conditions, changes in sea conditions and other factors.
(5) The total demand for materials in case of accidents shall not exceed the amount of materials in reserve at the land supply sites.
(6) The materials of each shore rescue base can only be distributed at its own land supply point. There is no distribution between each shore rescue base.

3.2 Model building

3.2.1 Material distribution model from the shore rescue base to each accident point
Here A1, A2, A3,...,Ap is each accident point. There are Np accident points and m kinds of relief materials.

\[ X = \begin{pmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{p1} & \cdots & x_{pm} \end{pmatrix} \]

is the number of materials which needed at the accident point matrix. L1, l2, l3...ln are n shore rescue bases, and li is currently able to provide relief supplies \( x_i = (x_{i1}, x_{i2}, \ldots, x_{im}) \).

Suppose the coastal rescue base li has \( y_i \) rescue ships, \( u_{ij} \) is li’s jth ship, with a capacity of \( Z_{ij} \) and a speed of \( v_{ij} \). Then, so that the total capacity of all rescue vessels in the offshore rescue base

\[ z_i = \sum_{j=1}^{y_i} z_{ij} \].

Because the rescue ship transportation will suffer from wind and waves in the water, this article need to introduce he influence of such factors to the winds and waves of impact factor \([11]\). With the ship’s capacity and static water transportation separately carried on the correction. According to the accident rescue base point and the shore of distance d, geographic coordinates calculated each accident rescue base point and the shore are calculated separately, and the delivery of time of the ship.

Because the loading and unloading efficiency of materials can be improved by mechanization, the loading and unloading time is not considered in this paper. So the time for the rescue ship to participate in the transportation is

\[ t_{ijk} = \tilde{t}_{ijk} + \bar{t}_{ijk} \]  \hspace{1cm} (1)

\[ t_{ijk} = \sum_{j=1}^{p} \sum_{j=1}^{y_i} \sum_{k=1}^{n} n_{ijk} \tilde{t}_{ijk} \]  \hspace{1cm} (2)

\[ t'_{ijk} = \max_{j=1,2,\ldots,y_i} t_{ijk} \]  \hspace{1cm} (3)

(1) is the time for the jth rescue ship of the shore base i to make one transportation trip to the accident point k. \( \tilde{t}_{ijk} \) and \( \bar{t}_{ijk} \) is the time for the rescue ship to make one trip. (2) is the total transport time of \( u_{ij} \) ship participating in all accident points. \( N_{ijk} \) is the number of transport between j ship at the shore rescue base i and the accident point k. (3) is the time which is taken for li to complete the material s transportation of accident point k. \( \tilde{t}_{ijk} \)represents the time that \( u_{ij} \) ship actually completed the material s transportation of accident point k.

In the process of distribution of relief materials, the highest level of relief materials shall be loaded
and distributed according to the priority of the relief materials until all the relief materials are transferred and transported. Assume that $m$ kinds of relief materials are divided into $m$ stages. Only one kind of materials will be transferred in each stage. When one kind of material is loaded, the next kind of material will be loaded when the capacity of the rescue ship is still available. Set $0, t_1, t_2, ..., t_m$ as the distribution time of $w$ kinds of relief materials before all the relief bases are distributed, then the distribution time of the $t$ type of relief materials is $T(w) = \max_{i=1,2,...,n} t_i$.

When the $s$-type materials are distributed, the times and traffic volume of the ship from the offshore base to the accident point should be recorded at each stage.

$$\min T(p,s), \forall p,s$$

$$v_i'(p,q) = \min \{Q_i'(p,q-1), z_i'(p,q)\}$$

$$\sum_{p=1}^{N_p} \sum_{k=1}^{n} \sum_{q=1}^{n} v_i'(p,q) \geq x_{ps}, \forall p,s$$

$$T(p,s) \leq T_{ps}, \forall p,s$$

$$v_i'(p,q) \geq 0$$

Formula (4) is the target model from the shore rescue base to each accident point, that is, the response time in this stage is the shortest. Formula (5) is the amount of surplus materials after $l$, the $q$th delivery of $A_p$, at the accident point, $Q_i'(p,q)$ represents the amount of surplus materials after the $q$th delivery of $A_p$. $z_i'(p,q)$ represents $l$, is the shipping capacity of the participating ship selected at the $q$th stage of $A_p$. Formula (6) ensures that the material quantity distributed to each accident point by each shore rescue base at each stage. And it meets the demand of each accident point for the material. Formula (7) ensures that each material reaches each accident point within the emergency limit period of the material. Formula (8) indicates that the materials distributed at each stage are non-negative.

3.2.2 Land material distribution model

The main purpose of the model at this stage is to minimize the transportation cost of land vehicles while meeting the material supply demand at the accident point.

Suppose each shore rescue base has $f_i$ land supply points, and the $w$ land supply point of shore rescue base $l_i$ is $P_{iw}$, $w=1, 2, ..., f_i$, $i=1, 2, ..., n$. The transportation time from each overland supply point to its shore-based rescue base is $t_{iw}$. The unit transportation cost is $r_{iw}$. The current storage of the sth material of $P_{iw}$ at the onshore supply point is $m_{iw}$. In addition, the demand for the sth material of the shore-based rescue base $l_i$ was sufficient. During the $q$th delivery, $l_i$ obtained $m_{iw}^q(q)$, that is the amount of the sth material supplied by $P_{iw}$. And $Q_{iw}^q(q)$ was the amount of the remaining sth material of the onshore supply point $P_{iw}$ after the $q$th delivery.

$$\min R = \sum_{i=1}^{n} \sum_{q=1}^{n} r_{iw} m_{iw}^q(q)$$

Constraints:

$$t_{iw} \leq \min_{j=1,2,...,f_i} t_{ijk} \forall I,s=1,2,...,f_i$$

$$m_{iw}^q(q) \leq Z_{iw}^q(q-1) \forall (I,s,q,w)$$

$$m_{iw}^q(q) \geq 0 \forall (I,s,q,w)$$

Equation (9) is the objective function, that the land transportation cost is the minimum. Formula (10) refers to any distribution of land transportation, which meets the requirements of the shore rescue base for the distribution of materials in terms of time. Formula (11) means that the quantity of materials supplied on land. It shall not exceed the actual supply of materials. Formula (12) means that the quantity of materials delivered on land shall be non-negative.
4. ALGORITHM DESIGN

a) Population initialization: Because the real number encoding can operate directly on the phenotype of the solution without the need for numerical conversion, this paper adopts the real number encoding, that regards the chromosome as a real number vector.

b) Fitness function: In the process of natural selection, the quality of individuals is mainly measured by the fitness function transformed by the target function. Since the aim of this paper is to minimize the rescue response time and cost, the inverse of the function value is taken as the fitness value. The fitness function is \( F = f(x) \).

c) Selection operation: Selection operation is to select the best individuals from the old population according to the probability. The selected excellent individuals will form a new superior population through recombination. And the new population will reproduce the next generation of individuals. In this paper, a roulette method is adopted to select individuals using the fitness ratio for selection. The probability of individual \( I \) being selected is \( p_i = \frac{F_i}{\sum_{i=1}^{N} F_i} \), wherein, the fitness value of individual \( I \) is \( F_i \). The number of individuals is \( N \).

d) Crossover operation: The so-called crossover operation refers to an operation in which some good genes of two parent individuals are replaced and recombined to form a new good individual according to the crossover probability. In this paper, the real number crossover method is mainly adopted. The crossover operation method of the \( k \)th chromosome \( a_k \) and the \( j \)th chromosome \( a_l \) is:

\[
a_{kj} = a_{kj}(1-b) + a_{lj}b, \quad a_{lj} = a_{lj}(1-b) + a_{kj}b
\]

where \( b \) is the random number in the interval \([0,1]\).

e) Variation operation: Variation operation is to maintain the diversity of the population by randomly selecting an individual from the population. The operation method for mutation of the \( j \)th gene \( a_{ij} \) of the \( i \)th individual is as follows:

\[
a_{ij} = \begin{cases} a_{ij} + (a_{ij} - a_{max}) \times f(g), & r \geq 0.5 \\ a_{ij} + (a_{min} - a_{ij}) \times f(g), & r < 0.5 \end{cases}
\]

Here \( a_{max} \) is the upper bound of gene \( a_{ij} \) \( a_{min} \) is the lower bound of gene \( a_{ij} \) \( F(g) = r_2(1 - g / G_{max})^2 \) and \( r_2 \) is a random number. \( g \) is the number of the current iteration, \( G_{max} \) is the number of the maximum evolution. \( F(g) = r_2(1 - g / G_{max})^2 \). \( R \) is the random number in the interval of \([0,1]\).

The algorithm flow is shown in figure 2

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**Figure 2. Algorithm flow chart**
5. ANALYSIS OF CALCULATION EXAMPLES

Suppose there is a maritime accident in a certain sea area, wind force 8, wind direction NE, wave direction N, wave level 4. A total of three accident point A1, A2, A3 are waiting for rescue respectively. They need five kinds of emergency aid for the m1, m2, m3, m4, m5. Due to the accident point scheduling priority on materials is different, the degree of demand for supplies of emergency accident point is divided into ten which ten is the highest grade. The accident point of the demand for goods and scheduling priority as shown in Table One. There is a total of four shore rescue bases participated in the rescue. The amount of material reserves of the shore rescue points is shown in Table Two. Table Three is the detailed information of the ships participating in the rescue. Table Four is the information of the land supply points.

In this paper, matlab is used to program the above calculation examples according to the genetic algorithm. The optimal deployment scheme is obtained, as shown in Table 5, Table 6 and Table 7.

| The accident point | m1 (dispatching priority) | m2 (dispatching priority) | m3 (dispatching priority) | m4 (dispatching priority) | m5 (dispatching priority) |
|--------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| 1                  | 11 (5)                    | 7 (8)                     | 15 (6)                    | 8 (7)                     | 10 (9)                    |
| 2                  | 12 (9)                    | 7 (7)                     | 12 (8)                    | 9 (5)                     | 11 (6)                    |
| 3                  | 10 (8)                    | 8 (6)                     | 10 (5)                    | 7 (7)                     | 6 (9)                     |

| Shore base | m1 | m2 | m3 | m4 | m5 |
|------------|----|----|----|----|----|
| 1          | 6  | 4  | 3  | 1  | 4  |
| 2          | 5  | 3  | 0  | 4  | 5  |
| 3          | 4  | 0  | 4  | 4  | 2  |
| 4          | 1  | 3  | 7  | 2  | 1  |

| ship | subordinate to the base | shipping capacity | time to A1 | time to return | time to A2 | time to return | time to A3 | time to return |
|------|--------------------------|-------------------|------------|----------------|------------|----------------|------------|----------------|
| 1    | 1                        | 6                 | 2          | 1              | 3          | 2              | 4          | 3              |
| 2    | 2                        | 8                 | 2          | 1              | 4          | 2              | 5          | 2              |
| 3    | 3                        | 5                 | 3          | 2              | 2          | 1              | 4          | 2              |
| 4    | 4                        | 7                 | 3          | 2              | 1          | 3              | 1          |                 |
| 5    | 4                        | 7                 | 4          | 2              | 3          | 2              | 2          | 1              |
| 6    | 4                        | 6                 | 4          | 2              | 3          | 2              | 2          | 1              |

| land supply point | Belong to the shore rescue base | supply capacity | Time to shore base | time to return |
|-------------------|---------------------------------|-----------------|---------------------|----------------|
| supply centre 1   | 1                               | 12              | 1                   | 1              |
| supply centre 2   | 2                               | 13              | 2                   | 1              |
| supply centre 3   | 3                               | 11              | 1                   | 1              |

| ship | A1 | A2 | A3 | time |
|------|----|----|----|------|
| 1    | 2 times | 1 time | 1 time | 18   |
| 2    | 2 times | 2 times | 1 time | 25   |
| 3    | 2 times | 0 time | 3 times | 28   |
| 4    | 0 time | 3 times | 0 time | 9    |
| 5    | 3 times | 0 time | 2 times | 24   |
| 6    | 0 times | 3 times | 0 time | 15   |
Table 6. Details of material transportation at each accident point are shown in the shore base

|   | A1m | A1m2 | A1m3 | A2m | A2m2 | A2m3 | A3m | A3m2 | A3m3 | A3m4 | A3m5 |
|---|-----|------|------|-----|------|------|-----|------|------|------|------|
| 1 | 1   | 1    | 1    | 1   | 1    | 1    | 1   | 1    | 1    | 1    | 1    |
| 2 | 2   | 3    | 2    | 3   | 3    | 3    | 3   | 2    | 3    | 2    | 3    |
| 3 | 0   | 1    | 3    | 1   | 2    | 2    | 4   | 3    | 5    | 4    | 1    |
| 4 | 5   | 3    | 6    | 3   | 2    | 7    | 0   | 8    | 0    | 1    | 3    |

Table 7. Land supply points for each shore base transport arrangements

| Land supply point | m1 | m2 | m3 | m4 | m5 | Delivery times | Completion time |
|-------------------|----|----|----|----|----|----------------|----------------|
| 1                 | 0  | 1  | 3  | 0  | 1  | 1             | 2              |
| 2                 | 2  | 1  | 2  | 8  | 4  | 4             | 2              |
| 3                 | 14 | 1  | 10 | 5  | 5  | 3             | 6              |

According to the calculation results, each of the four shore-based reaction bases participated in the rescue of the three accident points. Each shore-based reaction base was able to carry out the reasonable and effective distribution of materials according to the priority of the dispatch of materials at each accident point. The method in this paper can effectively realize the overall planning of the allocation of water rescue materials. This method made full use of the ships participating in rescue under the premise of ensuring the shortest rescue response time and the lowest land transport cost.

6. CONCLUSIONS

On the basis of the single point accident emergency supplies by sea deployment, considering the actual condition of water accident aid allocation, on the same waters more accidents when the number of relief supplies and various kinds of demand, and the problem that the bank rescue base capacity limited, this paper designed to meet the accident point to aid the scheduling priority conditions make rescue response time the shortest, land transport model of the lowest cost, through genetic algorithm approximate optimal arrangement scheme. However, in the design process of this paper, the drift of each accident point under the influence of environmental forces is not considered. Further improvement is needed.

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