Multiple Coverage Location Problem of Water Emergency Facilities in the Yangtze River

Xiaolan Luo*, Jiaqi Yang

School of Transportation, Wuhan University of Technology, Wuhan, Hubei, 430063, China

***Abstract* - The reasonability of water emergency facilities location in the Yangtze River has great influence on the water emergency rescue capabilities. Based on the different levels of the the rescue object of water emergency facilities, the characterisitics of water emergency facilities location in the Yangtze River is analyzed. Then, the multiple-coverage location model of water emergency facilities location in the Yangtze River is constructed, and the ant colony algorithm is applied to solve the model. Finally, the model is verfied by the example of water emergency facilities in the Three Gorges Reservoir area, which is presented to find out the location plan.**

Keywords - Water emergency facilities; Multiple-coverage location; Ant colony algorithm

I. INTRODUCTION

The emergency management of water emergencies is a system engineering of multi factors and multi aspects, in which the emergency resource guarantee is the material basis of the emergency management, including various emergency resources guarantee of every stage such as prevention, disaster relief and recovery, and the rescue base location is the foundation of the emergency resource guarantee. In 2013, the number of water emergencies of transportation ships of China is 262; the number of people of death and missing is 265; the number of sinking ships is 142, and the direct economic loss is 38.4 million RMBs, which is respectively down by 3.1%, 4.3%, 13.9% and 17.6% comparing to last year. The number of organizing and coordinating search and rescue operations by all levels of water search and rescue center of China is 2164 in the year of 2013, and the number of various types of boats and aircrafts coordinated are respectively 7507 and 386; in the rescue responsibility zone of China, the number of ships in distress and rescue are respectively 2129 and 1748, and the number of people in distress and rescue are respectively 21,379 and 20,692, and the rescue success rate is 96.8%. The occurrences of water emergencies have brought great harm to the safety of life and property, and the ecological environment, of which the important support condition is the emergency resource guarantee in the quick, orderly and efficient organization of the water emergency response action, on the purpose of controlling the extension of water emergencies, and minimizing the casualties and property losses, ecological environmental emergencies. And the reasonability of the emergency rescue base location of water emergency has a great influence on the emergency resource guarantee. The development of water transportation in the Yangtze River is very fast, which makes much more difficult in the safety supervision work, and the layout of water emergency facilities has a direct impact on the efficiency of the water emergency management work. In this background, the multiple-coverage location problem in the Yangtze River is analyzed in this paper.

With regard to the multiple-coverage location problem, Daskin constructs a multiple-coverage location model with the objectives of maximum multiple-coverage areas and minimum quantity of vehicles, and an application example is given to validate the feasibility and effectiveness of the model [1]. Hogan introduces backup covering location to solve the efficient processing problem of random demand vehicle to respond to a call [2]. Hasan proposes a backup covering location model which is based on maximum covering location model, and introduces the Lagrange relaxation algorithm to solve the problem [3]. Scott studies on the backup covering location model of the problem of the land protected species [4]. Xiao Junhua builds a dual-objective and multi-level coverage attenuation location model of emergency facilities, and uses the hierarchical sequence method to solve the model [5].

At present, the idea of multiple-coverage location is applied rarely in the emergency location area, and the study of emergency facilities location in the special water area such as the Yangtze River is less. Therefore, based on the idea of multiple-coverage location, this paper constructs the multiple-coverage location model of the water emergency facilities in the Yangtze River with regard to the characteristics of emergency facilities, and the solution algorithm is presented. Finally, the example is given to verify the model.

II. ANALYSIS ON THE LOCATION CHARACTERISTICS OF EMERGENCY FACILITIES IN THE YANGTZE RIVER

The geographical scope of the layout planning of the national water transportation safety supervision and rescue

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system is the water area which is supervised by the central government, and the Yangtze River water area of 2,700 km below the city of Yibin is included, which is the study area in this paper. In the planning, the water transportation safety and rescue force is divided into three levels such as comprehensive rescue base, rescue base and rescue station. Based on the actual conditions, the study object of this paper is the location of the comprehensive rescue base of the water emergency facilities in the Yangtze River. The rescue object of the water emergency facilities is the water emergencies occurred in the water area of the Yangtze River, and the water emergencies are divided into four grades including significant grade, larger grade, general grade and small grade. The water emergency facilities in this paper focus on dealing with the significant grade and larger grade of water emergencies, and also deal with the general grade and small grade of water emergencies.

The conditions of water emergencies above the small grade in the Yangtze River Maritime area between the year of 2010 and 2014 are shown in the Table 1, which suggests that the quantity of the water emergencies in the year of 2014 is 12.5 decreased by 1.5 compared to the quantity in the year of 2013, and down by 10.7%.

TABLE 1. WATER EMERGENCIES ABOVE THE SMALL GRADE IN THE YANGTZE RIVER MARITIME AREA

Year	Total quantity of water emergencies	Quantity of water emergencies above small grade	Quantity of Death and disappearance	Quantity of the sinking	Direct economic loss（10,000 RMB）
2010	235	22	28	19	1578
2011	196	18.5	12	13	1058
2012	153	15.5	27	13	1601.5
2013	168	14	37	12	1150
2014	125	12.5	24	8	708.1
Comparison by last year	Lowest	Lowest	Second lowest	Lowest	Lowest

Data sources: Changjiang Maritime Safety Administration, 2014

There are three features of water emergencies including strong abruptness, far from land, and great rescue difficulty. For example, the capsized event of Star in the East happened in 2015 June 1st which would lead to grave consequences if it was not controlled on time. In order to avoid more serious consequences, it is necessary to study on the location problem of the water emergency facilities. Based on the characteristics of the water emergency facilities in the national planning, this paper analyzes the location problem from the angle of multiple-coverage, which means that when a water emergency occurs, rescue ships and other resources of the first water emergency facility covering this water emergency is in use or in the return status, this water emergency can be rescued by the second water emergency facility covering this water emergency.

III. MULTIPLE-COVERAGE LOCATION MODEL OF WATER EMERGENCY FACILITIES IN THE YANGTZE RIVER

A. Model Assumptions and Parameters

There are three basic assumptions of the model, firstly, the position of alternative points of water emergency facilities is presented by kilometer rage of waterway of the emergency terminals docked by the rescue ships of water emergency facilities, the position of water emergencies is presented by the kilometer rage of waterway in the statistics table of water emergencies by the Changjiang Maritime Safety Administration. Secondly, the alternative points of water emergency facilities are distributed in the corresponding shore land position of the point in the water area of the Yangtze River, and in the calculation of the rescue distance between water emergency facilities and water emergencies, the waterway width is negligible compared to the kilometer rage of waterway. Thirdly, the rescue distance is the distance from the waterway kilometer rage of the terminal docked by rescue ships of water emergency facilities to the waterway kilometer rage of the water emergencies.

There are several parameters in the model, such as I is the collection of water emergencies points, and J is the collection of the alternative points of water emergency facilities. p is the quantity of water emergency facilities, and R is the coverage radius of water emergency facilities. k_j is the rescue capability of a single water emergency facility located in the point of j, which is represented by the quantity of water emergencies rescued by the water emergency facility. d_{ij} is the distance from the water emergency facility point to the water emergency point. If $d_{ij} \le R$, $a_{ij} = 1$, otherwise, $a_{ij} = 0$. If $d_{ij} > R$, $b_{ij} = 1$, otherwise, $b_{ij} = 0$. If the water emergency point is covered

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once, $u_i = 1$, otherwise, $u_i = 0$. v_i is defined as the ratio of the water emergency covered twice. There are two decision variables such as x_j and y_{ij}, if the water emergency facility is located in the point of j, $x_j = 1$, otherwise, $x_j = 0$. When the i of water emergency occurred, the j of water emergency facility is chosen to rescue, $y_{ij} = 1$, otherwise, $y_{ij} = 0$.

B. Model Construction of Multiple-coverage Location

There are three objectives in the multiple-coverage location model as following:

$$f_1 = max\sum_{i\in I} u_i \tag{1}$$

$$f_2 = max\sum_{i\in I} v_i \tag{2}$$

$$f_3 = min\sum_{i\in I}\sum_{j\in J} b_{ij} d_{ij} y_{ij} \tag{3}$$

The formula (1) is represented as the first objective, which refers to the maximum quantity of water emergencies covered at least once. The formula (2) is represented as the second objective, which refers to maximum quantity of water emergencies covered at least twice. The formula (3) represented as the third objective, which refers to the minimum total rescue distances of the whole emergency rescue system in the case of the location point and the water emergencies point excess the covering distance.

The constraint conditions of the model are as following:

$$\frac{d_{ij} y_{ij}}{v} \le 0.75, \forall i \in I, \forall j \in J \tag{4}$$

$$x_j * x_k * d_{j,k} \ge 200, j \in J, k \in J \tag{5}$$

$$v_i - u_i \le 0, \forall i \in I \tag{6}$$

$$\sum_{j\in J} y_{ij} \ge 1, \forall i \in I \tag{7}$$

$$\sum_{i\in I} y_{ij} \le k_j x_j, \forall j \in J \tag{8}$$

$$\sum_{j\in J} x_j = p \tag{9}$$

$$u_i \in \{0,1\}, \forall i \in I \tag{10}$$

$$v_i \in [0,1], \forall i \in I \tag{11}$$

$$x_j \in \{0,1\}, \forall j \in J \tag{12}$$

$$y_{ij} \in \{0,1\}, \forall i \in I, \forall j \in J \tag{13}$$

The formula (4) refers to the response time limit of water emergency facilities. The formula (5) refers to the distance limit between water emergency facilities. The formula (6) means that when the water emergency point is covered firstly by one water emergency facility, it can be covered secondly by other water emergency facility. The formula (7) means that every water emergency can be rescued by the water emergency facilities. The formula (8) means that the total quantity of the water emergencies covered by the water emergency facility cannot exceed the rescue capability of this water emergency facility. The formula (9) refers to the quantity constraint of water emergency facilities. The formula (10) defines the intermediate variable of u_i. The formula (11) defines the intermediate variable of v_i. The formula (12) and formula (13) respectively define the decision variables.

C. Model Solving Algorithm

The multiple-coverage location model of the water emergency facilities in the Yangtze River is NP-hard problem, then the ant colony algorithm of serial quantity optimization is applied to solve the model, the specific solving steps are as following:

Firstly, the parameters such as the scale of the ant, the number of iterations, the range of the optimization variables, and the interval length are initialized, and according to these parameters, the position of ants are initialized including objective evaluation and pheromone.

Secondly, the global transfer factor, pheromone evaporation coefficient and transfer length parameters are defined, and then the initial optimal solution is obtained according to the objective value and pheromone concentration.

Finally, the global optimal solution of each generation is obtained. Every solution is determined to meet the constraint conditions or not, if it does not meet, it will be to deal with punishment, and if it meets, the objective evaluation value will be updated, and the pheromone will also be updated, and finally, the optimal location of water emergency facilities is obtained.

IV. EMPIRICAL ANALY OF THE THREE GORGES RESERVOIR AREA

The Three Gorges Reservoir area is a very important part of the water area of the Yangtze River water, then it is represented as an example to verify the model and algorithm. The conditions of water emergencies in the Three Gorges Reservoir Area between the year of 2008 and 2012 are shown in the Table. 2, and the grades, the types and the quantity of water emergencies are suggested in the table. Through the comparison of the grades and the types of water emergencies, the data of water emergencies of small grade is clustered to thirty water emergency points, and then $J = I = \{i_1, i_2, \cdots, i_{80}\}$. Refer to the relevant national layout planning, the coverage radius of water emergency facility is set as R =150 kilometers. Considering the coverage area of water emergency facilities, and according to the condition of the grades and quantity of water emergencies happened every year, the rescue capability of one water emergency facility is set as four hundreds of small-grade water emergencies, and the conversion relationship between the different grades of water emergencies is as follows: significant grade: large grade: general grade: small grade=8:4:2:1. The amount of data of d_{ij} is very large, and it is not listed one by one. According to the national layout planning and combined with the coverage area of the Three Gorges Reservoir area, the quantity of water emergencies is determined as p =3. Considering that the city of Chongqing has been equipped with the rescue ship with the speed of up to 50 km/hour, the speed of rescue ship of water emergency facilities is set as v= 50 km/hour. Refers to the shipping cost of the upper reaches in the Yangtze River, and combined with the characteristics of higher cost of water rescue work, the unit rescue cost is set as c_{ij} = 25 RMBs/kilometer.

When the ant colony algorithm is applied to solve the example of the Three Gorges Reservoir area, the three objective functions are integrated into one objective function such as the formula (14), which means that the number of water emergencies is maximum.

$$f = max\sum_{i\in I} u_i + max\sum_{i\in I} v_i - (min\sum_{i\in I}\sum_{j\in J} b_{ij} d_{ij} y_{ij}) / R \quad (14)$$

TABLE 2. TYPES AND GRADES OF WATER EMERGENCIES IN THE THREE GORGES RESERVOIR AREA

	Collision	Sunk	Grounding	Stranding	Contact damage	Fire	Other	Total
Small grade	16	6	35	31	16	6	9	119
General grade	7	6	2	5	1	1	3	25
Large grade	10	7	0	1	1	0	1	20
Significant grade	1	3	0	0	1	0	0	5
Total	34	22	37	37	19	7	13	169

Data sources: Changjiang Maritime Safety Administration, 2014

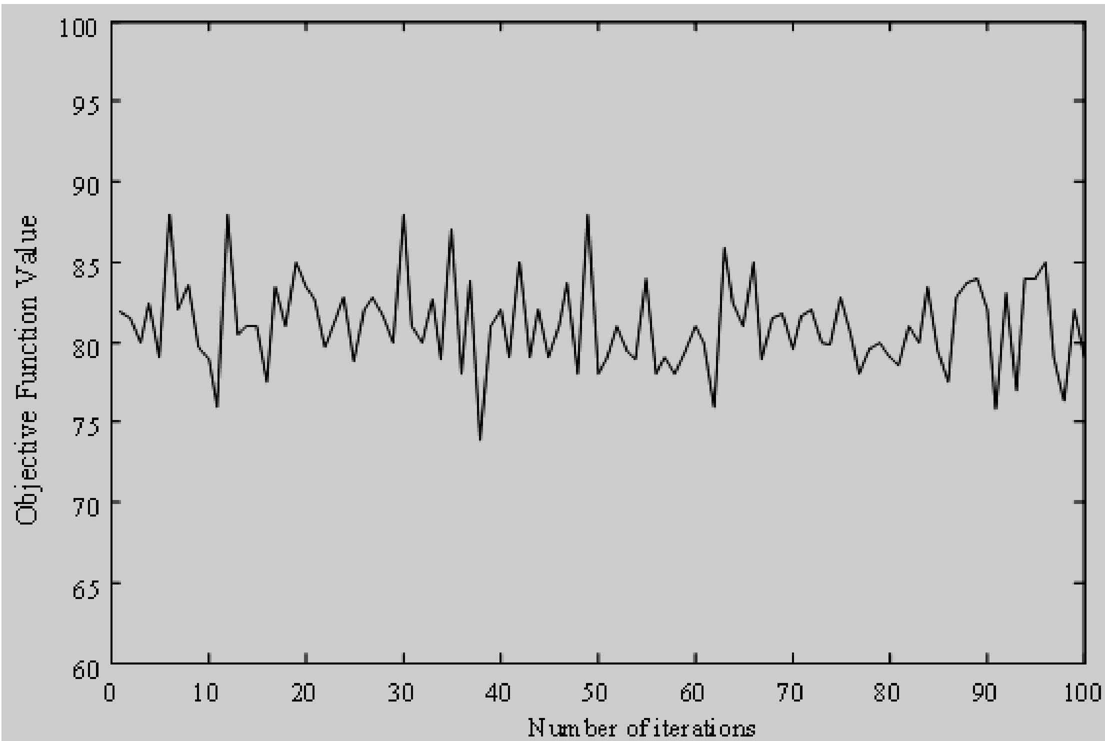

Figure 1. The diagram figure of water emergency facilities location

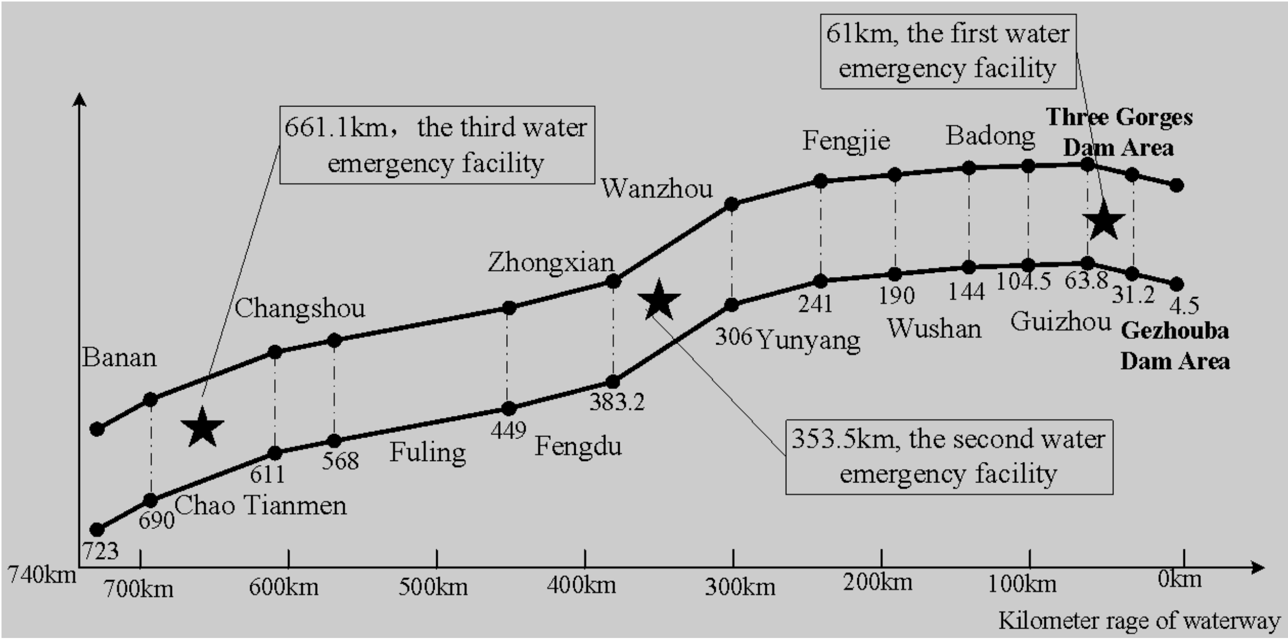

Figure 2. The result of the water emergency facilities location of emergency facilities in the Three Gorges Reservoir Area

MATLAB R2012b software is applied to run the program, and when the number of iteration is 100 times, the diagram of the objective function value and the number of iterations is obtained as shown in Figure 1, at this time, the optimal objective function value was 87.98, and the optimal location of water emergency facilities are corresponding shore land position of the waterway kilometers as 61km, 353.5km and 661.1km, which is shown in Figure 2. The first water emergency facility is located in the Three Gorges dam water area, covering 27 points of water emergencies which includes 3 points of significant grade, 5 points of water emergencies of large grade, 9 points of water emergencies of general grade, and 10 points of water emergencies of small grade. The second water emergency facility is located in the water area of the city of Wanzhou, covering 18 points of water emergencies which includes 1 points of significant grade, 5 points of water emergencies of large grade, 4 points of water emergencies of general grade, and 8 points of water emergencies of small grade. The third water emergency facility is located in the water area of the city of Chongqing, covering 35 points of water emergencies which includes 1 points of significant grade, 10 points of water emergencies of large grade, 12 points of water emergencies of general grade, and 12 points of water emergencies of small grade.

IV. CONCLUSION

This paper presents a multi-objective coverage location model of the water emergency facilities based on the idea of multiple-coverage. There are three objectives such as the maximum quantity of water emergencies covered at least once, the maximum quantity of water emergencies covered at least twice, the minimum total rescue distances of the whole emergency rescue system in the case of the location point and the water emergencies point excess the covering distance. The constraint factors include time limit, distance limit, rescue capability limit and so on. Finally, this paper draws two main conclusions. Firstly, to solve the problem of water emergency facility location in the Yangtze River, the alternative points of water emergency facilities and the water emergency points are presented as the points distributed on the line of the water channel, and the positions of both can be suggested by the kilometer rage of waterway. Secondly, through the multiple-coverage location model of water emergency facilities in the Yangtze River, the Three Gorges Reservoir Area is taken as an example, and finally it proposes location plan of water emergency facilities in the Three Gorges Reservoir Area.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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