Optimal allocation of emergency resources for safety production in container ports

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Abstract: The production of the container port is a complicated process, which belongs to the multi-works and multi-linked joint operations. It has the characteristics of decentralized operations, complex processes and many influencing factors, and it is difficult to avoid security accidents. In recent years, with the continuous increase in the throughput of China's container ports, safety issues have become increasingly prominent. It is of great significance to optimize the allocation of emergency resources without sacrificing resources. Firstly, the paper analyzed the characteristics of the safety of the container port production and the demand for the allocation of emergency resources. Secondly, based on the Cobb-Douglas production function, the emergency resource allocation model was established, aiming to minimize the total economic loss of production safety accidents by ensuring the total standard configuration amount of the emergency resources for production safety. Thirdly, with the help of the Matlab, the optimal allocation ratio was used to calculate the amount of emergency resources allocated to each emergency point. The purpose of this paper is to provide the decision-making basis for the optimization of the emergency resources allocation for the port safety production.

Keywords: container port, safety production, emergency resources, optimal allocation.

1. INTRODUCTION

Safety management is the precondition and guarantee for safety production in container port. At present, there are many studies on emergency material allocation under dynamic demand or uncertain demand at home and abroad, mainly through the establishment of a multi-objective robust optimization model and the use of intelligent algorithms [1-5]. There are relatively few researches on the allocation of emergency resources for container port safety production, which mainly focus on the optimization of container resource allocation and various accident emergency management issues. Some researchers used simulations to perform actual production situation of the container port and determined the optimal resource allocation scheme through repeated experiments [6]. Some scholars use traditional theories such as game theory and fuzzy comprehensive evaluation to compare and analyze various schemes to determine the optimal result [7-10].

Based on the input-output theory in economics, this paper studies the optimal allocation of emergency resources for port safety production, that is, using the most reasonable amount of emergency resources to meet the requirements of port safety production, so as to achieve the balance between the allocation of resources and the accident losses. The research provides new ideas and methods for optimizing the allocation of emergency resources under emergencies in container ports.

2. The status and demand of container port safety production

2.1. The status of container port safety production

In view of the complexity, diversity and particularity of the production operations of container ports, the safety management of port production is very important. Through the research on production accidents in some domestic container ports, the safety production status of the container port is concluded as follows.

1) The reserves of some emergency resource are not sufficient. In order to avoid wasting resources, most ports adopt real-time material preparation methods, such as wind protection and flood prevention. And most of the ports are not equipped with special vehicles to deal with emergencies, and the method of real-time dispatch of idle vehicles is adopted. The container port handling equipment is large in scale and prone to serious safety accidents, and better planning is needed in the input and reserve of emergency resources.

2) The integration of emergency resources needs improvement. The safety management of container ports involves different enterprises and organizations. Due to the different rights and interests between various departments, it will inevitably lead to various contradictions and conflicts, thus lacking the unified management of port emergency resources.

3) The support capacity of emergency resource needs improvement. Due to the wide range and diverse types of emergency resources, in the event of a sudden production safety accident, it is mainly the manual recording of emergency resource calls, followed by information processing, which will inevitably lead to flaws of management and cause a certain degree of confusion.

2.2. The demand for the allocation of emergency resources

By analyzing the status of production safety of some domestic container ports, the necessary emergency resources for container ports should include the following aspects.

1) Human resources. Human resources refer to all individuals and departments that can participate in emergency response, including emergency management personnel, emergency rescue personnel and related auxiliary personnel. The corresponding emergency management department should be set up to coordinate resources and ensure the smooth production of container ports.

2) Material resources. The emergency material resources in accidents are mainly used for rescue, including various tools, materials, equipment, and supplies. The reserved emergency resources required for the characteristics of practicability, advancement, and economy.

3) Information technology resources. The information resources in the port accident include not only the relevant information of the accident itself, but also the warning before the accident, the disposal method, personnel composition and resource allocation during the accident.

4) Financial resources. Financial resources refer to all kinds of financial funds, budgets, subsidies, insurance, and superior financial subsidy for emergency assistance in port production accidents. With sufficient financial resources, the internal and external integration and mobilization of emergency resources can be effectively promoted, and the economic losses and adverse effects brought by accidents can also be reduced.

3. Construction of port Emergency Resource allocation Model

3.1. Basic Principles for Optimizing the allocation of Emergency Resources

1) Independent construction and unified management

At present, the emergency resources of the port are mainly stored and allocated by various departments according to their own needs. However, due to the lack of overall planning of the port, there are serious multiple constructions in the entire system, resulting in waste of resources. Therefore, each port department should formulate a unified plan according to relevant laws and regulations to reasonably establish a repository of emergency resources, and comprehensively improve the efficiency of resource allocation.

2) Unified planning and optimal allocation

The sudden accident of port safety production requires the deployment of many emergency resources within a short period of time. However, since port emergency resources belong to different departments, the allocation of those resources requires the approval of the management department, which is not conducive to the externality of system. Therefore, under the premise of relevant laws and regulations of the port, the emergency resources should be planned in a unified way and the optimal allocation of emergency resources should be achieved.

3) Prevention-oriented and diverse resources deployed

Daily supervision and management is an important measure to prevent accidents. Many port emergency resources are fully deployed, but due to the lack of a good information warning mechanism, the optimal disposal time is missed. Therefore, the port should periodically forecast and analyze emergency supplies that may be required in the future, and carry out targeted procurement and storage of various emergency supplies.

4) Closer to the nearest and professional team first

In the process of emergency rescue, the time factor is particularly important, so emergency resources and emergency forces should be deployed nearby when the accident occurs. If the danger is more serious, professionals should be selected to assist them to reduce the additional casualties and losses caused by improper methods, capacity limitations and other conditions.

3.2. The allocation model based on the Cobb-Douglas production function

3.2.1. Model construction

The general form of the Cobb-Douglas production function is:

$$Y = A(t)L^{\alpha}K^{\beta}\mu \tag{1}$$

Among them, Y is the total industrial output value, $A(t)$ is the comprehensive technical level, L is the amount of labor invested (in units of thousands people), K is the amount of capital invested, generally refers to the net value of fixed assets, α is the elastic coefficient of labor output, β is the elastic coefficient of capital output, μ is the random interference effects.

According to Cobb-Douglas's production function, the factors of production in the input-output process are substitutable. It can be seen that there is a certain substitutability among emergency resources in the container port. Under certain conditions, increasing the resource allocation of one emergency point, and correspondingly reducing the resource allocation of another emergency point, can influence the total economic loss to a certain extent.

Using the Cobb-Douglas production function to establish the functional relationship between the emergency resource allocation and the total economic loss of the port accident, as shown in formula (2):

$$C = F(\chi_1, \chi_2, \cdots, \chi_n) = W\chi_1^{\alpha_1}\chi_2^{\alpha_2}\cdots\chi_n^{\alpha_n} \tag{2}$$

Among them, C is the total economic loss of production accidents at the container port, χ_i is the amount of emergency resources for the emergency point i, W is a parameter greater than 0, indicating the technical level , α_i is the elasticity parameter.

Set the total amount of emergency resources to be A, and establish an optimization model for the resource allocation of each emergency resource point, as shown in formula (3):

$$\begin{cases} C = F\left(\chi_1, \chi_2, \cdots, \chi_n\right) = W\chi_1^{\alpha_1}\chi_2^{\alpha_2}\cdots\chi_n^{\alpha_n} \\ \chi_1 + \chi_2 + \cdots + \chi_n = A, \chi_i \geq 0, i = 1, 2, \cdots, n \end{cases} \tag{3}$$

After examination, the function equation can be transformed into the problem of solving the conditional extreme value. First, the parameter λ is used to construct the Lagrangian function, as shown in formula (4).

$$L\left(\chi_1, \chi_2, \cdots, \chi_n, \lambda\right) = F\left(\chi_1, \chi_2, \cdots, \chi_n\right) + \lambda\left(\chi_1 + \chi_2 + \cdots + \chi_n - A\right) \tag{4}$$

Find first-order partial derivatives of the functions and construct the equations as formula (5):

$$\begin{cases} \dfrac{\partial L}{\partial \chi_n} = W\alpha_n \chi_1^{\alpha_1}\chi_2^{\alpha_2}\cdots\chi_n^{\alpha_{n-1}} - \lambda = \alpha_n \dfrac{C}{\chi_n} - \lambda = 0 \\ \dfrac{\partial L}{\partial \lambda} = \chi_1 + \chi_2 + \cdots + \chi_n - A = 0 \end{cases} \tag{5}$$

After elementary transformation it is not difficult to see formula (6):

$$\frac{\alpha_1}{\chi_1} = \frac{\alpha_2}{\chi_2} = \cdots = \frac{\alpha_n}{\chi_n} = \frac{\lambda}{C} \tag{6}$$

Let $\dfrac{\lambda}{C} = k$, there are $\chi_i = k\alpha_i$, substitute the original equations to get the formula (7-10):

$$\frac{\partial L}{\partial \lambda} = \chi_1 + \chi_2 + \cdots + \chi_n - A = k\left(\alpha_1 + \alpha_2 + \cdots + \alpha_n\right) - A = 0 \tag{7}$$

$$k = \frac{A}{\sum\limits_{i=1}^{n}\alpha_i} \tag{8}$$

$$\chi_i^* = k\alpha_i = \frac{A\alpha_i}{\sum\limits_{i=1}^{n}\alpha_i}(i = 1, 2, \ldots, n) \tag{9}$$

$$\lambda^* = C\frac{A}{\sum\limits_{i=1}^{n}\alpha_i}(i = 1, 2, \ldots, n) \tag{10}$$

Let $\chi^* = (\chi_1^*, \chi_2^*, \ldots, \chi_n^*)$, χ^*, λ^* are solutions that satisfy $\nabla L(\chi^*, \lambda^*) = 0$. After the above analysis and calculation, it can be known that the model has an optimal solution, and the optimized scale factor of emergency resource allocation for each emergency point is: $\chi_1^* : \chi_2^* : \cdots \chi_n^* = \alpha_1 : \alpha_2 : \cdots \alpha_n$.

3.2.2. Model soloving

1) Obtain the optimized proportional coefficients of the emergency resources for each berth by formulating the resource allocation model, the proportional coefficients for each berth are $\alpha_1, \alpha_2, \ldots, \alpha_n$.

According to the formula $C = F(\chi_1, \chi_2, \ldots, \chi_n) = W\chi_1^{\alpha_1}\chi_2^{\alpha_2}\ldots\chi_n^{\alpha_n}$, taking logarithm for each side:

$$\ln Y_t = \ln W + \alpha_1 \ln \chi_1 + \alpha_2 \ln \chi_2 + \ldots + \alpha_n \ln \chi_n \tag{11}$$

Thus the equation is transformed into a multiple linear regression equation. Firstly, the parameters $\ln Y_t, \ln \chi_1, \ln \chi_2, ..., \ln \chi_n$ can be calculated based on the statistics of a period of container port emergency resource allocation and economic loss obtained; Secondly, solving the multiple linear regression model to obtain the regression coefficient $\alpha_1, \alpha_2, ..., \alpha_n$; Finaly, carry out the R test and F test to verify the significance of the regression equation, so as to obtain the coefficient of the optimal proportion of each berth, that is $\alpha_1, \alpha_2, ..., \alpha_n$.

2) After obtaining the optimal allocation ratio between berths through the formulas above, determine the total required standard value of emergency resources. The specific solution process is as follows:

①From formula (10), it can be concluded that there is an inverse relationship between the total standard amount of emergency resource A and accidental loss C. Let q be a constant and obey the following mathematical relationship:

$$AC = q \tag{12}$$

②The least squares method is used to solve the constant q so that it can be obtained:

$$q = \sqrt{\frac{q_1^2 + q_2^2 + ... + q_n^2}{n}} \tag{13}$$

③Establish objective function of emergency resource demand standard value:

$$S = C + Ap \tag{14}$$

Among them, S is an economic index, which should be minimized in this model. p is the equivalent price index of emergency resources.

④Based on the prices of various emergency resources, the weights obtained by the analytic hierarchy process (AHP) are used to calculate the integrated emergency resource equivalent prices.

⑤Change formula (14) to the following form:

$$S = \frac{q}{A} + Ap \tag{15}$$

Since the specific values of k and p have been obtained, and both are positive, when the objective function reaches a minimum value, the value of A is $A^* = \sqrt{qp}$, A^* is the total standard value of the emergency resources obtained.

3) Under the condition that the total amount of emergency resources and the optimal proportion of each berth are known, the normalized and weighted integration coefficients are used to obtain the standard quantities of each resource for each berth.

4. Empirical analysis

Y Port is the largest comprehensive port area in Wuhan Port, with a capacity of 2,564 tons, of which the container throughput reaches 1 million TEU. There are six 5,000-ton container berths in the first and second container terminals. In view of the occurrence of some production safety accidents and relevant accident records during the production and operation of container terminal of Y Port, the fire accidents during the operation of the Phase 1 and Phase 2 container terminals at Y Port were selected as the main study object of this model. Six berths were used as emergency points of the model for empirical analysis.

4.1. Model calculation

1) Multivariate Linear Regression Analysis Based on Matlab

According to the "Port Industry Enterprise Production Safety Standardization Specification", combined with the actual production of Y Port and other experiences of similarly-sized ports, the total economic loss is based on simulation analysis of cargo damage, cargo difference and other related losses. Take t as the accident inspection period (each time period is reasonably valued according to the frequency of accidents) and C is the loss caused by the accident. Then, the relative loss or average loss of the loss amount C for the inspection period is $C_t = C/t$, the unit is 10,000 yuan/year.

The total amount of emergency resources allocated to each berth and the total economic losses of production accidents at various times are shown in Table 1.

Table 1: The total allocation of emergency resources in Y Port and the total economic loss of port production accidents

Time period t	Berth 1 X_1	Berth 2 X_2	Berth 3 X_3	Berth 4 X_4	Berth 5 X_5	Berth 6 X_6	Total $\sum X_i$	Average Y_t
t_1	0.12	0.24	0.03	0.15	0.07	0.06	0.67	7.6
t_2	0.16	0.11	0.07	0.02	0.13	0.23	0.72	15.7
t_3	0.02	0.06	0.14	0.12	0.19	0.13	0.66	12.4
t_4	0.08	0.15	0.18	0.29	0.05	0.16	0.91	10.3
t_5	0.04	0.05	0.30	0.18	0.03	0.17	0.77	14.0
t_6	0.13	0.22	0.25	0.13	0.21	0.20	1.14	11.2
t_7	0.23	0.19	0.17	0.05	0.11	0.10	0.85	12.7
t_8	0.21	0.08	0.21	0.06	0.07	0.14	0.77	9.9
$\sum$	0.99	1.10	1.35	1.00	0.86	1.19	6.49	93.8

Using Matlab to achieve multiple linear regression analysis, the correlation coefficients and parameters are shown in Table 2 and Table 3.

Table 2: Summary of Correlation Factors

Correlation Factors	R	R^2	F	Estimated standard error
	0.948	0.8997	60.4646	0.0001

Table 3: Summary of regression equation parameters

equation	coefficient	95% confidence interval	
		Upper limit	Lower limit
constant	1.3726	0.7431	2.0021
α_1	-0.4429	-0.6163	-0.2694
α_2	0.4686	0.2244	0.7129

equation	coefficient	95% confidence interval	
		Upper limit	Lower limit
α_3	0.2450	0.1257	0.3643
α_4	-0.4948	-0.6611	-0.3284
α_5	-0.2681	-0.4050	-0.1316
α_6	0.1489	-0.0119	0.3097

Firstly, the R-test of the correlation coefficient: $R = 0.948 > R_{0.05}(2)$, indicating that the correlation of multiple linear regression equations is significant. Secondly, conducting an F-test and the results shows that the regression results of multiple linear regression equations are also significant ($F_{0.05}(m-1, n-m) = F(5,2) = 19.30$). The fitting function between the amount of emergency resources and the total economic loss of Y port production accidents is:

$$\ln Y = 1.3726 - 0.4429 \ln \chi_1 + 0.4686 \ln \chi_2 + 0.2450 \ln \chi_3$$
$$- 0.4948 \ln \chi_4 - 0.2681 \ln \chi_5 + 0.1489 \ln \chi_6$$

$$Y(\chi_1, \chi_2, \chi_3, \chi_4, \chi_5, \chi_6) = 3.95 \chi_1^{-0.4429} \chi_2^{0.4686} \chi_3^{0.2450} \chi_4^{-0.4948} \chi_5^{-0.2681} \chi_6^{0.1489}$$

From the above formula, we can see that the optimum proportions of emergency resources in Y Port are 0.4429, 0.4686, 0.2450, 0.4948, 0.2681, and 0.1489, and the optimal allocation ratio of emergency resources for each berth is 0.214:0.227:0.118:0.239:0.130: 0.072.

2) Determine the equivalent price index of emergency supplies

Through sorting and screening, select several important materials that have a large impact on economic losses, establish an index system for emergency supplies, and use tomographic analysis(AHP) to determine the weights of indicators at all levels, as shown in Table 4.

Table 4: Weights of Major Emergency Resource Indicators in Fire Accidents

Target layer	Guidelines and indicators weights		Indicator layer and single-order weights		Total indicator weight
Emergency supplies A	Equipment tools B_1	0.22	Fire protection clothing C_{11}	0.12	0.0264
			Alarm facility C_{12}	0.10	0.022
	Medical accommodation B_2	0.35	Food C_{21}	0.10	0.035
			Medicine C_{22}	0.13	0.0455
			Tent C_{23}	0.12	0.042
	Firefighting supplies B_3	0.43	Fire extinguisher C_{31}	0.21	0.0903
			Fire hydrant C_{32}	0.13	0.0559
			Lighting facilities C_{33}	0.09	0.0387

By looking up relevant data, the basic prices of various emergency resources are determined, as shown in Table 5.

Table 5: Price list of major emergency supplies for fire accidents

Emergency supplies	Unit price (yuan)	Emergency supplies	Unit price (yuan)
Sound and light alarm equipment	500	Fire extinguisher	120
Fire protection clothing	800	Fire hydrant	500
Food	15	Tent	200
Medicine	30	Lighting facilities	70

The equivalent price index p of emergency supplies is:

$$p = (500 \times 0.1 + 800 \times 0.12 + 15 \times 0.1 + 30 \times 0.13 + 120 \times 0.21 + 500 \times 0.13$$
$$+ 200 \times 0.12 + 70 \times 0.09) / 10000 = 0.02719$$

3) Determination of the amount of emergency material requirements

According to the relationship between the standard of emergency resource demand and the economic loss $AC = q$, it should be known that the constant q should be solved now, and the least squares method should be used to find q through linear fitting. According to the sample values in Table 1, we can find out that $q_i = A_i \times C_i (i = 1, 2, 3, ..., 6)$, and the error is eliminated by means of root mean square, so that we can calculate q as follows:

$$q = \sqrt{\frac{q_1^2 + q_2^2 + q_3^2 + q_4^2 + q_5^2 + q_6^2}{6}} = 9.776$$

According to formula (15), the standard configuration quantity of emergency resource requirements can be obtained.

$$A^* = \sqrt{qp} = \sqrt{9.776 \times 0.02719} = 0.52$$

The standard amount of demand for various types of emergency supplies at various berths is shown in Table 6.

Table 6: standard quantities of emergency supplies at various berths

emergency supplies	berth 1	berth 2	berth 3	berth 4	berth 5	berth 6
Fire protection clothing	13	14	14	12	8	8
Alarm facility	10	12	11	11	7	7
Food	10	13	11	12	7	7
Medicine	14	15	15	16	9	9
Tent	13	14	14	15	8	8
Fire extinguisher	22	23	25	25	14	15
fire hydrant	14	15	15	16	8	9
Lighting facilities	10	9	10	11	6	6

4.2. Results Analysis

By comparing the current situation of emergency supplies in Y Port and the calculation results, we can see that the original emergency resources tend to be berth 3 during distribution, and emergency

supplies should be allocated to container berth 2 and berth 4 according to optimization results. When the port reserves emergency supplies, it shall increase the reserves of fire-fighting facilities supplies and appropriately reduce the reserves of medical drugs and living materials so as to obtain a better ratio of resource allocation.

5. CONCLUSION

Port production safety accidents occur from time to time in the port production process, and accidents can cause negative effects such as casualties, economic losses and environmental pollution. This paper establishes an emergency resource allocation model based on Cobb-Douglas production function, and determines various emergency resource weights and material distribution ratios through analytic hierarchy process and multiple linear regression fitting analysis to allocate emergency resources in container ports. For further research, the type of accidents should be considered more comprehensively, and a reasonable layout of emergency resource allocation and location should be made.

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