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Research article

Coordinated location-allocation of cruise ship emergency supplies under public health emergencies

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Abstract: For the rapid development of the cruise industry, the cruise disaster relief supply chain has attracted extensive attention, especially because COVID-19 cases on international cruise ships occurred. In this paper, we propose an idea of coordination layout for cruise ship emergency supplies, the problem optimized two objective functions of maximizing coverage satisfaction and minimizing the total cost, addressing the low efficiency of resource utilization at the same. By applying to cruise ship emergency supplies layout of Northeast Asia cruise port group system, using expert scoring method and AHP to evaluate cruise port security vulnerability. The NSGA-II algorithm is used to solve the multi-objective programming model. A numerical example shows that the optimization design model and method are valid and feasible, and the algorithm is efficient for solving the above collaborative location and allocation problem of sectional reserves, which can also offer a variety of decision-making options.

Keywords: cruise ship emergency supplies; public health emergencies; location-allocation; coordination; multi-objective optimization problem; NSGA-II

1. Introduction

Worldwide, the cruise industry has an annual passenger compound annual growth rate of 6.8% from 2009 to 2019, reaching 30 million passengers in 2019 [1]. To cope with rising demand and obtain economies of scale, cruise ships are becoming larger (i.e., many can carry up to 8000 passengers and crew) [2]. The large-scale cruise ships and the huge number of passengers and staff bring many challenges to cruise ship operations [3]. On the one hand, large-scale cruise ships can provide a humanistic design of environment of recreation space, in order to satisfy a continuous adaptation to customers' changing needs and desires, client satisfaction, and enjoyment. On the other hand, safety is the main pillar of this profitable business, and the high density of people, causes it sensitive to public safety risks. The development of the cruise economy is not plain sailing. For example, the Centers for Disease Control and Prevention (CDC) reports that an average of 10 cruise ships calling at U.S. ports break out of infectious diseases each year. In 2008 to 2009, two mass foodborne infections caused by norovirus infection occurred on "Diamond Princess" and "Precision Discovery" at Shanghai port. In 2010, a mass infection of influenza A occurred on "Fuji Maru" cruise ship. In 2003, the occurrence of SARS had a great impact on the development of the cruise economy, which made potential cruise consumers worry about the safety of cruise tourism. Therefore, various public health emergencies on the cruise ship had a certain impact on the health of tourists and the development of the cruise industry. Once patients board the ship, the risk of epidemic spread is high. As an important node of cruise service, cruise port has a significant feature of high personnel aggregation, it is easy to become the convergence point of all kinds of emergencies [4,5]. Once a major public security event of cruise ships occurs, it would be a serious threat to the overall public security, and also affect the sustainable development of economic and social for relevant regions. In addition, the diffusion and evolution process involves multi-agents, multi-dimensions and multi-factor interaction, which is a nonlinear complex large system. Hence, the importance of the cruise ship emergency supply is more than a minor problem, the development of viable disease risk management measures will guarantee the sustainability of cruise tourism.

In 2020, with the outbreak of COVID-19 on the Diamond Princess cruise ship, the cruise ship epidemic has become the focus of public opinion, and the prevention and control of cruise ship public health risk has become a hot topic in the current public view. The COVID-19 pandemic once brought the global cruise industry to a standstill. This has led to the realization that the development of viable disease risk management policies and measures will guarantee the sustainability of cruise tourism [6]. Cruise ship emergency supplies are the guarantee to deal with public health emergencies, and the construction of its support capacity is critical to the success of cruise ship public health emergency management. The secondary disasters caused by the psychological fear of passengers and crew in the public health emergencies of cruise ships, and the inadequate emergency supplies of cruise ships, pose a great challenge to the safety of cruise ships, and also put forward higher requirements for the layout of emergency supplies in cruise ports. The development of cruise tourism cannot be separated from the support of cruise ports. As an important node of cruise service, the cruise port is a natural interface connecting inland hinterland and Marine tourism, facing the rapidly developing global pandemic, it has to deal with double challenges [7,8]. Once the response is not timely will cause bad social public opinion. For example, in 2020, many countries and regions closed their borders and banned the arrival of cruise ships, "Diamond Princess" (called horror cruise), "Westerdam", "Costa Serena", "Grand Princess" and other cruise ships can't enter the cruise ports, facing the dilemma of drifting at sea, causing serious problems with cruise ship emergency supplies [9]. The timeliness of cruise ship emergency supplies (i.e., consumable food, medical equipment, medical treatment drugs, medical apparatus and instruments, and professional protective equipment) directly affects the prevention and treatment of cruise ships [10]. COVID-19 is still active and continues to spread worldwide, generating a considerable impact on the global economy and the cruise industry. However, there is no complete risk warning system, and normal reserve mechanism for cruise ship emergency supplies in response to the COVID-19 pandemic. With the rapid outbreak of the novel coronavirus worldwide, and especially on cruise ships, the effective management of the outbreak required concerted global efforts [11].

Motivated by the aforementioned issues, this study attempts to analyze the reasonable location-allocation of public health emergency resources among the regional cruise ports. And the key problem is how to optimize the coordinated layout of the cruise public health emergency supplies, and form a coordinated emergency supplies reserve system. Therefore, to improve the efficiency of cruise public health emergency rescue system, and avoid the waste of resources, this study introduces the concept of synergy based on the existing layout decisions, to strengthen the coordinated location-allocation construction of emergency resource reserve in the cruise port groups. It is imperative, therefore, we economize with the limited resources of each cruise port, and apply their maximum utility. Accordingly, it can promote the emergency response capacity of cruise ports, and enhance cruise emergency disposal efficiency.

The rest of the paper is structured as follows. Following the Introduction, Section 2 reviews the existing literature on cruise emergency management and emergency resource layout. The Problem and models used are described in Section 3. Section 4 presents the method. In Section 5, a numerical study is given, as well as the results of the analysis. Finally, conclusions and future research recommendations.

2. Literature review

2.1. Cruise emergency management

The cruise supply chain is global, complex and urgent. With the global layout of the cruise industry, the cruise supply chain is facing unexpected challenges in market mobility [12,13]. Véronneau and Roy [14] analyzed the planning process of the cruise supply chain, and pointed out that the focus of cruise operation is logistics supply. Sun, Feng, and Gauri [15] conducted a comprehensive review and research on China’s cruise industry from the distribution of cruise ports, cruise policies and cruise operations. In terms of cruise ship operation risk, relevant scholars studied and discussed four aspects: natural disasters, accident disasters, public health emergencies and social emergencies [16–19]. Mileske and Honeycutt [20] analyzed the selection of marine resources in natural and non-natural disasters on land and at sea, and designed disaster preparedness strategies for marine resources according to disaster type, responder ability and receiver demand, then pointed out that pre-disaster planning and flexible post-disaster strategies were necessary for disaster decision-making. Zhang et al. [21] adopted a comparative method to analyze the management measures taken by cruise ships in response to the COVID-19 pandemic, and suggested measures to deal with the “cruise dilemma”, including establishing and defining isolation standards on boards, enhancing the capacity of international organizations, the international community’s joint response to the pandemic, promoting cooperation between countries, building an effective mechanism for the broad participation of the whole society, and standardizing the release of information and reasonably guiding public social opinion. Ito, Hanaoka, and Kawasaki [22] investigated the relationship between cruise ship size and the number of COVID-19 confirmations. Considering the characteristics and particularities of international cruise ships, Sun and Zhao [23] evaluated the appropriateness of epidemic prevention measures taken by port countries for cruise ships from a legal perspective, and proposed future prevention and control measures for large cruise ships.

2.2. Emergency resource layout

Bakuli and Smith [24] proposed resource allocation in state-dependent emergency evacuation networks. Tzeng, Cheng and Huang [25] constructed a relief-distribution model using the fuzzy multi-objective programming method for designing relief delivery systems, considering three objectives: minimizing the total cost, minimizing the total travel time, and maximizing the minimal satisfaction during the planning period. Mete and Zabinsky [26] considered the deployment of medical inventory in the case of demand and transportation interruption, and constructed a two-stage stochastic model of location selection and inventory decision with the goal of expected cost minimization. Behrooz, Ekambaram and Babak [27] presented a bi-objective mixed integer programming (MIP) that helped to minimize both the total weighted time of completion of the demand points and the makespan of the total emergency relief operation, and a two-phase method was developed to solve the bi-objective MIP problem. Ghaffari et al. [28] presented a capacitated multi-stage operations scheduling problem, considering a supply chain network that consisted of local and global suppliers of medical relief items, regional and central DCs, and many customer demand points, with multi-stage lead times. Manupati et al. [29] addressed the location-allocation problem for convalescent plasma bank facilities, and developed a multi-objective mixed-integer linear program (MILP) model with the objective to minimize both the overall plasma transportation time and the overall plasma supply chain network cost. Ghaffarinasab and Kara [30] addressed risk-averse stochastic hub location problems where the risk is measured using the conditional β-mean criterion, and three variants of the classical multiple allocation hub location problem, namely the p-hub median, the p-hub maximal covering, and the weighted p-hub center problems are studied under demand data uncertainty represented by a finite set of scenarios.

Since the 2003 Bam earthquake and 2004 Indian Ocean tsunami, coordination has been broadly concerned by more and more scholars as being essential for disaster relief supply chains. For example, Besiou, Pedraza-Martinez, and Van Wassenhove [31] modeled vehicle supply chains (VSCs) in support of humanitarian field operations, applying system dynamics methodology. Maghsoudi et al. [32] empirically examined the impact of key theoretical modes of coordination, i.e., resource sharing, standardization of operations, and synchronization in disaster relief supply chains, on the performance of humanitarian organizations. Ritam et al. [33] proposed that needs and availabilities of resources information were especially useful for coordinating relief operations (e.g., food, water, medicines) in the affected region, and developed a novel methodology for matching need-tweets with availability-tweets, considering both resource similarity and geographical proximity.

Although these studies provided insight into various disaster recovery efforts, the coordinated layout of emergency relief was not properly addressed. Additionally, scarcity and/or redundancy of resources has resulted in humanitarian organizations (HOs) complementing each other's resources [34,35], which may lead to a moderating effect on coordination among the HOs. Against this background, this study will concentrate on the coordination and linkage of the overall emergency supplies reserve system, to avoid the waste and dissatisfaction of resources in the real world. A fuzzy multiple-objective model was used in this study and applied to a case study. Based on this case study, the corresponding measures needed for implementing the model have been put forward with additional scenario simulation.

3. Problem description and models

3.1. Existing layout strategy

At present, most emergency reserves of cruise ship public health are managed in accordance with the territorial principle. When dealing with small and medium-sized public health emergencies in cruise ports, it has the characteristics of great flexibility and professionalism. However, once a major public health emergency occurred, it often appeared to be in distress. If a small or medium public health emergency occurs in any part of the cruise ports A, B, C and D, the cruise ship emergency supplies administered by the territory can cope with it; When a major public health emergency occurs in cruise port D, the emergency resources demand exceeds its reserve capacity, and it needs to transfer emergency resources from other cruise ports. However, due to the lack of global emergency initiative and low efficiency of resource allocation, cruise port D has to wait for rescue for a long time, resulting in great losses of life and property. The reason is that the current allocation of cruise ship emergency resources is passive defense, instead of a pre-optimized design, which makes it difficult to share resources when dealing with major public health events, and easily leads to the phenomenon of supply and demand mismatch.

3.2. Coordinated layout strategy

The concept of emergency coordination is introduced into the existing location-allocation decision-making, which can reflect as following aspects: 1) Coordinated emergency resources, it is coordinated location, emergency reserve, and allocation of cruise ship emergency supplies; 2) Coordinated decision-making, which is an integration of regional cruise ports, to optimize the existing decision-making mode of territorial management, and obtain multiple coverages of the cruise port. Hence, it can fully optimize the reserve structure of emergency resources of reginal cruise ports, and meet the demand of cruise ports to the maximum extent once an emergency occurs.

When a coordinated emergency strategy is considered among multiple cruise ports, once a major public health emergency occurs in a cruise port, the emergency supplies repository in charge of the cruise port rescue, then it will be the first time to provide emergency supplies. In the cruise ship emergency reserve system composed of the regional cruise port group, other emergency supplies repository needs to provide subsequent emergency supplies for relief. Thus, we should solve the issues as below: In the scope of the regional cruise port group, selecting several ports to establish cruise public health emergency supplies repository from given alternative nodes; then configuring the appropriate public health emergency supplies, to satisfy emergency rescue demand at first and subsequent rescue demand of the regional cruise ports, aiming to decrease the cost of emergency services, and improve the cruise emergency supplies security.

3.3. Mathematical notations

For a better understanding of the subsequent mathematical model, here we give a comprehensive summary of all mathematical notations and definitions for various parameters and variables (see Table 1).

Table 1. Mathematical notations and definitions of various parameters and variables.

Var.	Definition
M	Set of the regional cruise ports, also the alternative nodes of cruise public health emergency supplies repository, $M = \{1,2,\cdots m\}$;
F_i	Fixed construction cost of a cruise emergency supplies repository at alternative node i;
Q_i	Maximum reserve capacity of a cruise emergency supplies repository;
d_{ij}	The distance from alternative node i of cruise emergency supplies repository to event node j of cruise ship port of call, where $i = j$, represents the alternative node of cruise emergency supplies repository is the event node of cruise ship port of call;
D_j	The first-time demand of cruise ship emergency supplies at cruise port j;
D_0	The first-time rescue coverage radius of the cruise emergency supplies repository;
D_u	Maximum rescue coverage radius of the cruise emergency supplies repository;
α_{ij}	The first-time coverage coefficient;
C_{ij}	The first-time rescue allocation cost coefficient, and the unit cost allocated from alternative node i of cruise emergency supplies repository to event node j of cruise ship port of call, including transportation cost and storage cost;
W_j	The weight of cruise port j that occurs public health emergency;
ε	Infinite positive number;
Y_i	Binary variable, where $Y_i = 1$ represents cruise port i is allocated emergency supplies repository and $Y_i = 0$ otherwise;
Z_{ij}	The quantity of emergency supplies allocated from alternative node i of cruise emergency supplies repository to event node j of cruise ship port of call;

3.4. Mathematical formulae

3.4.1. Coverage satisfaction function

The type of traditional maximum coverage location model is 0-1, but in fact, in the cruise port group, all emergency supplies repository can provide rescue services for the cruise ports when major public health emergencies happened. While the cruise port that occurs public health emergency is the allocation node of emergency supplies repository, the coverage satisfaction is 1, otherwise, the coverage satisfaction decreases with the increase of distance, and the coverage satisfaction function is shown below.

$$S(d_{ij}) = (D_u - d_{ij})/D_u \tag{1}$$

3.4.2. Coordinated location-allocation model

The coordinated location-allocation model of public health emergency supplies repository for cruise port group can be formulated as follows:

$$f_1 = min \textstyle\sum_i \sum_j C_{ij} Z_{ij} + \sum_i F_i Y_i \tag{2}$$

$$f_2 = max \textstyle\sum_i \sum_j W_j S(d_{ij}) Y_i \tag{3}$$

We consider that there is no difference of the emergency supplies between public health emergency supplies repository, and decision-making is depended on service satisfaction and cost factors comprehensively. Hence, Eq (2) shows that coordinated total cost is minimum among the cruise port group, including first-time emergency rescue cost and construction cost of emergency reserve repository. Equation (3) denotes that the total coverage satisfaction is maximum among the cruise port group.

In Eqs (2) and (3), constrains are denoted as

$$s.t. Z_{ij} \leq \varepsilon Y_i, \forall i, \forall j \tag{4}$$

$$Z_{ij} \leq \varepsilon Y_i, \forall i, \forall j \tag{5}$$

$$\sum_i Z_{ij} \geq D_j, \forall j \tag{6}$$

$$\sum_j Z_{ij} \leq Q_i, \forall i \tag{7}$$

$$Y_i \in \{0,1\}, \forall i \tag{8}$$

$$Z_{ij} \geq 0, \forall i, \forall j \tag{9}$$

Among the constraints, Eq (4) represents that the alternative node i of the cruise emergency supplies repository can provide first-time rescue service, when it is within the first-time rescue coverage radius at cruise port j. Equation (5) represents that the alternative node i can allocate emergency supplies to cruise port j, when emergency supplies repository is built in alternative node i. Equation (6) represents that the first demand of cruise ship emergency supplies must be met at cruise port j. Equation (7) represents that the allocated quantity of emergency supplies cannot exceed the maximum reserve capacity of the cruise emergency supplies repository. In Eqs (8) and (9), Y_i and Z_{ij} are decision variables, Y_i is a binary variable; Z_{ij} is a non-negative variable.

3.4.3. Vulnerability assessment of cruise port security

In the model, W_j is a key parameter, and it denotes the weight of each cruise port in a coordinated location-allocation emergency supplies system. Due to the different degrees of possible infection in different cruise ports during a major public health emergency, it is necessary to consider the differences in emergency resource requirements among cruise ports when conducting unified emergency resource location-allocation. Cruise port security vulnerability refers to an unstable state in which its security state is disturbed by external factors, it is related to the security state of the cruise port, and is expressed quantitatively by the security vulnerability index of the cruise port. From the perspective of system theory, according to 4M Theory (Man Factors, Machine Factors, Media Factors, Management Factors): human risk assessment generates unsafe behavior, a physical risk assessment that generates the unsafe condition, workplace assessment noise, dust and toxic substances, and evaluation defects administrative to generate the accident. 4M factor analysis is a multifaceted approach that is widely used in the investigation of accidents. Discovered by the United States National Transportation Safety Board (NTSB), many researchers have used 4M factor analysis and have modified it into new analysis models [36,37]. Most of the developed models are still used to analyze accidents, including studies that utilize the MoP model to analyze the characteristics of accidents that happened in five major ports of Japan [38]. 4M factor analysis is implemented in a problem-solving approach (fact-problem-solution) in order to assess the security vulnerability of cruise ports.

Thus, the internal factors affecting the security vulnerability of cruise ports include four systems and their interactions. Therefore, the risk factors of cruise port emergencies can be divided into: personnel quality V_1, facilities and equipment V_2, port environment V_3, and management level V_4, and they are interrelated and interact with each other. Besides, external factors affecting cruise port security vulnerability refer that cruise port is affected by external disturbance, including risk V_5 and exposure V_6. From here we see that both external and internal factors determine the security vulnerability of the cruise port, internal factors determine the safety of the cruise port, and external factors determine the degree of disturbance of the cruise port. Thus, the cruise port security vulnerability assessment model can be denoted as:

$$V = \frac{V_f}{V_s} \tag{10}$$

where V is the security vulnerability index of cruise port, is the disturbance degree of cruise port, and V_s represents security status of cruise port.

Next, V_f is determined by internal factors, including personnel quality V_1, facilities and equipment V_2, port environment V_3, and management level V_4, thus, we have

$$V_s = \beta_1 V_1 + \beta_2 V_2 + \beta_3 V_3 + \beta_4 V_4 \tag{11}$$

where β_1, β_2, β_3, β_4 represent weight contribution rates of personnel quality V_1, facilities and equipment V_2, port environment V_3, and management level V_4.

Besides, V_s is determined by external factors, which can be expressed as

$$V_f = \beta_5 V_5 + \beta_6 V_6 \tag{12}$$

where β_5, β_6 represent weight contribution rates of risk V_5 and exposure V_6.

1) Constructing evaluating indexes system of cruise port security vulnerability

On the basis of considering the accessibility of indicator data, this study selects crew and tourists, port supervisor, cruise ship, cruise ship, traffic environment, geographical position, staff management, regulatory framework, natural risk, man-made dangers, passenger throughput, and quantity of reception cruise ships as the secondary indicators for the vulnerability assessment of public health and security of cruise ports. And the specific hierarchy of the evaluating indexes system is shown in Table 2.

2) Determining indexes weight

Thinking of the fuzziness of some indexes, we adopt the method of Analytic Hierarchy Process (AHP) to confirm the weight of each index, and the initial data of some index are processed by expert consulting graded approach. Values for each indicator, and each index is divided into three values, primary corresponding to 1 to 3 points, secondary corresponding to 4 to 6 points, tertiary corresponding to 7 to 9 points. Then, experts are invited to give scores, and their scores are averaged as the score of the index. Factors of each criterion layer are presented as follows:

$$V_m = \sum_{n=1}^{s} \beta_{mn} V_{mn} \tag{13}$$

where V_{mn} is the value of index n for V_m, and β_{mn} is the weight of V_{mn}.

Table 2. Evaluation indexes system of cruise port security vulnerability.

Target layer	Subgoal layer	Criterion layer	Indicator layer
The security vulnerability index of cruise port (V)	Internal factors (Security status V_s)	Personnel quality (V_1)	Crew and tourists (V_{11})
			Port supervisor (V_{12})
		Facilities and equipment (V_2)	Cruise ship (V_{21})
			Cruise port (V_{22})
		Port environment (V_3)	Traffic environment (V_{31})
			Geographical position (V_{32})
		Management level (V_4)	Staff management (V_{41})
			Regulatory framework (V_{42})
	Internal factors (Security status V_f)	Risk (V_5)	Natural risk (V_{51})
			Man-made dangers (V_{52})
		Exposure (V_6)	Passenger throughput (V_{61})
			Quantity of reception cruise ships (V_{62})

4. Methodology

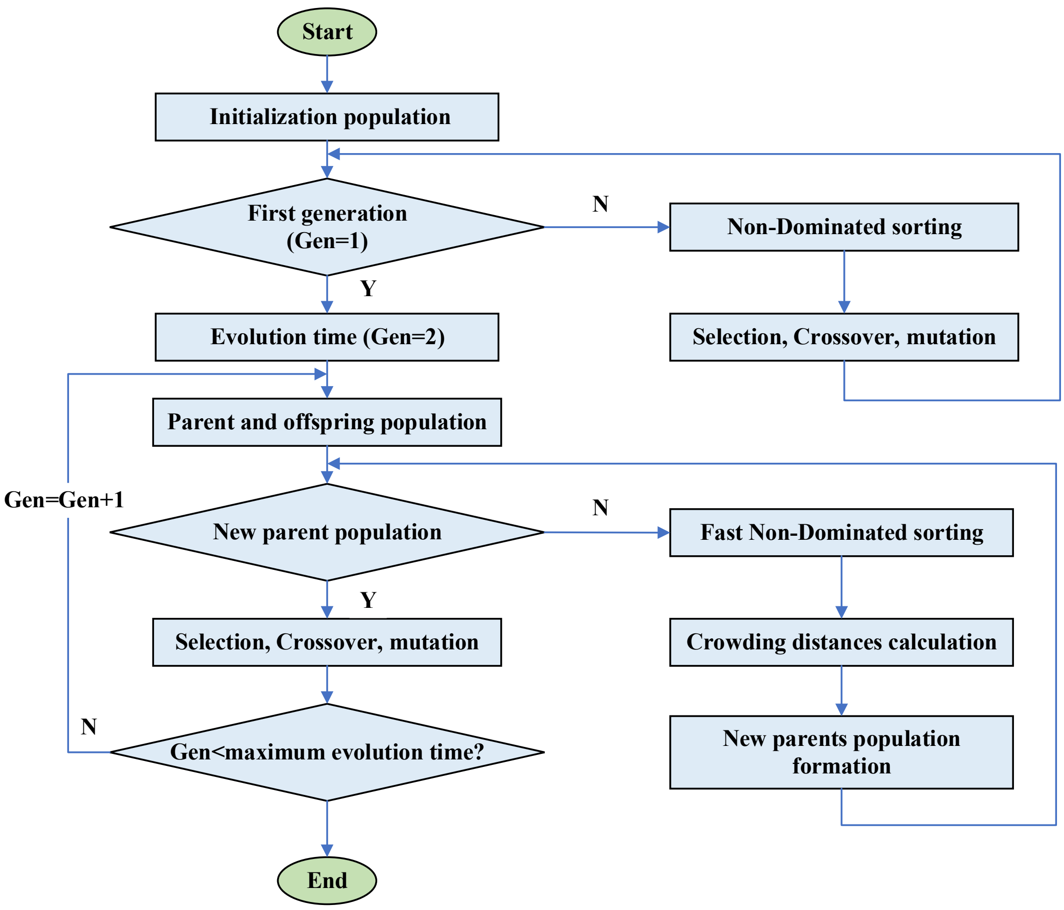

Figure 1. Flowchart of NSGA-II algorithm.

Non-Dominated Sorting Genetic Algorithm II (NSGA-II) is inspired by the theory of evolution, solving multi-objective optimization problems as a powerful decision space exploration engine based on a genetic algorithm (GA). Since its introduction in 2000, NSGA-II has been applied to a wide variety of searches and optimization problems owing to its lower computational complexity, elitism, and parameterless nature [39–41]. The coordinated location-allocation decision model proposed is dedicated to layout and allocating tasks to cruise ship emergency supplies, and it is a multi-objective optimization problem, considering multi-coverage with space and capacity constraints. The coordinated location-allocation problem is complex, large-scale, NP-hard, and involves several constraints, and we choose NSGA-II to solve it. For a multi-objective optimization problem, the task is to find the best compromise solution, known as "Pareto front", in the design domain. Further decisions can be made on the basis of the Pareto front according to the designer's subjective preferences. The flowchart of NSGA-II is outlined in Figure 1.

The procedure of the NSGA-II algorithm is stated below.

Step 1. Initialize the population, obtain the parent population;

Step 2. Non-dominant sorting and genetic operator, obtain the offspring population;

Step 3. Combine both the parent and offspring population, and fast non-dominated sorting, calculate the crowding distance;

Step 4. Produce a new parent population by selecting proper individuals;

Step 5. Obtain new offspring population by using genetic operator, and continue the generation until the maximum number of generations is reached.

5. Numerical study

At present, China has formed five cruise port groups, including Northeast, North, East, Southeast and South China, in which East and South China are the two regions with the most abundant cruise ports. In this study, we choose Northeast Asia cruise port group system as our research object, including Dalian Port International Cruise Center (A), Tianjin International Cruise Home Port (B), Yantai International Cruise Port (C), Qingdao Cruise Home Port (D), Lianyungang International Passenger Station (E), Shanghai Wusongkou International Cruise Port (F), Zhoushan Islands International Cruise Port (G), and Wenzhou International Cruise Port (H), as shown in Figure 2.

Figure 2. Northeast Asia Cruise Port Group.

5.1. Vulnerability assessment of cruise port security

Using AHP and experts scoring method in Section 3.4.3, ten experts in the field of port and navigation are invited to give scores, the indexes weight value are calculated (see Tables 3 and 4).

Table 3. The weight value of criterion layer.

Index	Personnel quality (V_1)	Facilities and equipment (V_2)	Port environment (V_3)	Management level (V_4)	Risk (V_5)	Exposure (V_6)
Value	0.07	0.29	0.48	0.16	0.5	0.5

Table 4. The weight value of index layer.

Index layer	Value
Crew and tourists (V_{11})	0.75
Port supervisor (V_{12})	0.25
Cruise ship (V_{21})	0.75
Cruise port (V_{22})	0.25
Traffic environment (V_{31})	0.40
Geographical position (V_{32})	0.60
Staff management (V_{41})	0.33
Regulatory framework (V_{42})	0.67
Natural risk (V_{51})	0.60
Man-made dangers (V_{52})	0.40
Passenger throughput (V_{61})	0.55
Quantity of reception cruise ships (V_{62})	0.45

Therefore, according the evaluation indexes system of cruise port security vulnerability, we calculate W_j, the weight of cruise port j that occurs public health emergency (see Table 5).

Table 5. The weight of cruise port that occurs public health emergency.

	A	B	C	D	E	F	G	H
W_j	7.0	7.7	5.6	7.2	6.6	9.1	6.0	6.2

From Table 5, we can see that the vulnerability weight of Dalian Port International Cruise Center (A), Tianjin International Cruise Home Port (B), Yantai International Cruise Port (C), Qingdao Cruise Home Port (D), Lianyungang International Passenger Station (E), Shanghai Wusongkou International Cruise Port (F), Zhoushan Islands International Cruise Port (G), and Wenzhou International Cruise Port (H) is 7.0, 7.7, 5.6, 7.2, 6.6, 9.1, 6.0, and 6.2 respectively.

5.2. Data

In this study, eight cruise ports in Northeast Asia cruise port group are selected for research, and these eight cruise ports are considered as alternative nodes of emergency supplies repository and event nodes of cruise ship port of call. The capacity of the cruise public health emergency supplies repository is 100, and the coverage distance D_u is 650. The fixed construction cost of cruise emergency supplies repository in each cruise port is different. We assume that the construction cost and capacity of emergency supplies repository in each cruise port are listed in Table 6, and the demand of cruise ports that occurs in public health emergencies is shown in Table 7. NSGA-II algorithm is used to solve the multi-objective programming optimization, to avoid local optima, population size as well as crossover and mutation operation need to be properly determined. The population size of 100 is employed. The crossover probability and mutation probability are 0.8 and 0.15, respectively.

Table 6. The cost and capacity of emergency supplies repository in each cruise port.

	A	B	C	D	E	F	G	H
F_i	500	600	300	400	300	750	300	300
Q_i	500	500	500	500	500	500	500	500

Table 7. The demand of cruise port that occurs public health emergency.

	A	B	C	D	E	F	G	H
D_j	255	375	230	275	240	455	230	245

Table 8. The distance from alternative node of cruise emergency supplies repository to event node of cruise ship port of call (n mile).

d_{ij}	A	B	C	D	E	F	G	H
A	0	220	90	278	346	548	577	740
B	220	0	203	443	511	713	742	905
C	90	203	0	247	315	517	546	709
D	278	443	247	0	102	403	432	595
E	346	511	315	102	0	374	403	566
F	548	713	517	403	374	0	139	302
G	577	742	546	432	403	139	0	186
H	740	905	709	595	566	302	186	0

Table 9. The first-time rescue allocation cost coefficient.

C_{ij}	A	B	C	D	E	F	G	H
A	0	65	45	75	80	85	85	90
B	65	0	65	80	85	90	90	100
C	45	65	0	65	70	85	85	90
D	75	80	65	0	45	80	80	85
E	80	85	70	45	0	80	80	85
F	85	90	85	80	80	0	45	75
G	85	90	85	80	80	45	0	60
H	90	100	90	85	85	75	60	0

Besides, we inquire about the distance from an alternative node i of cruise emergency supplies repository to the event node j of cruise ship port of call using Map Tools (see Table 8), and assume the first-time rescue allocation cost coefficient C_{ij} (see Table 9). When the alternative node of the cruise emergency supplies repository is the event node of cruise ship port of call, C_{ij} is 10.

5.3. Results analysis

During the multi-objective programming optimization, several runnings can be conducted. When all Pareto fronts under those runnings are consistent, the optimization indicates convergent, and then the complete non-dominant solutions are obtained. The algorithm converges quickly, and the Pareto front is basically stable after 200 iterations (see Figures 3 and 4). Figure 4 shows that the NSGA-II algorithm is convergent and efficient. When the number of cruise emergency supplies repository is 5, the Pareto front of optimal results is 2, the location nodes of cruise emergency supplies repository are A, B, E, F and G , respectively (see Figure 5).

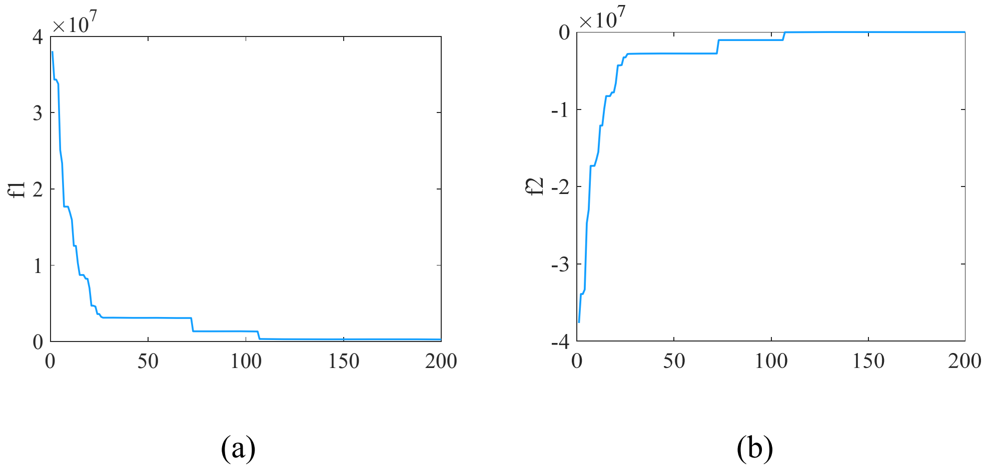

Figure 3. (a) the Pareto front of objective function f1, (b) the Pareto front of objective function f2.

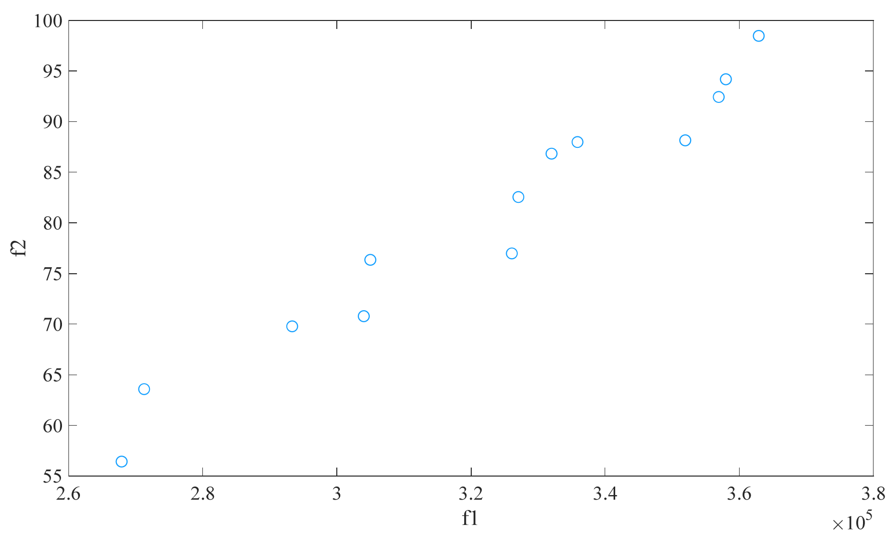

Figure 4. Pareto front of the optimal results.

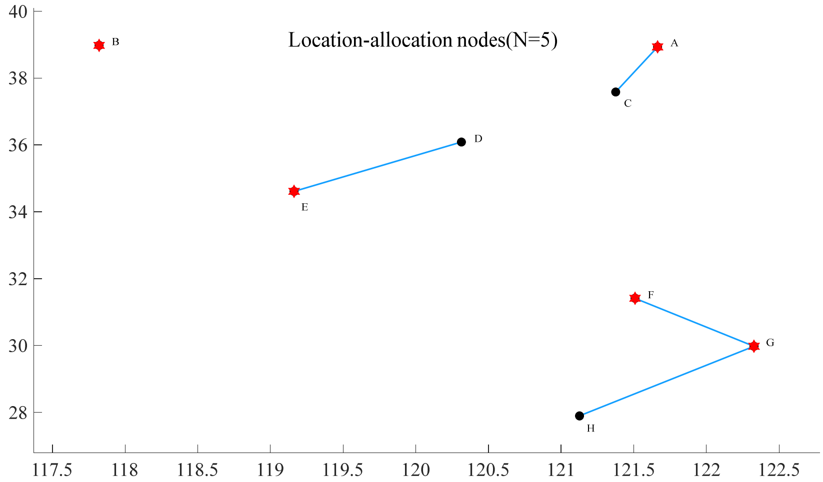

Figure 5. The location-allocation nodes (N = 5).

In the existing layout strategy, there is an emergency supplies repository for each cruise port in Northeast Asia cruise port group, that are A, B, C, D, E, F, G and H, then the capacity utilization is 57.63%, and the overall coverage satisfaction is 46.35. In the coordinated layout strategy, the coordination location-allocation model is solved by NSGA-II, and Pareto front of the optimal results is shown in Table 9. As can be seen in Table 10, with the increase in the number of cruise emergency supplies repositories, the capacity utilization rate decreases, the overall coverage satisfaction increases, and the total cost increases gradually. However, the total cost does not exceed the cost of the existing layout strategy, which indicates the superiority of emergency coordination for regional cruise ports. However, in the real-world, due to the weak economy of disaster relief, emergency rescue tasks should deal with threats to the safety of tourists regardless of the cost. Therefore, when the decision maker is given a certain total coverage satisfaction value, all feasible solutions due to this value can be found in the Pareto front.

Table 10. The calculation results based on NSGA-II method.

	Existing scheme	Scheme 1	Scheme 2	Scheme 3
Number of emergency resources reserves	8	7	6	5
Location of emergency resource repository service facility	A, B, C, D, E, F, G, H	A, B, D, E, F, G, H	A, B, E, F, G, H	A, B, E, F, G
Capacity utilization	57. 63%	65.85%	76.83%	92.20%
Overall coverage satisfaction	46.35	76.99	69.79	56.44
Total cost	351,944.30	326,088.13	293,343.06	267,915.80

6. Conclusions

The lack of coordination in cruise ship emergency supplies layout makes coordination efforts a greater challenge, and leads to low rescue efficiency and waste of resources. In this paper, from the perspective of relief coordination for regional cruise ports, we design a bi-level multi-objective model for location-allocation programming problem of cruise ship emergency supplies repository under major public emergency. Meanwhile, considering the different rescue capacities of cruise ports, we analyze the internal and external factors of cruise port security vulnerability, using an expert scoring method and AHP, calculate the weight of each index of the cruise port security vulnerability assessment model, thus, the weight of cruise port security vulnerability index is obtained.

This study set out to propose an intelligent model for the layout planning and decision of the cruise ship emergency supplies, and bring advancements to the coordination of cruise disaster relief supply chain. We highlight the following key contributions and findings of this study:

1) By introducing the idea of coordination, this research successfully interpreted the layout planning problem of cruise ship emergency supplies into a typical multi-objective optimization issue, involving objective functions of coverage satisfaction, and optimal cost. Based on NSGA-II, the Pareto front could be quickly and automatically searched, providing planners with sufficient optimal layout schemes as reference.

2) The decision-making strategy for planning scheme selection was presented. Using the expert scoring method and AHP, the weight of each index of the cruise port security vulnerability assessment could be further calculated according to objective data and subjective expertise, which enables the planners to make rapid and reasonable decisions.

3) The coordinated location-allocation model was successfully applied to the cruise ship emergency supplies layout of the Northeast Asia cruise port group system. The comparison between modeling results manifested the feasibility of the model. Results show that the actual use of the coordinated location-allocation model is efficient to improve the level of relief service, and achieve a wider range of system optimization allocation.

Further research should be carried out to establish an integrated layout planning model for cruise disaster supply chains with a complex network. Moreover, model calibration will be another significant future step that requires expert judgements and large sample data.

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Conflict of interest

The authors declare there is no conflict of interest.

References

1. CLIA, 2019 Cruise Trends and Industry Outlook. Cruise Lines International Association, Washington, 2021. Available from: https://cruising.org/news-and-research/research/2018/december/2019-state-of-the-industry.
2. J. W. Jeon, O. Duru, G. T. Yeo, Cruise port centrality and spatial patterns of cruise shipping in the Asian market, *Marit. Policy Manage.*, **46** (2019), 257–276. https://doi.org/10.1080/03088839.2019.1570370

3. D. Vukonic, T. Bielic, A. Russo, Organizational factors in management of "Mega Cruise ships" from crowd management control aspect, *Sci. J. Marit. Res.*, **30** (2016), 58–66. https://doi.org/10.31217/p.30.1.8
4. J. P. Mileski, G. Wang, L. L. Beacham, Understanding the causes of recent cruise ship mishaps and disasters, *Res. Transp. Bus. Manage.*, **13** (2014), 65–70. https://doi.org/10.1016/j.rtbm.2014.12.001
5. A. A. Papachristou, A. A. Pallis, G. K. Vaggelas, Cruise home-port selection criteria, *Res. Transp. Bus. Manage.*, **45** (2022), 100584. https://doi.org/10.1016/j.rtbm.2020.100584
6. H. Li, S. Meng, H. Tong, How to control cruise ship disease risk? Inspiration from the research literature, *Mar. Policy*, **132** (2021), 104652. https://doi.org/10.1016/j.marpol.2021.104652
7. A. A. Pallis, K. P. Arapi, A. A. Papachristou, Models of cruise ports governance, *Marit. Policy Manage.*, **46** (2019), 630–651. https://doi.org/10.1080/03088839.2019.1590657
8. A. A. Pallis, A. A. Papachristou, European Cruise ports: challenges since the pre-pandemic era, *Transp. Rev.*, **41** (2021), 352–373. https://doi.org/10.1080/01441647.2020.1857884
9. Critic, Cruise, Coronavirus: Which Cruise Ports Are Closed, Cruise News, 2021. Available from: https://www.cruisecritic.com/news/5097/.
10. L. F. Moriarty, M. M. Plucinski, B. J. Marston, E. V. Kurbatova, B. Knust, E. L. Murray, et al., Public health responses to COVID-19 outbreaks on cruise ships—worldwide, February-March 2020, *Morb. Mortal. Wkly. Rep.*, **69** (2020), 347–352. https://doi.org/10.15585/mmwr.mm6912e3
11. T. L. Lee, Global health in a turbulence time: a commentary, *Asian J. WTO Int'l Health L. Pol'y*, **15** (2020), 27–60.
12. S. Véronneau, J. Roy, Global service supply chains: An empirical study of current practices and challenges of a cruise line corporation, *Tourism Manage.*, **30** (2009), 128–139. https://doi.org/10.1016/j.tourman.2008.05.008
13. K. Wang, S. A. Wang, L. Zhen, X. B. Qu, Cruise service planning considering berth availability and decreasing marginal profit, *Transp. Res. Part B Methodol.*, **95** (2017), 1–18. https://doi.org/10.1016/j.trb.2016.10.020
14. S. Véronneau, J. Roy, RFID benefits, costs, and possibilities: The economical analysis of RFID deployment in a cruise corporation global service supply chain, *Int. J. Prod. Econ.*, **122** (2009), 692–702. https://doi.org/10.1016/j.ijpe.2009.06.038
15. X. Sun, X. Feng, D. K. Gauri, The cruise industry in China-Efforts, progress and challenges, *Int. J. Hospitality Manage.*, **42** (2014), 71–84. https://doi.org/10.1016/j.ijhm.2014.05.009
16. J. P. Rodrigue, W. Y. G. Wang, Cruise shipping supply chains and the impacts of disruptions: The case of the Caribbean, *Res. Transp. Bus. Manage.*, **45** (2020), 100551. https://doi.org/10.1016/j.rtbm.2020.100551
17. N. Wookjeong, S. Byeung-Hun, H. Wonhwa, Analysis of walking-speed of cruise ship passenger for effective evacuation in emergency, *Medico-Legal Update*, **19** (2019), 710–716. https://doi.org/10.5958/0974-1283.2019.00260.3
18. E. H. Cramer, D. D. Slaten, A. Guerreiro, D. Robbins, A. Ganzon, Management and control of varicella on cruise ships: A collaborative approach to promoting public health, *J. Travel Med.*, **19** (2012), 226–322. https://doi.org/10.1111/j.1708-8305.2012.00621.x
19. A. L. Freeland, J. G. H. Vaughan, S. N. Banerjee, G. H. J. Vaughan, Acute gastroenteritis on cruise ships–United States, 2008–2014, *Morb. Mortal. Wkly. Rep.*, **65** (2016), 1–5. https://doi.org/10.15585/mmwr.mm6501a1

20. J. P. Mileski, J. Honeycutt, Flexibility in maritime assets and pooling strategies: A viable response to disaster, *Mar. Policy*, **40** (2013), 111–116. https://doi.org/10.1016/j.marpol.2012.12.039
21. H. Zhang, Q. W. Wang, J. H. Chen, N. Rangel-Buitrago, Y. Q. Shu, Cruise tourism in the context of COVID-19: Dilemmas and solutions, *Ocean Coastal Manage.*, **228** (2022), 106321. https://doi.org/10.1016/j.ocecoaman.2022.106321
22. H. Ito, S. Hanaoka, T. Kawasaki, The cruise industry and the COVID-19 outbreak, *Transp. Res. Interdiscip. Perspect.*, **5** (2020), 100136. https://doi.org/10.1016/j.trip.2020.100136
23. S. Q. Sun, L. L. Zhao, Legal issues and challenges in addressing the coronavirus outbreak on large cruise ships: A critical examination of port state measures, *Ocean Coastal Manage.*, **217** (2022), 105995. https://doi.org/10.1016/j.ocecoaman.2021.105995
24. D. L. Bakuli, J. M. Smith, Resource allocation in state-dependent emergency evacuation networks, *Eur. J. Oper. Res.*, **89** (1996), 543–555. https://doi.org/10.1016/0377-2217(94)00230-4
25. G. H. Tzeng, H. J. Cheng, T. D. Huang, Multi-objective optimal planning for designing relief delivery systems, *Transp. Res. Part E Logist. Transp. Rev.*, **43** (2007), 673–686. https://doi.org/10.1016/j.tre.2006.10.012
26. H. O. Mete, Z. B. Zabinsky, Stochastic optimization of medical supply location and distribution in disaster management, *Int. J. Prod. Econ.*, **126** (2010), 76–84. https://doi.org/10.1016/j.ijpe.2009.10.004
27. B. Behrooz, P. Ekambaram, A. Babak, Bi-objective multi-resource scheduling problem for emergency relief operations, *Prod. Plann. Control*, **29** (2018), 1191–1206. https://doi.org/10.1080/09537287.2018.1542026
28. Z. Ghaffari, M. M. Nasiri, A. Bozorgi-Amiri, A. Rahbari, Emergency supply chain scheduling problem with multiple resources in disaster relief operations, *Transportmetrica A: Transport Sci.*, **16** (2020), 930–956. https://doi.org/10.1080/23249935.2020.1720858
29. V. K. Manupati, T. Schoenherr, S. M. Wagner, B. Soni, S. Panigrahi, M. Ramkumar, Convalescent plasma bank facility location-allocation problem for COVID-19, *Transp. Res. Part E Logist. Transp. Rev.*, **156** (2021), 102517. https://doi.org/10.1016/j.tre.2021.102517
30. N. Ghaffarinasab, B. Y. Kara, A conditional β-mean approach to risk-averse stochastic multiple allocation hub location problems, *Transp. Res. Part E Logist. Transp. Rev.*, **158** (2022). https://doi.org/10.1016/j.tre.2021.102602
31. M. Besiou, A. J. Pedraza-Martinez, L. N. V. Wassenhove, Vehicle supply chains in humanitarian operations: decentralization, operational mix, and earmarked funding, *Prod. Oper. Manage.*, **23** (2014), 1950–1965. https://doi.org/10.1111/poms.12215
32. A. Maghsoudi, S. Zailani, T. Ramayah, A. Pazirandeh, Coordination of efforts in disaster relief supply chains: the moderating role of resource scarcity and redundancy, *Int. J. Logist. Res. Appl.*, **21** (2018), 407–430. https://doi.org/10.1080/13675567.2018.1437894
33. D. Ritam, B. Moumita, G. Kripabandhu, G. Saptarshi, Utilizing microblogs for assisting post-disaster relief operations via matching resource needs and availabilities. *Inf. Process. Manage.*, **56** (2019), 1680–1697. https://doi.org/10.1016/j.ipm.2019.05.010
34. T. B. Seybolt, Harmonizing the humanitarian aid network: Adaptive change in a complex system, *Int. Stud. Q.*, **53** (2009), 1027–1050. https://doi.org/10.1111/j.1468-2478.2009.00567.x

35. G. Fenton, N, Altay, Relief supply chain management for disasters: humanitarian aid and emergency logistics, in *Journal of Humanitarian Logistics and Supply Chain Management*, Emerald Group Publishing Limited, (2012), 112–115. https://doi.org/10.1108/20426741211260769
36. C. Takeshi, A. Shinichi, K. Takeshi, Research on method of human error analysis using 4M4E, *JR East Tech. Rev.*, **2003** (2003), 59–65.
37. W. Mutmainnah, M. Furusho, The 4M overturned pyramid (MOP) model in maritime traffic system for safety at sea, *Navigation*, **191** (2015), 14–15. https://doi.org/10.18949/jinnavi.191.0_14
38. A. B. Sulistiyono, M. Furusho, Improvement of maritime tourism towards indonesia's global maritime fulcrum, *Navigation*, **199** (2017), 21–22. https://doi. org/10.18949/jinnavi.199.0_21
39. K. Deb, A. Pratap, S. Agarwal, T. Meyarivan, A fast and elitist multiobjective genetic algorithm: NSGA-II, *IEEE Trans. Evol. Comput.*, **6** (2002), 182–197. https://doi.org/10.1109/4235.996017
40. A. Asanjarani, S. H. Dibajian, A. Mahdian, Multi-objective crashworthiness optimization of tapered thin-walled square tubes with indentations, *Thin-Walled Struct.*, **116** (2017), 26–36. https://doi.org/10.1016/j.tws.2017.03.015
41. E. G. Bekele, J. W. Nicklow, Multi-objective automatic calibration of SWAT using NSGA-II, *J. Hydrol.*, **341** (2007), 165–176. https://doi.org/10.1016/j.jhydrol.2007.05.014

Appendix

Table A1. The judgment matrix of criterion layer index (V_1, V_2, V_3, V_4).

Index	Personnel quality	Facilities and equipment	Port environment	Management level
Personnel quality	1	1/4	1/5	1/3
Facilities and equipment	4	1	1/3	3
Port environment	5	3	1	2
Management level	3	1/3	1/2	1

Table A2. The judgment matrix of indicator layer index (V_{11}, V_{12}).

Index layer	Crew and tourists	Port supervisor
Crew and tourists	1	3
Port supervisor	1/3	1

Table A3. The judgment matrix of indicator layer index (V_{41}, V_{42}).

Index layer	Crew and tourists	Port supervisor
Crew and tourists	1	1/2
Port supervisor	2	1

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