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Research Article

Optimum Design of Ship Cabin Equipment Layout Based on SLP Method and Genetic Algorithm

Jinghua Li,[1] Hui Guo,[1] Shichao Zhang,[2] Xiaoyuan Wu,[2] and Liuling Shi[2]

[1] *College of Shipbuilding Engineering, Harbin Engineering University, Harbin 150001, China*
[2] *Shanghai Waigaoqiao Shipbuilding Co., Ltd., Shanghai 200137, China*

Correspondence should be addressed to Hui Guo; hui0625@hrbeu.edu.cn

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The engine room is the heart of a ship, and almost all of the main electromechanical equipment that supports the work on board can be found here. Finding a way to arrange the equipment in a small cabin space is an essential factor in the design and construction of a ship. However, in existing research, when an intelligent algorithm is used to optimize the design of a cabin, the established mathematical model is not comprehensive and the solution has not been evaluated. The optimal solution obtained is not feasible for the actual design of a ship. This can lead to unnecessary redesign work, which seriously affects design efficiency and increases design costs. In order to solve the above problems, this paper innovatively refers to a Systematic Layout Planning (SLP) method (normally applied to the layout of plant equipment) to the cabin equipment layout issue. The SLP method is used to quantitatively analyze the adjacency and logistics relationship between devices, and the mutual integration relationship between devices is obtained so that a preliminary layout scheme can be retrieved. The problem model is constructed by considering various factors such as the comprehensive relationship between the equipment and the stability of the cabin, and the corresponding objective function and constraint function are established to further design the variables, operators, and steps of the genetic algorithm. The initial solution obtained from the SLP method is used as part of an initial solution to the genetic algorithm, and the genetic algorithm is used to optimize the problem. Finally, the Analytic Hierarchy Process (AHP) is used to evaluate and optimize several groups of better schemes obtained by running multiple genetic algorithms and select the better schemes. The experimental design proves that the integrated design method has certain feasibility and superiority.

1. Introduction

The engine room is the heart of a ship. A large amount of main equipment supporting the work on board is arranged in the engine room. Arranging all kinds of equipment effectively is an important problem [1]. A reasonable layout can greatly reduce the ship design and construction cycle and, at the same time, reduce costs, and ensure ship operation safety. With research into and the application of an intelligent algorithm, the combination of an intelligent algorithm and equipment layout optimization has been attracting more and more attention.

The layout problem involves a lot of content, which is essentially a complex multidisciplinary combination optimization problem [2]. Its complexity is reflected in two aspects: on the one hand, the model is complex. Most layout problems are derived from actual real-world problems. Often, actual problems are difficult to describe accurately in mathematical language. Usually, assumptions can be used to simplify actual problems and then describe them in mathematical language to establish corresponding mathematical models. On the other hand, these calculations are complicated. The computational complexity of layout problems is a nondeterministic problem involving the complexity of the polynomial; that is, an exact solution to the problem cannot be found in a limited time. Therefore, most layout problems often end up not with an optimal solution, but rather a feasible solution that satisfies the constraints and has a better performance [3].

In terms of the optimization of facility layouts, the enlightenment period began in the early 20th century and went on to the 1930s. There was no systematic theory and

method due to the limitations of the times, but it relied on the subjective experience of human beings [4]. From the 1940s to the 1960s, the issue of facility layout entered a period of rapid development. During this period, researchers used system theory, cybernetics and other quantitative methods to optimize facility layouts and achieved good results [5]. Since the 1970s, with the popularity of computers and the emergence of various intelligent algorithms, the problem of facility layout optimization has once again entered another period of vigorous development [6]. The use of intelligent algorithms to optimize the layout of facilities has completely changed past business processes, and intelligent algorithms are widely used to successfully solve the problem of facility layout design [7–17].

The optimization of the layout of ship cabin equipment as a branch of facility layout optimization has also been a hot topic in recent years. Over time, many scholars have conducted a lot of research and achieved certain results. At present, in terms of the layout problem of cabin equipment, most research has combined the layout problem with the intelligent algorithm, optimized the algorithm, and yielded a better solution. A.I. Ölçer introduced a multiobjective genetic algorithm and fuzzy multiattribute set in the layout design of a ro-ro ship's cabin, which improved the efficiency of the cabin layout [18]. Y. Yang proposed a facility layout optimization design method for cabin maintainability as a method to improve the efficiency and quality of maintainability design and built a mathematical model for maintainability layout optimization. An improved particle swarm optimization algorithm was also used to improve calculation efficiency and accuracy and effectively solve the multipeak optimization problem [19]. Wang Y. L. generated the initial value of the genetic algorithm based on the energy method and then used the improved genetic algorithm to design the ship's cabin layout, which solved the problem of layout evaluation to some extent [20, 21]. Literature [22–25] elaborates the application of genetic algorithm in equipment layout problem in detail and proves that genetic algorithm has good robustness to this kind of problem through examples. Zheng X. L. proposed a method based on game theory to promote the multidisciplinary decision-making process involved in ship cabin layout design and, at the same time, developed a noncooperative game strategy, and determined the amount of equipment and furniture required for the corresponding location in order to achieve the highest possible performance in the cabin [26]. The above research only used intelligent algorithms to solve the problem, yet it did not consider how to generate a more effective initial solution, did not evaluate the obtained solution, and cannot determine whether the solution was the most feasible solution.

In 1961, Richard Joseph first proposed a systematic facility layout method [27], which enabled the plant's designers to perform quantitative analyses based on objective data from previous qualitative analyses that had been based on subjective experience. The application of this method is not limited to the industrial field but also used for various types of facility layout optimization (among others) and it is still used, improved, and innovated upon today. The Systematic Layout Planning Method (SLP) is generally applied to the layout design of workshop facilities [28–30], and research on applying the SLP method to the layout of ship facilities is relatively rare. Hu Yao et al. optimized the complex multiobjective combination optimization problem for the position layout of the interior cabin of a volumetric ship and comprehensively applied the SLP method to the heuristic method and the genetic algorithm (GA) in the intelligent algorithm to solve the problem and optimize the solution [31]. However, it only lays out the location of different compartments and does not optimize the design of the cabin interior. Moreover, simply using the SLP method to solve the layout of the cabin equipment only meets the adjacency and logistics requirements of the equipment and does not guarantee that the scheme meets ship stability and other performance requirements.

The Analytic Hierarchy Process (AHP) is a hierarchical weighted decision analysis method proposed by the Pittsburgh University Operations Researcher Professor Saaty in the early 1970s when he was studying the subject of the U.S. Department of Defense [32]. Z Gao et al. achieved good results by using the Analytic Hierarchy Process (AHP) and the Pure Output Data Envelopment Analysis (DEA) method [33]. When Wang Y L et al. laid out the cabin of the ship intelligently, the AHP method was used to evaluate several schemes obtained by using the algorithm,and finally the optimal solution was selected [21]. The above studies show that it is feasible and effective to apply the AHP method to equipment layout optimization, but there is still little research into the application of this method to the layout of ship cabin equipment.

Based on the above research, this paper creatively applies the SLP method to the cabin equipment layout optimization problem, establishes a corresponding mathematical model and uses a genetic algorithm to solve it. Finally, the AHP method is used to evaluate the multiple sets of solutions obtained. The rest of this paper is structured as follows. Section 2 uses the SLP method to analyze the adjacency requirements of the cabin equipment and the personnel circulation efficiency requirements and, on this basis, determines a comprehensive interrelationship between different equipment, thus determining the positional constraints across various pieces of equipment and using this as the method of evaluation. Section 3 comprehensively considers factors such as cabin weight, distance and stability and constructs corresponding mathematical models and constraints. Section 4 details the operator design of the genetic algorithm and generates a cabin layout based on the genetic algorithm. Section 5 is based on the AHP method and evaluates the scheme generated in the Section 4 to determine a better layout scheme. Section 6 concludes the research and identifies future work.

2. SLP Analysis of Simplified Layout of Equipment

SLP is the earliest method used in the design of factory and workshop equipment layout. It uses the relationship between logistics and nonlogistics of equipment as the main line and

Table 1: Definition of adjacent demand intensity level and coefficient.

strength grade	Strength coefficient	Meaning
1	1	The need for adjacency is very high
2	0.8	Higher adjacency demand
3	0.6	Contiguous demand
4	0.4	Lower adjacency demand
5	0.2	The need for adjacency is very low
6	0	No adjacency requirements

adopts a set of expressive legend symbols and concise work forms and, through the design process, solves the problem of factory and workshop equipment location layout design [34–36]. The cabin equipment layout problem is, in the final analysis, the layout optimization of the equipment, so the SLP method can also be used in the layout optimization design of the cabin equipment. However, regardless of the type of layout design being used, there are still some differences between the two layout problems. The main reason for this difference is that the location layout design of the cabin equipment is different from the layout design of the production system. The layout design of the production system primarily considers logistics transportation factors. Relevant research shows that about 20% of the processing costs are used for material transportation, and reasonable equipment layout can reduce the transportation cost of materials by at least 10%-20% [37]. However, in terms of the layout of the cabin equipment, the logistics relationship factor is not the primary factor, and the influence of the adjacency relationship is greater. Therefore, when using the SLP method, it is necessary to make adjustments to the constituent elements for the analysis of both the adjacent demand and the circulation relationship. At the same time, it is necessary to use the intensity coefficient to quantify the demand correlation between the constituent elements.

2.1. Analysis of Adjacent Demand Intensity between Equipment. According to certain layout criteria, the adjacent demand strength of each piece of equipment is determined and expressed by strength grade and strength coefficient. The adjacency demand strength between devices is determined according to certain arrangement criteria and is expressed by intensity level and intensity coefficient

$a_{jk} \in [0, 1]$ indicates the adjacent demand intensity between equipment j and k; the larger a_{jk} indicates that the adjacency demand between j and k is stronger. $a_{jk} = 0$ indicates that devices j and k have no adjacency needs; $a_{jk} = 1$ indicates that devices j and k must be adjacent. Matrix $A = [a_{jk}]_{n\times n}$ is a distribution matrix that represents adjacent demand intensity, in which only the adjacency relationship between equipment j and k is considered, while the adjacency relationship between k and j is not repeated and marked as empty. At the same time, there is no adjacency of equipment in $j = k$. The corresponding relationship between strength grade and strength coefficient is not present. As shown in Table 1 [38], the strength factor of the table is determined according to the demand relationship between the devices.

Table 2: Device type.

No.	Device name
1	Host
2	Alternator
3	General use pump for cabin bottom
4	Sewage comminution pump
5	Fire Extinguisher
6	Fuel tank
7	Domestic sewage cabinet
8	Staircase 1
9	Staircase 2

Table 3: Distribution of adjacent demand intensity in cabin.

No.	1	2	3	4	5	6	7	8	9
1	/	0.6	0	0	0	0	0	0	0
2	/	/	0.4	0.4	0	0.2	0.4	0	0
3	/	/	/	0.8	0	0.2	0	0	0
4	/	/	/	/	0	0	0.8	0	0
5	/	/	/	/	/	0.6	0	0.6	0.6
6	/	/	/	/	/	/	0	0	0
7	/	/	/	/	/	/	/	0	0
8	/	/	/	/	/	/	/	/	0
9	/	/	/	/	/	/	/	/	/

According to the equipment in Table 2, the layout criteria are as follows: the main engine and the generator should be closer, and the distance from the other equipment is far apart; the total pump at the bottom of the cabin is not related to the operation of other equipment; the relative degree of the sewage pulverizing pump and the living sewage water tank is higher and should be placed in a relatively close position; fire extinguishers should be placed close to the fuel tank and stairs for easy access.

The specific distribution matrix A of the relationship described above according to the analysis method in terms of the logistics and nonlogistics relationship using the SLP method is shown in Table 3.

2.2. Analysis of the Intensity of Circulation Relationship between Equipment. In terms of cabin equipment layout, as well as needing to consider the adjacent requirements of the operations between the various equipment, it is also

Table 4: Definition of strength grade and coefficient of circulation relationship.

strength grade	Strength coefficient	Meaning
1	1	The demand for circulation is very high
2	0.8	High demand for circulation
3	0.6	General circulation demand
4	0.4	Low demand for circulation
5	0.2	The demand for circulation is very low
6	0	Non circulation demand

Table 5: Distribution relationship intensity distribution in the cabin.

No.	1	2	3	4	5	6	7	8	9
1	/	0.8	0	0	0	0	0	0	0
2	/	/	0.6	0.6	0	0.2	0.4	0	0
3	/	/	/	0.8	0	0	0.2	0	0
4	/	/	/	/	0	0	0.8	0	0
5	/	/	/	/	/	0.6	0	0.6	0.6
6	/	/	/	/	/	/	0	0	0
7	/	/	/	/	/	/	/	0	0
8	/	/	/	/	/	/	/	/	0
9	/	/	/	/	/	/	/	/	/

necessary to consider the flow of personnel in order to ensure the location of the equipment is convenient for personnel installation, operation and evacuation.

Using b_{jk} to express the strength of the circulation relationship among personnel, $b_{jk} = 0$ indicates no circulation relationship between j and k; that is, people do not operate equipment from j to k; b_{jk} =1 indicates that j and k circulation is very high; that is, the frequency of personnel operating from j to k is very high. Matrix B is a distribution matrix representing the intensity of circulation relationships, distribution relationship grade, and intensity coefficient distribution, as shown in Table 4 [38].

For the circulation relationship, we mainly consider the staff's operation of the equipment and the circulation relationship from the host to the stairs during evacuation. For the logistics relationship, the layout of the pipelines and cables between the main engine and the generator is considered mainly, as well as the total use of the pump and the living water powder in the bottom of the cabin. The intensity of the logistics relationship between the crushing pump and the living water cabinet is also relatively small. Referring to the corresponding standard for ship engine room design [39–42], the circulation relationship between the equipment is clearly defined in the standard. Referring to the corresponding regulations in the standard, the personnel and logistics situation of the equipment in the cabin are determined. The distribution matrix B shown in Table 5 is obtained by selecting the flow intensity coefficient among the equipment.

In Table 5, it should be noted that there is no flow relationship between the equipment itself, as there is no flow intensity grade between equipment 1 and equipment 1; the flow intensity between equipment 1 and equipment 2 is the same as that between equipment 2 and equipment 1; only one of them is counted.

2.3. Analysis of the Comprehensive Relationship Strength between Equipment. The comprehensive inter-relationship table between devices is a combination of the adjacent demand distribution and the circulation relationship analysis, and the two relationships are integrated with each other to produce a table. Through a comprehensive analysis of the relationship between pieces of equipment, the location of each piece of equipment is reasonably planned and the equipment layout of the cabin is more reasonable.

When the intensity of the adjacent demand and the intensity of the circulation relationship are all determined, the subtarget can be weighted to be transformed into a multitarget strength coefficient to obtain the comprehensive relationship strength of the SLP analysis, and $f_{j,k}$ is expressed by the next formula: $f_{j,k}$ is determined by the following formula:

$$f_{j,k} = w_1 a_{j,k} + w_2 b_{j,k} \tag{1}$$

In the formula, $a_{j,k}$ and $b_{j,k}$ represent two strength values between the cabins j and k and w_1 and w_2 are weighted coefficients. The relative importance of the adjacency relationship and the circulation relationship is determined. The ratio of importance $w_1 : w_2$ (weighted value) should generally be in the range of 1:3~3:1. When $w_1 : w_2$ <1:3, the layout is affected by the adjacency relationship, and the key planning objective is the circulation relationship when the equipment is arranged. When $w_1 : w_2$ >3:1, it indicates that the adjacency relationship between devices is dominant [43]. When devices are deployed, the devices occupying an important proportion in the adjacency relationship are planned. Because the cabin equipment is in the actual ship operation, the adjacency relationship is more important and the reasonable adjacency relationship can save a lot of cabin space in order that the pipeline and circuit can be arranged more reasonably. Referring to the value of this weight in [44], thus, this article takes $w_1 : w_2$ =4:1, that is, $w_1 = 0.8$ and $w_2 = 0.2$. The distribution matrix F for synthesizing the strength of correlation is shown in Table 6.

The level of integrated correlation can be further determined based on the data in Table 6, that is, the level of comprehensive correlation between devices in the SLP method. The level is expressed as $\{A, E, I, O, U\}$ and the intensity interval corresponding to the level in the example is $\{[0.8, 1], [0.6, 0.8), [0.4, 0.6), [0.2, 0.4), [0, 0.2)\}$. The rank distribution is shown in Table 7.

Table 6: Comprehensive relationship intensity distribution between devices.

No.	1	2	3	4	5	6	7	8	9
1	/	0.64	0	0	0	0	0	0	0
2	/	/	0.44	0.44	0	0.2	0.4	0	0
3	/	/	/	0.79	0	0.16	0.04	0	0
4	/	/	/	/	0	0	0.8	0	0
5	/	/	/	/	/	0.6	0	0.6	0.6
6	/	/	/	/	/	/	0	0	0
7	/	/	/	/	/	/	/	0	0
8	/	/	/	/	/	/	/	/	0
9	/	/	/	/	/	/	/	/	/

Table 7: Comprehensive relationship level distribution between devices.

No.	1	2	3	4	5	6	7	8	9
1	/	E	U	U	U	U	U	U	U
2	/	/	I	I	U	O	I	U	U
3	/	/	/	E	U	U	U	U	U
4	/	/	/	/	U	U	A	U	U
5	/	/	/	/	/	E	U	E	E
6	/	/	/	/	/	/	U	U	U
7	/	/	/	/	/	/	/	U	U
8	/	/	/	/	/	/	/	/	U
9	/	/	/	/	/	/	/	/	/

This paper introduces genetic algorithms for subsequent optimization, so the purpose of SLP analysis is to determine the Positional relationship of a part of the equipment with relatively high comprehensive relationship strength. In the definition of the SLP relational grade, the highest level "A" must be close. The living sewage powder pump and the domestic sewage cabinet can be close together in order to facilitate the laying of cables and pipes. According to the requirements of the area of each item of equipment, the position constraints of the algorithm are determined according to the optimization of the algorithm, and the preliminary arrangement of the equipment sequence (7 4 3 1 2 6 8 5 9) is obtained. The above SLP analysis results can be used as part of the device sequence in the initial solution of the genetic algorithm to accelerate the convergence of the genetic algorithm.

3. Mathematical Model and Constraint Conditions for Optimization of Engine Room Layout

3.1. Establishment of Mathematical Model for Optimization of Engine Room Layout. The layout optimization problem can also be regarded as a path planning problem. The first problem is to establish an environment model of the cabin layout. In this paper, the cabin equipment is simplified and abstracted as follows: assume that the layout of the equipment in the cabin space is rectangular and the placement of the internal components of the equipment is also the optimal placement. A good layout of the interior equipment can coordinate the operation relationship among the ship cabin equipment, ensure the operation of the system, improve the circulation efficiency of the cabin crew, and reduce the time consumption of the circulation. In engineering layout problems, the basic layout forms include the single-line layout, multiline layout, site layout, ring layout and U-shaped layout. Most of the domestic related literatures refer to the site layout and multiline layout as multiline layout. The basic layout is shown in Figure 1 [35]. The layout position in the Figure is represented by two serial numbers: the upper left number is the layout position number, and the lower right number is the number of the facilities to be placed. Combined with the cabin structure framework, this paper has selected the multiline layout form.

The topology model of the cabin and equipment is shown in Figure 2. In the picture, the lower left corner of the cabin is the original point, l_j represents the length of the device j, h_{gk} represents the minimum horizontal spacing between equipment g and k, h_{j0} represents the minimum horizontal space between equipment j and the cabin boundary, and Δ_j represents the net distance between equipment j and device $j-1$ or the boundary. The value range is $[0, 1.5]$, s stands for device row spacing, s_0 represents the distance from the first line device to the workshop boundary, x_j is the x coordinates of the center of device j, and y_j is the y coordinates of the center of device j.

3.2. Objective Function. The goal of cabin layout optimization is to properly place the equipment in a manner that ensures the stability of the ship's structure and performance. Therefore, the objective function needs to meet the two objectives of flow intensity and adjacent strength according to the SLP method. In addition, it is necessary to consider balance and center of gravity requirements, equipment uniform arrangement and so on [39–42].

(1) Adjacent Intensity Target. The higher the close relationship between devices, the greater the flow intensity and the smaller the distance between devices, so the objective function for defining adjacency strength is as follows:

$$f_1(x) = \sum_{j=1}^{8} \sum_{k=j+1}^{9} A \times D(x) \tag{2}$$

The meanings of the letters in the above formula are as follows:

(1) $f_1(x)$ is the sum of the product of the equipment adjacency matrix A and the distance D between the devices.

(2) D is the distance matrix between devices, calculated using the following formula:

$$D_{jk} = \left|x_j - x_k\right| + \left|y_j - y_k\right| \tag{3}$$

(2) Circulation Intensity Target. The higher the degree of close relationship between devices is, the greater the adjacent strength and the smaller d_{ij} is, so the definition of the adjacent strength objective function is as follows:

$$f_2(x) = \sum_{j=1}^{8} \sum_{k=j+1}^{9} B \times D(x) \tag{4}$$

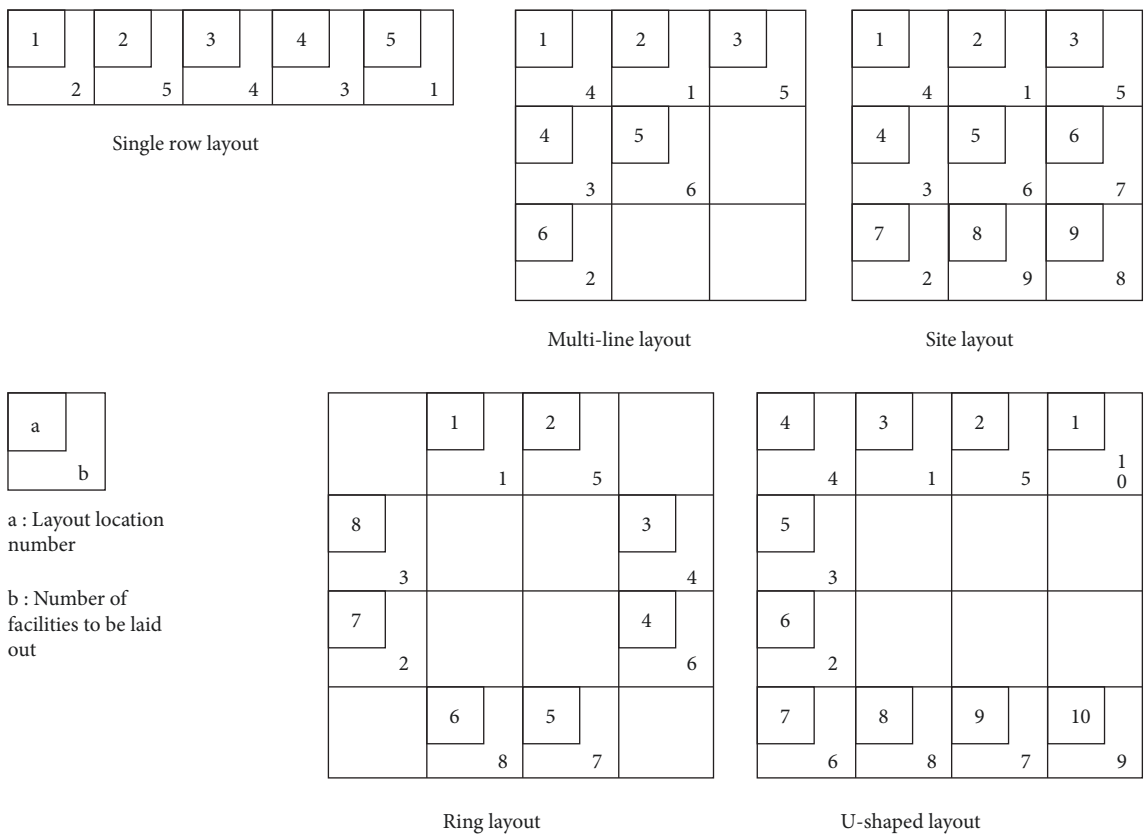

Figure 1: Classification of layout forms.

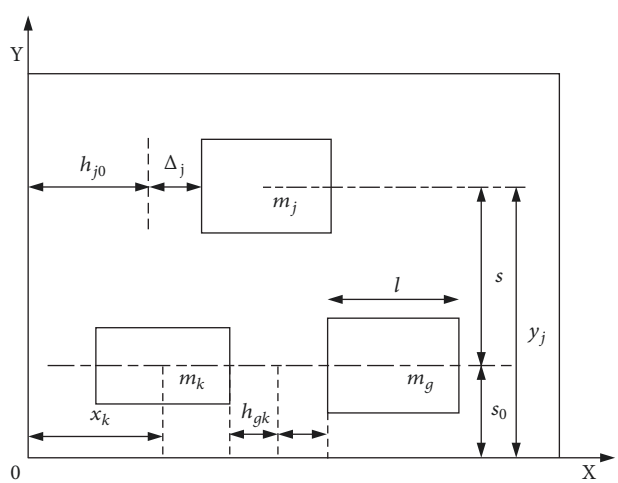

Figure 2: Topology model between cabin and equipment.

The meanings of the letters in the formula above are as follows:

(1) $f_2(x)$ is the sum of the product of the equipment circulation strength matrix B and the distance D between the devices.

(2) D is the distance matrix between devices, calculated using the following formula:

$$D_{jk} = \left|x_j - x_k\right| + \left|y_j - y_k\right| \tag{5}$$

(3) Ship Stability Requirements. In order to improve the stability of the ship and ensure that the ship has a large heel when sailing, ensure that the torque algebra and absolute value of the equipment for the midlongitudinal section are as small as possible. The distance between the center of gravity of the device and the longitudinal section is calculated as

$$f_3(x) = \left|\sum_{j=1}^{9} m_j \left(x_j - \frac{l}{2}\right)\right| \tag{6}$$

(4) Device Arranged Uniformly. Auxiliary machines should be arranged as closely as possible to around the cabins, mainly because if the auxiliary machines are arranged centrally on the longitudinal line side of the ship's nacelle, there will be a free liquid level in the equipment when the equipment is working normally. This will cause the moment of inertia to be unbalanced, thus affecting the stability of the ship. The following formula is used to control the equipment which has been evenly arranged in the cabin.

$$f_4(x) = \left|\sum_{j=1}^{9} \left(x_j - \frac{l}{2}\right)\right| \tag{7}$$

According to the mathematical model of the layout principle, it can be determined that the objective function of the cabin is

$$F(x) = \min \sum_{e=1}^{4} f_e(x) \tag{8}$$

3.3. Constraint

(1) Equipment Must Not Overlap. When the ship's cabin equipment is arranged, it should be ensured that there is no interference between the equipment:

$$\left|x_j - x_k\right| \geq \left[\frac{\left(l_j + l_k\right)}{2} + h_{jk}\right] z_{jp} z_{kp}, \quad j, k = 1, 2, \ldots, 9 \tag{9}$$

The formula for solving the horizontal axis of the device is

$$\begin{aligned} x_j &= x_k + \frac{\left(l_k + l_j\right)}{2} + h_{kj} + \Delta_j \\ &= h_{k0} + \Delta_k + \frac{\left(l_j + 2l_k\right)}{2} + h_{kj} + \Delta_j \end{aligned} \tag{10}$$

The formula for solving the ordinate of the equipment is

$$y_j = (k-1)\, s + s_0, \quad \text{if } z_{jp} = 1;\ j = 1, 2, \ldots, 9;\ p = 1, 2, \ldots, r.$$

$$z_{jp} = \begin{cases} 1, & \textit{Device } j \textit{ on line } p \\ 0, & \textit{other} \end{cases} \quad j = 1, 2, \ldots, 9;\ p = 1, 2, \ldots, r \tag{11}$$

where r is the total number of lines in the device layout.

(2) During the calculation of the layout of the ship's cabin equipment, each device is required to appear only once, which is

$$\sum_{p=1}^{r} z_{jp} = 1, \quad i = 1, 2, \ldots, 9; x_j, y_j \geq 0, \Delta_j \geq 0 \tag{12}$$

(3) The weight of the mechanical equipment arranged on the left and right sides should be kept as balanced as possible to avoid the ship's roll caused by the difference in weight on both sides, and w is the cabin width.

$$\sum_{0 \leq x \leq w/2} M_j \approx \sum_{w/2 < x \leq w} M_k \tag{13}$$

In summary, the mathematical model is established as

$$F(x) = \sum_{j=1}^{8} \sum_{k=j+1}^{9} A \times D(x) + \sum_{j=1}^{8} \sum_{k=j+1}^{9} B \times D(x) + \left|\sum_{j=1}^{9} M_j \left(x_j - \frac{L}{2}\right)\right| + \left|\sum_{j=1}^{9} \left(x_9 - \frac{L}{2}\right)\right|$$

$$s.t. \begin{cases} \left|x_j - x_k\right| \geq \left[\dfrac{\left(l_j + l_k\right)}{2} + h_{jk}\right] z_{jp} z_{kp}, \quad i, j = 1, 2, \ldots, 9 \\ \displaystyle\sum_{p=1}^{r} z_{jp} = 1, \quad j = 1, 2, \ldots, 9; x_j, y_j \geq 0, \Delta_j \geq 0, j = 1, 2, \ldots, 9 \\ \displaystyle\sum_{0 \leq x \leq w/2} M_j \approx \sum_{w/2 < x \leq w} M_k \end{cases} \tag{14}$$

By doing this, according to the rules and design experience of the cabin equipment layout, the objective function and constraints are determined, and the mathematical model of the cabin layout design is then established, which is ready for the next step whereby the genetic algorithm is used for intelligent optimization.

4. Genetic Algorithm Design

In this paper, the genetic algorithm is used to solve the model. The genetic algorithm can be independent of the specific field of the problem and has strong robustness to this type of the problem [45–50]. Therefore, the genetic algorithm can solve the layout problem of the cabin equipment.

According to the characteristics of the multiobjective optimization model of cabin equipment, this paper designs the chromosome coding, crossover, mutation, and algorithm flow of the genetic algorithm. The specific analysis is as follows.

4.1. Chromosome Coding. Encoding extended transposition expressions using two lists of device symbols and net spacing are

$$\left[\{m_1, m_2, \ldots, m_n\}, \{\Delta_1, \Delta_2, \ldots, \Delta_n\}\right] \tag{15}$$

where m_n represents the device serial number and Δ_n represents the net spacing between device $n-1$ and device n. At the same time, the automatic line-wrapping strategy is adopted; that is, when the sum of the lengths of the devices in the same row and the actual mutual spacing exceeds the maximum lateral space length limit, the last device of the bank automatically enters the next line.

4.2. Initial Population. The initial population is generated randomly. In order to speed up the convergence process of the genetic algorithm, the first device symbol sequence in the initial population can be replaced by the superior device symbol sequence obtained by the SLP method. In this case, the sequence of the cabin obtained by the SLP method (7 4 3 1 2 6 8 5 9) is used instead in order that the initial population is formed.

4.3. Fitness Function. Because of the automatic line break strategy, there is no device outside of the cabin area in the X-axis direction. Therefore, it is only necessary to determine whether the last row exceeds the cabin area in the Y-axis direction.

$$P_k = \begin{cases} 0, & s_0 + (m-1)\,s \le H \\ T, & other \end{cases} \tag{16}$$

where H is the width of the compartment, is an unreasonable penalty, and T is a positive large penalty value of 500.

The fitness function is:

$$fit\left(v_k\right) = \frac{1}{\left(F + P_k\right)} \tag{17}$$

In the formula, F is the objective function.

4.4. Select. The roulette selection mechanism is adopted - that is, the probability of each individual being selected is proportional to the fitness degree. If the population size is M and the fitness of the individual i is $fit(v_k)$, then the probability that the individual i is selected is $P_i = fit(v_k)/\sum_{i=1}^{m} fit(v_k)$ $(i = 1, 2, \ldots, M)$ - in other words, the population is selected according to the probability of obtaining a new population, and the higher the fitness, the greater the probability that the individual will be selected.

4.5. Cross. The crossover operation adopts the partial matching method of the two-point cross-binding repair program. The repair program can make the nonpopulation individuals in the cross become individual within the population, thus ensuring the smooth progress of the algorithm. The specific implementation steps of the crossover method are as follows:

For parent one and parent two, randomly find two numbers from 1 to 9 as the intersection position.

Father 1: $(a_7\ a_6\ a_5\ \boxed{a_9}\ a_1\ a_3\ \boxed{a_4}\ a_2\ a_8)$

Father 2: $(a_6\ a_2\ a_8\ \boxed{a_5}\ a_9\ a_7\ \boxed{a_1}\ a_3\ a_4)$

Exchange the parts between the two cross positions of the parent.

Child 1: $(a_7\ a_6\ a_5\ \boxed{a_5\ a_9\ a_7\ a_1}\ a_2\ a_8)$

Child 2: $(a_6\ a_2\ a_8\ \boxed{a_9\ a_1\ a_3\ a_4}\ a_3\ a_4)$

After the crossover, the same parent will have duplicate device numbers, nonrepeating device numbers will be retained and conflicting device numbers will be mapped in the corresponding order of the intermediate segments. In this example, the middle segment of Child 1 is $(a_5\ a_9\ a_7\ a_1)$, the middle segment of Child 2 is $(a_9\ a_1\ a_3\ a_4)$, the conflicting device numbers of Child 1 are a_5 and a_7, and the missing parts are a_3 and a_4. Therefore, it is necessary to use the a_3 and a_4 of the middle segment of Child 2 to fill the position. The complement order is complemented by the order of a_3 and a_4 in $(a_9\ a_1\ a_3\ a_4)$, and Child 2 is also padded as described above. Therefore, the result is:

Child 1: $(a_3\ a_6\ a_4\ \boxed{a_5\ a_9\ a_7\ a_1}\ a_2\ a_8)$

Child 2: $(a_6\ a_2\ a_8\ \boxed{a_9\ a_1\ a_3\ a_4}\ a_5\ a_7)$

Table 8: Layout scheme.

NO	Layout Scheme
1	[8,5],[2,1],[3,4,6],[7,9]
2	[7],[4,3],[2,9,6],[1,8,5]
3	[9],[7,8,5],[3,4,6],[2,1]
4	[8],[5,9],[3,4,7],[6,2,1]
5	[9],[1,2,7],[5,3,4],[8,6]
6	[9,6],[8,5,1],[7,3,2]

4.6. Variation. The mutation operation only operates on the net spacing portion of the device, assuming that the net spacing sequence for a given chromosome is $\{\Delta_1, \Delta_2, \ldots, \Delta_n\}$. Specify the mutated point Δ_i according to the probability of mutation, r is a given integer and $[U_{\min}, U_{\max}]$ is the range of values of the device's net spacing. Then, within this interval, r net spacing can be generated randomly: $\{\Delta_i^1, \Delta_i^2, \ldots, \Delta_i^r\}$. Replacing the variation point Δ_i with $\{\Delta_i^1, \Delta_i^2, \ldots, \Delta_i^r\}$, r new chromosomes can be produced. The best one can be selected from the r new chromosome to replace the original chromosome. In this case $r = 10$, $[U_{\min}, U_{\max}] = [0, 1.5]$.

4.7. Decoding. The layout adopts the automatic line-wrapping strategy. Therefore, an array with the field name Layout is added to the algorithm to store the sequence number of each line of equipment after each device sequence is generated by the iteration. The resulting layout scheme is the data in the array.

4.8. Algorithm Flow. Based on the above settings, the GA algorithm parameters are set as follows: population size is 50, crossover probability is 0.6, mutation probability is 0.1 and maximum iteration number is 200. The GA algorithm flow is shown in Figure 3.

Using MATLAB software to optimize the solution, the program can be run multiple times in order to obtain several groups of better solutions and select several sets of solutions as the selection scheme, as shown in Table 8.

Because of the multi-line layout and the word-wrap strategy, each bracket represents a line and starts at the first line.

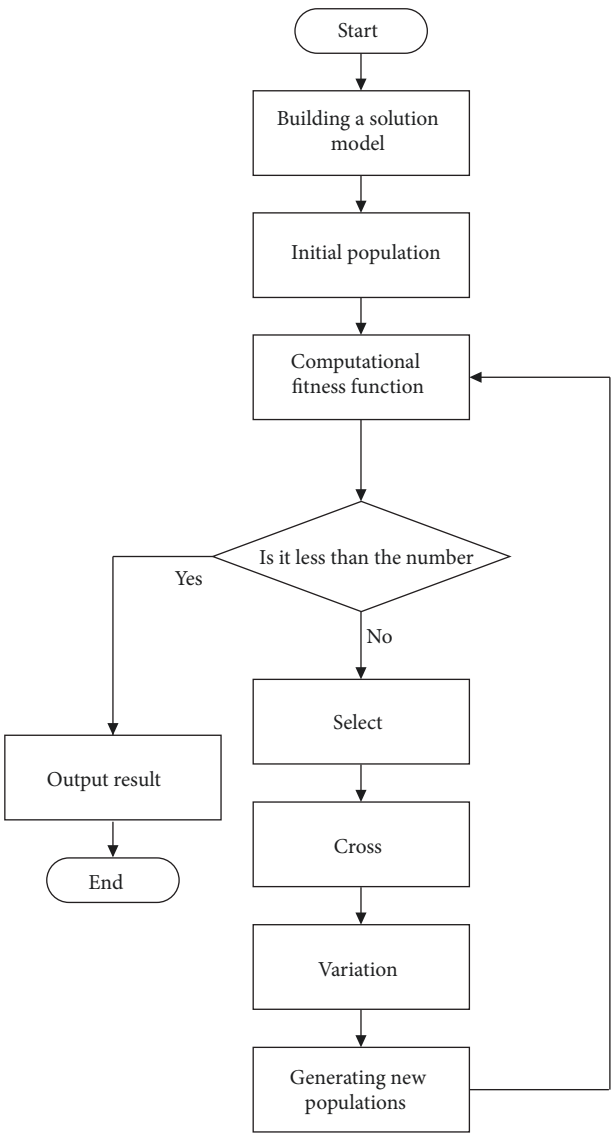

Figure 3: Algorithm flow.

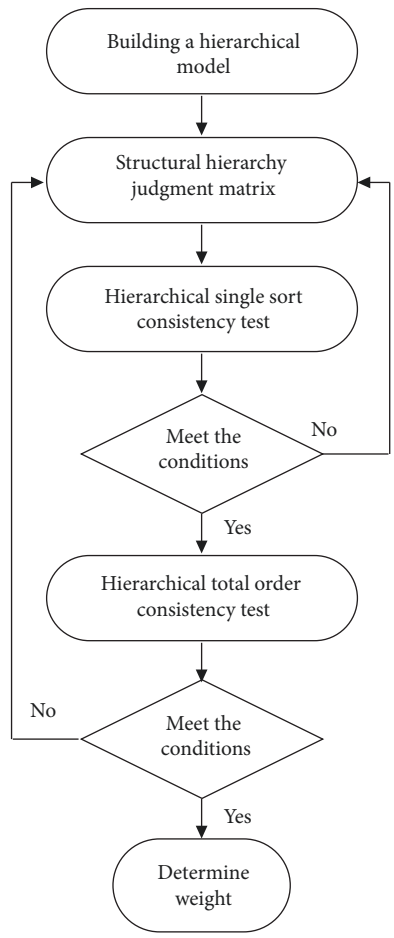

Figure 4: AHP Analysis flowchart.

5. AHP-Based Cabin Layout Scheme Selection

5.1. The Basic Principle of AHP Method. The Analytic Hierarchy Process (AHP) refers to a complex multi-objective decision-making problem as a system, which decomposes the target into multiple goals or criteria and then decomposes this into multiple levels of multiple indicators (or criteria, constraints). The hierarchical single order (weight) and total ordering are calculated by using a qualitative index fuzzy quantization method, which is used as the system method of targeting (multi-indicator) and a multi-scheme optimization decision. It is suitable for a target system with hierarchically-interlaced evaluation indicators, and the target value is difficult in order to quantitatively describe the decision problem. Of course, the biggest problem of analytic hierarchy process (AHP) is that it is difficult to guarantee the consistency of thinking when there are many evaluation indicators at a certain level (such as more than four). In this case, the Fuzzy Analytic Hierarchy Process (FAHP), which combines the advantages of the Fuzzy Method and the Analytic Hierarchy Process (AHP), can solve this problem well [51]. However, there are only three evaluation indicators in the criterion level of the problem studied in this paper, so the nonfuzzy analytic hierarchy process has been able to get a better evaluation scheme. When using the AHP method to model problems, the following steps are generally required: building a hierarchical model, constructing a judgment (pairwise comparison) matrix, hierarchical single ordering and consistency checking, hierarchical total ordering and consistency checking [52].

The AHP analysis flowchart shown in Figure 4 is established, and then the below six schemes are evaluated based on this.

5.2. Optimal Process

(1) Establish a Hierarchical Structure Model. According to the decision goal of this paper, the target layer is defined as follows: determine an optimal solution. According to the relevant indicators for evaluating the location layout of the

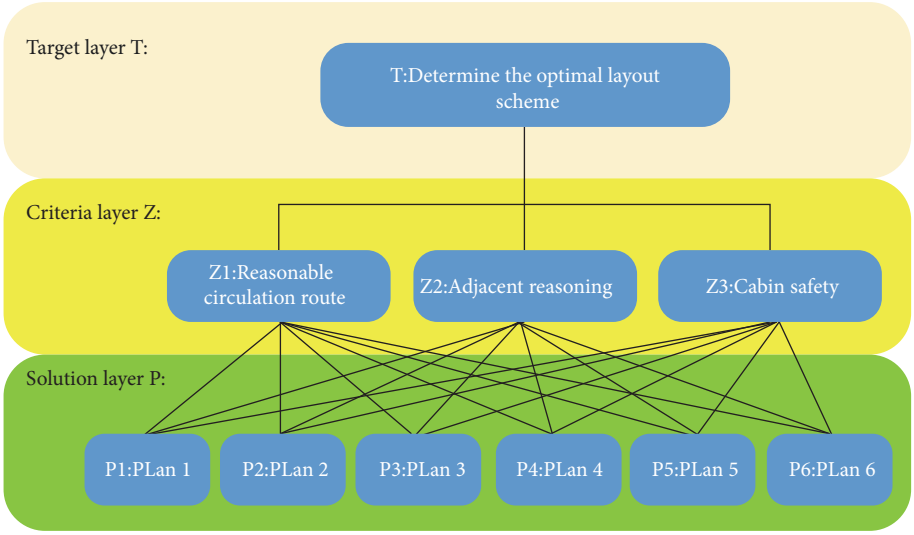

Figure 5: Hierarchy diagram.

cabin equipment, the criterion layer is defined as follows: the reasonable degree of the circulation line (i.e., when the operation route between the equipment in the scheme is lowest and the evacuation path is the shortest, the rationality of the circulation route of the scheme is higher); adjacent to the reasonable degree (i.e., the more the equipment must be in close proximity in the comprehensive correlation provided by the SLP method, the more reasonable the proximity of the scheme is); the safety degree of the cabin (that is, the layout of the scheme should be closer to the weight of the left and right sides, and the better the stability, the higher the safety of the cabin); and the scheme layer is the six schemes for the layout of the cabin equipment. The hierarchical structure is shown in Figure 5.

(2) Establish a Hierarchy of Judgment Matrices. When determining the weight between factors at each level, if it is only a qualitative result, it is often difficult to be accepted by others. The meaning of the judgment matrix is that the target problem is not compared with all the factors, but the two are compared with each other, and the difficulties involved in comparing factors with different properties are compared as much as possible in order to improve accuracy. For example, taking the target layer in Figure 5 (determining the optimal layout scheme) as the standard, it is more important to judge the rationality of the circulation line of the criterion layer and the reasonable degree of the adjacent level. I_{ij} is the result of comparing the importance of element i and element j, and the importance degree is assigned according to Table 9. The matrix formed by the comparison result of two pairs is called the judgment matrix. The judgment matrix has the following properties:

$$I_{ij} = \frac{1}{I_{ji}} \tag{18}$$

Table 9: Proportion criteria table.

Scaling	Factor i ratio factor j
1	Equally important
3	Slightly important
5	Stronger important
7	Strongly important
9	Extremely important
2,4,6,8	Intermediate value of two adjacent judgments

According to the scale value in Table 9, the criteria layer contains three criteria: the reasonable degree of Z1 circulation line, the reasonable degree of Z2 adjacency, and the safety degree of Z3 cabin. The optimal layout scheme is determined relative to the target layer, according to ship engine room design specifications and references [42, 53], and the two points are scored to obtain the judgment matrix of the criterion layer for the target layer.

$$Z_{ij} = \begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{5} \\ 2 & 1 & \frac{1}{3} \\ 5 & 3 & 1 \end{bmatrix} \tag{19}$$

Similarly, establish the decision matrix of the scheme layer for the criterion layer [42, 53]. $P1_{ij}$ indicates the importance of scheme i and scheme j relative to the rationality of the criterion layer circulation line; $P2_{ij}$ indicates the importance of scheme i and scheme j relative to the rationality of the criterion layer; $P3_{ij}$ indicates the importance of scheme i

Table 10: Hierarchical single sort solution results.

Judgment matrix	Z_{ij}	$P1_{ij}$	$P2_{ij}$	$P3_{ij}$
Maximum eigenvalue	3.004	6.489	6.351	6.146
Feature vector	0.122	0.272	0.357	0.252
	0.230	0.228	0.242	0.256
	0.644	0.184	0.103	0.144
		0.109	0.103	0.082
		0.130	0.105	0.171
		0.078	0.091	0.096

and scheme j relative to the safety and reasonableness of the criteria compartment.

$$P1_{ij} = \begin{bmatrix} 1 & 1 & 2 & 3 & 2 & 4 \\ 1 & 1 & 2 & 3 & 1 & 2 \\ \frac{1}{2} & \frac{1}{2} & 1 & 2 & 3 & 2 \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{2} & 1 & 2 & 1 \\ \frac{1}{2} & 1 & \frac{1}{3} & \frac{1}{2} & 1 & 3 \\ \frac{1}{4} & \frac{1}{2} & \frac{1}{2} & 1 & \frac{1}{3} & 1 \end{bmatrix}$$

$$P2_{ij} = \begin{bmatrix} 1 & 2 & 4 & 3 & 5 & 2 \\ \frac{1}{2} & 1 & 2 & 3 & 4 & 2 \\ \frac{1}{4} & \frac{1}{2} & 1 & \frac{1}{2} & 1 & 2 \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{2} & 1 & 2 & 1 \\ \frac{1}{5} & \frac{1}{4} & 1 & \frac{1}{2} & 1 & 3 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & 1 & \frac{1}{3} & 1 \end{bmatrix} \tag{20}$$

$$P3_{ij} = \begin{bmatrix} 1 & 1 & 3 & 3 & 1 & 2 \\ 1 & 1 & 2 & 3 & 2 & 2 \\ \frac{1}{3} & \frac{1}{2} & 1 & 2 & 1 & 2 \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{2} & 1 & \frac{1}{2} & 1 \\ 1 & \frac{1}{2} & 1 & 2 & 1 & 2 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & 1 & \frac{1}{2} & 1 \end{bmatrix}$$

(3) Hierarchical Single Sort. The eigenvector corresponding to the largest eigenvalue $\lambda_{\max}$ of the judgment matrix is normalized (so that the sum of the elements in the vector is equal to 1) and is denoted as ω. The element of ω is the ordering weight of the same level factor for the relative importance of a factor of the previous level factor. This process is called hierarchical single ordering. The normalized vector is set to ω, the weight of each factor. The solution results are shown in Table 10.

Table 11: Average random consistency indicator RI standard value.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45

Table 12: Judgment matrix CR value.

Judgment matrix	Z_{ij}	$P1_{ij}$	$P2_{ij}$	$P3_{ij}$
CR	0.003	0.079	0.057	0.024

(4) Hierarchical Single Sort Consistency Test. Whether it is possible or not to confirm the hierarchical ordering, a consistency check is required. This so-called consistency check refers to determining the allowable inconsistency range for the matrix M. Herein, the unique nonzero eigenvalue of the n-order uniform matrix is n and the largest eigenvalue of the n-th order positive reciprocal matrix is M, if and only if M is a uniform matrix. The definition consistency index CI is

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{21}$$

Considering that the deviation of consistency may be caused by one of any random reason, when testing whether the judgment matrix has satisfactory consistency, it is also necessary to compare the CI with the random consistency index RI to obtain the test coefficient CR, and the formula is as follows:

$$CR = \frac{CI}{RI} \tag{22}$$

Generally, if CR<0.1, the judgment matrix is considered to pass the consistency test; otherwise, there is no satisfactory consistency. The random consistency index RI is related to the order of the judgment matrix and the matrix order is generally larger. The probability of a uniform random deviation is also greater, and the corresponding relationship is shown in Table 11.

Calculate the CR value of each judgment matrix according to the above formula as shown in Table 12.

It can be seen from Table 12 that the CR value of each judgment matrix is less than 0.1, indicating that the judgment matrix established in this paper is correct.

(5) The Total Order of the Hierarchy. Calculating the weight of all factors at a certain level for the relative importance of the highest level (total target) is called the total order of the hierarchy. This process is carried out, in order, from the highest level to the lowest level. The weight of each factor at the bottom is calculated according to the following formula:

$$W_i = \sum_{j=1}^{m} b_j \omega_i \quad (i = 1, 2, \ldots, n) \tag{23}$$

where W_i is the weight of the i-th factor P_i of the solution layer to the target layer factor T. m, n is the number of target layer and criterion layer factors. b_j is the weight of the j-th factor Z_j in the criterion layer to the target layer factor A. ω_i

Table 13: Hierarchical Total Ordering.

Z layer P layer	Z_1 0.122	Z_2 0.230	Z_3 0.644	Z-layer total ordering of target layer P
P_1	0.272	0.357	0.252	0.277
P_2	0.228	0.242	0.256	0.248
P_3	0.184	0.103	0.144	0.138
P_4	0.109	0.103	0.082	0.090
P_5	0.130	0.105	0.171	0.150
P_6	0.078	0.091	0.096	0.092

Table 14: Calculate the required parameter values.

Judgment matrix	Z_1	Z_2	Z_3
CI_j	0.098	0.070	0.029
b_j	0.122	0.230	0.644
RI_j	1.240	1.240	1.240

is the weight of the program layer factor to the criterion layer factor Z_j.

According to the above steps, the weight of each factor in the target layer is as shown in Table 13.

(6) Hierarchical Total Order Consistency Test. First, calculate the CR value according to the following formula:

$$CR = \frac{\left(\sum_{j=1}^{m} CI_j b_j\right)}{\left(\sum_{j=1}^{m} RI_j b_j\right)} \tag{24}$$

The parameter values required to solve the above equation can be obtained as shown in Table 14.

The data in Table 14 should be placed into the above formula in order to obtain the consistency ratio CR=0.038 of the total order of the hierarchy, which is less than 0.1[54].

Based on the above analysis, according to the weights of the six schemes in Table 13, the ranking of the six layout schemes can be obtained as follows: Scheme 1 > Scheme 2 > Scheme 5 > Scheme 3 > Scheme 6 > Scheme 4. Therefore, after the AHP analysis, Scheme 1 is the optimal solution among the six layout schemes.

6. Conclusions

In this paper, the problem of the optimal design of ship cabin equipment layout is solved. The SLP method is used to analyze and determine the comprehensive relationship between each item of equipment. Circulation strength analysis is helpful for designers to choose the most effective layout of machinery and equipment. In addition to the analysis of circulation intensity, it is also important to analyze the route of the staff when they walk in the cabin during their work, to facilitate the work of the staff. These problems are not considered in traditional cabin layout design. At the same time, the genetic algorithm is used to solve the model. Finally, the AHP method is used to evaluate and optimize the scheme and a more suitable layout scheme is obtained. Compared with the simple use of intelligent algorithms, the integrated design method can more accurately quantitative analyze and express the relationship between each device and use it to evaluate the solution produced by the algorithm, which improves the accuracy of the feasible solution to some extent. On the other hand, there are relatively few studies on the application of the SLP method to the layout of cabin equipment. This paper provides some ideas for using this method to optimize the layout of cabin equipment. At the same time, the method of AHP is introduced into the evaluation and selection of equipment layout scheme. The idea is simple and clear, and there is no need to establish complex mathematical model. It is very effective for multiobjective system decision-making, and the quantitative information needed after simplification is simple and easy to be accepted by decision-makers. By analyzing the subjective and fuzzy factors, the system error is reduced and the correctness of the selected layout scheme can be guaranteed to a greater extent. Of course, the comprehensive design method proposed in this text still has some shortcomings in the expression and constraints of the model. Further research and discussion are required in order to further improve the effectiveness of the integrated design method.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Jinghua Li and Hui Guo contributed equally to this work.

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