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Research Article

Influence Factor of Naval Vessel's Equipment under Optimized Sailing Strategy

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A naval vessel is a large and complex weapon system that can be divided into three hierarchical structures: ship-subsystem-equipment. Optimization of the sailing strategy has improved the use of the equipment and thus the success ratio of sailing missions. Still, the contribution of reliability and maintainability of different hierarchical structures to the sailing mission success ratio has not been quantitatively analyzed. To solve this problem, the fundamental principle for optimizing each subsystem is proposed based on mathematical analysis to determine the improvement sequence at the subsystem level; at the equipment level, the reliability maintainability parameters are adjusted to observe the change in the mission success probability, influence factors are calculated as the basis for the improvement of the underlying equipment. In practical engineering applications, technical and economic costs also need to be considered, and difficulty degree is defined. The difficulty degree and influence factor are integrated, and the specific reliability engineering, specific maintainability engineering, and reliability & maintainability integrated engineering are implemented respectively. The improvement sequence of each equipment is determined under the optimized sailing strategy to provide a reference and basis for the implementation of naval equipment improvement projects.

1. Introduction

In the situation of multimilitary-kinds and multiforce coordinated operations, ships performing sailing operations have strict time requirements to arrive at the destination on time; if they arrive early, they will exposure the ship's objectives and operational intentions, and if they arrive late, they cannot achieve the coordinated operational intentions.

About the sailing strategy is currently divided into conventional strategy and optimized strategy. Among them, the conventional mission strategy [1] does not take into account the equipment failure that may arise in the subsequent distance. It assumes that there will always be no mission interruption and ship stop events during the subsequent mission. The calculation of speed is the remaining sailing distance divided by the remaining sailing time. This conventional strategy can make sure that the naval vessel will not arrive at the destination too early, but when the mission interruption or speed reduction event lasts for a long time, it may easily lead to failure to finish the mission at the final time (i.e., not arriving on time) and cause mission failure. Considering this factor, the literature [2] proposed an optimized sailing strategy to improve the mission success probability by establishing a real-time simulation model to predict equipment failure that will occur in the subsequent mission process in real-time and adjusting speed in advance to reduce the probability of not arriving on time.

Mission success probability is one of the criteria to measure equipment effectiveness, and its optimization can effectively improve equipment effectiveness. Through the optimized sailing strategy, the mission success probability is improved and the equipment effectiveness is increased from the perspective of how the system is used. The naval ship, as a large and complex weapon system, has numerous subsystems and affiliated equipment that constitute multiple hierarchies. How do these different hierarchies function in relation to each other, such as how changes in the reliability and maintainability metrics of the underlying equipment affect the mission success probability of the whole ship. The wide variation in reliability and maintainability across equipment causes some equipment to become weak links in the system, and optimizing the equipment on these weak links can achieve the quickest improvement in mission success probability at the least cost. The issue of determining the impact relationships between the hierarchies and describing them quantitatively is worth exploring.

A number of scholars have explored in this field, and the literature [3] used mathematical analysis to determine the rules for improving the availability of naval ship's systems. The literature [4–7] studied the minimum cost allocation scheme under the target system reliability requirements, using genetic algorithms, particle swarm algorithms, and component importance assessment. Yadav and Zhuang [8] allocated failure rate reduction (improvement) targets to subsystems or components, which effectively exploited the potential for improvement. Huang et al. [9] use fuzzy mathematical methods to solve multi-objective system reliability optimization problems. Bhattacharjee et al. [10] investigated the redundancy allocation problem of time-dependent components to optimize system reliability. These above-given literature mostly studies the optimal allocation scheme for system reliability and availability indexes, while the coordinated optimization of different hierarchical structures under mission success indexes is less studied.

This paper analyzes the problem of optimizing the mission success probability of naval equipment and establishes three hierarchies of ship-subsystem-equipment. The contribution of reliability and maintainability of different hierarchies to the ship mission success probability and the coordinated improvement relationship are quantitatively analyzed under the optimized sailing strategy with the ship's sailing mission as the background. It provides a basis for implementing reliability and maintainability improvement projects.

2. Analysis of Ship Sailing Mission and Strategies

When a naval vessel is in a cooperative sailing task, it should not reach too early, or the vessel would expose itself early and be attacked by the enemy; nor can it reach late, or it will miss cooperative combat opportunity. The results of the sailing task are summarized into 4 types.

(1) Mission success (MS).

The ship arrives at its destination at the specified time and the system is available.

(2) Not arriving (NA).

Due to a long stop or system downgrade event, the ship could not reach its destination at the end of the mission. The sailing mission is failed and the simulation process ends early.

(3) Unfinished repair (UR).

Equipment failure causes the ship to be suspended, and repairs are not completed until the end of the mission. The sailing mission is failed.

(4) Fatal Fault (FF).

During the mission, there is a fatal equipment failure that led to a suspension of the sailing, and the mission ends prematurely because the fatal fault could not be repaired.

According to ship sailing mission requirements, the relationship between sailing distance and time can be expressed as Figure 1.

Due to the strict time requirements of the ferry mission, there are different strategies to choose from to perform the ferry mission, currently there are two main strategies, first is the conventional ferry strategy, the conventional is essentially an optimistic assumption of the future. Under the conventional strategy, it is assumed that there will be no ship stoppage in the remaining voyage, and the speed change is always adjusted passively after the repair of stoppage and speed reduction events are completed.

We assume that $T_{\max}$ is total time, $S_{\max}$ is total distance, S_t is the cumulative distance, and $v_{\mathrm{p,min}}$ is the ship minimum plan speed, and the calculation is in the following equation:

$$v_{\mathrm{p,min}} = \frac{S_{\max} - S_t}{T_{\max} - t}. \tag{1}$$

That is the conventional strategy (here named strategy A). Under the conventional one, $v_{\mathrm{p}}^{\mathrm{A}} = v_{\mathrm{p,min}}$. The superiority is that naval vessel will not expose itself due to arriving early under strategy A. If the ship stops too long before the ending, the vessel cannot reach its destination on time. Thus, an optimized strategy [2] is proposed (named strategy B).

The optimized strategy builds a virtual ship model. During mission, virtual ship anticipates the ship stop and speed reduction events by real-time simulation. The possible stop time and down speed time are subtracted in advance when calculating the speed under the optimized strategy. Set the possible ship stop time is MT_F and speed reduction is MT_D. Simulation time consumed by virtual ship is Δtime. θ_k is output coefficient of the propulsion subsystem which limits the maximum speed of the ship. The plan speed in optimized strategy is

$$v_{\mathrm{p}}^{\mathrm{B}} = \begin{cases} \dfrac{S_{\max} - S_t}{T_{\max} - t - \left[MT_F + \sum_{k=1}^{n-1} MT_{D,k} \cdot \left(1 - \theta_k\right)\right] \cdot \left[\left(T_{\max} - t\right)/\left(T_{\max} - t + \Delta\mathrm{time}\right)\right]}, & S_t < S_{\mathrm{TH}}, \\ \left(S_{\max} - S_t\right)/\left(T_{\max} - t\right), & S_t \geq S_{\mathrm{TH}}. \end{cases} \tag{2}$$

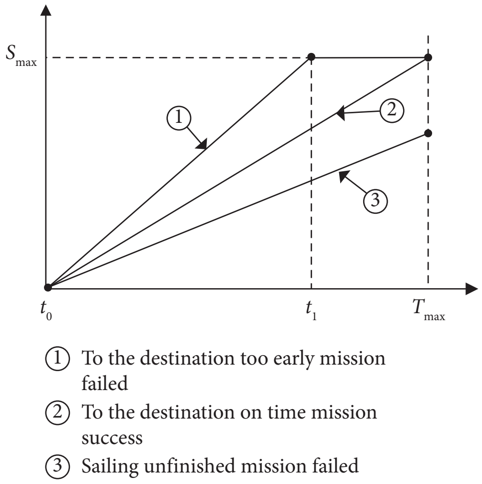


FIGURE 1: The relationship between sailing distance and time.

The real ship would not trigger the virtual model after it reaches S_{TH}. Because if it continues to predict may lead to early arrival.

3. Improvement Principles and Definition of Influence Factors

The fundamental goal of equipment (e.g., naval vessel) is to perform a variety of missions in a timely, reliable, and effective manner. This means being available when needed (availability A), reliable during the mission (dependability D), and sufficiently capable during the execution of the mission (capability C). The U.S. Industry Weapon Systems Effectiveness Advisory Council's effectiveness evaluation model, WSEIAC (also known as the ADC model) [11, 12]. The calculation is shown in the following equation:

$$E = A \times D \times C. \tag{3}$$

Therefore, when the equipment is performing missions, the premise of the conventional combat capability is the availability of its components and the reliability & maintainability of equipment are fully guaranteed, and these factors will together support the conventional capability of the equipment.

Large-scale weapon systems usually have a complex hierarchical structure. Taking a ship as an example, if the ship is considered as a whole, it can include three levels: ship-subsystem-device, as shown in Figure 2.

For a typical naval vessel, which is composed of several subsystems [3], the mission success probability D for the whole ship is expressed as follows:

$$D = D_1 \times D_2 \times \cdots \times D_n. \tag{4}$$

Assuming $D_1 < D_2 < \cdots < D_n$, we set $D_1 \longrightarrow D_1 + \delta d$, $D_2 \longrightarrow D_2 + \delta d, \ldots, D_n \longrightarrow D_n + \delta d$, It is known that when $D_1 \longrightarrow D_1 + \delta d$, there is $D + \delta D = (D_1 + \delta d)\ D_2 \cdots D_n = D_1 D_2 \cdots D_n + \delta d D_2 D_3 \cdots D_n$.

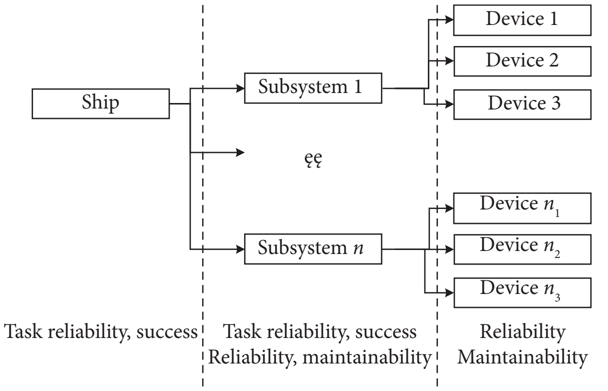


FIGURE 2: Ship equipment hierarchy.

By the same token, we have $D + \delta D = D_1 (D_2 + \delta d) D_3 \cdots D_n = D_1 D_2 \cdots D_n + \delta d D_1 D_3 \cdots D_n$ when $D_2 \longrightarrow D_2 + \delta d$.

When $D_n \longrightarrow D_n + \delta d$, there is $D + \delta D = D_1 D_2 \cdots (D_n + \delta d) = D_1 D_2 \cdots D_n + \delta d D_1 D_2 \cdots D_{n-1}$.

Since $D_1 < D_2 < \cdots < D_n$, a comparison of the above equation yields $\delta d D_2 D_3 \cdots D_n > \delta d D_1 D_3 \cdots D_n > \cdots > \delta d D_1 D_2 \cdots D_{n-1}$. Therefore, the principle of improvement at the subsystem level can be obtained, i.e., prioritizing the subsystem with the lowest mission success probability can make the overall mission success probability rise the fastest.

In turn, for the subsystem D_i, which is composed of equipment, it can be expressed as the following mapping:

$$\begin{aligned} D_i &= f\left(D_{i,1}, D_{i,2}, \ldots, D_{i,n}\right), \\ D_i' - D_i &= f\left(D_{i,1}, D_{i,2}, \ldots, D_{i,n}\right). \end{aligned} \tag{5}$$

The mission success probability of the device is determined by its reliability and maintainability. Since the mission success is determined by the dynamic operation of the device during the mission, taking into account the power output and status of the system, and combined with the mission criterion for a comprehensive determination. Therefore, there is a complex mapping relationship between the mission success probability of the equipment and the $R\&M$ parameters, expressed as follows:

$$D_{i,j} = g_{i,j}\left(R_{i,j}, M_{i,j}\right). \tag{6}$$

$R_{i,1}$ indicates the reliability of the equipment and $M_{i,1}$ indicates the maintainability of the equipment.

$$D_i = f\left(g_{i,1}\left(R_{i,1}, M_{i,1}\right), g_{i,2}\left(R_{i,2}, M_{i,2}\right), \cdots, g_{i,n}\left(R_{i,n}, M_{i,n}\right)\right). \tag{7}$$

Based on the above-given analysis, this paper defines the impact factor as follows. Under the optimized sailing strategy, the value obtained by dividing the increase in mission success probability by the increase in reliability or maintainability index after improving the reliability or maintainability parameters of the equipment and making certain corrections is the influence factor of the equipment.

The calculation is shown in the following equation:

$$\mathrm{IF}_{i,j} = \frac{\Delta D_i/D_i}{\Delta R_{i,j}/R_{i,j}} \times 10^2. \tag{8}$$

That is, the impact of equipment *R&M* parameters on the ship's mission success probability, and the equipment with a large influence factor is prioritized for improvement. The above-mentioned is the influence factor algorithm for the reliability special project of the equipment, and the same algorithm for solving the influence factor for the maintainability special project of the equipment.

If the *R&M* parameters are adjusted simultaneously to perform a comprehensive reliability and maintainability improvement project, the influence factor is

$$\mathrm{IF}_{i,j} = \left[\frac{\Delta D_i}{D_i} \cdot \frac{1}{\left(1 + \Delta R_{i,j}\right) \cdot \left(1 + \Delta M_{i,j}\right) - 1}\right] \times 10^2. \tag{9}$$

4. Case Study

For simplicity, the ship's power and electrical subsystems were modeled as an example, and the reliability parameters (MTBF) and maintainability parameters (MTTR) [1] of the equipment belonging to the ship's power and electrical subsystems were taken in the range shown in Table 1 after reviewing the data, researching and investigating, and declassifying.

The reliability block diagram of equipment is constructed as Figure 3.

Gas turbines and diesel have four states, working-3, degradation-2, failure-1, and unrepairable failure-0. Diesel generator set, reduction equipment, propellers, and shaft have three states, working-2, failure-1, and unrepairable failure-0. Monitoring and auxiliary device have two states, working-2, and failure-1.

The power output of the gas turbine and diesel engine is in Table 2.

Set initial simulation parameters, $T_{\max} = 200\mathrm{h}$, $S_{\max} = 4500\mathrm{nm}$, $v_{\max} = 35\mathrm{kn}$, the threshold for changing plan speed calculation under strategy B $S_{\mathrm{TH}} = 0.95 \cdot S_{\max}$, trigger interval for virtual ship $T_{\mathrm{TH}} = T_{\max}/20$, total simulation times 10^5. Using this as the standard case, the subsequent equipment influence factor calculation is based on this parameter, and the simulation result is in Table 3.

Since $D_{\mathrm{propulsion}} < D_{\mathrm{power}}$ according to the conclusion it is known that improving the propulsion subsystem first can improve the mission success probability most quickly.

Special reliability engineering is implemented for the equipment to determine the influence factor of each subsystem equipment on the mission success probability, and the improvement process is shown as follows:

(1) Determine the system mission success probability target value D_t according to the mission requirements.

(2) Calculate the initial value D of the current mission success probability of the system.

(3) Calculate $\Delta D = D_t - D$. If $\Delta D > 0$ or $\Delta D < 0$ but $|\Delta D| < \varepsilon$, go to step 4. If not, improvement is completed. ε indicates the allowable error.

(4) Increase the reliability parameters of the device by 50%, respectively and calculate the task success rate, followed by the device impact factor IF.

(5) Evaluate the equipment improvement difficulty degree β.

(6) Integrate the equipment improvement order according to the impact factor IF and difficulty degree β.

(7) Perform improvements in order according to the integrated ranking calculated in step 6. After each improvement, go to step 3 until $\Delta D < 0$ and $|\Delta D| \geq \varepsilon$. If the target task success rate is still not reached after all the equipment has completed the reliability special improvement works, then carry out the maintenance special works improvement.

The repairability improvement process is the same as the reliability improvement process. The improvement process is shown in Figure 4.

Based on the standard case, a special reliability improvement project was implemented for the underlying equipment to improve the reliability index of the equipment by 20% in turn, and the influence factor was calculated, and the results are in Table 4.

In Table 4, the gas turbine has the largest impact factor of 3.221, followed by the diesel engine of 1.246. In fact, a preliminary analysis of the reliability parameters of the equipment, MTBF = 1250 h for the gas turbine and MTBF = 2000 h for the diesel engine, can also be expected to improve the mission success probability most for these two devices, but it is not possible to calculate quantitatively the proportional relationship between the two devices. The influence factor can be quantified to provide a more accurate scientific basis for the implementation of the improvement project.

In the process of equipment index optimization and improvement, it is also necessary to consider the engineering technical difficulty and economic cost, which is quantified in this paper using the difficulty coefficient β_{ij}, where $0 < \beta_{ij} \leq 1$. The difficulty coefficient of each equipment index improvement is determined comprehensively by expert survey method and hierarchical analysis method, etc. The difficulty degree β is used to determine the influence factor weights and the weighted improvement order. Since the higher the difficulty degree, the lower the improvement order is, $\mathrm{IF}\,(1 - \beta_{ij})$ is used as the weighted influence factor and reranked. It should be noted that if some equipment can no longer improve reliability and maintainability parameters under existing technical conditions or is extremely difficult, then the equipment can be obtained with $\beta_{ij} = 1$, which means that there is no need to improve the equipment either. The weighted influence factor $\mathrm{IF}\,(1 - 1) = 0$ is calculated and the order of improvement is the last one, which corresponds to the results of the analysis.

Table 1: Range for equipment reliability and maintainability.

Subsystem	Equipment	Degradation (h)	Repairable fault (h)	Fatal fault (h)	Repair (h)
Propulsion subsystem	Gas turbine	1,250~1,600	1,250~1,600	12,500~16,000	32~21
	Diesel engine	2,000~2,400	2,000~2,400	20,000~24,000	8~6
	Gearbox	—	7,500~10,500	75,000~105,000	10~7
	Shaft	—	10 000~13 000	100,000~130,000	12~9
	Propeller	—	10,000~13,000	100,000~130,000	12~9
	Auxiliary & Monitoring device	—	5,000~7,500	—	2~1.5
Electrical power subsystem	Diesel generator	—	2,000~2,500	20,000	40~35
	Power monitoring device	—	10,000~12,500	—	2~1.5
	Front main distribution board	—	5,000~6,500	50,000~65,000	15~12
	Rear main distribution board	—	5,000~6,500	50 000~65,000	15~12

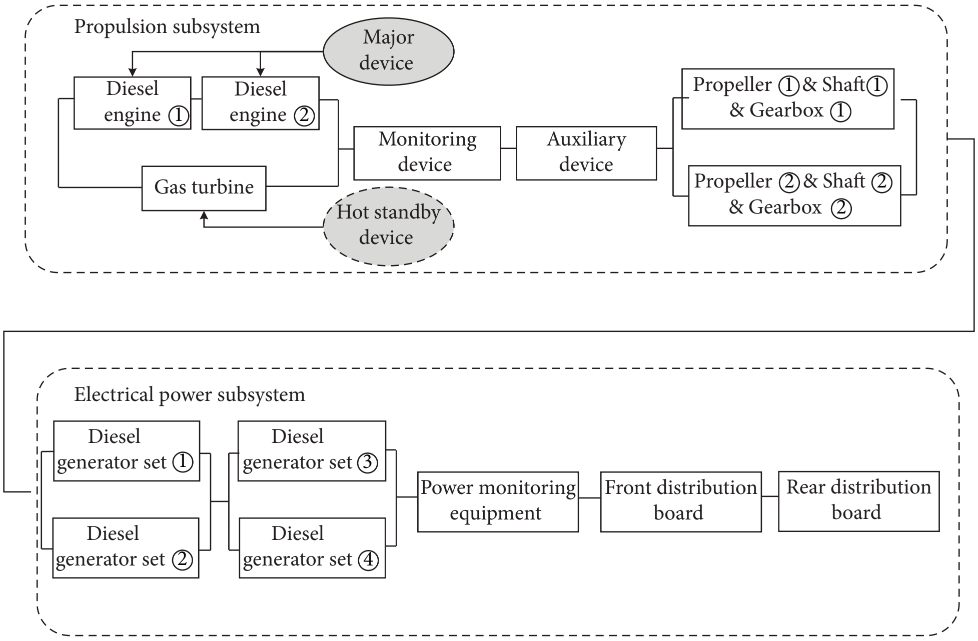


Figure 3: Reliability block diagram.

Table 2: Diesel and gas turbine power output.

Gas turbine status	Diesel engine ① status	Diesel engine ② status	Propulsion subsystem power output coefficient θ (%)
3	3	≥2	100.00
3	≥2	3	100.00
≥2	3	3	100.00
2	3	2	60.00
2	2	3	60.00
0&1	2	3	60.00
0&1	3	2	60.00
0&1	3	3	60.00
3	0&1	3	60.00
3	3	0&1	60.00
3	≤2	≤2	60.00
	Others combinations		0.00

Table 3: Standard case analysis.

Hierarchy	Simulation times	MS	NA	UR	FF
Ship	100000	0.90283	0.07917	0.00971	0.00829
Propulsion subsystem	100000	0.92671	0.07078	0.00221	0.00030
Electrical power subsystem	100000	0.97151	0.01256	0.00784	0.00809

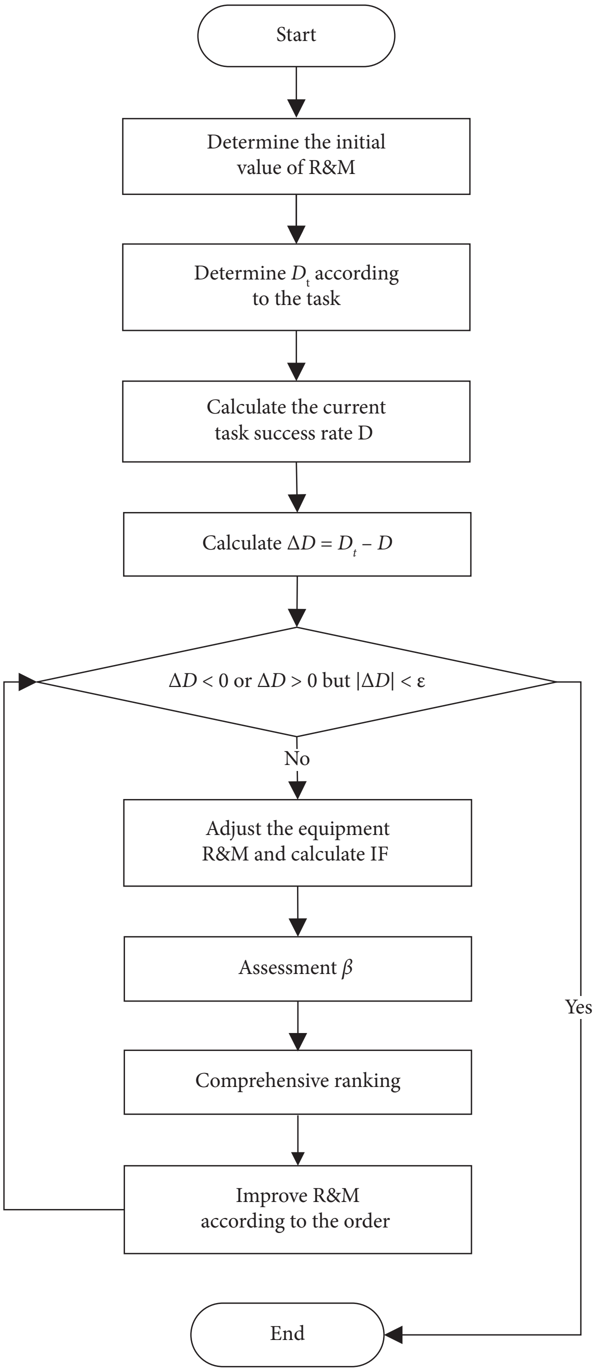


Figure 4: Flow chart of equipment optimization and improvement.

The reliability impact factors of the equipment are ranked in Table 5.

In Table 5, for the propulsion subsystem, the gas turbine has the highest influence factor when not weighted, followed by the diesel engine, and the ranking result is also consistent with the lower MTBF of the two devices, which are given priority in the improvement. However, after considering the difficulty degree β, it makes the order of reduction gear take priority over these two devices. As shown in Figure 5.

The biggest influence factor in the electrical power subsystem is the front and rear main distribution boards. Although the diesel generator sets are not highly reliable, they have a higher risk resistance and improve system reliability due to the existence of the parallel structure, so the influence factor of the diesel generator sets is lower. The front and rear main distribution boards do not have high reliability because of the nonexistence of a parallel structure, so this part has a higher influence on the mission success probability.

The maintenance-specific engineering was implemented for the equipment, and the maintenance impact factor of the equipment was calculated and ranked with the difficulty degree β. The calculation process was consistent with the reliability-specific engineering, and the result is in Table 6.

In addition to implementing the above two reliability and maintainability-specific projects, a combined reliability and maintainability project can also be implemented, i.e., the *R&M* parameters of the equipment can be improved simultaneously and the mission success impact factor of the equipment can be calculated. The result is in Table 7.

By deriving the influence factors under the above-given three improvement approaches, then there are three strategies for optimizing the mission success probability.

(1) First *R* then *M*, i.e., implement the reliability-specific engineering first, and then implement the maintenance-specific engineering if the target mission success probability cannot be achieved

(2) M first, then *R*, i.e., implement maintenance-specific engineering first, and then implement reliability-specific engineering if the target mission success probability cannot be achieved

(3) *R&M* at the same time, i.e., implement reliability and maintainability integrated engineering, and improve the *R&M* parameters of the equipment one by one in order until the target mission success probability is achieved

According to the typical case in Section 3, the initial task success rate D is 0.90283, and if the target value is set as $D_t = 0.92$, the optimization is implemented according to the above three strategies, respectively, and the optimization result is in Table 8.

The results in Table 8 are represented using a radar plot, as shown in Figures 6–11.

Figures 6 and 7 show the optimization results of the special reliability improvement project for the propulsion and power subsystems. In order to reach the target task success probability, all equipment in the propulsion subsystem needed to be optimized and the upper limit was reached. From Figure 7, the fold of the optimized values in the propulsion subsystem has all covered the upper MTBF limit.

The target mission success probability is finally achieved after the electrical power subsystem optimized one front main distribution board. A total of 7 types of equipment are optimized to achieve the target success rate.

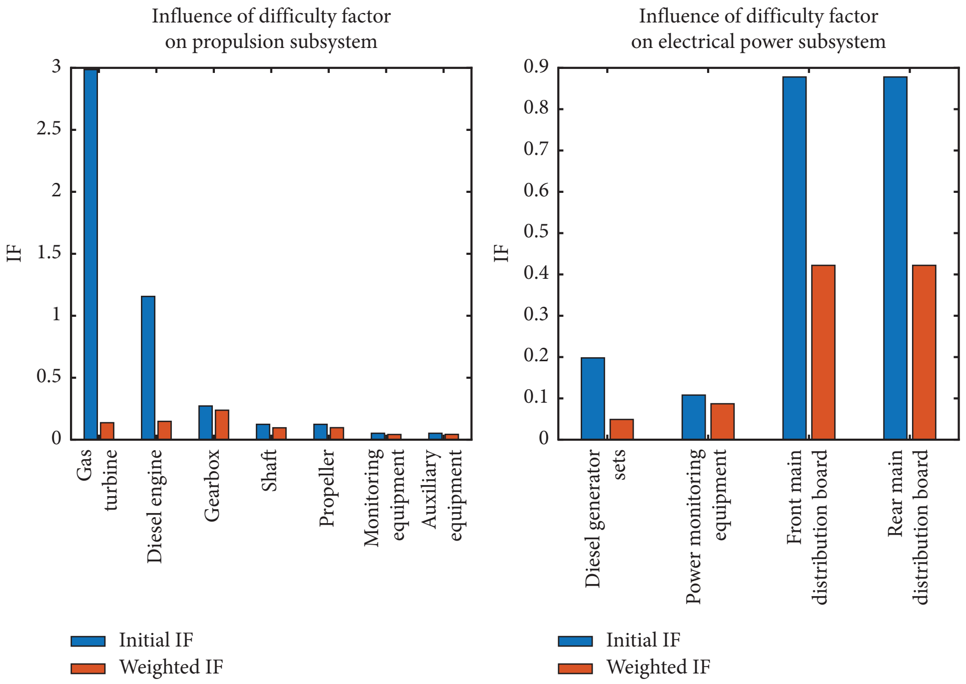
Figures 8 and 9 show the optimization results of the maintainability-specific improvement engineering for the propulsion and power subsystems. 7 types of equipment in

Table 4: Influence factors of special engineering for equipment reliability.

Subsystem	Equipment	ΔR	D	D'	ΔD	IF
Propulsion subsystem	Gas turbine	+20%	0.92671	0.93268	0.00597	3.221
	Diesel engine	+20%		0.92902	0.00231	1.246
	Gearbox device	+20%		0.92725	0.00054	0.291
	Auxiliary device	+20%		0.92681	0.00010	0.054
	Shaft	+20%		0.92695	0.00024	0.129
	Monitoring device	+20%		0.92681	0.00010	0.054
	Propeller	+20%		0.92695	0.00024	0.129
Electrical power subsystem	Diesel generator sets	+20%	0.97151	0.97191	0.00040	0.206
	Power monitoring device	+20%		0.97173	0.00022	0.113
	Front main distribution board	+20%		0.97327	0.00176	0.906
	Rear main distribution board	+20%		0.97327	0.00176	0.906

Table 5: Improvement order of equipment reliability special projects.

Subsystem	Equipment	IF	Subsystem order	β	Weighted IF	Weighted order
Propulsion subsystem	Gas turbine	3.221	1	0.954	0.148	3
	Diesel engine	1.246		0.872	0.159	2
	Gearbox device	0.291		0.125	0.255	1
	Monitoring device	0.054		0.194	0.044	7
	Shaft	0.129		0.221	0.100	4
	Propeller	0.129		0.213	0.102	5
	Auxiliary device	0.054		0.166	0.045	6
Electrical power subsystem	Diesel generator sets	0.206	2	0.753	0.051	3
	Power monitoring equipment	0.113		0.195	0.091	2
	Front distribution board	0.906		0.519	0.436	1
	Rear distribution board	0.906		0.519	0.436	1


Influence of difficulty factor on propulsion subsystem

Influence of difficulty factor on electrical power subsystem

Figure 5: Influence of difficulty degree on the order of equipment improvement in each subsystem.

Table 6: Improvement order of equipment maintenance special works.

Subsystem	Equipment	IF	Subsystem order	β	Weighted IF	Weighted order
Propulsion subsystem	Gas turbine	3.038	1	0.944	0.170	6
	Diesel engine	0.523		0.852	0.077	7
	Monitoring device	0.394		0.198	0.316	2
	Propeller	0.297		0.217	0.233	4
	Shaft	0.297		0.235	0.227	5
	Auxiliary device	0.394		0.174	0.325	1
	Gearbox device	0.281		0.135	0.243	3
Electrical power subsystem	Diesel generator sets	0.196	2	0.789	0.041	3
	Power monitoring device	0.087		0.186	0.071	2
	Front distribution board	0.818		0.498	0.411	1
	Rear distribution board	0.818		0.498	0.411	1

Table 7: Improvement order of comprehensive reliability and maintainability improvement engineering.

Subsystem	Equipment	IF	Reliability β	Maintain-ability β	Weighted difficulty factor	Weighted IF	Weighted order
Propulsion subsystem	Gas turbine	3.674	0.954	0.944	0.949	0.187	1
	Diesel engine	1.144	0.872	0.852	0.862	0.158	2
	Shaft	0.201	0.221	0.235	0.228	0.155	3
	Propeller	0.201	0.213	0.217	0.215	0.158	2
	Auxiliary device	0.042	0.166	0.174	0.170	0.035	4
	Gearbox device	0.215	0.125	0.135	0.130	0.187	1
	Monitoring device	0.042	0.194	0.198	0.196	0.034	5
Electrical power subsystem	Diesel generator sets	0.202	0.753	0.789	0.771	0.046	3
	Power monitoring device	0.114	0.195	0.186	0.191	0.092	2
	Front distribution board	1.088	0.519	0.498	0.509	0.534	1
	Rear distribution board	1.088	0.519	0.498	0.509	0.534	1

Table 8: Optimization results of each equipment index.

Order	Strategy one		Strategy two		Strategy three		
	Equipment	R	Equipment	M	Equipment	R	M
1	Gearbox device	10,500	Auxiliary device	1.5	Gearbox	10,500	6
2	Diesel engine	2,400	Monitoring device	1.5	Gas turbine	1,600	18
3	Gas turbine	1,600	Gearbox device	6	Shaft	13,000	8
4	Propeller	10,300	Shaft	8	Diesel engine	2,150	7
5	Shaft	10,300	Propeller	8			
6	Auxiliary device	7,500	Gas turbine	18			
7	Monitoring device	7,500	Diesel engine	5			
8	Front distribution board	6,000	Front distribution board	10			
9			Rear distribution board	10			
10			Diesel generator sets	36			
D'	0.92080	0.92124	0.92156				

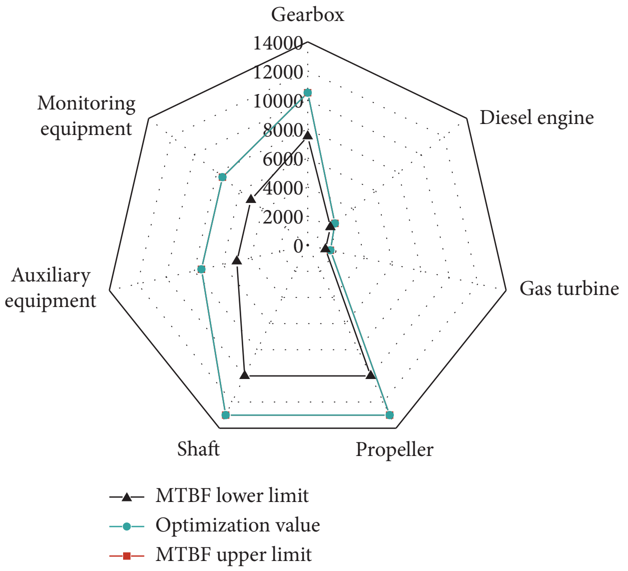


Figure 6: Propulsion subsystem reliability optimization results.

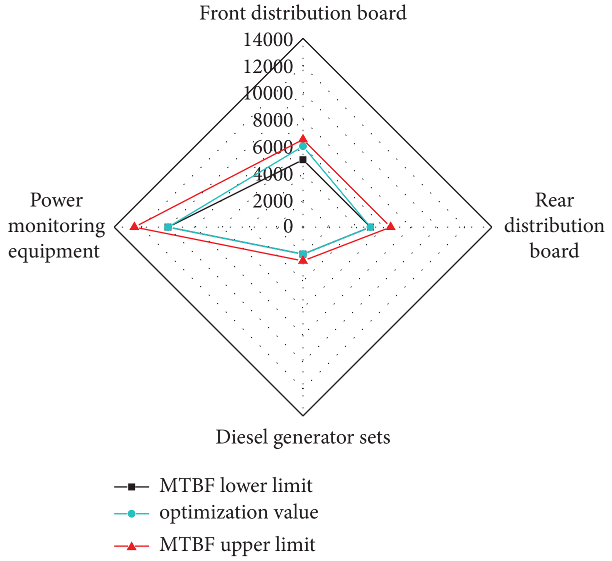


Figure 7: Electrical power subsystem reliability optimization results.

the propulsion subsystem need to be optimized and the maintainability parameters are optimized to the lower limit. The power subsystem requires the optimization of 3 types of equipment, including the front main switchboard, the rear main switchboard, and the diesel generator set.

In the comprehensive reliability and maintainability improvement engineering, the number of equipment to be improved is significantly reduced, and only four types of equipment in the propulsion subsystem need to be improved to achieve the target mission success probability. The reliability and maintainability parameters of gearbox, gas turbine, and shaft need to be improved to the optimal value, and the MTBF of the diesel engine is 2150 h and MTTR is 7 h, which can make the mission success probability increase to 0.92156.

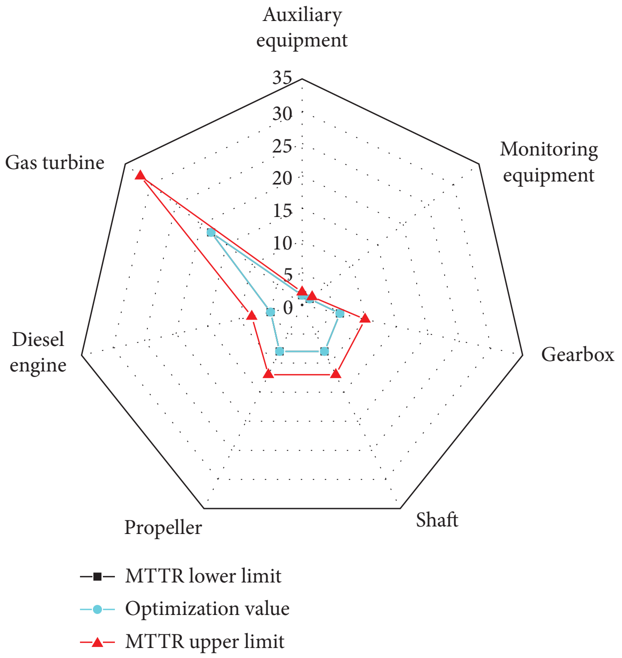


Figure 8: Propulsion subsystem maintainability optimization results.

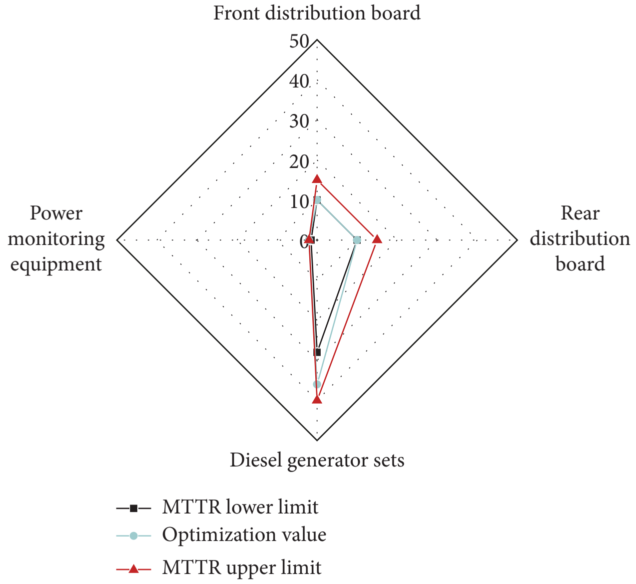


Figure 9: Electrical power subsystem maintainability optimization results.

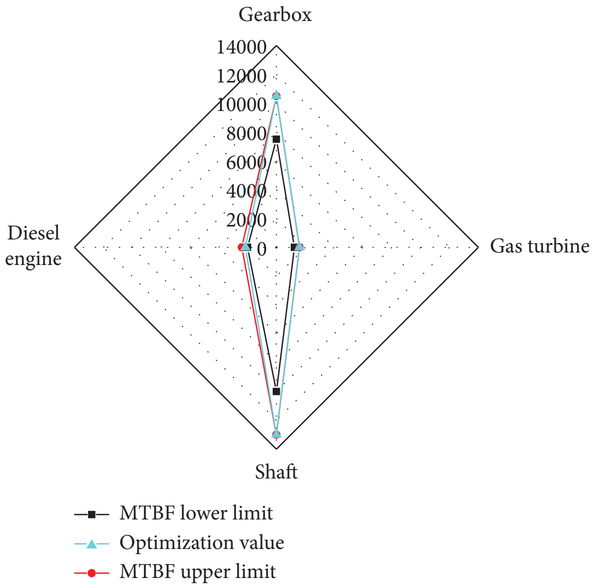


Figure 10: Reliability optimization value of comprehensive improvement engineering.

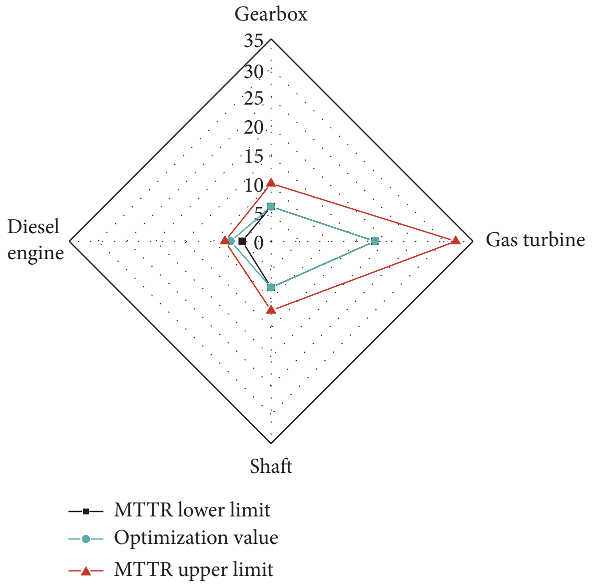


Figure 11: Maintainability optimization value of comprehensive improvement engineering.

5. Conclusion

Set the backdrop of a naval vessel sailing mission, the principle of coordination and optimization among multiple hierarchies of ship equipment is determined under the optimized sailing strategy. Firstly, three hierarchies of the ship-subsystem-equipment are constructed, and the improvement principle is derived at the subsystem level through mathematical derivation, i.e., the lower the mission success probability of the subsystem, the higher the improvement priority; at the equipment level, based on typical cases, the influence factor of each equipment on the ship mission success probability under the optimized sailing strategy is calculated by adjusting the reliability R and maintainability M parameters of the equipment one by one, i.e., the higher the factor, the higher the improvement priority. The technical difficulty and economic cost of improving the $R\&M$ parameters in actual engineering are also considered to determine the improvement order of the equipment comprehensively. And, for the characteristics of reliability engineering and maintainability engineering, three improvement strategies are established to provide a basis for implementing ship equipment reliability and maintainability improvement engineering. The research in this paper is currently conducted only in the context of naval equipment and will be extended to more complex systems equipment in subsequent studies.

Data Availability

The MATLAB code used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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