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An Evaluation of the Engine-Room Resources Based on the Analytic Hierarchy Process Approach

Ji An[1], Yun Liu[1], Dongdong Du[2], Tingchen Wang[1], Runze Liu[1], Ling Fang[1], Yujie Sun[3], Chen Liu[3]

[1]Merchant Marine College, Shanghai Maritime University, Shanghai, China
[2]Wu Song Maritime Safety Administration, Shanghai, China
[3]Yangshan Port Maritime Safety Administration, Shanghai, China
Email: anji@shmtu.edu.cn, 18368094768@163.com, sameul_du@163.com, 949881530@qq.com, runzy@126.com, lingfang@shmtu.edu.cn, sunyujie@shmsa.gov.cn, liuchen@shmsa.gov.cn

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Abstract

The resources in the engine room are comprised of many factors, meanwhile, numerous factors affecting these resources. All of these factors are necessarily simplified and hierarchized so that the studies or practice on the engine-room resource management (ERM) have clear priorities. As such, the analytic hierarchy process (AHP) was utilized as the study technique for this purpose. Five categories of resources in the engine room were specified as top criteria. These resources include personnel resources, consumable resources, information resources, equipment resources, and environmental resources. Twenty-two sub-criteria were identified in accordance with the five resources of the ERM. The ERM principles such as assertiveness and leadership were considered as sub-criteria for personnel resources. The sub-criteria were ranked by using a 1 - 9 Saaty scale. Results revealed that personnel resources were the most important resources in the ERM, followed by equipment resources, information resources, environmental resources, and consumable resources. And assertiveness and leadership were the most important factor in the personnel resources, followed by consideration of team experience, effective communication, obtaining and maintaining situational awareness, planning and time management, and allocation, assignment, and prioritization of resources. The findings imply that personnel resources are of vital importance in the ERM. Due to the significance of assertiveness and leadership in personnel resources, it is recommended that the non-technical skills of seafarers ought to be taken into account in seafarer training and ship resource management.

Keywords

Engine-Room Resource Management, Analytic Hierarchy Process, Personnel Resources, Assertiveness, Leadership

1. Introduction

Engine room resources are comprised of numerous factors, and apparently we cannot treat them as important as equally. It is necessary for manager in the engine-room resource management (ERM) to analyze engine room resources in terms of relative importance as well as relationship between each other. At this insight, the hierarchy analysis towards engine room resources is the core objective of this paper.

As an extensively adopted management method, ERM dedicates to achieve marine vehicle's effective operation by effectively utilizing and managing personnel resources, consumable resources, information resources, equipment resources and environmental resources in the engine-room [1]. To further prevent the merchant shipping accidents caused by the human factor, ERM was listed in the Manila Amendment to the International Convention on Standards of Training, Certification, and Watch-keeping (STCW) for Seafarers as part A for mandatory requirements by International Maritime Organization (IMO) [2]. Since the ERM had been upgraded as mandatory requirements of STCW, the shipping industry has great responsibilities to make certain the elaborated requirements of ERM.

The STCW 2010 requirements regarding ERM principally comprised with five key concerns, which are effective communication, allocation, assignment, and prioritization of resources, obtaining and maintaining situational awareness, consideration of team experience, and assertiveness and leadership [3]. Plenty of factors composing engine room resources, and we cannot treat these factors equally as they play different roles in ERM. It is thus necessary for the manager in the ERM to analyze the priority of engine room resources in terms of relative importance as well as the relationship between each other. In this way, the references are provided for crew training regarding ERM. More importantly, the shipping industry will thereby determine the focus of ERM and make corresponding measures for improvement in the efficacy of the ERM.

This study aims to assess engine room resources to decide a clear priority between these resources. The analytic hierarchy process (AHP) method is utilized for providing a ranking and prioritization weights of engine-room resources. Section 2 presents the technical background of AHP and its related application in literature. Section 3 interprets the method we proposed. Section 4 provides the results and demonstrates its implication with a discussion. Section 5 ends with a conclusion.

2. A Literature Review of AHP

As a multi-criteria decision making (MCDM) problems solving method, the AHP technique was first proposed by Saaty [4]. The method aims to obtain comparative weights for each element of a systematic hierarchy structure bases on several criteria. The hierarchical structure comprises of top and sub-criteria would be constructed by composing pairwise comparisons of individual judgments. And the comparative importance of the decision for sub-criteria is determined by adopting the pairwise comparison. The AHP method consists of three parts [5]: organizing and dividing the complex problems into a hierarchy; evaluating the comparative importance of the factors at every single level of the hierarchy; synthesizing relative importance of the factor in the hierarchy and determining a ranking and the prioritization weights of decision alternatives.

Because the AHP approach is competent to solve complicated decision-making problems with both subjective and objective evaluations methods, it has been so far applied in a wide range of decision problems, such as supplier selecting [6] [7], the human settlement [8], respiratory protection program [9], hospital site selection [10], measuring the sustainability of cities [11], etc. Owing to easy to use and simplicity, the AHP has been studied abundantly and widely applied in nearly all applications related to MCDM by integrating other methods such as quality function deployment (QFD), factor analysis (FA), fuzzy set theory, goal programming (GP), genetic algorithm (GA), and so on.

The AHP method has been successfully used in a number of MCDM applications. For instance, M.C. Carnero [12] performed modeling of decision making for selecting the instrumentations and diagnostic techniques in the predictive maintenance programs combine using FA and AHP. Another study on MCDM applications was conducted by Dweiri and Al-Oqla [13] for material selection. In this study, the authors used AHP to decide a material for a product by means of Expert Choice software. Likewise, Sachdeva *et al.* [14] had provided a multi-criteria failure mode analysis for a paper mill to determine the most suitable maintenance strategy by using AHP. Also, Meddaoui and Bouami [15] proposed to select a proper maintenance strategy for the heavy industry by utilizing the AHP technique.

Apart from applying in MCDM situations among shore-based sphere, AHP have been caught sight of personnel who work on maritime field due to its unique strength in evaluating different criteria. For instance, Wu *et al.* [1] proposed a developed quantitative performance evaluation method for ERM. In this method, AHP was utilized to construct evaluation criteria through surveying to collection opinions of experts who was proficient in one aspect of ERM. Likewise, in order to evaluate maritime labor convention requirements at the operational level, Akyuz *et al.* [16] integrated AHP and balanced scorecard (BSC) to design an evaluation model and this model was applied successfully in the evaluation process. Given the study on AHP utilization in the maritime field is deficient and the advantage of AHP in resolving MCDM problems, we first attempt to adopt the AHP technique to evaluate several resources in the ERM.

The purpose of this study was to decide the priority of engine room resources.

Since there are multiple factors constituting every single engine room resource, we must set the priority of engine room resources according to the importance weights of these factors. In other words, several important factors composing every single resource of five engine room resources are equivalent to multiple criterions, which determines the eventual priority of five engine room resources. Stated another way, this paper attempts to assess several resources in the engine room, sub-resources of which were taken into evaluation criterions. Therefore, the evaluation of engine room resources can be considered as an MCDM problem. As previously noted, since the AHP approach has been applied successfully in solving MCDM problems, the AHP method is thus employed to assess a ranking of engine room resources in this study.

3. Method

A flow chart for our method is shown in **Figure 1**. First of all, a hierarchy structure of the ERM will be built to form a questionnaire which is comprised of pairwise comparison matrixes. After that, participants' understanding and judgments about the ERM are obtained through the completion of the table. The priority weight of every engine-room resource and its consistency will be determined by applying the AHP approach. Finally, a final result will be concluded after checking the participants' opinions for consistency. A detailed description of proposed method can be stated as follows:

Step 1. Building a hierarchy structure model by five categories of engine-room resources. A hierarchy structure model is built according to five categories resources of engine-room [1]: personnel resources (B_1), equipment resources (B_2), consumable resources (B_3), information resources (B_4), and environmental resources (B_5).

Step 2. Establishing pairwise comparison matrices: a relative importance scale suggested by Saaty [17] is used to compose pairwise comparison matrices of criteria. As indicated in **Table 1**, the numbers 1, 3, 5, 7 and 9 in the scale 1 - 9 of the AHP stands for "equally important", "moderately important", "strongly important", "demonstrably important", and "extremely important". The remaining numbers which belong to intermediate values are applied only if the compromise is required.

Each criterion $a_{ij}\left(i, j = 1, 2, 3, \cdots, n\right)$ in matrix A represents the comparative

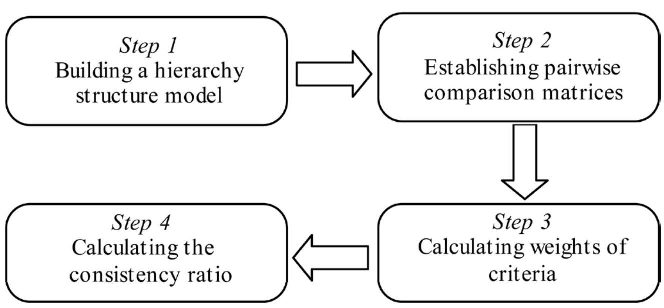

Figure 1. Flow chart of the proposed method.

Table 1. Comparative importance scaling of AHP.

Scales	Definition
1	Equally important
3	Moderately important
5	Strongly important
7	Demonstrably important
9	Extremely important

importance of ith elements with comparison to the jth elements. Namely, a higher value of a_{ij} means a stronger priority of criteria a_i over a_j. Amongst, $a_{ij} = 1$ when $a_{ji} = 1/a_{ij}$ and $i = j$.

$$A = \left(a_{ij}\right)_{n \times n} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

$$a_{ij} > 0; a_{ij} = 1/a_{ji}; a_{ij} = 1$$

Step 3. Calculating weights of criteria: Equation (2) can be used to calculate the priority weights of every criterion ($w_1, w_2, w_3, \cdots, w_j$).

$$w_i = \frac{1}{n} \sum\nolimits_{j=1}^{n} \frac{a_{ij}}{\sum\nolimits_{k=1}^{n} a_{kj}} \tag{2}$$

Step 4. Calculating the consistency ratio (CR): To do the consistency test and provide consistency of data, Saaty [17] proposed consistency index (CI) to check whether the judgments on every single pairwise as well as the whole hierarchy is consistent or not. CI can be computed as follows:

$$\text{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{3}$$

where $\lambda_{\max}$ is the maximum eigenvalue of the matrix, n denotes the dimension of the matrix. In order to calculate the $\lambda_{\max}$, Vargas [18] suggested an equation as follow:

$$\lambda_{\max} = \frac{\sum\nolimits_{j=1}^{n} a_{ij} w_j}{w_i} \tag{4}$$

Then, CR is computed to decide satisfactory consistency. In order to obtain an acceptable consistency, the CR value should be smaller than 0.1. The following equation is used to calculate CR:

$$\text{CR} = \frac{\text{CI}}{\text{RI}} \tag{5}$$

Table 2 presents the random index (RI) values. The CR should be equal to or

Table 2. Random index values.

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

less than 10% for being considering a reasonable consistency level of the matrix.

3.1. Sample and Data

To realize the proposed method, survey based on brainstorming meetings which aims to collect data for the study was conducted. Initially, survey questionnaires were sent to relevant personals, including experts, engine room resource managers, and human resource managers of shipping companies. Thereafter, the purpose and procedures of the survey were explained appropriately. Following which, discussions by the way of brainstorming sessions were performed. The discussions principally revolve around the comparison of five engine room resources and sub-criteria such as ERM principles. Participants were asked to give judgment concerning the comparison of each element in the comparison matrix established by their views. Finally, survey results were received.

In this survey, a total of 80 questionnaires were issued. 76 questionnaires were received, for a response rate of 95%. After 2 ineligible questionnaires were left out, 74 usable samples were obtained, yielding an eligible rate of 92.5%.

3.2. Determining Sub-Hierarchy Evaluation Criteria

Personnel resources in the engine room indicate all the manual and non-manual workers available in the engine-room, which includes engineers, master mechanic, oilers, coppersmith, and cadets, etc. Allocation, assignment, and prioritization of resources refer to resources are assembled and distributed as required in appropriately priority for achieving optimal job performance. When seafarers perform tasks, it is necessary for them to make a priority on the resources which influence their working arrangement. Under these circumstances, considering some factors such as safety is necessary for them to make proper decisions. At this insight, allocation, assignment, and prioritization of resources is one of the sub-criteria for personnel resources.

Seafarer is the occupation whose schedule is regular. In term of work arrangements, the crewmembers in the engine room should make elaborated working plans in order to ensure the work assignments finish as efficiently as possible. Given the necessity of planning and the characteristics of the schedule for seafarers, planning and time management was considered as one of sub-criteria for personnel resources.

Hetherington *et al.* [19] argued that communication is one of the essential skills of particular importance for performance and safe in all high-risk industries. Especially, multi-national, multi-cultural crews communicated in pronouncedly different ways when they work together in a ship. Crews from diverse nations in the ship may be not able to communicate properly and precisely with each other as a result of race, culture, and religion differences. It is of note that the effect of a problem caused by communication on crewmembers that come from different regions is conspicuous. These problems include confusing communication, communication barriers, alienation, and discrimination, which may result in safety incidents on board if not to be properly resolved. There are various difficulties for intercultural communication and the significance of effective communication is therefore highlight. IMO [20] proclaimed that all the seafarers in the ship should be capable of using one common language, English in particular, so that the communication between each other is unambiguous, and message can be transmitted on consistently successful. Therefore, effective communication was also selected to be one of the sub-criteria for personnel resources.

Consideration of team experience in the ERM in general means all members of the engine room share experience of a precise comprehension of concurrent associated systems state, and predict external environment in order to carry out assignments safely and efficiently. From this, consideration of team experience was chosen as a sub-criterion of personnel resources.

According to Endsley's point of view [21], situation awareness is the perception of various factors in specific situations or environments, understanding the meaning of the situation and the projections regarding how the situation develops. Grech *et al.* [22] pointed out that from 1987 to 2000, 71% of 177 maritime accidents as a result of human error in the ship operations reports on eight different countries can be ascribed to situation awareness. It is seen that obtaining and maintaining situational awareness is paramount for seafarers to achieve safe watch-keeping and navigation. Thus, we think that obtaining and maintaining situational awareness can be classified as sub-criteria of personnel resources.

Assertiveness refers to a kind of psychological state which enables a person to communicate equally and authentically with others without infringing on the legitimate interests of the others. It is often imperative for a seafarer to be assertive within the engine room. Namely, when made a judgment concerning safe navigation, a seafarer has to assert his judgment without any hesitation, irrespective of his rank or station within the ship. In particular, in emergency times, after in-depth consideration, a seafarer who is responsible at that moment has to assert his decision without compromising stances.

It is perhaps no surprise that leadership is an important skill for ERM. By researching on airline crews, Ginnett [23] posited that more effective leaders in the plane (e.g., captains) played a positive role in the work involving the whole group of crew and addressing task requirements. Situations sometimes arise in the engine room are fairly alike with those on an airplane. It may be thought that every single member of the ERM is a leader under some specific conditions at the time they manage engine room resources. Meanwhile, seafarers will work by their leader and carry out assignments as instructed. Overall, good leadership can be conducive to motivate seafarers to higher performance. To sum up, assertiveness and leadership was identified as another sub-criterion for personnel resources.

Therefore, top criteria personnel resources (B_1) in the ERM can be argued to consist of six sub-criteria: allocation, assignment, and prioritization of resources (C_{11}), planning and time management (C_{12}), effective communication (C_{13}), consideration of team experience (C_{14}), obtaining and maintaining situational awareness (C_{15}), and assertiveness and leadership (C_{16}).

Equipment resources refer to all of installations, machinery and instruments on shipboard, encompassing auxiliary device, main propulsion device, emergency equipment, anti-pollution equipment, deck machinery, and piping system. In this sense, sub-criteria for equipment resources (B_2) are main propulsion device (C_{21}), auxiliary device (C_{22}), emergency equipment (C_{23}), deck machinery (C_{24}), anti-pollution equipment (C_{25}), and piping system (C_{26}). Consumable resources are a generic term of all such resources which include oils, water resources, supplies, spare parts, and tools. Hence, marine oil supplies (C_{31}), marine freshwater resources (C_{32}), spare parts material supply (C_{33}), and labor insurance tool rationing (C_{34}) are considered as four sub-criteria for consumable resources (B_3).

Information resources (B_4) are all the information in the ship including all the used documents such as company, ship and departmental regulations. In this paper, we specified international and domestic laws (C_{41}), company, ship and departmental regulations (C_{42}), and engine-room organization and procedures (C_{43}) as three sub-criteria for information resources. Ship navigation environment and seafarer working conditions are environmental resources (B_5). At this insight, engine-room environment (C_{51}), sailing environment (C_{52}), and natural meteorological environment (C_{53}) were specified as sub-criteria for environmental resources.

The number of 22 sub-resources was determined based on the five categories of resources in the ERM. As shown in **Table 3**, while six sub-criteria are used and evaluated for personnel resources (B_1) and equipment resources (B_2), consumable resources (B_3) are evaluated by the four sub-criteria. Besides, the information resources (B_4) and environmental resources (B_5) are both assessed by the three sub-criteria.

3.3. Constructing Pairwise Comparison Matrix

After the engine room resources were further categorized, pairwise comparison matrices of criteria are composed by means of a comparative importance scale which expresses comparisons numerically. The survey results derived from different respondents were transformed into numeric data.

First of all, top criteria (five resources of ERM) were compared. Every single participant was required to decide the importance level of each criterion according to a relative importance scale. The comparison results are shown in **Table 4**.

After comparing the five engine room resources, a pairwise comparison matrix for each sub-criterion was composed. **Table 5** illustrates a comparison matrix for personnel resources (B_1). **Tables 6-9** present the comparison matrixes for equipment resources (B_2), consumable resources (B_3), information resources (B_4) and environmental resources (B_5), respectively.

Table 3. Sub-criteria for five resources of the ERM.

Top criteria	Sub-criteria
Personnel resources (B_1)	Allocation, assignment, and prioritization of resources (C_{11})
	Planning and time Management (C_{12})
	Effective communication (C_{13})
	Consideration of team experience (C_{14})
	Obtaining and maintaining situational awareness (C_{15})
	Assertiveness and leadership (C_{16})
Equipment resources (B_2)	Main propulsion device (C_{21})
	Auxiliary device (C_{22})
	Emergency equipment (C_{23})
	Deck machinery (C_{24})
	Anti-pollution equipment (C_{25})
	Piping system (C_{26})
Consumable resources (B_3)	Marine oil supplies (C_{31})
	Marine freshwater resources (C_{32})
	Spare parts material supply (C_{33})
	Labor insurance tool rationing (C_{34})
Information resources (B_4)	International and domestic laws (C_{41})
	Company, ship and departmental regulations (C_{42})
	Engine-room organization and procedures (C_{43})
Environmental resources (B_5)	Engine-room environment (C_{51})
	Sailing environment (C_{52})
	Natural meteorological environment (C_{53})

Table 4. Comparison matrix of top criteria.

	B_1	B_2	B_3	B_4	B_5
B_1	1	4	9	8	7
B_2	1/4	1	7	3	5
B_3	1/9	1/7	1	1/4	1/2
B_4	1/8	1/3	4	1	3
B_5	1/7	1/5	2	1/3	1

Table 5. Comparison matrix for personnel resources.

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}
C_{11}	1	1	1/4	1/3	1/2	1/7
C_{12}	1	1	1/2	1/4	1/3	1/6
C_{13}	4	2	1	1	2	1/5
C_{14}	3	4	1	1	3	1/3
C_{15}	2	3	1/2	1/3	1	1/2
C_{16}	7	6	5	3	2	1

Table 6. Comparison matrix for equipment resources.

	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}
C_{21}	1	7	9	7	8	7
C_{22}	1/7	1	5	5	6	3
C_{23}	1/9	1/5	1	2	3	1
C_{24}	1/7	1/5	1/2	1	2	1
C_{25}	1/8	1/6	1/3	1/2	1	1/2
C_{26}	1/7	1/3	1	1	2	1

Table 7. Comparison matrix for consumable resources.

	C_{31}	C_{32}	C_{33}	C_{34}
C_{31}	1	3	2	3
C_{32}	1/3	1	1	2
C_{33}	1/2	1	1	2
C_{34}	1/3	1/2	1/2	1

Table 8. Comparison matrix for information resources.

	C_{41}	C_{42}	C_{43}
C_{41}	1	5	2
C_{42}	1/5	1	1/3
C_{43}	1/2	3	1

Table 9. Comparison matrix for environmental resources.

	C_{51}	C_{52}	C_{53}
C_{51}	1	3	7
C_{52}	1/3	1	5
C_{53}	1/7	1/5	1

3.4. Calculating Criteria Weights

After establishing the comparison matrix, the priority weights of each criterion were computed by using Equation (2). The priority weights of the top criteria are shown in Table 10. Table 11 displays the priority weights of sub-criteria for every resource.

3.5. Calculating Criteria Weights

The consistency of the matrix was verified for the sake of checking the consistency level of judgments in the pairwise comparison. Equations (3)-(5) can be used to calculate the CR of matrixes. As a result, Table 12 illustrates the CR for top criteria and sub-criteria.

From Table 12, we can find that all data converted into matrix are seen as having satisfactory consistency level owing to CR is less than 0.1.

Table 10. Priority weights of top criteria.

Engine room resources	Priority weight
B_1	0.5645
B_2	0.2369
B_3	0.0355
B_4	0.1073
B_5	0.0558

Table 11. Priority weights of sub-criteria for each resource.

		Priority weight
Personnel resources (B_1)	Allocation, assignment, and prioritization of resources (C_{11})	0.0548
	Planning and time management (C_{12})	0.0562
	Effective communication (C_{13})	0.1563
	Consideration of team experience (C_{14})	0.1948
	Obtaining and maintaining situational awareness (C_{15})	0.1147
	Assertiveness and leadership (C_{16})	0.4232
Equipment resources (B_2)	Main propulsion device (C_{21})	0.5570
	Auxiliary device (C_{22})	0.2066
	Emergency equipment (C_{23})	0.0738
	Deck machinery (C_{24})	0.0571
	Anti-pollution equipment (C_{25})	0.0358
	Piping system (C_{26})	0.0697
Consumable resources (B_3)	Marine oil supplies (C_{31})	0.4577
	Marine freshwater resources (C_{32})	0.2007
	Spare parts material supply (C_{33})	0.2222
	Labor insurance tool rationing (C_{34})	0.1194
Information resources (B_4)	International and domestic laws and regulations (C_{41})	0.5815
	Company, ship and departmental regulations (C_{42})	0.1095
	Engine-room organization and procedures (C_{43})	0.3090
Environmental resources (B_5)	Engine-room environment (C_{51})	0.6490
	Sailing environment (C_{52})	0.2791
	Natural meteorological environment (C_{53})	0.0719

Table 12. Consistency ratio for top criteria and sub criteria.

	CR
Engine room resources (Top criteria)	0.0619
Personnel resources (Sub-criteria)	0.0520
Equipment resources (Sub-criteria)	0.0669
Consumable resources (Sub-criteria)	0.0170
Information resources (Sub-criteria)	0.0032
Environmental resources (Sub-criteria)	0.0559

4. Results and Discussion

The results of the overall internal and global ranking are shown in Table 13. As shown in Table 13, assertiveness and leadership (C_{16}) is the most crucial factor in terms of ERM principles as its internal priority weight is highest. Moreover, consideration of team experience (C_{14}) can be viewed as the most important element, which is followed by effective communication (C_{13}), obtaining and maintaining situational awareness (C_{15}), and planning and time management (C_{12}). Furthermore, allocation, assignment, and prioritization of resources (C_{11}) are obtained as the least significant factor for the ERM principles. It seemly means that the actualization of C_{11} depends on other ERM principles' successful proceeding.

From the perspective of internal ranking, C_{16} is the most superior sub-factor for personnel resources and C_{14} follows it. It is of note that the priority weight of

Table 13. Overall performance result of evaluation.

Top criteria	Priority weight	Global ranking	Consistency ratio (CR)	Sub-criteria	Internal priority weight	Internal ranking	Global priority weight	Global ranking
Personnel resources	0.5645	1	0.0520	C_{11}	0.0548	5	0.0309	11
				C_{12}	0.0562	6	0.0317	10
				C_{13}	0.1563	3	0.0882	4
				C_{14}	0.1948	2	0.1101	3
				C_{15}	0.1147	4	0.0647	5
				C_{16}	0.4232	1	0.2389	1
Equipment resources	0.2369	2	0.0669	C_{21}	0.5570	1	0.1320	2
				C_{22}	0.2066	2	0.0489	7
				C_{23}	0.0738	3	0.0175	12
				C_{24}	0.0571	5	0.0135	16
				C_{25}	0.0358	6	0.0085	18
				C_{26}	0.0697	4	0.0165	13
Consumable resources	0.0355	5	0.0170	C_{31}	0.4577	1	0.0162	14
				C_{32}	0.2007	3	0.0072	20
				C_{33}	0.2222	2	0.0079	19
				C_{34}	0.1194	4	0.0042	21
Information resources	0.1073	3	0.0032	C_{41}	0.5815	1	0.0624	6
				C_{42}	0.1095	3	0.0332	9
				C_{43}	0.3090	2	0.0117	17
Environmental resources	0.0558	4	0.0559	C_{51}	0.6490	1	0.0362	8
				C_{52}	0.2791	2	0.0156	15
				C_{53}	0.0719	3	0.0040	22

C_{16} is much more than that of C_{14}. This result suggested to us that assertiveness and leadership plays a significantly important role in the personnel resources of the ERM. As Horberry *et al.* [24] pinpointed, many shipwrecks caused by human errors were found correlated with seafarer poor psychological quality such as low in assertiveness. Likewise, Ginnett [23] noted in his research that leader effective behaviors exert a proactive impact in addressing the interactions required on group work. As leaders in the engine-room, the chief engineer and the second engineer leader behavior impose great influence on ordinary seafarers. Furthermore, seafarers' psychological capital such as assertiveness can impose great influence on ordinary working assignments. Based on literature and results analysis, we argued that assertiveness and leadership are irreplaceable factors in the ERM. And assertiveness and leadership have to be borne in mind when cultivating and training seafarers.

Thereafter, for equipment resources, C_{21} is indicted to be the most crucial sub-factor, and C_{22} follows it. It indicates that the main propulsion and auxiliary machine device have incredible importance in the ERM from managers' standpoint. Understandably, the main propulsion device and auxiliary machine device constitutes the main body of the engine room in terms of hardware apparatus, the role of which is salient. Amongst, main propulsion device is much more important than other sub-criteria of B_2, which can be derived from priority weight in **Table 11**.

In information resources, C_{41} can be observed as the most significant sub-factor, followed by C_{43} and C_{42}, respectively. It shows that laws and regulations have remarkable significance for managers in the ERM. Generally speaking, the objective of the ERM is to make the efficacy of the engine room maintain a rational level, so that the ship's safe navigation is warranted. On the other hand, the management of engine room resources must conform to relevant laws and regulations, so the laws and regulations related to ERM are also caught attention in daily work in the engine room. Consumable resources are considered to be the least superior factor, in which C_{31} can be obtained to be the most important sub-factor as its internal priority weight is highest. C_{33} follows it as the second crucial sub-factor. Lastly, C_{51} is observed to be the most significant sub-factor in environmental resources, followed by C_{52} and C_{53}, respectively. As workplace where seafarers perform management assignments, engine room environment directly exert influence on seafarers by a number of ways. It enlightens us that change engine room environment better is an urgent task which in need of struggle from the whole shipping industry.

From the perspective of global ranking, C_{16} is found to be the most important sub-criteria while C_{21} follows it as the second superior factor among the 22 criteria. This result reveals that assertiveness and leadership is an essential and key factor in the ERM, and therefore should be received enough attention from the shipping industry. Moreover, C_{53} can be found to be the least important sub-factor, and C_{34} follows it among all the factors. This finding suggested that the natural meteorological environment will no more an extremely crucial factor affecting ERM.

5. Practical Implications

The findings demonstrate that personnel resources are the most important resource in the ERM. Namely, it implies that the sub-criteria of personnel resources such as effective communication, assertiveness and leadership, consideration of team experience, obtaining and maintaining situational awareness play an overwhelmingly important role in the ERM. Hence, it is extremely significant that the training regarding non-technical skills should be conducted on seafarers intentionally. The second most important resource is the equipment resources, which demonstrates the comparative importance of the equipment within the ERM. And it means that main propulsion device, auxiliary device, emergency equipment, deck machinery, anti-pollution equipment, and piping system are important equipment which should be treated in earnest for the ordinary management in the engine room. In addition, the findings also indicate that consideration of team experience is another important principle of ERM from the point of managers and experts. It reminds us that when seafarers work in the engine room, keep close communication with colleagues and pay attention to changes in the surroundings is pretty necessary.

ERM is one of the principal topics in STCW 2010. Despite there are a large number of requirements in maritime regulations, the potential impact of the ERM are very profound and far-reaching. The ERM not only contributes to safe navigation for the ships but also provides training guidelines for seafarers. Thus, the ERM is considered as the necessary instrument which will be the pillar of ship resource management. Our results indicated that personnel resources were the most important resources in the ERM. In this sense, the shipping industry should struggle to put the ERM requirements regarding personnel resources into practice. Moreover, it was observed that assertiveness and leadership was the most important factor in personnel resources. Hence, crew training concerning non-technical skills should be promptly and effectively put into action by maritime administrators and ship management companies.

6. Limitation and Future Direction

There are several limitations to this study. Firstly, a limited number of sub-criteria were used in this study, which means further potential alternatives were not taken into account. Some potentially significant factors affecting engine room resources evaluation were not included in the analysis. For example, team building plays an important role in ERM. However, we only include engine room resource principles and time management in personnel resources (B_1) and did not evaluate team building. Likewise, other top criteria may also neglect some further sub-criteria. Secondly, a relatively small number of participants in this study mean that sample and data used in this study are not enough to deduce results that can be generalized. Therefore, we recommend that, in future research, further sub-criteria should be included in case that a more accurate result is achieved. Furthermore, a relatively large-scaled sample is advocated to attain by selecting from the state-own shipping company and private shipping company. Also of note, although AHP we adopted in this study is commonly regarded as an available methodological tool for solving MCDM problems, other methods (e.g., fuzzy logic) are strongly recommended to combine with AHP for obtaining more precise results.

7. Conclusions

This study aims to assess all kinds of resources in the ERM. To this end, a method based on the AHP technique is adopted. A comprehensive survey was conducted, and priority weight of resources in the engine room was provided by the AHP technique. The study demonstrated that personnel resources were the most important resources in the ERM. Furthermore, assertiveness and leadership, as one of the ERM principles, was the most important factor in personnel resources. In sum, it was concluded that personnel resources undoubtedly play a considerately crucial role in the ERM. And the significance of ERM principles for managers is salient.

Based upon the results of this study, it is recommended that, in the ERM, the managers such as chief engineer should attach importance to personnel resources. Put differently, seafarers as the subject in the ERM, whose role is noteworthy. Furthermore, ERM principles, especially assertiveness and leadership should be kept in mind when seafarer training institutions evaluate seafarers. In view of the amount of time been spent in the ERM, training is limited and short at present, whereas the amount of training content regarding ERM is large in accordance with STCW 2010 [25], we suggested that presently the training focus of ERM should be transfer to personnel resources. We hope our work will shed some lights on seafarer training and evaluation regarding ERM and the improvement in the efficacy of the ERM.

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Conflicts of Interest

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

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