A Hierarchical Competency Model for Decision Support in Seafarer Selection *

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Abstract

This paper presents a hierarchical competency model developed as part of an information technology framework to enhance decision support in seafarer selection within crewing companies. The proposed approach addresses the challenges of maritime recruitment by introducing a formalized and adaptive methodology for candidate evaluation under uncertainty. At the core of the framework lies the position profile model, which defines an ideal seafarer profile through a hierarchy of competency groups—professional, technical and navigational, managerial, personal, and psychophysical. Each group incorporates a structured set of weighted criteria determined by experts according to their significance and evaluation ranges. The Analytic Hierarchy Process (AHP) is applied to establish the priorities among criteria, while a qualitative–quantitative evaluation scale converts expert judgments into normalized values between 0 and 1. The proposed framework supports systematic, transparent, and adaptive decision-making by integrating compliance with international maritime standards and considering critical human factors such as stress resilience, physical endurance, and motivational stability. Validation using a case study for a passenger vessel captain demonstrates that the model enhances objectivity, increases evaluation reliability, and accelerates decision-making in personnel selection. The research outcomes confirm the model's potential as a core component of decision support systems (DSS) for intelligent and data-driven management of maritime human resources.

Keywords

hierarchical competency model, decision support system, seafarer selection, maritime personnel, crewing company, analytic hierarchy process , multi-criteria evaluation, stress resilience, adaptive decision-making, stress resilience.

1. Introduction

The global economy relies heavily on maritime transportation, which accounts for nearly 80% of international trade volume and remains the core element of global logistics networks. This dominance stems from the capacity of ships to carry vast quantities of goods over long distances at relatively low costs. The dependence on maritime transport continually generates a high demand for qualified seafarers and support personnel capable of ensuring the efficiency and safety of maritime operations [4]. Consequently, increasing academic attention has been directed toward understanding the work and role of seafarers in global shipping [10].

In recent decades, the intensification of international trade and the restructuring of logistics chains have considerably increased the complexity of requirements for maritime personnel. Beyond traditional navigational and technical skills, modern seafarers must demonstrate advanced technological proficiency, safety awareness, and the ability to work effectively within culturally diverse crews – competencies that have become strategic assets for shipping companies [9]. Within this context, maintaining the quality of crew selection emerges as a crucial factor for crewing

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companies that recruit and evaluate maritime specialists on behalf of shipowners [7]. The efficiency of these processes directly affects operational performance and client satisfaction. As emphasized in [8], the implementation of systematic personnel management practices in crewing companies contributes to their organizational sustainability, confirming the need for a comprehensive approach to recruiting, developing, and retaining seafarers.

At the same time, the crew selection process in crewing companies remains complex and multi-staged, involving the verification of qualifications, experience, and psychological readiness of candidates. Studies reveal that this process demands significant managerial and expert involvement, diverting resources from strategic tasks and increasing administrative costs [7]. Moreover, traditional selection techniques often fail to exploit the potential of modern digital personnel management technologies, which promote flexibility and improve the objectivity and effectiveness of evaluation outcomes.

Given these challenges, the advancement of computerized tools for seafarer search and selection has become an urgent necessity. Human–machine decision-making technologies, in particular, provide a rational balance between formalized and expert-based procedures. By applying logical and mathematical methods under conditions of uncertainty and dynamic data variability, such technologies enhance decision support, optimize personnel selection, and ensure adaptive management processes in crewing companies.

2. Research background and motivation

Existing theoretical and applied research on personnel selection, along with implemented computer-based recruitment systems, demonstrates a predominant reliance on multi-criteria decision-making (MCDM) approaches [1, 3, 5, 7, 12]. These studies apply various mathematical methods to evaluate candidates according to multiple weighted factors. For instance, the Profile Matching method [1] compares each candidate's competencies with those of an "ideal" profile, identifying competency gaps. In contrast, the Weighted Product method [3] uses exponential weight coefficients to aggregate criteria, allowing both positive and negative attributes to be reflected in the overall evaluation. The range of evaluation criteria differs across studies: [1] focuses on general and specialized skills, while [3] incorporates additional indicators such as work experience, GPA, and interview performance. Meanwhile, [12] employs a fuzzy expert system, enabling the assessment of qualitative characteristics and improving flexibility under conditions of uncertainty by adapting criteria to specific vacancies.

The findings of these studies collectively indicate that shifting toward information technology–based approaches – particularly those leveraging decision support systems – can substantially improve personnel selection processes in crewing companies. Such companies often operate under conditions of poorly structured decision-making and incomplete data certainty, where expert knowledge and formal models must be effectively integrated. Moreover, research [11] shows that seafarer performance depends not only on technical qualifications but also on broader factors such as job attitude, loyalty, remuneration, and career development opportunities. Therefore, models for maritime personnel selection must account for these multidimensional influences. Developing such systems requires not only methodological rigor and empirical grounding but also careful adaptation to the specific operational characteristics of crewing activities.

A review of existing approaches has revealed several limitations and challenges ("pain points") that constrain their direct application in the crewing industry [1, 3, 5, 12]:

- Insufficient consideration of maritime-specific factors. Most personnel selection methods emphasize general indicators – education, work experience, and interview results – while overlooking critical maritime competencies such as navigation system proficiency, stress resilience, and physical endurance. These aspects are essential for effective work under shipboard conditions and must be incorporated into the evaluation framework.

- Limited adaptability to rapid crew rotation. Due to the short-term nature of contracts, crewing companies frequently need to replace personnel on short notice. However, many existing methods require recalculating weight coefficients and conducting full-scale analyses for each candidate, making them too time-consuming for real-world operations.
- Inadequate consideration of loyalty and repeat employment. Retaining experienced and reliable seafarers is a key goal for crewing companies, yet most models fail to account for loyalty indicators or performance history across previous contracts.
- Insufficient integration of international standards and certifications. Seafarers must comply with mandatory certifications such as STCW, but current systems do not automatically verify or assess these credentials, complicating candidate evaluation.
- Neglect of psychological assessment. Life at sea requires exceptional stress tolerance and adaptability to isolation, yet psychological and behavioral factors are rarely incorporated into existing selection algorithms.

To address these gaps, some recent studies have introduced more specialized models. For example, [7] proposed a dynamic model that evaluates candidates based on current competencies and investment in skill enhancement, offering insights into future professional growth. Nevertheless, this approach does not fully account for short-term contracts or the psychophysical aspects of candidates, and it heavily depends on the completeness and accuracy of input data – particularly problematic for newcomers without prior experience. Similarly, [2] applied the Fuzzy AHP method for selecting seafarers on tanker vessels, combining technical, educational, and psychological criteria. While this reduced uncertainty and improved precision, it did not address the issues of rapid personnel turnover, seafarer loyalty, or the need for dynamic system adaptation in high-rotation environments.

3. Research Problem and Objectives

The primary aim of this study is to enhance the computer-based tools used for searching and selecting maritime personnel in crewing companies. This objective is pursued by addressing a range of challenges that directly affect the efficiency, consistency, and reliability of personnel selection outcomes.

The proposed research focuses on the development of an information technology (IT) framework built upon the modern capabilities of decision support systems. The framework integrates the processes of candidate evaluation and selection into a structured technological environment that formalizes procedures, defines their sequence, and establishes clear rules for decision-making. It also identifies responsible actors, models, and evaluation methods to ensure the systematic organization of complex, poorly structured processes characteristic of crewing operations.

The design of this technology, developed with consideration of the operational and regulatory specifics of crewing companies, is guided by the following principles.

Development of a human–machine expert evaluation system based on the established DSS model base. Ensuring systemic consistency between formalization tools, mathematical models, and the procedures for obtaining expert information from decision-makers (DMs), clients, and specialists designated by company management (HR and personnel security departments). Application of qualitative analysis methods with interpretation in quantitative dimensions to facilitate structured evaluation. Use of a fuzzy inquiry framework for assessing qualitative criteria under uncertainty, enabling structured representation of expert judgments. Integration of position profiles into the candidate selection process, providing a hierarchical, multi-level, and flexible description of client requirements that includes professional, navigational, psychological, and physical competencies relevant to specific voyages.

Formalization of dynamic decision-making adaptation mechanisms to accommodate frequent crew rotations and situational variability. Incorporation of compliance verification processes for international maritime standards and certifications. Enhancement of expert evaluation tools to improve the reliability and reproducibility of qualitative assessments. Development of multi-level evaluation scales combining qualitative and quantitative metrics to measure candidate conformity with position profile requirements as an ideal point of multi-criteria analysis. Provision of alternative evaluation pathways and methods, allowing the system to adjust to real operational contexts and the dynamic characteristics of candidate data over time.

Based on these principles, the study develops a comprehensive framework for implementing the DSS-based information technology. This framework defines the structure of the model base, its interconnections with the processes of candidate search, selection, and evaluation, as well as the methods applied at each stage. Most of the models and methods incorporated in this research build upon the authors' earlier theoretical and experimental work, the results of which have been adapted and refined for the specific needs of the crewing industry. Supporting references to these studies are summarized in Table 1.

Table 1
Processes, Models, and Methods of Implementation

Process	DSS Model Base	Implementation Methods
Process 1. Definition of candidate requirements for personnel search, selection, and recruitment	Position profile model for maritime personnel Hierarchical model of candidate evaluation criteria	Multi-criteria analysis method Direct expert evaluation method Analytic hierarchy process method
Process 2. Search and selection of candidates for further evaluation	Position profile model for maritime personnel (sections R1, R2, R4) Candidate database model Lexicographic analysis model	Algorithmization of candidate filtering procedure based on lexicographic analysis
Process 3. Establishing the qualitative characteristics of candidates	Position profile model for maritime personnel (section R3) Structured scale model for evaluating criteria values Model for setting criteria values under uncertainty conditions	Direct expert evaluation method
Process 4. Comprehensive multi-criteria candidate evaluation	Position profile model for maritime personnel (section R3) Comprehensive multi-criteria candidate evaluation model	Linear aggregation method for criteria Ideal point method
Process 5. Evaluation of results and decision-making	Decision Capturing Model	

Most of the models and methods for implementing the processes of the information technology modules under consideration have been the subject of theoretical and experimental studies by the authors in other scientific works [6]. A significant recent development in the research on scenario building, which requires key modifications to previous studies to adapt them to the specific requirements of personnel search and selection in a crewing company, was the creation of position profile models for maritime personnel. These models serve as the foundation for implementing the core processes of the technology.

4. Framework of the Hierarchical Competency Model for Seafarer Selection

At the core of the proposed framework lies the position profile model, which serves as a formalized representation of the ideal seafarer profile and a central element of the hierarchical competency model for decision support in crewing companies. This model provides a structured and systematic approach to evaluating candidate suitability through a hierarchy of competency groups and criteria defined for specific maritime positions. Each application context – characterized by the attributes of vessel, shipowner, and voyage – determines the corresponding set of requirements, competency weights, and performance expectations applied during the personnel selection process.

The development of the model involves the following key participants:

- Decision-Makers – departments or employees of the crewing company responsible for the search and selection of candidates for the designated application context;
- Client – departments or employees of the shipowner's company responsible for crew formation and defining specific requirements for candidates based on their perspectives.

The position profile model is designed to formalize and optimize the company's personnel search and selection processes by providing clients with tools to formulate candidate requirements. These requirements are assessed in terms of professionalism, personal qualities, physical endurance, and psychological resilience under varying situational conditions for crew formation on a defined application context.

The position profile model is seen as a flexible tool that establishes an appropriate informational structure for formalized, multi-faceted personnel requirements. It is oriented towards the ability to add new assessment aspects and adjust their priorities depending on the relevant situational conditions for decision-making.

In this scenario, the position profile model (PM) consists of four sections:

$$PM =< R1, R2, R3, R4 >, \quad (1)$$

R1 – the first section of the position profile model, which defines the position requirements dictated by existing international standards and regulations governing the maritime industry:

$$R1 = \{IS_i\}, IS_i \in IS, i = 1, I, \quad (2)$$

where IS represents a set of regulatory conditions, licenses, safety certificates, and qualifications that act as a limiting factor in candidate selection.

R2 – the second section of the model, which defines the set of professional responsibilities for the corresponding position MR. The composition and importance of these responsibilities are determined by the decision-maker, who adheres to existing standards for the position as well as specific individual requirements:

$$R2 = MR_j, MR_j \in MR, j = \overline{1, J}, \quad (3)$$

where MR represents a set of professional responsibilities, compliance with which is a limiting factor in candidate selection.

R3 – the third section of the model, which includes subsections defining the requirements for the qualitative characteristics of candidates for the respective position in terms of:

professional competencies of the candidate, the composition of which is determined by a set of criteria – KG1;
evaluation of the candidate's technical and navigational competencies – KG2;

managerial competencies – KG3;
communicative competencies – KG4;
physical and psychological condition – KG5.

Thus, to construct a position profile for a specific application object, a hierarchical model of the set of criteria for evaluating the qualitative attributes of candidates P has been developed (4). The Analytical Hierarchy Process (AHP) by T. Saaty was employed in its construction. AHP incorporates expert evaluations, typically in the form of pairwise comparisons between alternatives, and considers different levels within the hierarchy of evaluation criteria. At the first level of the hierarchy, groups of position competencies are defined; at the second level, competency criteria for each group are specified:

$$P = \{KG_l, V_l^{*+}, V_l^{*-}, \beta_l\{KG_{l_y}, V_{l_y}^{*+}, V_{l_y}^{*-}, \beta_{l_y}, \beta_{l_y}^R\}\}, \quad (4)$$
$$KG_l \in P, l = \overline{1, L}, KG_{l_y} \in KG_l, y = \overline{1, Y^l}.$$

At the first level of the hierarchy, the groups of job competencies $\{KG_l\}, l = \overline{1, L}$, are defined; at the second level, $\{KG_{l_y}, y = \overline{1, Y^l}$ – the competency criteria for each group (see Table 2, columns 1 and 2).

The priority assessment (weighting) of indicators is established for the two levels of the profile model hierarchy:

at the level of competency groups (Table 2, column 3):

$$\{\beta_l\}, l = \overline{1, L}, 0 \le \beta_l \le 1; \sum_{l=1}^{L} \beta_l = 1\,; \quad (5)$$

at the level of the competency criteria within each group (see Table 2, column 4);

$$\{\beta_{l_y}\}, y = \overline{1, Y^l}, 0 \le \beta_{l_y} \le 1; \sum_{y=1}^{Y^l} \beta_{l_y} = 1; \quad (6)$$

and the aggregated influence of the y-th criterion on the overall candidate evaluation index, taking into account all groups of criteria (Table 2, column 5):

$$0 \le \beta_{l_y}^R \le 1; \beta_{ly}^R = \beta_l \times \beta_{ly}; \sum_{l=1}^{L} \sum_{y=1}^{Y_l} \beta_{ly}^R = 1. \quad (7)$$

$V_{l_y}^{*+}, V_{l_y}^{*-}$ – are the reference values of the candidate evaluation interval for the y-th criterion within the l-th competency group. Specifically, $V_{l_y}^{*+}$ represents the optimal (most desirable) value, while $V_{l_y}^{*-}$ – denotes the minimum acceptable value as determined by experts, according to the established evaluation scale (Table 2, columns 6 and 7).

V_l^{*+}, V_l^{*-} – are the reference values of the evaluation interval for the l-th group of criteria. V_l^{*+}denotes the optimal (most desirable) value, and V_l^{*-} – is the minimum acceptable value of the candidate's indicator within the l-th competency group, according to the established evaluation scale for the corresponding position at the specified application object (see Table 2, columns 8 and 9):

$$V_l^{*+} = \sum_{l=1}^{Y_l} \beta_{l_y} \times V_{l_y}^{*+}; \quad (8)$$
$$V_l^{*-} = \sum_{l=1}^{Y_l} \beta_{l_y} \times V_{l_y}^{*-};. \quad (9)$$

Table 1 illustrates, as an example, the approach to data representation in the job profile of a passenger vessel captain for a specific voyage.

Table 2
Job Profile of a Passenger Vessel Captain

Competency Groups and Evaluation Criteria		Calculated Indicators						
Code	Title	β_l	β_{l_y}	β_{ly}^R	V_l^{*+}	V_l^{*-}	$V_{l_y}^{*+}$	$V_{l_y}^{*-}$
1	2	3	4	5	6	7	8	9
1.	**KG1 – Group of Professional Competencies of the Candidate**	**0,3**			**0,83**	**0,59**		
1.1	Possession of additional certifications and licenses aimed at enhancing professional knowledge and skills.		0,2	0,06			0,8	0,5
1.2	Level of maritime education		0,2	0,06			0,8	0,5
1.3	Experience working on vessels of a similar type		0,3	0,09			0,9	0,7
1.4	Knowledge of the English language		0,3	0,09			0,8	0,6
	Total for Group 1	**0,3**	**1**	**0,3**				
2	**KG2 – Group for Assessment of Technical and Navigational Skills of the Candidate**	**0,25**			**0,9**	**0,64**		
2.1	Proficiency in modern navigation systems: Experience working with ECDIS, ARPA, RADAR, GPS, ballast control systems, and power plants.		0,6	0,15			0,9	0,6
2.2	Knowledge of international maritime regulations (COLREGs, SOLAS, MARPOL): Ability to apply regulations to ensure safety at sea.		0,4	0,1			0,9	0,7
	Total for Group 2	**0,25**	**1,0**	**0,25**				
3	**KG3 – Human and Managerial Skills of the Candidate**	**0,25**	-		**0,86**	**0,76**		

Competency Groups and Evaluation Criteria		Calculated Indicators						
Code	Title	β_l	β_{l_y}	β_{ly}^R	V_l^{*+}	V_l^{*-}	$V_{l_y}^{*+}$	$V_{l_y}^{*-}$
1	2	3	4	5	6	7	8	9
3.1	Crew leadership: Experience in effectively managing multinational crews, ability to motivate, resolve conflicts, and allocate responsibilities.		0,4	0,1			0,9	0,7
3.2	Crisis management: Ability to make rapid decisions in emergency situations (storms, fires, accidents, medical incidents).		0,4	0,1			0,9	0,8
3.3	Planning and organization: Ability to organize onboard workflows, manage documentation, and ensure compliance with procedures	0,25	0,2	0,05			0,7	0,6
	Total for Group 3	**0,25**	**1**	**0,25**				
4	**KG4 – Personal Qualities**	**0,1**			**0,76**	**0,58**		
4.1	Responsibility: Awareness of the level of responsibility for the crew, passengers, and the vessel		0,2	0,02			0,7	0,6
4.2	Stress resistance: Ability to work effectively under psychological and physical stress		0,2	0,02			0,8	0,6
4.3	Communicativeness: Well-developed skills in effective communication with crew, port authorities, and shipowners.		0,2	0,02			0,7	0,5
4.4	Analytical thinking: Ability to analyze situations and make strategic decisions.		0,4	0,04			0,8	0,6
	Total for Group 4	**0,1**	**1**	**0,1**				
5	**KG5 – Physical and Psychological Condition**	**0,1**	**-**		**0,78**	**0,565**		

Competency Groups and Evaluation Criteria		Calculated Indicators						
Code	Title	β_l	β_{l_y}	β_{ly}^R	V_l^{*+}	V_l^{*-}	$V_{l_y}^{*+}$	$V_{l_y}^{*-}$
1	2	3	4	5	6	7	8	9
5.1	Medical fitness: Possession of a valid medical certificate (e.g., MLC Medical Certificate) confirming fitness for work on board.		0,35	0,035			0,8	0,5
5.2	Psychological resilience: Assessment of stress tolerance, adaptability to long voyages, and absence of dependencies (alcohol, drugs).		0,45	0,045			0,8	0,6
5.3	Physical endurance: Ability to work under extreme weather conditions and perform physical tasks when necessary.		0,2	0,02			0,7	0,6
	Total for Group 5	**0,1**	**1,0**	**0,1**				
	Total	***1,0***						

The entire set of indicators for the multicriteria evaluation of candidates, including the reference values defined in the job profile, is based on qualitative measurement characteristics. These characteristics are interpreted into a numerical representation in the form of normalized scores within a range from 0 to 1. The foundation for candidate assessment and determination of evaluation results is a set of candidate evaluation scales. Each scale proposes the use of seven qualitative levels for candidate assessment $W_g, g = \overline{1,7}$:

W_1 – purely high value of the criterion;
W_2 – high value of the criterion;
W_3 – very good value of the criterion;
W_4 – good value of the criterion;
W_5 – average value of the criterion;
W_6 – low value of the criterion;
W_7 – purely pessimistic evaluations of the criterion's values.

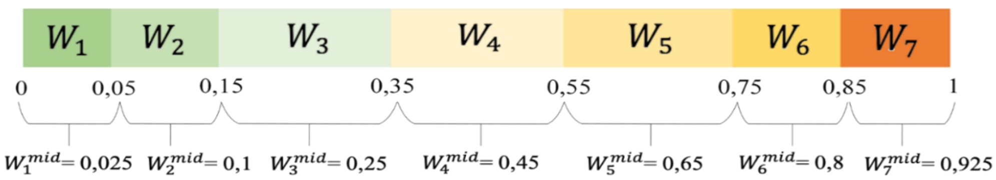

Figure 1: Scale of Qualitative and Quantitative Evaluations of Candidate Characteristics.

Since the proposed gradation represents a certain qualitative scale, a structuring scale of preferences is established for each level W_g , their boundary and average values within the range of 0 to 1 (Fig. 1):

$$\{W_g^{min}, W_g^{max}, W_g^{mid}\}, \text{де} W_g^{mid} = (W_g^{min} + W_g^{max})/2. \quad (10)$$

For each level of gradation in the evaluation scale, the substantive essence of compliance requirements is determined.

Table 3 presents an example of constructing a candidate evaluation scale based on the composite assessment indicator, accompanied by a qualitative interpretation of each evaluation level.

Table 3
Candidate Evaluation Scales Based on the Composite Assessment Indicator.

$W_g^{\square}$	W_g^{min}	W_g^{max}	W_g^{mid}	Qualitative Interpretation of Candidate Assessment
W_1	0,8	1	0,9	Exceptionally high indicator value. The candidate fully meets the optimal and ideal requirements of the position profile across all evaluation criteria
W_2	0,6	0,8	0,7	High indicator value. The candidate meets the optimal and ideal requirements of the position profile in the most significant criteria
W_3	0,4	0,6	0,5	Average indicator value; requires further decision-maker analysis using additional group indicators.
W_4	0,2	0,4	0,3	Low indicator value; requires further analysis by the decision-maker using indicators from the additional group and those at the l-th competency group level.
W_5	0	0,2	0,1	Clearly pessimistic indicator values, indicating the respondent meets only the minimum acceptable requirements of the position profile across all competency groups. This constitutes grounds for candidate rejection

The data in section R3 serve as the informational foundation for solving the personnel selection optimization problem based on the defined set of criteria.

R4 – the fourth section of the profile model, which defines the set of contract conditions (CC) for the corresponding position at the specified application context:

$$CC = \{CC_e\}, CC_e \in CC, e = \overline{1, E}, \quad (11)$$

where CCe – e-th contract conditions.

5. Conclusions

The conducted research confirms the relevance and effectiveness of enhancing information technologies to support the processes of searching, evaluating, and selecting maritime personnel in crewing companies. Given the complexity of decision-making under conditions of uncertainty, the study highlights the importance of formalized yet flexible tools capable of reflecting the operational dynamics and industry-specific requirements of maritime recruitment.

As a result, a hierarchical competency model for decision support in seafarer selection has been developed and integrated into an information technology framework built on a structured model base within a decision support system. The core of this framework is the position profile model, which organizes evaluation criteria into multi-level competency groups (KG1–KG5): professional, technical, managerial, personal, and psychophysical. The model employs the Analytic Hierarchy Process to determine the weight and priority of criteria, while normalized evaluation scales and the ideal point method are used to quantify the degree of candidate compliance with position requirements.

Furthermore, the framework introduces a structured qualitative evaluation scale that translates expert judgments into standardized quantitative values. This approach ensures objectivity, reproducibility, and transparency in the assessment process. Complementary components of the methodology include lexicographic analysis for candidate filtering, fuzzy logic models for handling uncertainty and qualitative indicators, mechanisms for verifying compliance with international maritime standards and certifications, and tools for evaluating psychological resilience, stress tolerance, and physical readiness – factors critical for effective performance in maritime conditions.

The proposed DSS framework significantly enhances the transparency, adaptability, and efficiency of personnel selection in crewing companies. It enables organizations to:

- Align candidate evaluation with position- and voyage-specific requirements;
- Reduce subjectivity in decision-making;
- Improve the planning and execution of crew rotations; and
- Ultimately strengthen the overall quality and safety of maritime operations.

Nevertheless, further development of the model is required to accelerate the selection process under conditions of high crew turnover and to enable the integration of real-time data for dynamic personnel management and continuous system adaptation.

6. Declaration on Generative AI

The authors have not employed any Generative AI tools.

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