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A Ranking of Critical Competencies for Future Seafarers in the Scope of Digital Transformation

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Abstract: The effects of Industry 4.0, which caused a paradigm shift in many industries in the light of digital transformation and autonomous systems, began to be seen in the maritime sector as well. Both the academy and the pioneers of the industry accelerated the studies on autonomous ships and started their sea trials. Accordingly, with the proliferation of autonomous ships, it is expected that the current competencies of seafarers will not be sufficient, and they will need new competencies in accordance with the digital age. Aim of this study is to rank critical competencies to contribute to the literature about the competencies that will be required in the digital era. Firstly, key competencies and sub competencies were extracted from literature. Then a fuzzy analytic hierarchy process was utilized to rank competencies with the data gathered from a survey designed to collect expert opinions. Results revealed that cognitive skills such as reasoning and decision making, problem and conflict solving, and critical thinking are expected to be most important competencies of seafarers in digital era. They are followed by operational skills, individual skills, and social skills. Study demonstrated that seafarers would need to be prepared new skills and competencies through Industry 4.0.

Keywords: maritime industry 4.0; maritime digitalization; digital transformation; maritime competence; fuzzy analytic hierarchy process

1. Introduction

Industry 4.0 has ushered in a new era of information technology, which has also affected the maritime industry. With the introduction and integration of Internet of Things (IoT), Big Data, Artificial Intelligence, Cloud Computing, Digital Twin, Blockchain and automation technologies in the previous decade, the Industry 4.0 digital revolution has evolved. This digitalization is forcing maritime industry, as well as all other industries, to look outside of their scope, forcing them to constantly redefine their previous practices in order to keep up with the changing world. The digital shipping revolution, Shipping 4.0 (Shahbakhsh et. al., 2022), paved the way for the concept of autonomous transportation in the maritime industry. Moreover, with the introduction of Maritime Autonomous Surface Ships (MASS) significant developments have taken place over the last few years by academics and the International Maritime Organization (IMO). These developments are mostly focused on technical advancements and implementations regarding autonomous systems. However, the gap among common practice, competence and future opportunities is observed to be growing (Oksavik et. al., 2021). It has been observed that the maritime industry's employment pattern will be drastically altered as a result of these technological advancements, necessitating the availability of highly qualified human resources (Cicek et. al., 2019). Therefore, the skill standards for seafarers will need to be reviewed as part of the digitization process (Sharma and Kim, 2021). This paper focuses on identifying and ranking the emerging critical competencies for future seafarers due to the reflections of Industry 4.0 in the maritime sector.

The aim of this study is to contribute to the literature about the competencies that future seafarers will need in the digital era. The rapidly widening gap between the current qualifications and the future needs shows that a strategy should be determined in the short, medium and long terms in this regard. While these strategies are being determined by all the stakeholders of the maritime industry, it is aimed to create a critical competency ranking that they can consider.

The future competencies were identified and structured preliminarily in the study. Data from maritime sector experts and maritime academics was gathered using a pairwise comparison table to rate the relative importance of competencies. Analytic Hierarchy Process (AHP) was applied to analyze data collected. Also, fuzzy logic is combined with AHP (FAHP) to reduce inaccuracies due to an inability to compensate for ambiguity in human logic.

The structure of this paper is as follows. The literature review is presented in section 2. Section 3 explains the theoretical framework involving the process of FAHP. The results of FAHP and discussion is given in Section 4 where the critical competency ranking for future seafarers are presented and finally the study ends with conclusions.

2. Literature Review

Despite Industry 4.0 has gained great importance in both production of goods and services, there is no significant definition but technologies such as big data analytics, autonomous and adaptive robots, cyber physical infrastructure, simulation, horizontal and vertical integration, internet of things, cloud systems, additive manufacturing and augmented reality are the necessities for a successful adaptation of Industry 4.0 (Ustundag & Cevikcan, 2017). Maritime industry started to follow the path opened by Industry 4.0 percept like many industries. Some pioneers in the maritime industry lead the way of digital transformation of shipping using those technologies onboard. Therefore, Shipping 4.0 may refer to digital transformation of shipping that enables digitalization in all aspects of shipping (Shahbakhsh et. al., 2022). The term emerged to describe the digitalization in shipping that reflects the similar developments in land-based industries under Industry 4.0 (Kavallieratos et. al., 2020). Digitalization, via Shipping 4.0, will result in several improvements to ship operations, crew, and automation that will together improve maritime productivity (Emad et. al., 2021). Hence, it can be said that the most important outputs of Shipping 4.0 are smart ports and autonomous ships. Although autonomous systems such as autopilot, e-navigation or the integrated bridge systems have been used on ships for a long time, Shipping 4.0 promises a future where ships can be managed remotely, or decision-making processes can be done by automated systems of ships. Since seafarers will be a part of this automation process as onboard crew or remote operators who have to deal with autonomous systems, it is safe to expect that new competencies and skills related to new technologies would be needed in the future shaped by Shipping 4.0.

The most important conventions regulating international shipping such as SOLAS and MARPOL were implemented after some disasters that affect both human life and marine environment. This was perhaps inevitable, as it was difficult to see the coming of these disasters in those years. However, as it is clear that digital transformation and Industry 4.0 will change the future of many industries, IMO has taken pioneering steps in the introduction of autonomous ships. Firstly, Maritime Safety Committee (MSC) specified that IMO should take the leading role in an environment where technological developments are advancing very rapidly and agreed to add commercially operated ships in autonomous mode to their agenda by starting to conduct a regulatory scoping exercise (RSE) after a proposal from several member states (IMO, 2017). Then, in 2018, integrating new and advancing technologies in the regulatory framework was included as one of the strategic directions in the Strategic Plan of IMO to facilitate a smooth transition process to the digital era in the shipping industry.

RSE for safety treaties was completed in 2021 with an outcome of MSC.1/Circ.1638, and supreme outcome of circular can be considered as defining the varying degrees of autonomy (IMO, 2021). The degrees of autonomy for the MASS were defined as shown in Table 1.

Table 1: Four Degrees of MASS (IMO, 2021)

Degree	Autonomy Level	Description
Degree One	Ship with automated processes and decision support	Seafarers are on board to operate and control shipboard systems and functions while some operations may be automated and at times be unsupervised but with seafarers on board ready to take control.
Degree Two	Remotely controlled ship with seafarers on board	The ship is controlled and operated from another location. Seafarers are on board to take control and to operate the shipboard systems and functions.

Degree Three	Remotely controlled ship without seafarers on board	The ship is controlled and operated from another location. There are no seafarers on board.
Degree Four	Fully autonomous ship	The operating system of the ship is able to make decisions and determine actions by itself.

Another significant outcome of the RSE is highlighting the need for developing MASS terminology and definitions, especially for international agreed definitions and clarifications for the terms “master”, “crew” and “responsible person” in Degree Three and Degree Four. Since Degrees 2 and 3 require a remote-control center and remote operators, addressing the functional and operational requirements of the remote-control center and the possible designation of remote operator as seafarer can be denoted as another high-priority outcome of RSE.

MSC has classified safety-related IMO instruments as high, medium, and low priority according to their potential to be affected by the transition to autonomous ships and has determined what changes each regulation needs for each degree of autonomy. The instruments such as SOLAS III, IV, V and STCW which directly affects the competencies and skills of seafarers were considered as high priority. For Degree 2 and 3, it was foreseen that amendments to their existing content or a completely new code should be implemented.

In the evaluation of STCW Convention under MASS process, there are two options which are the determination that remote operator will be a seafarer and the determination that remote operator will not be a seafarer in Degree 2 and Degree 3. In both degrees, in determining the remote operator as seafarer, MSC states that new requirements, amendments and flexibilities introducing modern technologies and automated processes can be made through existing code. In determination that remote operator is not a seafarer, MSC states that in addition to amending existing code, a new instrument including new provisions to address role and responsibilities of remote operator may be needed.

The Legal Committee of IMO have also included RSE on their agenda for the conventions under their authority. When the exercises of both committees are examined, it can be clearly seen that defining the role and responsibilities of master, officers and remote operators are high-priority subjects for MASS process and clarifying this subject was strongly advised for the future work.

IMO has not only studied the direction in which regulations will evolve in the future but has also prepared an interim guide to be applied today. “Interim Guidelines for MASS Trials” was approved by MSC to provide assistance to industry members dealing with autonomous shipping technologies and related authorities such as coastal states, flag states and port states to create an environment for autonomous ship trials that would not be less than current maritime safety and security levels (IMO, 2019). Sea trials of autonomous ships are done by some of the leading companies of the maritime industry today. NYK carried out a sea trial with an autonomous car carrier with seafarers onboard [URL-1]. Wartsila in corporation PSA Marine practiced a successful sea trial of a harbor tug project in 2019 [URL-2]. Rolls-Royce and Finferries have successfully completed a fully autonomous voyage and a remote operated voyage of a ferry including docking operations without human interference [URL-3]. Yara Birkeland operated by Kongsberg became the first fully electric and autonomous ship that also had autonomous loading, discharging and mooring systems [URL-4]. MUNIN is a project to create and test a concept for an autonomous ship, which is described as a vessel that is mostly steered by automated on-board decision systems but is managed by a remote operator at a shoreside control station [URL-5].

Like the progress in the industry, academic studies have gained momentum in recent years. Areas of focus on academic papers on autonomous ships can be classified as navigation and collision avoidance, cost and benefit analysis, financial and environmental sustainability, regulatory framework, and human factor and training (Veitch and Alsos, 2022; Bratic et. al., 2019). Although there are some studies on the responsibilities and competencies of seafarers in the era of autonomous ships, considering that they will be the operators of technological advances and new legal regulations, it can be considered that the studies on this subject are insufficient.

3. Methodology

The Analytic Hierarchy Process (AHP) proposed by Saaty (1988) is a widely used multi-criteria decision-making process that uses pairwise comparison to establish the weights of criteria and the rankings of alternatives in an organized manner (Liu et.al., 2020). However, AHP does not consider the ambiguity in human logic and is criticized for the inaccuracies resulting from this. As a result, the fuzzy sets proposed by Zadeh (1965) are combined with AHP as a prominent approach to reduce such ambiguity. The fuzzy set theory represents ambiguity that cannot be explained by conventional mathematical terms. It is well known that the theory is quite effective when dealing with problems that lack sharp boundaries and precise numbers. Furthermore, fuzzy numbers are similar to human natural language rather than rigid mathematical terms and equations. Therefore, fuzzy AHP (FAHP) is regarded as a suitable analysis method in this study. The steps of this method are explained below.

Step 1: Establishing the model

The problem was decomposed in a tri-level hierarchical model, which includes goal (ranking of critical competencies for future seafarers), key competencies, and sub-competencies. To determine the key and sub-competencies, a literature review was made regarding future seafarers' required competencies in the light of Shipping 4.0 as shown in Table 2.

Table 2. Overview of future seafarers' competencies

KEY COMPETENCIES	SUB-COMPETENCIES	LITERATURE
OPERATIONAL	Operations Monitoring and Analyzing	Cicek, K., Akyuz, E., & Celik, M. (2019), Oksavik, A., et.al. (2021).
	Information and Data Processing	Tran, T. N. M. (2018), Oksavik, A., et.al. (2021), IAMU(2019), Cicek, K., Akyuz, E., & Celik, M. (2019), Sharma, A., & Kim, T. E. (2021)
	Programming	Tran, T. N. M. (2018), IAMU(2019), Cicek, K., Akyuz, E., & Celik, M. (2019), Sharma, A., & Kim, T. E. (2021), Shahbakhsh, M., Emad, G. R., & Cahoon, S. (2022)
	Ability to Manage Cyber Security	Sharma, A., & Kim, T. E. (2021)
	STEM knowledge	Tran, T. N. M. (2018), IAMU(2019), Sharma, A., & Kim, T. E. (2021), Emad, G. R., Enshaei, H., & Ghosh, S. (2021), Shahbakhsh, M., Emad, G. R., & Cahoon, S. (2022)
	Law and Legislation awareness	IAMU(2019), Cicek, K., Akyuz, E., & Celik, M. (2019)
COGNITIVE	Problem and conflict solving	Nguyen, L. (2018), IAMU(2019), Cicek, K., Akyuz, E., & Celik, M. (2019), Sharma, A., & Kim, T. E. (2021), Kilpi, V., Solakivi, T., & Kiiski, T. (2021)
	Reasoning and Decision making	IAMU (2019), Cicek, K., Akyuz, E., & Celik, M. (2019)
	Ability to cope with complexity	Tran, T. N. M. (2018), IAMU(2019), Cicek, K., Akyuz, E., & Celik, M. (2019), Sharma, A., & Kim, T. E. (2021)
	Critical Thinking	Nguyen, L. (2018), Tran, T. N. M. (2018), IAMU(2019), Sharma, A., & Kim, T. E. (2021)
SOCIAL	Communication	Tran, T. N. M. (2018), IAMU (2019), Cicek, K., Akyuz, E., & Celik, M. (2019), Sharma, A., & Kim, T. E. (2021), Oksavik, A., et.al. (2021), Shahbakhsh, M., Emad, G. R., & Cahoon, S. (2022)
	Teamwork	Tran, T. N. M. (2018), Cicek, K., Akyuz, E., & Celik, M. (2019), Sharma, A., & Kim, T. E. (2021), Oksavik, A., et.al. (2021), Kilpi, V., Solakivi, T., & Kiiski, T. (2021)
	Adapting to cultural differences	IAMU (2019), Cicek, K., Akyuz, E., & Celik, M. (2019), Sharma, A., & Kim, T. E. (2021), Oksavik, A., et.al. (2021)
	Leadership	Nguyen, L. (2018), Tran, T. N. M. (2018), IAMU (2019), Cicek, K., Akyuz, E., & Celik, M. (2019), Sharma, A., & Kim, T. E. (2021), Oksavik, A., et.al. (2021), Emad, G. R., Enshaei, H., & Ghosh, S. (2021), Shahbakhsh, M., Emad, G. R., & Cahoon, S. (2022)
INDIVIDUAL	Adaptability and Flexibility	Tran, T. N. M. (2018), Cicek, K., Akyuz, E., & Celik, M. (2019), Sharma, A., & Kim, T. E. (2021), Kilpi, V., Solakivi, T., & Kiiski, T. (2021)
	Energy Efficiency Knowledge and Awareness	Tran, T. N. M. (2018), Cicek, K., Akyuz, E., & Celik, M. (2019)
	Sustainable point of view	IAMU (2019), Cicek, K., Akyuz, E., & Celik, M. (2019)

Ability to work under pressure	Cicek, K., Akyuz, E., & Celik, M. (2019), Sharma, A., & Kim, T. E. (2021)
Self-Learning Motivation	Nguyen, L. (2018), Cicek, K., Akyuz, E., & Celik, M. (2019)

Step 2: Survey implementation

The RSE indicated in MSC.1/Circ.1638 Annex that the potential designation of a remote operator as a seafarer was identified as a common theme in several IMO instruments and that is a high priority potential gap; especially their competency, responsibility, and the role as a remote operator.

Therefore, in this study masters with more than at least 5 years of experience and academics holding a master/chief engineer license were chosen as the sampling target. Other than the masters and chief engineers, academics with similar sea experience were also chosen because they educate and train seafarers to have the necessary competencies.

A questionnaire survey was used to collect data from selected maritime sector experts. Academic experts in the maritime industry examined and validated the survey's content. The questionnaire was divided into two sections. The first section involved demographic questions, and the second section was for respondents to rate the relative importance of paired criteria of the sub-competencies on a scale of '1 = extremely unimportant' to '9 = extremely important.'

Respondents were briefed about the 4 stages determined by IMO in the autonomous ship transition process, and they were asked to make their evaluations in terms of the competencies expected of seafarers who will take part in the degree 2 and 3 of this process. The data were collected via e-mail using a pair-wise comparison table prepared regarding the theoretical framework given in Figure 1. A total of 5 valid questionnaires were used for further analysis.

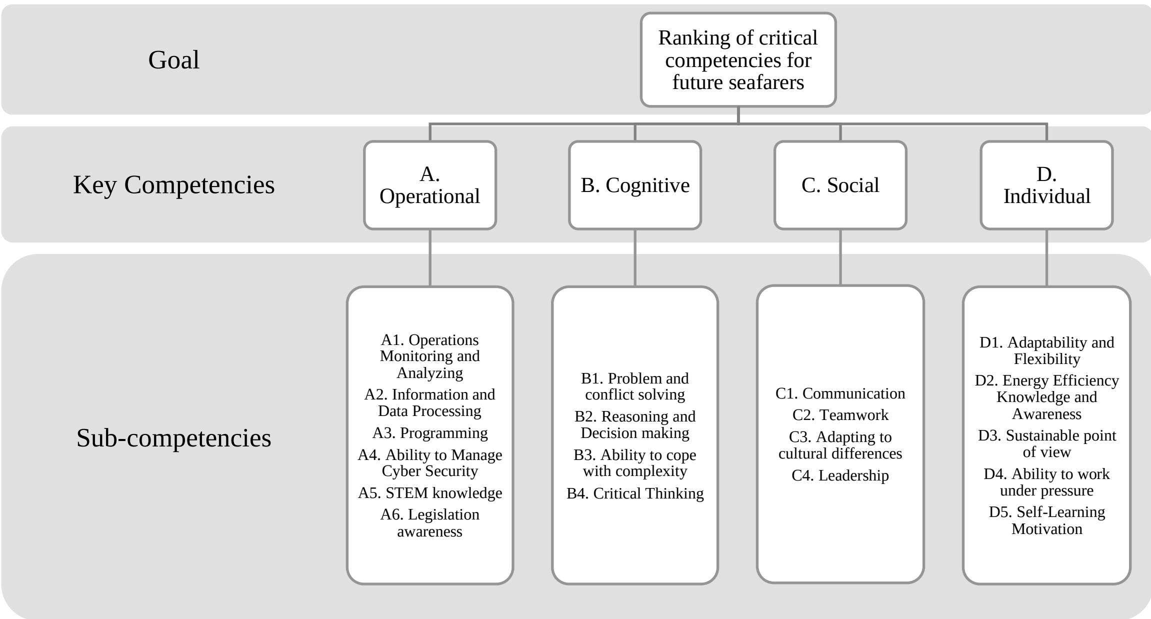

Figure 1. The theoretical framework of AHP

Step 3: Conversion into fuzzy numbers

Fuzzy numbers are normal and convex types of fuzzy sets. Although these numbers can be demonstrated by a variety of shapes, triangular and trapezoidal shapes are the most useful for practical implementations (Yoon, 1996). A triangular fuzzy number (TFN) consists of three points, represented by (l, m, u) where l, m, and u denote the smallest possible value, the most promising value, and the largest possible value providing a fuzzy set respectively (Chang, 1996). In this study, the triangular membership function which is defined below is used.

$$\mu_M(x)\begin{cases}\frac{x-l}{m-l}, l < x < m \\ 1, x = m \\ \frac{u-x}{x-m}, m < x < u \\ 0, l \geq x \geq u\end{cases} \quad (1)$$

Figure 2 shows the membership function of triangular fuzzy number, while Table 3 shows the triangular fuzzy numbers used in this study.

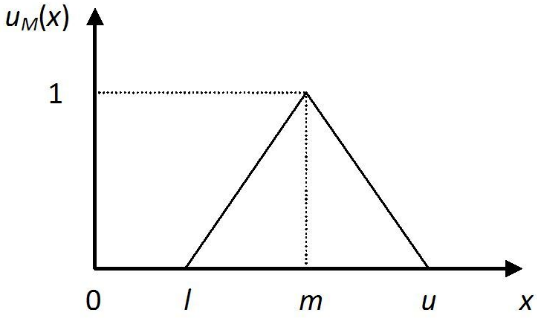

Figure 2. Membership function of triangular fuzzy number

Table 3. Triangular fuzzy numbers.

Relative importance	Linguistic Scale	Fuzzy Number	Triangular Fuzzy Number
1	absolutely low	1/9	1/9,1/9,1/9
2	very low	1/7	1/6,1/7,1/8
3	low	1/5	1/4,1/5,1/6
4	fairly low	1/3	1/2,1/3,1/4
5	medium	1	1,1,1
6	fairly high	3	2,3,4
7	high	5	4,5,6
8	very high	7	6,7,8
9	absolutely high	9	9,9,9

Step 4: Creating a Pairwise Comparison Matrix with Fuzzy Values

The geometric mean method is used to combine the 5 fuzzy comparisons that were collected. The consolidated fuzzy value of paired judgments is then used to create a comparison matrix. Matrix represents a n x n pairwise comparison matrix, as shown below.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \quad (2)$$

Step 5: The fuzzy weights

In order to calculate fuzzy weights (Wi) with combining the weights given by different experts, the geometric mean technique is used as shown in the below formula:

$$Z_i = (a_{i1} \times a_{i2} \times \ldots \times a_{in})^{\frac{1}{n}}, \forall_i = 1, 2, \ldots, n \quad (3)$$

$$W_i = Z_i \times (Z_1 \times Z_2 \times \ldots \times Z_n)^{-1}, \forall_i = 1, 2, \ldots, n \quad (4)$$

Step 6: The consistency ratio

The consistency ratio (CR) should be calculated to avoid inconsistencies in the comparison matrix. For the matrix's consistency to be acceptable, the CR must be less than 0.10. (Saaty, 1988). If not, the comparison matrix should be reviewed again. The CR can be calculated using the equations (5) and (6) where λmax is the eigenvalue of the matrix, CI is the consistency index, and RI is the random index which is used as 1,62 according to Hayrapetyan (2019) regarding the matrix size that is 19.

$$CR = \frac{CI}{RI} \quad (5)$$

$$CI = \frac{\lambda max - n}{n-1} \quad (6)$$

Step 8: Normalization

The BNP values should be normalized to compare the relative importance of key and sub-competencies:

$$NW_i = \frac{BNP_i}{\sum_{i=1}^{n}(BNP_i)}\ , \forall_i = 1, 2, \ldots, n \quad (8)$$

4. Results of the FAHP and Discussion

The weights and ranking of key competencies and sub-competencies are shown in Table 4. The consistency ratio was calculated as 0,0691, less than 0,10. The most important key competency is evaluated as cognitive skills that comprises the three most important sub-competencies which are reasoning and decision making, problem and conflict solving, and critical thinking. Prominence of these competencies highlights that as digitalization progresses, making wise decisions will become more complex in maritime operations. This is supported by the fact that the other sub-competency of cognitive skills, "ability to cope with complexity" ranks 7th in overall.

Operational skills rank as the second most important key competency. Its sub-competencies, such as “operations monitoring and analyzing”, “information and data processing”, “managing cyber security” and “STEM knowledge” are also relatively high ranked, emphasizing the importance of seafarers having a thorough understanding of digitalization skills in order to manage, process, and comprehend increasingly complex data in order to handle and optimize operations. Also, the ranking of “law and regulations awareness” as 4th in overall may indicate that remarkable amendments in international maritime regulations are expected. However, low ranking of “programming” can be interpreted as the operator role of seafarer would retain.

The third important key competency is individual skills. Relatively high ranking of “ability to work under pressure” among other sub-competencies of individual skills can be an indicator of a working environment where the pressure on operators is increased due to a reduced labor force and increased computerized operations. It can also be interpreted that individual competencies are already required qualifications for seafarers and will continue as such. Besides, the low importance of energy efficiency awareness may be due to the thought that energy efficiency will be achieved as a result of decisions during the construction rather than the operation of the ship.

The fourth important key competency is social skills. The most important sub-competency here is communication. This is most likely due to communication still being a major barrier in multicultural workplaces such as maritime. Furthermore, there will still be people involved in MASS operations in the 2nd and 3rd degrees, leaving room for human error, albeit reduced. It is likely that there are similar reasons that leadership is relatively important in social key competency. Although there will be less human interaction in automated systems, taking efficient decisions in a complex computerized environment under pressure based on the data gathered from various electronic systems would still require a different kind of leadership skills. Sub-competencies such as teamwork and adapting to cultural differences were at the bottom of the ranking. One major reason for this could be that these competencies are already included in the skill sets that seafarers are expected to have at the very least.

Table 4. Analysis results of FAHP

Key Competency	Weights	Rank	Sub-Competency	Weights	Rank
A. Operational	0,2940	2	A1. Operations Monitoring and Analyzing	0.0673	6
			A2. Information and Data Processing	0.0705	5
			A3. Programming	0.0399	14
			A4. Ability to Manage Cyber Security	0.0560	9
			A5. STEM knowledge	0.0658	8
			A6. Law and Legislation awareness	0.0707	4
B. Cognitive	0,3645	1	B1. Problem and conflict solving	0.0772	2
			B2. Reasoning and Decision making	0.0847	1
			B3. Ability to cope with complexity	0.0665	7
			B4. Critical Thinking	0.0731	3
C. Social	0,1614	4	C1. Communication	0.0451	11
			C2. Teamwork	0.0342	16
			C3. Adapting to cultural differences	0.0191	19
			C4. Leadership	0.0414	13
D. Individual	0,1801	3	D1. Adaptability and Flexibility	0.0347	15
			D2. Energy Efficiency knowledge and awareness	0.0306	18
			D3. Sustainable point of view	0.0435	12
			D4. Ability to work under pressure	0.0480	10
			D5. Self-Learning Motivation	0.0318	17

CR=0,0691

5. Conclusion

This study contributes to the literature on the digital era competency requirements for future seafarers. The critical competencies gathered from the literature were evaluated by the determined experts based on the IMO's 2nd and 3rd MASS degrees and prioritized. In this context, the study first demonstrated that as the human-machine interface becomes more extensive, cognitive skills will become more prominent. On the other hand, law and legislation awareness, which is evaluated as one of the most important operational competencies within this study, has highlighted the importance of determining the legal framework that will enforce many sub-topics to evolve with the introduction of MASS. Furthermore, as reflected throughout the industry, the irreversible digitalization shift has demonstrated that seafarers will need to be prepared for skills such as information and data processing, as well as the ability to manage cyber security, in addition to their traditional training.

The IMO has already stated that STCW should be amended in MSC.1/Circ.1638. However, as revealed by this study, skills and competencies other than those provided in traditional maritime education will be required, necessitating a fundamental change in the curriculum of MET institutions, including training of trainers.

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