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Are We Ready for Digitalisation? A Study of the Challenges and Barriers to Digitalisation and Technology Use in the Turkish Maritime Sector

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ABSTRACT

With each passing day, maritime organisations are equipped with more technology, and these systems form a structure that creates international networks. Digitalisation will have implications and effects on value creation, business models, horizontal and vertical integration, services and work organisation. While digital technologies in the maritime sector reduce risks owing to transparency, adaptability, traceability, flexibility and scalability, can also give discernible improvements in terms of operational processes, cost reductions, etc.. In the developing maritime sector, there are a variety of digital technology-related challenges that remain to be overcome, but there is no structured overview of the main types of challenges/barriers encountered by specialists. In this study, we explore the challenges/barriers to digitalisation in the maritime sector and how these are perceived by employees in this sector. The aim of our research is to identify these challenges/barriers and understand the relationships between them. To categorise the challenges/barriers, the DEMATEL approach was used. As a result of the analysis, it is seen that the main hindrances to digitalisation in the maritime sector are the problems of complexity, integration and interoperability. In contrast, the difficulties of performance appraisal and scalability emerge as the least important issues affecting the implementation of digital technologies in this area. Our results indicate that economic problems exert a significant causal influence on the other challenges/barriers.

Keywords: digitalisation, maritime, challenges, barriers

INTRODUCTION

The essential structure of Industry 4.0 relies on internet-based, cyber-physical systems that can process and transfer big data, and smart production areas in which the Internet of Things (IoT) is integrated with services. Industry 4.0 has nine basic components: the IoT, autonomous robots, artificial intelligence (AI), big data, augmented reality (AR), virtual reality (VR), layered manufacturing, cloud operations, cyber security, simulation applications and system integration. Digital technologies are not only related to the use of machinery and equipment in the production process, but also to services, and provide interconnections between information, objects, services and people. Industry 4.0 is expected to bring about a paramadigmatic change in business processes, in addition to improving production capabilities based on technology. Digital technologies will have implications and effects on value creation, business models, horizontal and vertical integration, services and work organisation.

The total volume of world trade carried out via seaway is 75%. The increase in trade volume due to the globalisation of the world's economy has intensified the use of maritime

transport, which provides rapid and safe trans-continental transportation. With each passing day, this sector is equipped with more technology, and these systems form a structure that creates international networks. Various digital technologies can be defined parametrically for the operation of a ship, its cargo and fuel loading, berthing and maintenance, and these can provide significant advantages in terms of improving efficiency in ships and ports. While digital technologies in the maritime sector reduce risks owing to transparency, adaptability, traceability, flexibility and scalability, can also give discernible improvements in terms of operational processes, cost reductions, etc.. However, with these new digital technologies come specific risks such as spoofing or data manipulation, which need to be further analysed. The European Network and Information Security Agency has identified the risks in the maritime sector as follows: low awareness and focusing, the complexity of maritime systems, the absence of a holistic management approach and the insufficiency of national/international coordination, the inadequacies of cyber security in terms of maritime regulations, the absence of a holistic approach to cybersecurity, the lack of economic incentives and initiatives for increasing cybersecurity, and the lack of incentives for motivation and collaboration [1]. Although there are various challenges related to digital technologies in the emerging maritime sector that need to be overcome, there is no structured overview of the main categories of challenges/barriers that are encountered by specialists. There is still a dearth of literature on factors such as socio-economic, managerial, and behavioural aspects, especially in this sector. Furthermore, there is no theory about the relationship between the challenges/barriers in the literature that would allow for an understanding of how they depend on each other and their significance.

In this study, we explore the challenges/barriers to digitalisation in the maritime sector and how these are perceived by employees in this field. To address the gap in the literature, the following research questions are considered:

RQ1. What are the main challenges/barriers to adopting and implementing digital technologies in the maritime sector?

RQ2. What are the relationships between these challenges and barriers?

RQ3. Which challenges/barriers should be addressed first to enable development of the maritime sector?

In this study, experts are selected from the maritime sector to make an evaluation based on the conditions in Turkey, and this work is therefore narrow in scope. The data used in the research include the opinions of experts in the sector, and are constrained by the quality/quantity of these experts and their approaches to the subject. Although there are some studies in the literature on digitalisation in the Turkish maritime sector, there is as yet no study of how the difficulties and obstacles to digitalisation are perceived by practitioners in the sector. The main contribution of our work is that it identifies the expected opportunities and challenges in the field of digitalisation in the Turkish maritime sector, which will help practitioners make better management decisions to achieve corporate competitiveness and to address future demand.

LITERATURE REVIEW

In this section, we discuss the main obstacles to the use of digital technologies in the maritime sector. Fourteen challenges/barriers to the adoption of digital technologies were identified as a result of reviewing the literature using various databases. These difficulties were confirmed by expert opinions, and are summarised in Table 1.

Tab. 1. Challenges/barriers to adopting and implementing digital technologies in the maritime sector

Code	Barrier	Description	Author/reference
B1	Privacy and security problems	This category refers to cyber cases that may occur as a result of digitalisation, such as the seizure of information by unauthorised persons and the disclosure, modification or deletion of information.	Hossain et al. [2] Triska et al. [3] Chiappetta [4] Bolat and Kayışoğlu [5] Gao et al. [6] Progoulakis et al. [7] Kumar and Mallick [8] Thabit et al. [9] Kanwal et al. [10] Balkan [11]
B2	Lack of legal and regulatory policies	This refers to the fact that there are uncertainties in the use of digital technologies due to the lack of legal regulations and policies, and that the consequences that may arise in the case of any security problem remain legally unclear.	Agarwala [12] Babica et al. [13] Shin et al. [14] Ceylani et al. [15] Brunila et al. [16]
B3	Difficulties of performance appraisal	This category refers to the difficulties in measuring and evaluating the effectiveness and success level of digitalisation in any subject.	Al-Fuqaha et al. [17] Zhang and Lam [18] Aslam et al. [19]
B4	Complexity, integration and interoperability problems	This refers to the technical hardware and software problems that may arise when integrating existing machines and equipment with different technologies and network systems, and the synchronisation problems that may arise due to many devices being connected to the internet at the same time.	Hossain et al. [2] Progoulakis et al. [7] Thabit et al. [9] Al-Fuqaha et al. [17] Khan et al. [20] Alop [21]
B5	Resistance of organizational culture	This category refers to the resistance and traditional attitudes of managers and personnel in the organisation due to the uncertainty in the potential cost-benefit expectations that can be obtained from the use of digital technologies.	Progoulakis et al. [7] Brunila et al. [16] Shin and Shin [22] Yorulmaz and Derici [23]

B6	Economic problems	This refers to the economic problems caused by digitalisation, which can lead to financial losses, an inability to recover investments, and the need for large budgets and extensive capital for investments.	Balkan [11] Al-Fuqaha et al. [17] Alop [21] Shin and Shin [22] Yorulmaz and Derici [23]
B7	Technical infrastructure and network design problems	This category refers to a lack of infrastructure (such as internet connections, electricity, etc.) required to support digital technologies and applications, and the problems in managing large numbers of devices and resources over various networks.	Kumar and Mallick [8] Thabit et al. [9] Alop [21] Wang et al. [24]
B8	Lack of standardisation	Digital technologies and applications need directives and discipline, i.e. standardisation. This category refers to problems related to issues such as identification, communication and security, which play a critical role in the successful implementation of digital technologies.	Gao et al. [6] Al-Fuqaha et al. [17] Wang et al. [24] Bouhlal et al. [25] Al-Qaseemi et al. [26]
B9	Data management problems	Multiple devices communicating with each other generate large amounts of data that can overwhelm computer infrastructures and lead to higher energy consumption. This category refers to the problems that may arise in managing large amounts of data collected by different devices and sensors.	Gao et al. [6] Shin et al. [14] Wang et al. [24] Ma et al. [27]
B10	Lack of awareness	This refers to the lack of awareness and perception of the benefits that can be achieved in terms of value, profitability and effective use of time through the use of digital technologies.	Bolat and Kayışoğlu [5] Thabit et al. [9] Kanwal et al. [10] Zhang and Lam [18] Shin and Shin [22]
B11	Lack of management support	This is associated with the resistance of decision-making managers towards the use of digital technologies and a lack of support for the problems that may be encountered with digital applications.	Gao et al. [6] Shin et al. [14] Balkan [11] Zhang and Lam [18]
B12	Scalability	Organisations must keep up to date in order to manage issues related to the sizes of networks, increasing amounts of data and complexities in the use of digital technology. This category refers to the potential problems associated with scalability.	Triska et al. [3] Al-Fuqaha et al. [17] Ma et al. [27]
B13	High energy requirements	Efficient energy consumption is the main criterion for digitalisation. This category refers to potential problems that may arise due to the high amounts of energy used by digital technologies and applications.	Al-Fuqaha et al. [17] Zhang and Lam [18] Sanchez-Gonzalez et al. [28]
B14	Lack of qualified personnel	Digital technologies require highly trained personnel for their use, implementation and development. This category refers to the potential problems that may arise in finding technical staff and experienced personnel in this field.	Kumar and Mallick [8] Babica et al. [13] Brunila et al. [16] Yorulmaz and Derici [23] Demirel [29] Ellingsen and Aasland [30]

METHODOLOGY

In this section, we introduce a sequential solution to address the research problems identified above, which consists of three stages, as shown in Fig. 1. Stage 1 involves iterative expert meetings and a critical analysis of the literature with the aim of identifying the challenges/barriers to digitalisation in the maritime sector. Stage 2 involves analysing and synthesising the complex relationships among these challenges/barriers, and identifying the priority weights for these challenges/barriers depending on their interdependencies. Stage 3 focuses on validation, and involves exploring the correlations between findings when the decision makers are split into random groups, and identifying the changes in the credibility and inconsistency when a random decision maker is removed from the expert group.

The item collection process was first carried out, based on the literature analysis. We evaluated the collected items by merging terms with the same meaning or modifying their meanings. A draft version of the challenges/barriers to digitalisation in the maritime sector was then developed and submitted to experts, including academicians and practitioners, for evaluation. The feedback from the expert group was incorporated into the model after a meticulous analysis by the authors. The draft model was submitted to the expert group for final review, and finally, the challenges/barriers to digitalisation in the maritime sector were proposed.

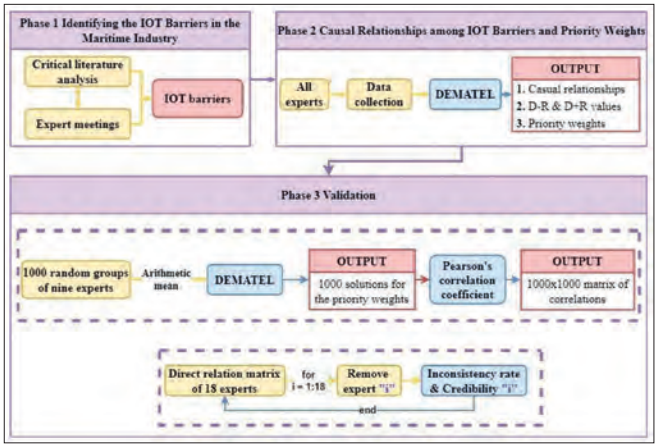

Fig. 1. Proposed solution for identifying the barriers to digitalisation in the maritime sector

The aims of this study were to identify these challenges/barriers and to understand the relationships between them. To categorise these challenges/barriers, an approach based on Decision Making Trial and Evaluation Laboratory (DEMATEL) was used. A systems analysis that includes aspects such as digitalisation and the maritime sector has complex dimensions and relationships that need to be clarified. The DEMATEL method, which was introduced by Fontela and Gabus [31], was used to explore the interdependencies among the criteria and solve for the priority weights of these criteria.

The interdependencies among the criteria indicated cause and effect relationships, and were visualised using an impact-diagraph map. Reliability and generalisability were of primary importance, and needed to be demonstrated.

The data collection process was conducted between August and Septemer 2023. It included a questionnaire associated with the DEMATEL method that contained a pairwise comparison of the challenges/barriers related to digitalisation in the maritime sector, and was based on a five-level scale, where no influence was denoted as '0', low influence as '1', medium influence as '2', high influence as '3', and very high influence as '4'. The questionnaires were delivered to 18 experts, whose profiles are shown in Table 2.

Tab. 2. Profiles of experts

		Frequency	Percentage (%)
Stakeholder group	ICT expert	3	16.7
	ICT manager	5	27.8
	Technology development manager	1	5.5
	Shipyard project manager	2	11.1
	Human resources manager	1	5.5
	General manager ministry advisor	1	5.5
	Ship ownership fleet manager	1	5.5
	Academician	3	16.7
	Port authority	1	5.5
Education	Bachelor's degree	8	44.4
	Master's degree	7	38.9
	PhD	3	16.7
Experience (years)	10–15	11	61.1
	16–20	5	27.8
	21+	2	11.1

RESULTS

Eighteen experts participated in the data collection process, and the direct relation matrix was obtained by averaging their responses to each question. The calculation steps reported by Roy et al. [32] were followed, and the total relation matrix in Table 3 was obtained accordingly.

The highlighted cells in Table 3 indicate the influences of one challenge/barrier over another. These interdependencies were constructed by determining the threshold value for the total relation matrix. The threshold value was set to the average value (μ = 0.279) plus one standard deviation (σ = 0.057) of the total relation matrix. The standard deviation approach is derived from the natural language aspect of opinions, and one standard deviation from the average corresponds to an opinion between important and very important. Hence, Fig. 2 represents the cause and effect relations among the challenges/barriers for values above the threshold.

The D and R values in the total relation matrix (Table 3) represent the sums of the rows and columns, respectively, whereas the D+R and D−R values indicate the intensity and the stance of the influence, respectively. Relatively high D+R values suggest that a given challenge/barrier interacts intensely with others, both in terms of influencing (cause) and being influenced (effect). The significance of B4(8.97), B6(8.79) and B1(8.73) as key drivers, as indicated by their larger D+R values, is evident based on the information in Table 4. Furthermore, positive and negative D−R values suggest that one challenge/barrier influences (cause) and is influenced (effect) by others, respectively. The results obtained from the DEMATEL analysis indicate that challenges/barriers B6(0.93), B10(0.69) and B14(0.63) exert a significant causal influence (cause) on others, whereas challenges/barriers B3(−1.42), B9(−1.25) and B12(−1.05) are strongly affected (effect) by others.

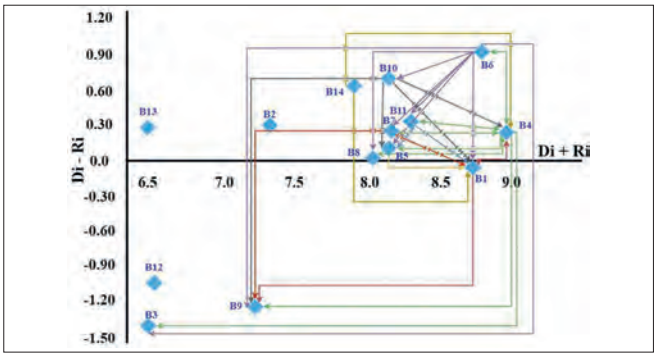

Fig. 2. Impact-diagraph map

A further outcome of the DEMATEL analysis is the identification of the priority weights of challenges/barriers, as shown in Table 3, which are derived from the interdependencies among these barriers. The primary challenge hindering the digitalisation of technology in the maritime sector is B4, with

Tab. 3. Total relation matrix

Barrier	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	D_i	R_i	D_i+R_i	D_i-R_i
B1	0.283	0.288	0.311	0.351	0.326	0.325	0.317	0.324	0.342	0.305	0.327	0.298	0.247	0.298	4.34	4.39	8.73	-0.06
B2	0.314	0.201	0.264	0.294	0.298	0.285	0.277	0.284	0.286	0.276	0.301	0.256	0.209	0.270	3.82	3.52	7.34	0.29
B3	0.204	0.165	0.148	0.198	0.200	0.189	0.181	0.183	0.204	0.174	0.194	0.180	0.144	0.172	2.54	3.95	6.49	-1.42
B4	0.382	0.290	0.336	0.298	0.342	0.337	0.344	0.346	0.368	0.319	0.339	0.326	0.262	0.311	4.60	4.36	8.97	0.24
B5	0.337	0.285	0.309	0.331	0.247	0.308	0.291	0.295	0.308	0.300	0.315	0.276	0.235	0.289	4.13	4.01	8.14	0.11
B6	0.391	0.330	0.349	0.388	0.366	0.283	0.357	0.357	0.375	0.339	0.365	0.334	0.294	0.333	4.86	3.93	8.79	0.93
B7	0.350	0.260	0.303	0.355	0.290	0.305	0.247	0.323	0.340	0.283	0.303	0.308	0.258	0.278	4.20	3.97	8.17	0.24
B8	0.334	0.262	0.302	0.339	0.287	0.295	0.304	0.239	0.323	0.267	0.278	0.294	0.237	0.267	4.03	4.02	8.05	0.01
B9	0.257	0.187	0.226	0.261	0.219	0.220	0.224	0.221	0.188	0.202	0.213	0.212	0.167	0.194	2.99	4.24	7.23	-1.25
B10	0.354	0.302	0.323	0.350	0.342	0.320	0.322	0.328	0.339	0.245	0.335	0.302	0.250	0.307	4.42	3.73	8.15	0.69
B11	0.345	0.297	0.314	0.341	0.337	0.319	0.313	0.314	0.331	0.311	0.256	0.298	0.251	0.302	4.33	3.98	8.31	0.35
B12	0.218	0.170	0.210	0.234	0.195	0.190	0.207	0.219	0.229	0.178	0.191	0.154	0.162	0.180	2.74	3.79	6.53	-1.05
B13	0.280	0.204	0.246	0.280	0.241	0.246	0.270	0.265	0.273	0.223	0.243	0.253	0.156	0.207	3.39	3.11	6.49	0.28
B14	0.347	0.279	0.312	0.344	0.320	0.311	0.311	0.319	0.334	0.308	0.320	0.298	0.236	0.231	4.27	3.64	7.91	0.63

a priority weight of 0.0823 (8.2%). The second most important challenge/barrier to the implementation of digital technologies is B6, which has a priority weight of 0.0815 (8.1%). Closely following this is B1, which is ranked as the third most significant challenge/barrier with a priority weight of 0.0792 (7.9%). B3, with a priority weight of 0.0579 (5.7%), and B12, with a priority weight of 0.0589 (5.8%), emerge as the least significant challenges/barriers to implementing digital technologies in the maritime sector.

Tab. 4. Priority weights of the challenges/barriers associated with digitalisation

Barrier	Weight	Ranking	Barrier	Weight	Ranking
B1	0.0792	3	B8	0.0740	7
B2	0.0663	10	B9	0.0659	11
B3	0.0579	14	B10	0.0769	5
B4	0.0823	1	B11	0.0778	4
B5	0.0749	6	B12	0.0589	13
B6	0.0815	2	B13	0.0591	12
B7	0.0722	9	B14	0.0731	8

Two approaches are employed to address the reliability and generalisability of the findings. The first is based on the inconsistency rate and credibility, which indicate participant consensus [35]. A methodology was employed wherein individual decision-makers were removed one by one, in contrast to the prevailing approach in the existing literature, which involves eliminating a single decision-maker from the group. The greatest inconsistency rate and its related minimal level of credibility were calculated as 1.46 and 98.54% less than the threshold value of 5%. The findings indicate that a group consensus was established, meaning that increasing the number of individuals involved in the decision-making process will not have an impact on the final result.

The second measure is Pearson's correlation coefficient. A total of eighteen experts were randomly assigned to give 1,000 groups consisting of nine experts. A DEMATEL analysis was conducted for each group to obtain the relevant priority weights. Pearson's correlation coefficient was used to assess the correlations among the groups, resulting in a total of 1000×1000 correlations. The minimum correlation between pairs of groups was calculated as $r>.87 (p<0.001)$, indicating a high level of agreement among the groups.

DISCUSSION

In this study, an multiple-criteria decision making (MCDM) problem was analysed based on the use of criteria to determine the challenges/barriers to the use of digital technology in the maritime sector. Firstly, we note that the decision process on the use of digital applications posed a problem for decision makers. In our analysis, the importance levels and weights of the criteria that were thought to be effective for the decisions were determined based on expert opinion, and the challenges/barriers that were thought to be most effective in terms of the establishment/development of digital systems involving large and long-term investments were identified. It was found that all the criteria played important roles in digitalisation. As a result of the analysis, it could be observed that the main challenge/barrier to digitalisation in the maritime sector was B4 (complexity, integration and interoperability problems) with a value of 8.2%. In second place was B6 (economic problems), with a value of 8.1%, and in third place was B1 (privacy and security problems), with a value of 7.9%. B3 (difficulties of performance appraisal), with a weight value of 5.7%, emerged as the least important challenge/barrier to the implementation of digital technologies in the maritime industry. When efforts are made towards digitalisation, a system can easily become vulnerable and unsTable due to its extreme complexity, and may collapse due to the influence of external factors and the occurrence and accumulation of internal turmoil. This is probably why the experts ranked this as the most important criterion. The results of our analysis indicate that B6 (economic problems) with a value of 9.3% exerted a significant causal influence (cause) on other challenges/barriers. Maritime companies in Turkey have a cautious attitude to digitalisation, due to concerns about costs and the difficulty of adaptation. The fragility of the economic structure in Turkey and financial difficulties in the maritime sector emerged as the main challenges to digitalisation. Our results overlap with those of prior researchers who have emphasised the high impact of complexity, integration, privacy, security, economic factors and cost criteria in maritime digitalisation, such as Hossain et al. [2], Bolat and Kayışoğlu [5], Progoulakis et al. [7], Thabit et al. [9], Balkan [11], Al-Fuqaha et al. [17], Alop [21], Shin and Shin [22], and Yorulmaz and Derici [23]. The originality of our study and its difference from the studies mentioned above are associated with two aspects: we determine the basic criteria for the perception of digitalisation in Turkish maritime enterprises, and emphasise the importance of change management in these areas. The sector must have the trained and qualified labourwork to use these digital systems, and to make a quick and accurate results. In order to create a high-quality labour force for the maritime industry, the training system needs to be managed in a dynamic way to meet the needs of the sector. Furthermore, new protocols are required to ensure compatibility in communication between heterogeneous things (living things, vehicles, phones, appliances, goods, etc.). The main priorities include increasing the cyber-awareness of stakeholders, re-evaluating the physical security of digital assets, implementing business continuity plans and ensuring the convergence of cyber-physical security elements. When implementing digitalisation, companies need a clear vision that is shared with employees. In addition to focusing on internal issues, companies should also analyse developments in the IT industry, both locally and globally. A combination of various digital technologies and automation can improve the monitoring, control and planning of business processes in the shipping industry and ports. When planning digital integration, the security of cyber-physical systems should be re-evaluated by focusing on policies and action plans for the business continuity. The participation and support of management in the digitalisation process is one of the key success factors; the expected benefits caused by digitalisation

for the organisation will increase the motivation of managers to invest limited resources in digitalisation [33]. In addition, digitalisation management and monitoring are required to ensure the delivery of high-quality, cost-effective services to customers. This requires the transformation of all fundamental economic paradigms.The most difficult of these is not only the maritime business community, but the entire consumer society adopts these principles and beliefs.

CONCLUSION

In this study, we explored the challenges/barriers to digitalisation in the maritime industry and how these are perceived by employees in the Turkish maritime sector. To categorise these challenges, the DEMATEL approach was used. As a result of this analysis, it was found that the main obstacle to digitalisation in the maritime industry is related to complexity, integration and interoperability problems. In addition, our results indicate that economic problems exert a significant causal influence (cause) on other challenges/barriers. Since the experts who gave their opinions in the study made their evaluations based on the conditions in Turkey, the weights of the criteria are different from the results in the literature. This is important, especially in view of the potential differences in IT structure and culture between countries.

Although a lot of research has been done on digital technologies, there is a need for more efforts to allow this field to mature. In future work, different results may be obtained and evaluated through studies involving users in the maritime sector. A study that gathered the opinions of both experts and employees in the global maritime sector on this subject would be more comprehensive. If different criteria were added to this study, different analysis methods were used, and special conditions for global ports were evaluated, the results could be examined and comparative studies could be carried out. Again, pilot research would be useful, especially in terms of determining the expectations and demands in the sector and in businesses where developmental activities will be carried out in this direction. Differentiation would be revealed more clearly by monitoring the process through a study in which the opinions of employees were collected before and after digital technologies are introduced. In addition, we note that this study was conducted in 2023, only a very short time since the use of digital technologies in the sector and the effects of the global COVID-19 epidemic continued. In this respect, the data that will be obtained as the effects of digitalisation become more evident within a few seasons will enable future studies to be more comprehensive and meaningful.

The Turkish maritime sector still has a long way to go in regard to digitalisation, and it is not yet too late to analyse the current situation and to develop processes and procedures for digitalisation. By identifying weak points and improving these areas, the maritime industry can start investing in digitalization step by step. Decision makers and practitioners in this industry should start by increasing economic investments and creating regulations to solve the basic problems associated with digitalisation. The first Stage will involve creating infrastructure for new technologies and training personnel on the operating and use of new technologies. In addition, employees' awareness of digitalization should be increased, and their training and experience in ensuring awareness should be improved. Digital technologies remain very new and expensive, as global technical standards have not yet been clarified for this industry, which increases the hesitation and resistance of individuals and institutions. Furthermore, as the general governing and rule-maker of the maritime sector, IMO must create norms for digital technologies and take the lead on digitalisation in order to eliminate international differences. Finally, when the rules fully implemented in all countries in accordance with IMO's unified norms, Turkey will be ready to respond to the international digitalisation environment within the framework of cooperation in the future.

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