EVALUATION OF THE EFFECTS OF INDUSTRY 4.0 ON THE MARITIME SECTOR WITH FUZZY AHP – VIKOR HYBRID METHOD

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M Mollaoğlu, Zonguldak Bulent Ecevit University, **H Demirel,** Istanbul Technical University and **A Balın,** Istanbul University

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SUMMARY

Industry 4.0 technology has affected almost every sector in the world. The maritime sector is one of them that has been affected by this technology. In this study, components of the maritime sector were prioritised to find out which of them should comply with this transformation primarily. Many different criteria were taken into consideration for the solution of such problems. Therefore, multi-criteria decision-making (MCDM) methods are required to solve this problem. The Fuzzy AHP (Analytic Hierarchy Process) method was employed for revealing the prioritisation ranking of the industry 4.0 effects on the maritime sector. Afterwards, VIKOR (VlseKriterijumska Optimizacijia I Kompromisno Resenje) method was employed for obtaining the prioritisation level of the maritime sector components for complying with the Industry 4.0 transformation. A group of experts assessed and compared 22 criteria and scored them for each alternative. The proposed method was employed through the experts' assessments. Results were displayed and suggestions were given for further studies.

Keywords: Industry 4.0, Maritime Transportation, Multi Criteria Decision Making, Fuzzy AHP-VIKOR Method

1. INTRODUCTION

Change and development have always been a part of people's lives. These changes have affected people in almost every field from lifestyles to human relations, from education to business. One of the most important triggers of these changes are industrial revolutions. A total of 4 industrial revolutions were taken place until today, and each industrial revolution brought significant changes to the business world. In the first industrial revolution, people invented steam-powered machines (Schwab, 2017; Seremet & Kam, 2019). With the second industrial revolution, electricity was invented, and the mass production process started. Computers and the internet have been used in business processes since the third industrial revolution (Drath & Horch, 2014). The development of automation reduced the human factor in the systems used in production and enabled technological devices to communicate among themselves. This situation has opened a new dimension in technologies and initiated the fourth industrial revolution. Industry 4.0 was first mentioned at the Hannover fair in 2011 (Hermann *et al*., 2016). It aims to decrease production costs, flexible production structure that can adapt to quick changes, establish close relationships among customers, achieve human-machine interaction with interoperability, provide fully autonomous and effective workflow, faster and reliable data flow with every party in the production process (Pereira & Romeo, 2017; Balkan, 2020). In this context, Industry 4.0 technology affected peoples' daily life and almost every sector. One of the sectors that were affected by this transformation is the maritime sector. Maritime transportation is a derived demand, therefore it both affects and is affected by the world economy and trade (UNCTAD, 2020). The maritime sector has also a very dynamic structure that is influenced by changes and regulations. Due to the Industry 4.0 technology and promising transformation effects, the necessity of a study examining the influences of Industry 4.0 on the maritime sector was revealed.

In the literature, authors found various examples of Industry 4.0 technology's effects on the maritime sector. Lukas *et al.* (2014) explained the applications and economical barriers of augmented reality technologies in the maritime sector. Harrison *et al.* (2015) made route selection for automated vehicles in the container ports by using TOPSIS (Technique for Order Preference by Similarity) method. Haraldson (2015) emphasized the importance of coordination between each party thanks to digitalization. However, he also emphasized that companies should not neglect the data-privacy and cyber-security terms. Therefore, Sen (2016) advocated that companies should take precautions such as determining the company priorities, determining the standards, risk assessment. On the other hand, Nita & Mihailescu (2017) stated, the integration of big data and internet of things technologies might help decision-makers and managers to make efficient future decisions. In addition to this, Yang *et al.* (2018) evaluated different perspectives on the internet of things. They explained the internet of things applications on automated ports. The benefits of the internet of things technologies such as decreasing cost in the long term, energy efficiency, and decreasing emissions stem from port equipment. Kostidi & Nikitakos (2019) emphasized the potential benefits of additive manufacturing technology to the maritime sector by providing easy distribution and flexible production options. On the other side, Bucak *et al.* (2019) focused on Industry 4.0's effects on the maritime sector. They made a SWOT analysis to reveal each perspective for maritime business by proposing the AHP method. At the end of the applied method, 'Opportunities' in this technology were found more dominant than others, and 'High Throughput in Ports' was selected as the most important sub-criterion by the experts. Furthermore, Torbacki & Kijewska (2019) applied a different MCDM method. They employed DEMATEL (Decision Making Trial and Evaluation Laboratory) method to evaluate the relationship level of the main components of Industry 4.0 technology in the logistic sector. On the other hand, Zhang & Lam (2019) focussed on the adaptation of big data analytics for maritime businesses. They applied comprehensive MCDM methods for finding out the managerial, cultural, and technical barriers to big data adaptation. As a result of the Fuzzy AHP-TOPSIS methods, the analysis revealed 'Lack of Understanding of How to Use Analytics to Improve the Business' was the most important barrier to big data adaptation. Likewise, Szlapka *et al.* (2019) investigated the Industry 4.0 adaptation of logistic companies. Moreover, they evaluated the company-based adaptation levels by employing the grey decision model method. Balcı (2021) prioritised the digitalization processes in container shipping services by the AHP method. The results showed that the most important main criteria were organizational and collaboration resources. The results also indicated that the most important sub-criteria were organizational culture for learning and innovativeness and integration of digital services.

Even though there was a broad range of MCDM applications in the literature, the general tendency of the studies was on the overview of Industry 4.0 technology. Moreover, most of the studies mentioned the potential transformation of the digitalization processes. As it seen in the literature, studies that evaluated it with MCDM methods generally focused on choosing the best alternative in complicated situations or weighting the criteria that affected the decision-making process. However, any particular study about which component of the maritime sector ought to comply with this transformation primarily was not found. Therefore, the main aim of this study is to prioritise the effects of industry 4.0 on the maritime sector and obtain which components of the maritime sector should undertake and lead Industry 4.0 transformation according to these effects.

In the present study, Fuzzy AHP-VIKOR hybrid method based on fuzzy sets was employed in the prioritising of components of the maritime sector. In the following part, the proposed method and application steps were introduced. After this, the proposed method was applied, the experts who were consulted for their evaluations were introduced and findings of the analysis were presented. In the conclusion, the results were interpreted and suggestions for future studies were given.

2. FUZZY AHP-VIKOR HYBRID METHOD

2.1 FUZZY AHP METHOD

AHP method was first developed by *Thomas L. Saaty in* the early 1970s. AHP method is a decision-making process that helps decision makers to prioritise the many alternatives and weighting the criteria in the process. Thus, this method has been widely used in many different academic and practical areas (Saaty, 1980; Celik & Akyuz, 2018; Gul *et al.,* 2018). This method focusses on the pairwise comparison for each criterion. The most significant advantage of employing this model is to transform qualitative evaluations of the experts to the quantitative variables (Bucak *et al*., 2021). Generally, it is very common that decision makers to use linguistic variables to evaluate criteria and alternatives. On the other hand, linguistic variables are represented by fuzzy numbers (Akyuz, 2016). Table 1 represents the linguistic variables and their fuzzy numbers for the criteria (Chiou & Tzeng, 2001). Table 2 shows fuzzy linguistic scores for the alternatives (Demirel *et al*., 2018). Buckley (1985) proposed Fuzzy AHP to remove uncertainties in experts' reviews and the decision-making process.

Table 1. Fuzzy Evaluation Scores for the Criteria

Linguistic Expression	Scale of fuzzy number
Absolutely Strongly (AS)	(3.50, 4.00, 4.50)
Very Strong (VS)	(2.50, 3.00, 3.50)
Fairly Strong (FS)	(1.50, 2.00, 2.50)
Slightly Strong (SS)	(0.50, 1.00, 1.50)
Equal (E)	(1.00, 1.00, 1.00)
Slightly Weak (SW)	(0.67, 1.00, 1.00)
Fairly Weak (FW)	(0.40, 0.50, 0.67)
Very Weak (VW)	(0.29, 0.33, 0.40)
Absolutely Weak (AW)	(0.22, 0.25, 0.29)

Table 2. Fuzzy Evaluation Scores for the Alternatives

Linguistic Expressions	Fuzzy score
Very poor (VP)	(0.00, 0.00, 1.00)
Poor (P)	(0.00, 1.00, 3.00)
Medium poor (MP)	(1.00, 3.00, 5.00)
Fair (F)	(3.00, 5.00, 7.00)
Medium good (MG)	(5.00, 7.00, 9.00)
Good (G)	(7.00, 9.00, 10.00)
Very good (VG)	(9.00, 10.00, 10.00)

In the following steps, the mathematical equations were given of the Fuzzy AHP method.

Step 1: In this step, the geometric mean of each row of matrices was calculated for weighting the criteria and alternatives. First of all, the geometric means of the first parameters in each row's triangular fuzzy numbers were calculated.

$$a_{1l}=[1\times a_{12l}\times\ldots\times a_{1nl}]^{1/n} \quad (1)$$

After that, the geometric mean of each row's triangular fuzzy numbers second and third parameters was calculated one by one.

Step 2: The sum of the geometric mean values in each row was calculated.

Step 3: Fuzzy weights were calculated accordingly in equation 2.

$$\tilde{U}_i = \sum_{j=1}^{n} \left(\tilde{W}_j \tilde{r}_{ij}\right), \forall i. \tag{2}$$

In equation 3, "$\tilde{U}_i$" referred to utility level of *i*th alternative, "$\tilde{w}_j$", represented the weight of the *j*th criteria. Plus, "$\tilde{r}_{ij}$" revealed the performance of the *i*th alternative for the *j*th criteria.

Step 4: In step 3, it was presented the fuzzy weights of each criterion. However, it was necessary to find Best Non-Fuzzy Performance Value (BNP) of the criteria to make proper evaluation for final ranking. According to the fuzzy logic, defuzzification process of each criterion is required to obtain quantifiable results (Wu *et al.,* 2009; Chen *et al.,* 2011). There are various methods to calculate crisp values of the weighted criteria such as mean of maximal (MOA), center of area (COA) and $\propto$–*cut*. In this article, it was used COA method (See eq. 3) which was a quite easy and practical way to calculate BNP values. The ranking will be performed for each of the criteria by using the BNP value.

$$BNP_0 = \frac{\left[\left(UR_0 - LR_0\right) + \left(MR_0 - LR_0\right)\right]}{3} + LR_0 \tag{3}$$

Step 5: After the defuzzification step Consistency Index (CI) was calculated in equation 4. CI value must be lower than 0.1 (10%) to make acceptable evaluations. Consistency index is calculated to find out the knowledge of experts on a related topic by comparing each criterion. All of the CI results are presented in Appendix Table A1.

$$CI = \frac{\left(\lambda_{max} - n\right)}{\left(n-1\right)} \tag{4}$$

Where *n* refers to the number of criteria.

Step 6: In the last stage, criteria were ranked as the highest value through the lower value. After that Fuzzy VIKOR method was applied for choosing the best alternative in the light of the Fuzzy AHP method.

2.2 FUZZY VIKOR APPROACH

VIKOR, multi-criteria optimization and compromise solution method, first developed by Opricovic in 1998, is the minimum "individual regret" for the "majority" and "opponent" of the decision-maker to rank and select options in a range of alternative sets. This method aims to determine a compromise solution for ranking and selecting considering conflicting criteria. The compromise ranking algorithm VIKOR has the following equations (Opricovic, 1998; Opricovic & Tzeng, 2004; Kaya & Kahraman, 2011; Gul *et al*., 2016; Demirel *et al.,* 2020).

Supposing that a number of decision makers refers , the degrees of alternatives in accordance with each criterion could be calculated as in equation 5.

$$\tilde{x}_{ij} = \frac{1}{K}\left[\tilde{x}_{ij}^{1}(+)\tilde{x}_{ij}^{2}(+)\ldots(+)\tilde{x}_{ij}^{K}\right], \tag{5}$$

where $\tilde{x}_{ij}^{K}$ was the rating of the *K*th expert for *i*th alternative in accordance with the *j*th criterion.

After obtaining the weights of criteria with the help of the Fuzzy AHP method, weighted decision matrices were constructed.

Next step was to determine the fuzzy best value $(FBV, \tilde{f}_j^*)$ and fuzzy worst value $(FWV, \tilde{f}_j^-)$ of all criterion functions. Following equation revealed the calculation of *FBV* and *FWV*. *FBV* is the maximum and *FWV* is the minimum value of each criterion's decision matrix.

Then the values of $\tilde{S}_i$ and $\tilde{R}_i$ were computed with following equations (6 and 7).

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{w}_j \left(\tilde{f}_j^* - \tilde{x}_{ij}\right) / \left(\tilde{f}_j^* - \tilde{f}_j^-\right) \tag{6}$$

$$\tilde{R}_i = \max_j \left[\tilde{w}_j \left(\tilde{f}_j^* - \tilde{x}_{ij}\right) / \left(\tilde{f}_j^* - \tilde{f}_j^-\right)\right] \tag{7}$$

where $\tilde{S}_i$ referred to the separation measure of from the fuzzy best value, and $\tilde{R}_i$ to the separation measure of A_i from the fuzzy worst value.

In the next step, $\tilde{S}^*$, $\tilde{S}^-$, $\tilde{R}^*$, $\tilde{R}^-$ and $\tilde{Q}_i$ values were calculated (See equation 8,9,10):

$$\tilde{S}^* = \min_i \tilde{S}_i \qquad \tilde{S}^- = \max_i \tilde{S}_i \tag{8}$$

$$\tilde{R}^* = \min_i \tilde{R}_i \qquad \tilde{R}^- = \max_i \tilde{R}_i \tag{9}$$

$$\tilde{Q}_i = v\left(\tilde{S}_i - \tilde{S}^*\right) / \left(\tilde{S}^- - \tilde{S}^*\right) + (1-v)\left(\tilde{R}_i - \tilde{R}^*\right) / \left(\tilde{R}^- - \tilde{R}^*\right) \tag{10}$$

The index $min_i\tilde{S}_i$ and $min_i\tilde{R}_i$ were related to maximum majority rule, and a minimum individual regret of an opponent strategy respectively. Plus, v referred the confidence level of the experts which is between 0-1 value. In this study, v was assumed to be 0.5.

Next stage was the defuzzification of the triangular fuzzy numbers $\tilde{Q}_i$ and ranking the alternatives by the index $\tilde{Q}_i$. Triangular fuzzy numbers $\tilde{C} = (c_1, c_2, c_3)$ can be converted into a crisp number in equation 11:

$$P\left(\tilde{C}\right) = C = \frac{c_1 + 4c_2 + c_3}{6} \tag{11}$$

Consequently, the best alternative with the minimum of Q_i was calculated. Figure A1 (see Appendix Figure A1) summarized the Fuzzy AHP-VIKOR hybrid method.

3. AN APPLICATION FOR PRIORITISATION OF THE COMPONENTS OF THE MARITIME SECTOR

In the maritime sector, it is significant to reveal the prioritisation level of the maritime business components (Port, Shipyard, Shipping Companies, Public Institutions) under the effects of the Industry 4.0 transformation. In this study, the proposed method was employed to find out the weights of the effects of Industry 4.0 technology on the maritime sector and prioritisation ranking of components for complying with this transformation. 5 main criteria, and also 22 sub-criteria were determined under the main criteria. Forming main criteria and sub-criteria provides decision makers more consistent and noncomplex decision-making hierarchy. In the determination process of the criteria, opinions were considered with experts from different components of maritime business and existing literature about the effects of Industry 4.0 technology in maritime business evaluated. Main criteria C1 and sub-criteria (C1.1, C1.2, C1.4, C1.5, and C1.6) were inspired from the Harrison *et al.,* (2015), Yang et al., (2018), and Balkan (2020) studies. C1.3 was taken from the expert opinions. Main criteria C2 and sub-criteria (C2.1, C2.2, and C2.3) were inspired from Mandalaki & Manesis, (2013), Sen *et al.,* (2016), Sanchez-Gonzalez *et al.,* (2019). Main criteria C3 and sub-criteria (C3.1, C3.2, C3.3, and C3.4) on the other hand, were taken from Fruth & Teuteberg (2017), Kostidi & Nikitakos (2019). Sub-criteria C3.3 and C3.4 were inspired by expert assessments. The main criteria which are C4 and sub-criteria (C4.1, C4.2, C4.3, and C4.4) were taken from Haraldson (2015), Stanić *et al*., (2018), and Balkan (2020). Main criteria C5 and sub-criteria (C5.1, C5.2, C5.3, C5.4, and C5.5) were inspired from Sanchez Gonzalez *et al.,* (2019). C5.3, C5.4 and C5.5 were taken into consideration after expert assessment. Determined criteria and their brief descriptions are presented in Table 3. On the other hand, components of the maritime sector and its short definitions, which are also alternatives of the study, were given in Table 4. Components of the maritime business were taken from expert opinions and literature (Takahashi, 2016; Stanić *et al*., 2018; Yang *et al.,* 2018).

Table 3. Determined Criteria and Brief Descriptions

Main Criteria	Criterion Number	Name of the Criterion	Brief Description
C1. Autonomous Operation	C1.1	Carrying on the operations by using internet of things technologies	Connecting all electronic devices that are involved in the operation to the internet or each other.
	C1.2	Using autonomous vehicles	Conducting the whole vehicles involved in the operation autonomous way.
	C1.3	Augmented reality technology	Real-world objects obtain a rich physical appearance through computers.
	C1.4	Equipment monitoring	Tracking and tracing the equipment involved in the operational process.
	C1.5	Using the equipment that have artificial intelligence	The equipment involved in the operational process has artificial intelligence technology.
	C1.6	Human-machine interaction	People and machines in operation are in constant interaction and communication.
C2. Safety and Security	C2.1	Data privacy	Companies or institutions keep their information confidential or limited to other parties.
	C2.2	Cyber security	Companies or institutions always be able to protect themselves against external cyber threats.
	C2.3	Simulation technology	Making rehearsals of operations with the help of simulation technology to avoid safety and security problems.
C3. Sustainability	C3.1	Cloud computing	Sharing information within a certain system among employees.
	C3.2	Using additive manufacturing technologies	Production with the help of 3D printers.
	C3.3	Providing continuous trainings	Providing regular and continuous trainings for employees to keep up with changing technologies.
	C3.4	Generating new business models	With the development of technology, the emergence of different internet-based business lines and models.

C4. Coordination	**C4.1**	Providing strong data and information flow among the supply channels	The strong and continuous flow of data and information between different channels in the maritime industry.
	C4.2	Communicating by cyber-physical systems	Providing communication between the parties by connecting the physical world to the virtual computing world with the help of sensors.
	C4.3	Horizontal and vertical integration	Horizontal Integration refers to the information and process flow of businesses both within themselves and with other businesses. On the other hand, Vertical integration refers to the unification of flexible and smart systems that play a role in ensuring this integration.
	C4.4	Interoperability	More than one piece of equipment can work together in a compossible way.
C5. Environmental Effect	**C5.1**	Optimizing resources through 3D printing	Keeping the resource efficiency at the optimum level with the help of 3D printers.
	C5.2	Using electrical or hybrid equipment and systems	Continuation of the systems used with resources that are less harmful to the environment.
	C5.3	Efficient consumption of energy resources	Consumption of energy resources is more efficient way.
	C5.4	Using renewable energy systems	Using renewable resources such as solar and wind power etc.
	C5.5	Environmental supply chain operations	Using systems or equipment that diminish the environmental impact of operations involved in the supply chain.

Table 4. Components of The Maritime Sector and Short Definitions

Number	Name	Definition
A1	Port	Ports are coastal facilities where ships' loading and unloading activities are carried out, appropriate logistic services are provided to cargoes, or transportation modes of cargo are changed.
A2	Shipyard	Shipyards are the institutions that undertake the construction of ships, boats, tugboats, fishing boats, and similar vessels moving in the sea.
A3	Shipping Companies	Shipping companies are the institutions that directly or indirectly play a role in the transportation of a product, raw material, or final product from one point to another, carry out their operational process and also follow the documentation processes. This sample includes ship or tugboat owning companies, broker companies, freight forwarders.
A4	Public Institution	They are the institutions that play a role in the auditing, regulating, law-making and implementing of these regulations in maritime transport. This sample includes port authorities, the maritime general directorate, and other related institutions.

After the presentation of whole criteria and alternatives, the application of the study can be expressed. The hierarchical structure of the study was formed according to these criteria and alternatives. Figure A2 (see Appendix Figure A2) shows the research model.

The criteria were evaluated through pairwise comparisons by ten experts (EXP1, EXP2, EXP3,…., EXP10). The expert's details were presented in Table 5. According to the assessments of the experts, the integrated criteria weight matrix was formed. As an example, a pairwise comparison questionnaire of the main criteria was given in Table 6. The linguistic expressions and their fuzzy sets for the criteria were given in Table 1. After the expert's evaluations, the Consistency Index were calculated and the results for the whole experts were given in Table A1 (see Appendix Table A1).

Table 5. Details of the Experts

Expert No	Area of Maritime Business	Experience	Educational Level
EXP-1	Port	30 years	Graduate
EXP-2	Port	18 years	Graduate
EXP-3	Port	10 years	Graduate
EXP-4	Port	6 years	Master's Degree
EXP-5	Public Inst.	5 years	Graduate
EXP-6	Public Inst.	12 years	Graduate
EXP-7	Shipping Comp	20 years	Master's Degree
EXP-8	Shipping Comp	28 years	Graduate
EXP-9	Shipyard	7 years	Graduate
EXP-10	Shipyard	14 years	Graduate

Table 6. Pairwise Comparison Survey of Main Criteria

		C1	C2	C3	C4	C5
C1	EXP-1	1	SS	FS	FS	AS
	EXP-2	1	FW	SW	FS	SW
	EXP-3	1	SW	SS	E	VS
	EXP-4	1	FW	E	FS	FS
	EXP-5	1	VW	FW	SW	AW
	EXP-6	1	FW	AW	E	FW
	EXP-7	1	AS	SS	SS	AS
	EXP-8	1	FS	SS	SS	SW
	EXP-9	1	AW	E	E	E
	EXP-10	1	SW	FS	SS	FS
C2	EXP-1	SW	1	SS	SS	VS
	EXP-2	FS	1	SS	AS	SS
	EXP-3	SS	1	VS	SS	AS
	EXP-4	FS	1	FS	AS	AS
	EXP-5	VS	1	SS	FS	SW
	EXP-6	FS	1	FW	FS	E
	EXP-7	AW	1	VW	VW	E
	EXP-8	FW	1	SW	SS	VW
	EXP-9	AS	1	AS	AS	AS
	EXP-10	SS	1	AS	VS	AS
C3	EXP-1	FW	SW	1	E	FS
	EXP-2	SS	SW	1	VS	E
	EXP-3	SW	VW	1	SW	SS
	EXP-4	E	FW	1	FS	FS
	EXP-5	FS	SW	1	SS	SW
	EXP-6	AS	FS	1	AS	FS
	EXP-7	SW	VS	1	E	VS
	EXP-8	SW	SS	1	E	FW
	EXP-9	E	AW	1	E	E
	EXP-10	FW	AW	1	SW	E
C4	EXP-1	FW	SW	E	1	FS
	EXP-2	FW	AW	VW	1	VW
	EXP-3	E	SW	SS	1	VS
	EXP-4	FW	AW	FW	1	E
	EXP-5	SS	FW	SW	1	VW
	EXP-6	E	FW	AW	1	FW
	EXP-7	SW	VS	E	1	VS
	EXP-8	SW	SW	E	1	AW
	EXP-9	E	AW	E	1	E
	EXP-10	SW	VW	SS	1	SS
C5	EXP-1	AW	VW	FW	FW	1
	EXP-2	SS	SW	E	VS	1
	EXP-3	VW	AW	SW	VW	1
	EXP-4	FW	AW	FW	E	1
	EXP-5	AS	SS	SS	VS	1
	EXP-6	FS	E	FW	FS	1
	EXP-7	AW	E	VW	VW	1
	EXP-8	SS	VS	FS	AS	1
	EXP-9	E	AW	E	E	1
	EXP-10	FW	AW	E	SW	1

"Note: AS= Absolutely Strong, VS= Very Strong, FS= Fairly Strong, SS= Slightly Strong, E= Equal, SW= Slightly Weak, FW= Fairly Weak, VW= Very Weak, AW= Absolutely Weak"

According to the Table A1 consistency index of each expert's evaluation was below 0.10. Therefore, criteria can be weighted, and alternatives can be prioritised with respect to these results. According to the integrated evaluations, weights of the criteria are shown in Table 7.

Table 7. Fuzzy AHP Weight and BNP Values of Each Main and Sub-Criteria

	Criteria	Fuzzy Weight	BNP
C1	**AUTONOMOUS OPERATION: 0.204**		
C1.1	Carrying on the operations by using internet of things technologies	(0.04,0.041,0.042)	0.0411
C1.2	Using autonomous vehicles	(0.039,0.039,0.041)	0.0398
C1.3	Augmented reality technology	(0.018,0.018,0.018)	0.0179
C1.4	Equipment monitoring	(0.04,0.041,0.042)	0.0411
C1.5	Using the equipment that have artificial intelligence	(0.033,0.032,0.031)	0.0320
C1.6	Human-machine interaction	(0.033,0.032,0.031)	0.0318
C2	**SAFETY and SECURITY: 0.268**		
C2.1	Data privacy	(0.123,0.121,0.118)	0.1208
C2.2	Cyber security	(0.074,0.077,0.077)	0.0757
C2.3	Simulation technology	(0.071,0.07,0.073)	0.0715
C3	**SUSTAINABILITY: 0.212**		
C3.1	Cloud computing	(0.06,0.061,0.061)	0.0609
C3.2	Using additive manufacturing technologies	(0.037,0.035,0.034)	0.0350
C3.3	Providing continuous trainings	(0.06,0.062,0.061)	0.0611

C3.4	Generating new business models	(0.055,0.054,0.056)	0.0553
C4	**COORDINATION: 0.155**		
C4.1	Providing strong data and information flow among the supply channels	(0.049,0.051,0.05)	0.0499
C4.2	Communicating by cyber-physical systems	(0.038,0.037,0.037)	0.0374
C4.3	Horizontal and vertical integration	(0.025,0.025,0.024)	0.0248
C4.4	Interoperability	(0.042,0.042,0.044)	0.0428
C5	**ENVIRONMENTAL EFFECT: 0.161**		
C5.1	Optimizing resources through 3D printing	(0.014,0.014,0.014)	0.0140
C5.2	Using electrical or hybrid equipment and systems	(0.036,0.036,0.035)	0.0356
C5.3	Efficient consumption of energy resources	(0.042,0.042,0.041)	0.0416
C5.4	Using renewable energy systems	(0.041,0.042,0.041)	0.0413
C5.5	Environmental supply chain operations	(0.027,0.028,0.03)	0.0288

According to the expert's evaluations, the two most significant criteria were determined as C21- Data privacy (0.1208) and C22- Cyber security (0.0757). On the other hand, the two least important criteria were found C5.1- Optimizing resources through 3D printing (0.0140) and C1.3- Augmented reality technology (0.0179) respectively.

Table A2 (see Appendix Table A2) presents the assessments from the 10 experts used for prioritising the alternatives. The linguistic expressions and their fuzzy sets for the alternatives were given in Table 2. These data were used for applying the Fuzzy VIKOR method.

The assessment values were given by experts for prioritising the components of maritime businesses. These criteria were evaluated under the effects of Industry 4.0 technology. Calculations of S, R, and Q values through the expert's evaluation were given in Table 8. Furthermore, Table 9 expresses the prioritisation ranking of the components of maritime business with respect to the results of the evaluation.

Table 8. The Evaluation Value of Each Component

	A1	A2	A3	A4
S	0.464	0.486	0.503	0.457
R	0.052	0.078	0.077	0.042
Q	0.197	0.821	0.973	0.016

Table 9. Prioritisation Ranking of The Components

	A1	A2	A3	A4
S	2	3	4	1
R	2	4	3	1
Q	2	3	4	1

As it expressed in Table 8 and Table 9, Fuzzy VIKOR method's proposed final prioritisation ranking was obtained as A4 > A1 > A2 > A3. Besides, this method compared with the results of the Fuzzy AHP. The prioritisation ranking of the alternatives under the Fuzzy AHP was A4: 6.913 > A1: 6.851 > A2: 6.770 > A3: 6.680. Ranking of every component of maritime businesses same for the Fuzzy VIKOR method. These two approaches significantly revealed the same results. Furthermore, sensitivity analysis was applied to review of the strongness and persistency's of employed method. This analysis was performed by using v values, which refers to the confidence level of experts. v value changes 0.1 increment between 0 and 1 values. In this research, the v value assumed as 0.5 were interpreted as their values and ranking in Table 8 and 9. The result of the sensitivity analysis for each increment in *v* values is shown in Table 10 and Table 11. Moreover, their graphically presentation were in Figure 1 and Figure 2. In Figure 1, it was revealed the graph of prioritisation ranking changes for each alternative under different v values. Alternative values of A1 and A2 have a negative correlation between values. However, A3 and A4 have a positive correlation with the different v values. Prioritisation ranking on the other hand, changed only 0.0 and 0.1 values for A2 and A3. Apart from this, there were no ranking changes for the alternatives.

Table 10. The Q_i for Different v Values

	A1	A2	A3	A4
v=0.0	0.234	1.000	0.946	0.002
v=0.1	0.226	0.964	0.951	0.005
v=0.2	0.219	0.929	0.956	0.008
v=0.3	0.212	0.893	0.962	0.010
v=0.4	0.205	0.857	0.967	0.013
v=0.5	0.197	0.821	0.973	0.016
v=0.6	0.190	0.786	0.978	0.018
v=0.7	0.183	0.750	0.984	0.021
v=0.8	0.176	0.714	0.989	0.023
v=0.9	0.169	0.678	0.995	0.026
v=1.0	0.161	0.643	1.000	0.029

Table 11. The Prioritisation Ranking for Different v Values

	A1	A2	A3	A4
v=0.0	2	4	3	1
v=0.1	2	4	3	1

v=0.2	2	3	4	1
v=0.3	2	3	4	1
v=0.4	2	3	4	1
v=0.5	2	3	4	1
v=0.6	2	3	4	1
v=0.7	2	3	4	1
v=0.8	2	3	4	1
v=0.9	2	3	4	1
v=1.0	2	3	4	1

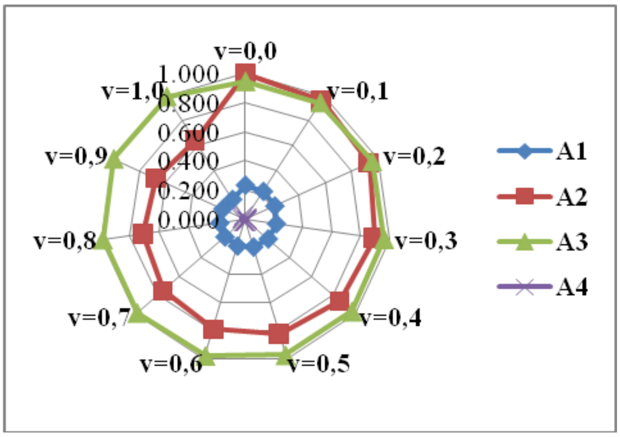

Figure 1. Sensitivity Analysis for Q_i Values

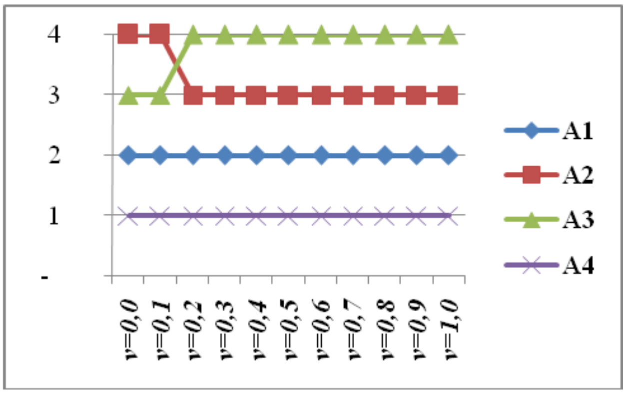

Figure 2. Ranking Changes for Different v Values

4. CONCLUSION

In recent years, different studies were made for evaluating the effects of Industry 4.0 technology on the maritime sector. In this study, the Fuzzy AHP-VIKOR hybrid method was employed to find out the effects of Industry 4.0 technology on the maritime sector. Experts' opinions were assessed with fuzzy-based sets to remove inconsistent judgements and possible conflicting outcomes.

In this paper, firstly, consistency indices were calculated for each experts' evaluations to be able to apply the Fuzzy AHP method. Secondly, criteria were weighted according to the experts' evaluations by Fuzzy AHP, which is a great method for weighting the criteria. After then, alternatives were prioritised to reveal which components of the maritime sector need to first comply with the Industry 4.0 transformation. Consequently, the "Data Privacy" and "Cyber Security" criteria have the highest importance level under the Industry 4.0 effect respectively. In 2017, Maersk shipping company has been affected from encrypted malware and more than 200 million USD was lost (Soyer, 2020). Furthermore, the Mediterranean Shipping Company (MSC) closed down its website of the company for data protection from malware attacks. (Seatrade-Maritime, 2022). This situation caused the company to have monetary and operational losses. It is clearly seen that data privacy and cyber security have the utmost importance to preventing the maritime business components from huge financial losses. As a result of the alternative evaluations, "Public Institutions" were determined as the most prioritised component among the alternatives. "Ports" were found as the second prioritised alternative by a narrow margin in comparison with public institutions. In the meantime, "Shipyards" have the 3rd prioritisation ranking. On the other hand, "Shipping Companies" have the lowest prioritisation ranking among the others. According to the sensitivity analysis, were shown in Figure 1 and Figure 2, the prioritisation ranking of the alternatives was consistent except for too little differences. These figures revealed the strongness and persistency of the employed method.

When the results were evaluated, they clearly revealed that public institutions should have the prior role of complying with the Industry 4.0 transformation. On the other side, ports should adapt to Industry 4.0 transformation at least as much as public institutions and minimize the margin of human error by transforming all systems involved in their operations into an autonomous form. On the other hand, it is suggested that ports give utmost importance to issues related to information privacy and cyber security in terms of automation systems. Malwares and cyber-attacks may cause a huge amount of financial damage to maritime business components. Although, it was created a prioritisation level for the components, every sector should be prepared for digital acceleration.

The questionnaire applied specific group of experts might be interpreted as a limitation of the study. Increasing the number and variety of experts may enhance the purity of the study. In addition to this, other MCDM methods such as TOPSIS and ELECTRE (Elimination Et Choix Traduisant la Realité) may be employed to the similar problem for comparing the results.

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6. APPENDIX

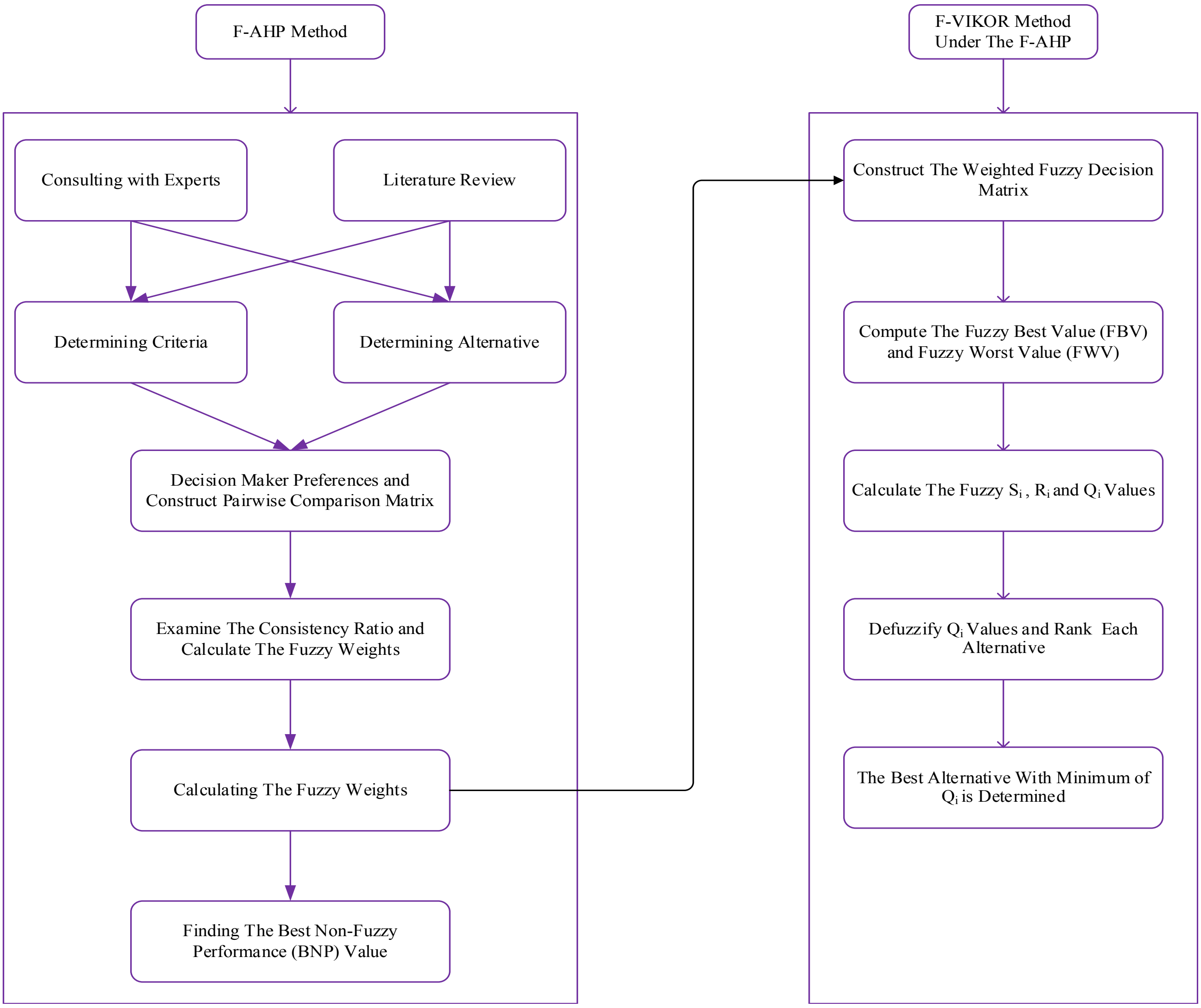

Figure A1. Fuzzy AHP-VIKOR Hybrid Method Process

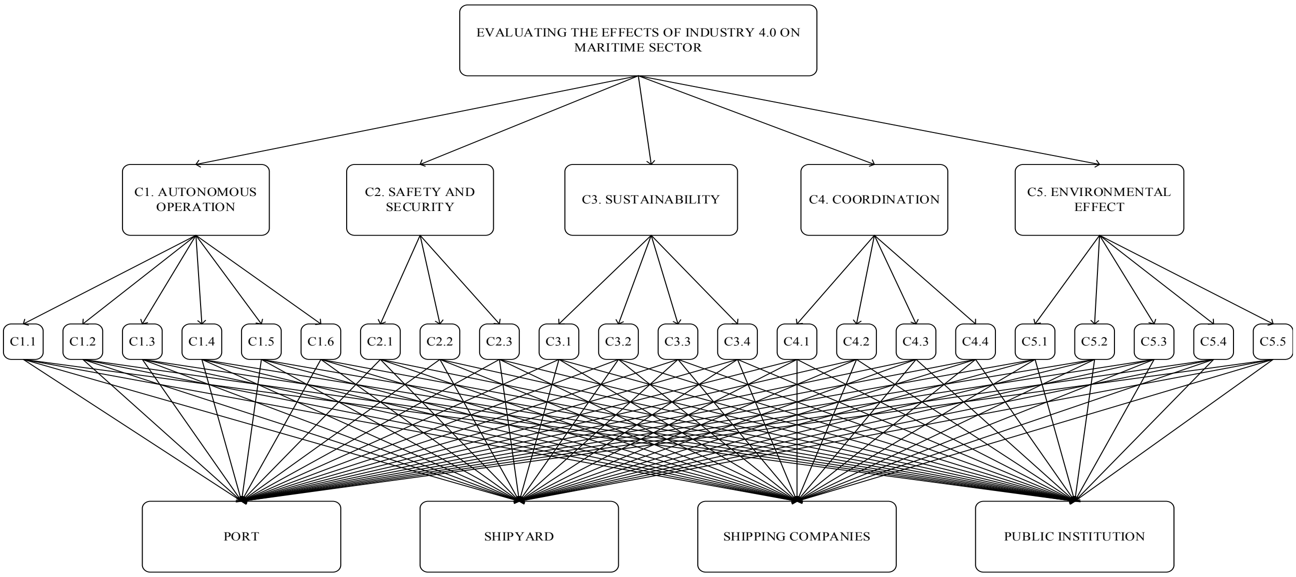

Figure A2. Research Model

Table A1. Consistency Index Results for Each Experts

Expert	Main Criteria	Autonomous Operation	Safety and Security	Sustainability	Coordination	Environmental Effect
EXP-1	0.04	0.03	0.00	0.01	0.03	0.04
EXP-2	0.04	0.06	0.00	0.06	0.05	0.04
EXP-3	0.02	0.06	0.07	0.04	0.05	0.03
EXP-4	0.04	0.02	0.01	0.03	0.05	0.03
EXP-5	0.05	0.03	0.00	0.06	0.03	0.04
EXP-6	0.04	0.07	0.00	0.05	0.09	0.04
EXP-7	0.03	0.08	0.00	0.06	0.03	0.02
EXP-8	0.10	0.09	0.03	0.09	0.01	0.06
EXP-9	0.00	0.02	0.03	0.03	0.00	0.00
EXP-10	0.02	0.04	0.03	0.06	0.03	0.05

Table A2. Linguistic Variables of Alternative Evaluations

		C1.1	C1.2	C1.3	C1.4	C1.5	C1.6	…	C5.1	C5.2	C5.3	C5.4	C5.5
A1	EXP-1	P	MG	F	F	MP	G	…	P	G	G	G	G
	EXP-2	F	MG	F	G	F	G	…	P	G	G	MG	G
	EXP-3	MG	G	MP	MG	P	MG	…	MP	G	G	G	G
	EXP-4	G	G	G	G	MG	G	…	MG	G	G	MG	G
	EXP-5	MP	P	MP	F	P	MP	…	P	F	MG	MG	MG
	EXP-6	G	G	F	G	G	MG	…	P	G	G	G	G
	EXP-7	MG	G	MP	F	G	MG	…	MP	G	G	G	G
	EXP-8	MG	G	F	G	G	G	…	P	G	G	G	G
	EXP-9	F	F	G	G	F	G	…	P	G	G	G	G
	EXP-10	MG	G	MG	G	G	MG	…	F	G	G	G	MG
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
A4	EXP-1	MG	MG	F	MG	G	MG	…	F	MG	MG	MG	MG
	EXP-2	MG	MP	P	MG	MP	F	…	MP	MG	MG	MP	G
	EXP-3	G	G	F	MG	MP	MG	…	MG	G	G	G	MG
	EXP-4	G	MP	G	G	MP	MP	…	MG	P	P	P	P
	EXP-5	P	P	P	MP	P	P	…	P	P	G	G	G
	EXP-6	G	P	P	P	P	P	…	P	P	G	G	G
	EXP-7	MG	G	F	MG	G	MG	…	MG	G	G	G	G
	EXP-8	G	G	F	G	G	G	…	MG	G	G	G	G
	EXP-9	G	P	P	G	P	P	…	P	G	G	G	G
	EXP-10	MG	F	F	G	MG	F	…	F	F	MG	MG	MG

