THE APPLICATION OF FUZZY AHP – VIKOR HYBRID METHOD TO INVESTIGATE THE STRATEGY FOR REDUCING AIR POLLUTION FROM DIESEL POWERED VESSELS

(DOI No: 10.3940/rina.ijme.2020.a3.621)

H Demirel, **M Mollaoğlu**, **U Bucak**, Zonguldak Bülent Ecevit University, **T Arslan**, Med Marine Company and **A Balin**, Istanbul University

KEY DATES: Submitted: 26/02/20; Final acceptance: 01/07/20; Published: 07/10/20

SUMMARY

The negative impact of air pollution on human health had become a vital issue as a result of the increasing use of fossil fuels in recent years. In this context, maritime transportation is one of the most contaminant sectors by using much more fossil fuels. Ships which have a major role in maritime transport, directly affect human health via its emissions, especially in marine areas close to the land such as around the ports, canals, and straits. In this study, strategies were gathered by evaluating International Maritime Organization (IMO) regulations, European Union (EU) recommendations and the applications of the ship owner companies to reduce air pollution stem from ships, and considering the priority perception of these strategies, the effect level of the strategies at the marine areas where ships are approaching the land was analysed by the Fuzzy Analytic Hierarchy Process-Visekriterijumska Optimizacija I Kompromisno Resenje (AHP-VIKOR) hybrid method. As a result of the study, the most effective strategies appeared as “Forbiddance of Heavy Fuel Oil (HFO) usage on Ships” and “Detection of Low Sulphur Fuel Usage by the help of Remote Detector Systems”, and it was seen that these strategies would be most effective in canal or strait passing of the ships. It was also revealed that the relevant expert opinions and IMO regulations meshed together, and it was pointed out the applications for increasing fuel quality.

1. INTRODUCTION

According to the International Energy Agency (IEA) (2017), in 1971 CO_2 emissions depend on the global fuel consumption were measured 15 gigatons, in response to 32 gigatons measured in 2015 which increased approximately 2 times vis-à-vis results made in 1971. Annual gas emissions that caused by maritime transportation sector equals approximately 2.5% of the total annual gas emissions with its about 940 million tonnes of CO_2 emissions (ec.europa.eu). Ships cause air pollution through notably including greenhouse gasses (GHGs), nitrogen oxide (NO_x), sulphur oxide (SO_x) and particulate matters (Zhu *et al.,* 2017). Uddin and Karim (2018) emphasized that a major interest was made in the GHGs from among the other marine pollutants from ships. For instance, gas emissions caused by the accommodation of a passenger on the cruise ship were determined to be 5 times higher than those emitted by visitors staying in any luxury hotel (Maragkogianni *et al.,* 2015). CO_2 emissions from maritime transportation are higher than the gas emissions created by Germany, known as one of the most important industrial countries (EC, 2013). At the same time, ships are the most important manufacturers of particulate matter at the port towns, and they compound diseases that threaten human health, especially asthma and heart attack, increase the number of in-patients and premature death (Corbett *et al.,* 2007). Air pollution caused the death of 50.000 people only in Europe (EC, 2011).

At this point, IMO brought a new regulation in 1997, called “Air Pollution Prevention at Sea” as 6^{th} Annex of The International Convention for the Prevention of Pollution from Ships (MARPOL) agreement to prevent air pollution from ships. This agreement came into force in 2005, was updated in 2008. According to this update, the new decisions that are ‘ships should not use more than 0.5 % sulphur containing fuel’ and ‘they should have scrubber to use up to 3.5 % sulphur containing fuel’ would had been valid from the year 2020. As a result of this regulation, especially low sulphur fuel prices increased end of the 2019. So, ship owners lined up to equip scrubbers in shipyards. Thus, advance ordering customers gained a competitive advantage. However, COVID-19 pandemic gave global trade a deep shock as of first month of 2020 and the boot is on the other foot. Oil prices regressed all time low due to shut downs of the manufactories and the Saudi/Russian fuel price war. Shipyards were shut down as happened in other manufactories. In this way, competitive advantage passed into other hand. And non-scrubber fitted ships, especially tankers, navigated with high freight rates and low fuel prices. On the other hand, CO_x levels had been reduced by nearly 50 per cent in 2020 (www.bbc.com). Surely the lion’s share of this achievement should go for pandemic, but IMO 2020 restrictions have success in itself. Lately, number of members of International Windship Association (IWSA), not-for-profit organisation that is dedicated to the supporting direct wind propulsion in commercial shipping, have increased day by day. As an overview, an alternative fuel seeking (methanol, wind force, etc.) for decarbonisation of the leading ship owner companies (Maersk, K Line, etc.) displayed success of IMO 2020 restrictions.

Recently, companies generally preferred to use the scrubber system owing to its cost advantage to comply with IMO 2020 regulations. This system works great as well as brings some disadvantageous was seen. Accordingly, usage of scrubber in ships causes disadvantageous situations such as occupying the body volume of the ships, increasing the lightship weight and reducing the ship's balance (Chorowski *et al.,* 2015). On the other hand, glowing enhancement, oil emulsion or biological fuel usage come into the forefront as some of the methods used for reducing air pollution. Inadequate quality exhaust gas emissions of old ships and the high costs caused these methods to be ineffective in solving these problems. (Pham & Nguyen, 2015). Kopela (2017) presented her apprehensions about the challenges that maybe happened in the oversight of these precautions taken related to fuel use and detecting possible violations. Accordingly, she emphasized that it would be difficult to control the use of appropriate fuel in open seas and that the requirement for high-cost equipment in control by the coastal states could not be fulfilled regularly in certain regions. While the restrictive regulation introduced by IMO is very important step to reduce air pollution from ships, considering the above situations, it should be considered to improve additional strategies and to encourage precautions to reduce air pollution, rather than just conducting studies to enhance fuel quality. Beşikçi *et al.* (2016) evaluated Ship Energy Efficiency Management Plan (SEEMP) adopted by IMO and its precautions on ships' energy efficiency by using Fuzzy AHP method. As it is known, IMO brought a series of regulations restricting air pollution from ships, and the last regulation came into force on January 1, 2020. Mueller *et al.* (2011) stated that the studies focused especially on the detection of regional air pollution, the type of ship, the type of fuel and the characteristics of ship emissions. As a result of the literature review conducted in that study, the researchers generally tackled issues such as regional measurement strategies to comply with IMO 2020 and the actual situation of the world fleet against IMO 2020. Among the studies worked on adaptation strategies, the idea of improving fuel quality or usage of alternative fuels came into prominence predominantly. Zhu *et al.* (2017) determined eight strategies for preventing air pollution from ships. Although, Liquified Natural Gas (LNG) fuel use was determined as the most effective technical strategy against the emission, the most effective economic strategy is the 'Diesel Particulate Filter System' usage.

Likewise, Chorowski *et al.* (2015) demonstrated the technical suitability of LNG fuel use on ships especially in Special Emission Control Areas (SECA) to comply with the restrictions brought by IMO. Nizic *et al.* (2017) upheld the fuel type should be changed to adapt IMO 2020. They evaluated strategies such as using lower sulphur fuel, equipping scrubber system or using LNG fuel in terms of investment and operating costs, the convenience of repair and maintenance and safety level. In this sense, Bailey & Solomon (2004) suggested that diesel fuel used by ships should be replaced with cleaner versions, even LNG and propane gas should be used as alternative fuels. Pham & Nguyen (2015) made suggestions for cleaning of the exhaust gas in the central gas cleaning system before being released into the air with the 'Exhaust Gas Treatment System'. It is important to follow and monitor these proposed strategies for improving fuel quality as much as they were put into action. Chen *et al.* (2019) who emphasized the drone usage for controlling gas emissions of ships, made recommendations on how to use the drone at the operational, tactical and strategic levels. Saxe & Larsen (2004) who referred to the importance of monitoring gas emissions, defended that nitrogen dioxide emissions from ships in Danish ports affected people employed in the ports. And they suggested some strategies should be improved to control and measure nitrogen dioxide emissions of ships in the port area. On the other hand, Borkowski *et al.* (2013) drew attention on the emissions emitted by auxiliary generators used by ships during their stay at the port, depending on the generator type and frequency of usage.

Because of these reasons, there is a validity problem in the measurements. The authors tested the model that has been developed for solving this problem, on a ROPAX (roll-on/roll-off passenger) ship. Maragkogianni *et al.* (2015) performed a similar emission measurement on cruise ships and detected the emission levels emitted by ships in the 5 important Greek ports in 2013 and determined that these ships emitted the highest emission in the port of Piraeus. Moreover, the damage caused by pollution from cruise ships to all ecology in Greece had been evaluated by CAFE and NEEDS methods and according to the optimistic scenario, these losses would have 12.4 million euros social cost, would have stood in 24.3 million euros for the pessimistic scenario. McArthur & Osland (2013) who carried out similar study at Bergen port, determined that the cost of air pollution from ships to the region would have been 38.02 million Norwegian kroner according to the optimistic scenario and that would have stood in 172 million Norwegian kroner according to the pessimistic scenario by using CAFE method. Additionally, McArthur & Osland (2013) advised about the usage of electric both at port and ship side to reduce air pollution in ports. Ballini & Bozzo (2015) conducted a cost-benefit analysis of providing coastal electricity to the ship for reducing air pollution from ships in ports and they emphasized that carbon dioxide emissions would have been decreased by using this system. They also emphasized that this system is economically worthy for investment. In these studies, the gas emission levels of the ships were measured outside of the ports. For instance, Kesgin & Vardar (2001) made emission measurements from ships in the Straits of Istanbul and Canakkale and they determined that the emissions of transhipment ships have more than 50% share in all transport emissions. Furthermore, Matthias *et al.* (2010) made measurements for air pollution on the North Sea, they underlined that this region should be declared as a private sphere mentioned in IMO regulation related with fuel quality decisions to reduce emissions.

Some researchers stated what extent of air pollution originating from ships at the times they each wrote were. They also expressed what kind of precautions taken and the regulations applied against this pollution. Bluewater Network (2000) drew attention to awareness of air pollution originating from ships before spreading large masses and the report found that current IMO regulations at that time were inadequate. So, the United States Environmental Protection Agency (US EPA) should had extended the content of relevant regulations. Lin & Lin (2004) laid emphasis on the importance of the protocol that IMO accepted in 1997 and implemented in 2005 and aimed at reducing the release of gases such as nitrogen oxide, sulphur oxide and volatile organic compounds emitted from ships. In their study, they also emphasized that this protocol should be obligatory for all ship owners. Burgel (2007) expressed that sulphur emissions are the most polluting contaminant among the whole pollutants widely used by ships and requirement to be reduced is exist. Following this, Wang & Corbett (2007) examined the possible costs and benefits of decreasing sulphur dioxide emissions on ships in US West Coastal waters. They underlined that sulphur emissions would have been further decreased when the sulphur content in fuel was diminished to 0.5 %, as in the IMO 2020 regulations. Moreover, Nikopoulou (2017) developed a model to calculate additional costs for reducing NO_x and SO_x emissions from ships. On the other hand, *Yang et al.* (2012) employed AHP method to present a guide for ship owners to select its NO_x and SO_x emissions control technique. Finally, Kopela (2017) stated that requirements for improving relevant definitions, validating measurement methods and taking additional precautions are among the recent topics of IMO regulations against air pollution from ships.

Strategies for reducing air pollution from ships that were revealed by IMO, European Commission (EC) and leading ship owner companies and its fields of application (especially close to human settlement ones) constituted our research model (shown in Figure 1). Thus, the application efficiency of the strategies in marine areas which have heterogeneous structure in terms of ship call density, population density and ship stay duration. IMO 2020 applications are new issue in academia and this study is one of the unique research due to giving additional strategies to IMO 2020 restrictions as a suggestion.

In this study, strategies for reducing air pollution stem from ships were evaluated. In the case of implementing these strategies, it was determined in which marine area will be more sensitive to these strategies for reducing air pollution. In the following part of the study, the methods employed in the analysis were introduced and the application steps were expressed. Thereafter, the problem of the study was described, the experts whose opinions were taken were introduced and the results of the analysis were presented. In the conclusion section, the results of the analysis were evaluated, and recommendations were made.

2. METHODOLOGY

2.1 FUZZY ANALYTIC HIERARCHY PROCESS

The AHP method, advanced by Thomas L. Saaty, is one of the decision-making methods for sorting the hierarchical problems and can carry out to solve a complicated multi-criteria problem. However, sometimes AHP method cannot perform properly on uncertainty situations. Therefore, AHP was integrated with fuzzy logic and in addition to this Fuzzy AHP method was revealed. In this study Fuzzy AHP method was preferred because of its competence on better representation of real life problems. Hence, Fuzzy methods can more easily uncouple data sets from each other while ranking among criteria and alternatives. The first study about Fuzzy AHP is done by van Laarhoven and Pedrycz (1983). They compared fuzzy rates that expressed from triangular fuzzy numbers. On the other hand, Buckley (1985) determined the fuzzy priority of comparison rates by using the trapezoid fuzzy numbers. In 1996, Chang developed the Fuzzy Extended Analytical Hierarchy Process (FEAHP) method, which is widely used in the literature, for lowering the subjective judgments. The methodology of this study based on Buckley's AHP and Fuzzy Vikor method are given in the following.

2.1 (a) Application Steps

Step 1: Pairwise comparison matrices for criteria, sub-criteria, and alternatives are constructed and experts' evaluations using linguistic terms are collected. Each element of the pairwise comparison matrix (a_{ij}) is a fuzzy number corresponding to linguistic term. Accordingly, pairwise comparison matrices are shown below.

$$\tilde{A}^k = \begin{vmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{a}_{m1} & \tilde{a}_{m2} & \dots & 1 \end{vmatrix} \quad (1)$$

where $(\tilde{a}_{ij})$ represents the expert's evaluation on comparison of ^{i}th element of ^{j}th element.

A linguistic variable can be defined as a variable of which values consist of words or sentences in language naturally and artificially. By this method, it is employed this sort of expressions to make a comparison among way of reducing air pollution selection evaluation criteria by using several basic linguistic terms; ''absolutely important,'' ''very strongly important,'' ''essentially important'', ''weakly important'' and ''equally important'' as to a fuzzy five-level scale which presented in Table 1 (Chiou, 2001).

Table 1. Fuzzy Numbers and Linguistic Scales

Fuzzy Number	***Linguistic Scales***	***Scale of fuzzy number***
$\tilde{1}$	*Equally Important (EQ)*	*(1,1,3)*
$\tilde{3}$	*Weakly Important (WK)*	*(1,3,5)*
$\tilde{5}$	*Essentially Important (ES)*	*(3,5,7)*
$\tilde{7}$	*Very Strongly Important (VS)*	*(5,7,9)*
$\tilde{9}$	*Absolutely Important (AB)*	*(7,9,9)*

Step 2. The consistency of each fuzzy pairwise comparison matrix is examined. In order to check the consistency of the fuzzy pairwise comparison matrices, pairwise comparison values are defuzzied by the graded mean integration approach. Assume $\tilde{A} = [\tilde{a}_{ij}]$ is a fuzzy positive reciprocal matrix and $A = [a_{ij}]$ is its defuzzied positive reciprocal matrix. Providing that the result of the comparisons of $A = [a_{ij}]$ is consistent, then it can be implied that the result of the comparisons of $\tilde{A} = [\tilde{a}_{ij}]$ is also consistent. According to the graded mean integration approach, a triangular fuzzy number $\tilde{A} = (l, m, u)$ can be transformed into a crisp number by employing the below equation:

$$A = \frac{l + 4m + u}{6} \tag{2}$$

If the pairwise comparisons are not consistent, experts must re-evaluate the pairwise comparisons.

Step 3. In this step, the geometric mean of each row of matrices is calculated for weighting the criteria and alternatives. Firstly, the geometric mean of the first parameters in each row's triangular fuzzy numbers are calculated (Buckley, 1985).

$$\begin{aligned} a_{1l} &= [1 \times a_{12l} \times \dots \times a_{1nl}]^{1/n} \\ a_{2l} &= [a_{21l} \times 1 \times \dots \times a_{2nl}]^{1/n} \\ a_{il} &= [a_{n1l} \times a_{n2l} \times \dots \times 1]^{1/n} \end{aligned} \tag{3}$$

Afterward, the geometric mean of each row's triangular fuzzy numbers second and third parameters are calculated respectively:

$$\begin{aligned} b_{1m} &= [1 \times b_{12m} \times \dots \times b_{1nm}]^{1/n} \\ b_{2m} &= [b_{21m} \times 1 \times \dots \times b_{2nm}]^{1/n} \\ b_{im} &= [b_{n1m} \times b_{n2m} \times \dots \times 1]^{1/n} \end{aligned} \tag{4}$$

The geometric means of the third parameters are measures as follows (Buckley, 1985):

$$\begin{aligned} c_{1u} &= [1 \times c_{12u} \times \dots \times c_{1nu}]^{1/n} \\ c_{2u} &= [c_{21u} \times 1 \times \dots \times c_{2nu}]^{1/n} \\ &\dots \\ c_{iu} &= [c_{n1u} \times c_{n2u} \times \dots \times 1]^{1/n} \end{aligned} \tag{5}$$

The sum of the geometric mean values in the row is a_{1s} for low parameters, a_{2s} for medium parameters and a_{3s} for upper parameters. Lastly, $\tilde{r}_{ij}$ matrix is obtained by using the values of a_{ij}.

$$\tilde{r}_{ij} = \begin{vmatrix} \left(\frac{a_{1l}}{a_{3s}}, \frac{b_{1m}}{a_{2s}}, \frac{c_{1u}}{a_{1s}}\right) \\ \left(\frac{a_{2l}}{a_{3s}}, \frac{b_{2m}}{a_{2s}}, \frac{c_{2u}}{a_{1s}}\right) \\ \vdots \\ \left(\frac{a_{il}}{a_{3s}}, \frac{b_{im}}{a_{2s}}, \frac{c_{iu}}{a_{1s}}\right) \end{vmatrix} \tag{6}$$

Step 4. Fuzzy weights and values sum accordingly the equation 7 as follows.

$$\tilde{U}_i = \sum_{j=1}^{n} (\tilde{W}_j \tilde{r}_{ij}), \ \forall i. \tag{7}$$

Here in 7th equation, "$\tilde{U}_i$" refers to utility level of ith alternative, "$\tilde{w}_j$, the weight of the jth criteria. Besides, "$\tilde{r}_{ij}$" express the performance of the ith alternative for the jth criteria.

Step 5. In this step, defuzzification and normalization of Fuzzy numbers are defuzzied and normalized for determining the order of importance the criterion and alternatives. After that stage, Consistency Index (CI) is calculated.

$$CI = \frac{(\lambda_{\max} - n)}{n - 1} \tag{8}$$

Step 6. In the last stage, the best alternative is determined as the highest value, the same as the classical AHP.

2.2 FUZZY VIKOR APPROACH

After obtaining the weight vector thanks to Buckley's Fuzzy AHP, this research goes on implementing the steps of the VIKOR method. VIKOR method based on the concepts that compromise the programming of multi-criteria decision making (MCDM). These concepts were first developed by Yu (1973) and Zeleny (1982). The methodology basically performs on fundamental that each alternative can be evaluated on each criterion function. The ranking will be presented by comparing the rate of closeness to the ideal alternative. In Fuzzy VIKOR method, decision-makers should use linguistic variables to evaluate the score of alternatives relating to criteria. It is given to the linguistic scale for the evaluation of the alternatives in Table 2 (Kaya and Kahraman, 2011).

Supposing that a decision group has K number of people, the degrees of alternatives in accordance with each criteria can be calculated as in equation 9.

$$\tilde{x}_{ij} = \frac{1}{K}\left[\tilde{x}_{ij}^{1}(+)\tilde{x}_{ij}^{2}(+)\dots(+)\tilde{x}_{ij}^{K}\right], \quad (9)$$

where $\tilde{x}_{ij}^{K}$ is the rating of the Kth decision-maker for ith alternative with respect to jth criterion.

After obtaining the weights of criteria and fuzzy ratings of alternatives in regard to each criterion, fuzzy multi-criteria decision-making problem in matrix format is expressed as follows:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix}, \quad (10)$$

$$W = [w_1, w_2, \dots, w_n], \quad j = 1,2,\dots,n,$$

where $\tilde{x}_{ij}$ is the rating of the alternative A_i in the matter of criterion $j(i.e. C_j)$ and w_i denotes the importance weight of.C_i

Next step is to determine the fuzzy best value $(FBV, \tilde{f}_j^*)$ and fuzzy worst value $(FWV, \tilde{f}_j^-)$ of all criterion functions:

$$\tilde{f}_j^* = \max_i \tilde{x}_{ij}, \ j \in B; \ \tilde{f}_j^- = \min_i \tilde{x}_{ij}, \ j \in C. \quad (11)$$

Then, the values $\tilde{w}_j(\tilde{f}_j^* - \tilde{x}_{ij})/(\tilde{f}_j^* - \tilde{f}_j^-)$, $\tilde{S}_i$ and $\tilde{R}_i$ are computed in order to obtain:

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{w}_j (\tilde{f}_j^* - \tilde{x}_{ij})/(\tilde{f}_j^* - \tilde{f}_j^-) \quad (12)$$

$$\tilde{R}_i = \max_j \left[\tilde{w}_j(\tilde{f}_j^* - \tilde{x}_{ij})/(\tilde{f}_j^* - \tilde{f}_j^-)\right] \quad (13)$$

where $\tilde{S}_i$ refers to the separation measure of A_i 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 are calculated:

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

$$\tilde{R}^* = \min_i \tilde{R}_i, \qquad \tilde{R}^- = \max_i \tilde{R}_i \quad (14)$$

$$\tilde{Q}_i = v(\tilde{S}_i - \tilde{S}^*)/(\tilde{S}^- - \tilde{S}^*) + (1-v)(\tilde{R}_i - \tilde{R}^*)/(\tilde{R}^- - \tilde{R}^*) \quad (15)$$

The index $min_i \tilde{S}_i$ and $min_i \tilde{R}_i$ are related to maximum majority rule, and a minimum individual regret of an opponent strategy respectively. Besides, v is introduced as the weight of the strategy of the maximum group utility, usually v is assumed to be 0,5.

The next stage is the defuzzification of the triangular fuzzy number $\tilde{Q}_i$ 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 by employing the following equation:

$$P(\tilde{C}) = C = \frac{c_1 + 4c_2 + c_3}{6} \quad (16)$$

Table 2. Fuzzy Evaluation Scores for the Alternatives

Linguistic Terms	*Fuzzy Score*
Very Poor (VP)	*(0,0,1)*
Poor (P)	*(0,1,3)*
Medium Poor (MP)	*(1,3,5)*
Fair (F)	*(3,5,7)*
Medium Good (MG)	*(5,7,9)*
Good (G)	*(7,9,10)*
Very Good (VG)	*(9,10,10)*

Consequently, the best alternative with the minimum Q_i is determined.

3. APPLICATION

In this section, developed strategies against air pollution caused by ships globally are prioritized and the effect level of these strategies measured by Hybrid Fuzzy AHP-VIKOR method was described step by step. Thus, the problem is expressed, the competency levels of the experts whose opinions were taken for analysis were introduced and the application steps of the method defined in the previous section for the solution of this problem were explained.

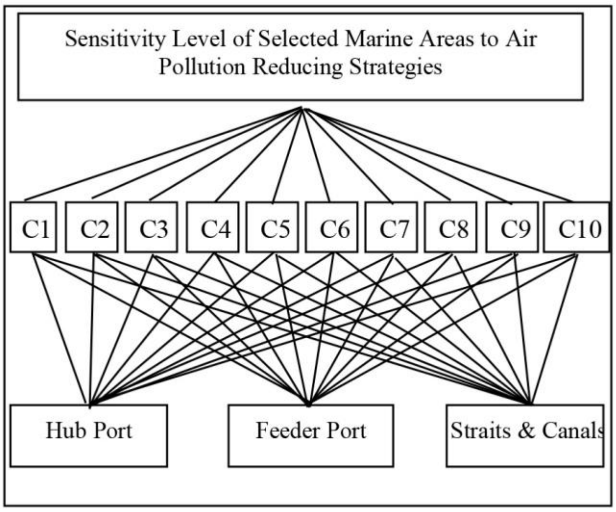

Figure 1. Research Model

3.1 PROBLEM DESCRIPTION

Air pollution can be caused by many substances. The use of some air pollutants is strictly controlled, but the harmful effects of some ones occur over time. As an example, it can be given the fact that fuel raw materials used for transportation and energy production have significantly increased the amount of carbon across the world over the years. As a transportation mode, marine vehicles are held responsible for 15% of total sulphur emissions in the world and 13% of nitrogen emissions. In addition, approximately 70% of these emissions are measured at distances less than 400 km to land, so this directly affects human health (Zhen et al., 2019). As a result of this situation, the 'Air Pollution Prevention at Sea' agreement, which was added to the MARPOL convention as Annex VI in 1997 by MEPC, the IMO sub-working group, was adopted. Currently, 63 countries carrying 88.9% of the world's tonnage have become parties to this Protocol.

Table 3. Definition of Strategies

Strategies	Definitions
Establishing Current Determination System	It refers to the minimum exposure of the ships to the counter current and to the maximum benefit from current along the direction of the ship, thereby reducing emissions by using the main engine power most effectively.
Forbiddance HFO usage on Ships	It means that the use of HFO on ships is completely prohibited and that ships reduce their emissions by using Marine Gas Oil (MGO), Marine Diesel Oil (MDO) fuels.
Detection of Low Sulphur Fuel Usage by the help of Remote Detector Systems	It explains the importance of monitoring the ships with the method of attaching sensors under the bridge or by the drone detector systems in order to control the compliance with fuel standards of the IMO effectively.
Using Tugboats Operated by Electric or Liquefied Natural Gas (LNG)	It is expressed that the main engines of the tugboat-class ships used in ports and canals are compatible with alternative fuel systems.
Decreasing Speed Limits	Emission reduction is explained as a result of applying speed limits or reducing existing limits in port areas and during passing through canals or straits.
Reducing Anchorage Time	It is stated that the waiting times of the ships, indirectly emissions, before loading/unloading in port areas or passing through the canals or straits can be reduced as a result of good planning.
Using 'Ship Routing System'	Emission reduction is expressed as a result of determining the most suitable rotation with the use of routing system.
Providing Cost Effective Applications to Green Ships	It is stated that the ships which carry out additional works, beyond the mandatory rules for reducing emissions, should have an advantage in port and canal or strait charges.
Providing Priority of Sea Route or Berthing to Green Ships	It is a priority of sea route or berthing for ships conducting additional works to the mandatory rules for reducing emissions, in channel passage or port berthing.
Fund Allocation for the use of Electric Tugs	It is the support of electric tugboats with incentive policies such as funds.

Although the 2020 update of this regulation is a revolution in improving fuel quality, this regulation needs to be supported by additional strategies already to reduce air pollution stems from ships. In this study, preventive strategies have been developed by taking into consideration the recommendations of IMO and EC and related practices of ship owner companies to reduce air pollution from ships (Han, 2010). Also it was tried to determine effect level of these strategies in marine areas where close to human living spaces. The strategies developed to reduce the air pollutant emissions produced by the ships were expressed in Table 3 and the selected marine areas in what are tried to be evaluated its sensitivity level to these strategies were defined in Table 4.

Table 4. Alternatives of This Study

Code	Alternative	Definition
A1	Hub Port	Port where ship call and population density exist.
A2	Feeder Port	Port where relatively low ship call density but longer ship stay duration.
A3	Straits and Canals	Passage points where high population and ship call density but shorter stay period.

3.2 DETERMINING OF EXPERTS

In this study, it was tried to evaluate the strategies abating air pollution stem from ships. It is also tried to determine impacts of the strategies, if these strategies would have implemented in the related marine areas where ships call (hub ports, feeder ports, passing through straits and canals). The fuzzy AHP-VIKOR hybrid method was employed to evaluate these qualitatively expressed strategies by experts. At this point, experts' quality and its qualifications to solve the problem are very crucial for the validity of the study. For this reason, the experts were chosen among the ocean-going masters (OGM) and chief engineers (CE) who worked for a long time in the relevant marine areas in where the effectiveness levels of the related strategies were investigated. The fact that the selected five experts have an average of 12.6 years of sea trial and the least experienced one has 10 years of sea trial (seen in Table 5) shows that the experts can interpret the strategies that can be applied at the relevant points in the best manner. Thus, the selected experts were asked first to prioritize aggregate strategies. Then, they were asked in which marine areas the related strategies would be more effective in the second phase of this study. Experts agreed on the solution of the problem and thus the results of the study were presented.

Table 5. Profiles of the Experts

Profession	Experience	Consistency Score
OGM-1	14 years	0.7
OGM-2	10 years	0.8
OGM-3	11 years	0.9
CE-1	17 years	0.9
CE-2	11 years	0.7

3.3 FINDINGS

As a result of the expert evaluations (shown in Table 6), dependent on the fuzzy sets, we may conclude that "Forbiddance of Heavy Fuel Oil (HFO) usage on Ships" with its 0.154 score and "Detection of Low Sulphur Fuel Usage by the help of Remote Detector Systems" with its 0.122 score had become two foremost criteria. On the other hand, criteria that are "Reducing Anchorage Time" (0.075), "Establishing Current Determination System" (0.084), "Decreasing Speed Limits" (0.084) and "Providing Cost Effective Applications to Green Ships" (0,085) were seen as ones of the least important criteria.

Table 6. Fuzzy AHP Weights of Dimensions and Criteria for Decision-Makers

	Criteria	Fuzzy Weight	BNP
	TECHNICAL		
C1	Establishing Current Determination System	(0.085,0.083,0.085)	0.084
C2	Forbiddance of HFO usage on Ships	(0.158,0.159,0.014)	0.154
C3	Detection of Low Sulphur Fuel Usage by the help of Remote Detector Systems	(0.12,0.124,0.121)	0.122
C4	Using Tugboats Operated by Electric or LNG	(0.11,0.111,0.11)	0.110
	OPERATIONAL		
C5	Decreasing Speed Limits	(0.083,0.083,0.087)	0.084
C6	Reducing Anchorage Time	(0.077,0.074,0.076)	0.075
C7	Using 'Ship Routing System'	(0.088,0.087,0.088)	0.088
	MARKET BASE		
C8	Providing Cost Effective Applications to Green Ships	(0.1,0.1,0.1)	0.100
C9	Providing Priority of Sea Route or Berthing to Green Ships	(0.084,0.083,0.087)	0.085
C10	Fund Allocation for the Use of Electric Tugs	(0.096,0.097,0.099)	0.097

S, R, Q value were calculated for each alternative, results, and ranking of the alternatives are shown in Table 7 and Table 8, respectively. Table 7 demonstrates that "Passing through Straits and Canals" was chosen as the most appropriate alternative with its 0.32 Q value, where "Feeder Port" type was determined as the last option with its 0.52 Q value. "Hub-Port" alternative was ranked as the second with its 0.50 value.

Table 7. The Evaluation Value of Each Frequent Calling Areas of Ships

	A1	A2	A3
S	0.47	0.40	0.40
R	0.07	0.52	0.12
Q	0.50	0.52	0.32

Table 8. Ranking of the Calling Areas by VIKOR

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

According to $Q(a(2)) - Q(a(1)) > 1/(m - 1)$ (where $Q(a(2))$ is the suboptimal scheme in Q rank tables and Q's VIKOR evaluation value), we can get $Q(A1) - Q(A2) = 0.500 – 0,318 = 0.182 < 1/2$. However, according to the second rule, the acceptable best alternative can be considered to be A3 due to the similarity of S, R and Q rank.

In this paper, a sensitivity analysis was applied to evaluate of robustness and steadiness of the proposed approach. Hence, the weight of the strategy of the maximum group tool. "v" was used as changed between 0 and 1 as increasing by 0.1. The results of the sensitivity analysis were presented in Table 9 and Table 10 and graphically in Figure 2 and Figure 3. This study also presumed that the v value corresponds to 0.5 while the Q values of each alternative A1, A2, and A3 are '0.400, 0.516, 0.318' respectively. The ranking order of the four alternatives is A3 > A1 > A2.

When v value in Table 9 corresponded to 0.0, then the Q values of each A1, A2, and A3 were '0.000, 1.000 and 0.583' respectively. The ranking order in Table 9 of the three alternatives was also A1>A3>A2 and also it was shown in Figure 3. This study confirmed that the results of the ranking orders of all three alternatives, by using the proposed approach, were consistent. Furthermore, the proposed approach found the gap between the Q values of port types.

Table 9. The Qi Values for Different Maximum Group Utilities.

	A1	A2	A3
v=0,0	0.000	1.000	0.583
v=0,1	0.100	0.903	0.530
v=0,2	0.200	0.806	0.477
v=0,3	0.300	0.709	0.424
v=0,4	0.400	0.613	0.371
v=0,5	0.500	0.516	0.318
v=0,6	0.600	0.419	0.265
v=0,7	0.700	0.322	0.212
v=0,8	0.800	0.225	0.159
v=0,9	0.900	0.128	0.106
v=1,0	1.000	0.031	0.053

Table 10. The Ranking of the Alternatives for Different Maximum Group Utilities

	A1	A2	A3
v=0,0	1	3	2
v=0,1	1	3	2
v=0,2	1	3	2
v=0,3	1	3	2
v=0,4	2	3	1
v=0,5	2	3	1
v=0,6	3	2	1
v=0,7	3	2	1
v=0,8	3	2	1
v=0,9	3	2	1
v=1,0	3	1	2

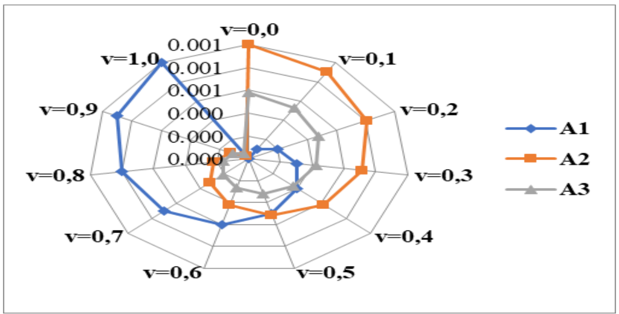

Figure 2. Sensitivity Analysis of "Q" Values

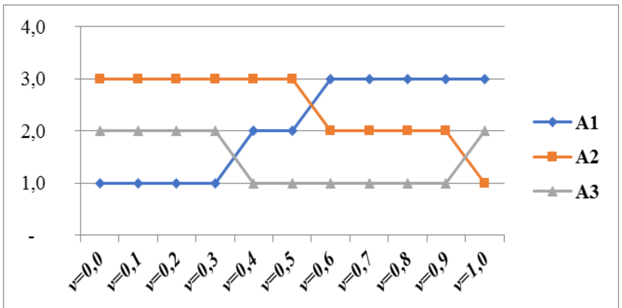

Figure 3. Sensitivity Analysis of Ranking

4. CONCLUSION

Although the effects of some emissions that cause air pollution are not immediately harmful, these emissions have gradual significant impacts in time on human health and the environment when released into the air. Sulphur emissions, one of that kind of contaminant, had been underestimated in the past years. On the other hand, as a result of rapid developments in the world trade, the air pollution stem from ships reached significant points. In response to this, IMO had taken a series of decisions against air pollution caused by ships.

Recently, IMO 2020 applications and promoting this regulation with some additional precautions are one of the most important issues. In this study, a hybrid analysis was employed to the additional strategies developed. According to the results obtained from the evaluations on prioritization of strategies, the strategy that is 'Prohibition of the use of HFO in ships' has the highest priority, and it is determined that the second highest priority strategy is 'To control the usage of low sulphur fuel with the detector systems'. Accordingly, coming into prominence of these two strategies indicates that the fuel quality regulations implemented by IMO for the prevention of air pollution were supported by our experts. Besides, this result supports that the most effective method for controlling air pollution is the use of clean fuel and providing best practices for monitoring clean fuel consumption. Another result of this analysis can be stated that the usage of HFO is the most important reason of air pollution from the ships. The ranking of the priority scores of the other 8 strategies obtained in the range of 0.084 - 0.110 shows that these strategies should also be taken into consideration. It is also showed that promoting regulations which support fuel quality improving in ships with these additional strategies is important to control air pollution effectively.

According to the analysis results on the preventive effect level of the related strategies in ship calling areas, canals and straits was determined to be more sensitive than feeder and hub ports. While most of the ships approaching the ports, manoeuvring around the berth, berthing at the ports, changes HFO with a cleaner fuel MDO for using in their main engine. Furthermore, ships use auxiliary machines during anchoring and auxiliary machines are operated by consuming MDO. On the other hand, canal and strait passing of the ships can be carried out by using HFO. Accordingly, the experts emphasized the quality of fuel when evaluating these strategies and they determined that strategies have the highest effect level in the canal and strait passing where ships use more heavy fuels in than other alternatives. Therefore, it can be concluded that the evaluations made by the experts are supportive of each other and they support the regulations of the IMO to improve fuel quality.

5. REFERENCES

1. BAILEY, D., and SOLOMON, G. (2004). *Pollution prevention at ports: clearing the air.* Environmental impact assessment review, 24(7-8), 749-774.
2. BALLINI, F., and BOZZO, R. (2015). *Air pollution from ships in ports: The socio-economic benefit of cold-ironing technology.* Research in Transportation Business & Management, 17, 92-98.
3. https://www.bbc.com/news/science-environment-51944780 (Accessed 19 March 2020).
4. BEŞIKÇI, E. B., KECECI, T., ARSLAN, O., and TURAN, O. (2016). *An application of fuzzy-AHP to ship operational energy efficiency measures.* Ocean Engineering, 121, 392-402.

5. BORKOWSKI, T., NICEWICZ, G., and TARNAPOWICZ, D. (2013). *The methodology used in defining air pollution from ships mooring in ports.* Zeszyty Naukowe/Akademia Morska w Szczecinie, 36(108), 17-22.
6. BUCKLEY, J. J. (1985). *Ranking alternatives using fuzzy numbers.* Fuzzy sets and systems, 15(1), 21-31.
7. BURGEL, A. P. (2007). *Air Pollution from Ships: Recent Developments.* WMU Journal of Maritime Affairs, *6*(2), 217-224.
8. CHEN, J., WANG, S., QU, X., and YI, W. (2018). *A Modelling Framework of Drone Deployment for Monitoring Air Pollution from Ships.* International Conference on Intelligent Interactive Multimedia Systems and Services, Gold Coast, Australia, 281-288.
9. CHIOU, H. K. (2001). *Fuzzy hierarchical evaluation with grey relation model of green engineering for industry.* International Journal of Fuzzy Systems, *3*(3), 466-475.
10. CHOROWSKI, M., DUDA, P., POLINSKI, J., and SKRZYPACZ, J. (2015). *LNG systems for natural gas propelled ships*. IOP Conference Series: Materials Science and Engineering, Macau, China.
11. CORBETT, J. J., WINEBRAKE, J. J., GREEN, E. H., KASIBHATLA, P., EYRING, V., and LAUER, A. (2007). *Mortality from ship emissions: a global assessment.* Environmental science & technology, 41(24), 8512-8518.
12. HAN, C. H. (2010) *'Strategies to reduce air pollution in shipping industry'*, The Asian Journal of Shipping and Logistics, 26(1), 7-29.
13. https://ec.europa.eu/clima/sites/clima/files/transport/shipping/docs/marine_transport_en.pdf (Accessed 25 February 2020).
14. https://webstore.iea.org/co2-emissions-from-fuel-combustion (Accessed 25 February 2020).
15. KAYA, T., and KAHRAMAN, C. (2011). *Fuzzy multiple criteria forestry decision making based on an integrated VIKOR and AHP approach.* Expert Systems with Applications, 38(6), 7326-7333.
16. KESGIN, U., and VARDAR, N. (2001). *A study on exhaust gas emissions from ships in Turkish Straits.* Atmospheric Environment, *35*(10), 1863-1870.
17. KOPELA, S. (2017). *Making ships cleaner: Reducing air pollution from international shipping.* Review of European, Comparative & International Environmental Law, 26(3), 231-242.
18. LIM, K. (2017). *The role of the International Maritime Organization in preventing the pollution of the world's oceans from ships and shipping.* UN Chronicle, 54(2), 52-54.
19. LIN, B., and LIN, C. Y. (2006). *Compliance with international emission regulations: Reducing the air pollution from merchant vessels.* Marine Policy, 30(3), 220-225.
20. MARAGKOGIANNI, A., and PAPAEFTHIMIOU, S. (2015). *Evaluating the social cost of cruise ships air emissions in major ports of Greece.* Transportation Research Part D: Transport and Environment, 36, 10-17.
21. MATTHIAS, V., BEWERSDORFF, I., AULINGER, A., and QUANTE, M. (2010). *The contribution of ship emissions to air pollution in the North Sea regions.* Environmental Pollution, 158(6), 2241-2250.
22. McARTHUR, D. P., and OSLAND, L. (2013). *Ships in a city harbour: An economic valuation of atmospheric emissions.* Transportation Research Part D: Transport and Environment, 21, 47-52.
23. MUELLER, D., UIBEL, S., TAKEMURA, M., KLINGELHOEFER, D., and GRONEBERG, D. A. (2011). *Ships, ports and particulate air pollution-an analysis of recent studies.* Journal of Occupational Medicine and Toxicology, 6(1), 31.
24. NETWORK, B. (2000). *A stacked deck: Air pollution from large ships.* URL: http://www. earthisland. org/bw/stacked. pdf. (Accessed 25 February 2020.).
25. NIKOPOULOU, Z. (2017). *Incremental costs for reduction of air pollution from ships: a case study on North European emission control area.* Maritime Policy & Management, 44(8), 1056-1077.
26. NIŽIĆ, F., FRANČIĆ, V., and OROVIĆ, J. (2017). *Ships' Solutions for meeting the International requirements regarding the reduction of Air Pollution.* Pomorski zbornik, 53(1), 53-65.
27. PHAM, H. T., and NGUYEN, T. M. (2015). *Solution to Reduce Air Environmental Pollution from Ships.* TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 9(2), 257-261.
28. SAATY, T. L. (1980). *The Analytic Hierarchy Process.* McGrawHill, New York, 1980. Revised edition, Paperback (1996, 2000), Pittsburgh: RWS Publications.
29. SAXE, H., and LARSEN, T. (2004). *Air pollution from ships in three Danish ports.* Atmospheric Environment, *38*(24), 4057-4067.
30. UDDIN, M. M., and KARIM, M. S. (2018). *Prevention, reduction and control of marine pollution from ships.* International Marine Environmental Law and Policy, 60-68.
31. WANG, C., and CORBETT, J. J. (2007). *The costs and benefits of reducing SO2 emissions from ships in the US West Coastal waters.* Transportation Research Part D: Transport and Environment, 12(8), 577-588.
32. YANG, Z. L., ZHANG, D., CAGLAYAN, O., JENKINSON, I. D., BONSALL, S., WANG, J.,

HUANG, M. and YAN, X. P. (2012). *Selection of techniques for reducing shipping NOx and SOx emissions.* Transportation Research Part D: Transport and Environment, 17(6), 478-486.
33. YU, P. L. (1973). *A class of solutions for group decision problems.* Management Science, 19(8), 936-946.
34. ZELENY, M. (1998). *Multiple criteria decision making: Eight concepts of optimality.* Human Systems Management, 17(2), 97-107.
35. ZHEN, L., ZHUGE, D., MURONG, L., YAN, R., and WANG, S. (2019). *Operation management of green ports and shipping networks: overview and research opportunities.* Frontiers of Engineering Management, 152-162.
36. ZHU, M., LI, K. X., SHI, W., and LAM, J. S. L. (2017). *Incentive policy for reduction of emission from ships: A case study of China.* Marine Policy, 86, 253-258.

