EVALUATION OF THE POTENTIAL HAZARDS OF SHIP-GENERATED WASTE IN MARITIME INDUSTRY USING A TYPE-2 FUZZY ANALYTICAL HIERARCHY PROCESS

(DOI No: 10.3940/rina.ijme.2020.a3.639)

E Celik, Istanbul University, Department of Transportation and Logistics, Istanbul, Turkey, **O Soner**, Van Yuzuncu Yil University, Department of Maritime Transportation and Management Engineering, Van, Turkey, **E Akyuz**, and **O Arslan**, Istanbul Technical University, Department of Maritime Transportation and Management Engineering, Istanbul, Turkey

KEY DATES: Submitted: 22/04/20; Final acceptance: 02/09/20; Published: 07/10/20

SUMMARY

Ships create a large amount of pollutions to marine and coastal environment where its pollutants have negative effects to human and maritime habitat. Depending on the nature of ship-generated waste, rules and regulations determine discharging procedures. This paper focuses on evaluating of potential hazards of ship-generated wastes on the environment whether it may be discharged into the sea or disposed of on port facilities. Thus, marine and costal environmental effects can be discussed analytically to improve human and ecological health. To achieve this purpose, analytic hierarchy process (AHP) extended with interval type-2 fuzzy sets (IT2FSs) is used. While AHP method is used for prioritizing the potential ship-generated waste, the IT2FSs deal with uncertainty and vagueness in the process of obtaining expert decision. Beside assessment of the environmental impacts, the paper contributes to enhance coastal and marine environmental awareness with respect to the ship-generated waste.

1. INTRODUCTION

Marine pollution causes a serious threat to human life and marine habitat. Since there are a large amount of marine pollutions, one of the challenges is ship-generated wastes such as oil bilge water, sludge, slops, food waste, plastics, etc. (EMSA, 2018). Depending on the nature of ship-generated waste, the maritime authorities have adopted a set of rules and regulations whether it can be disposed on shore or discharged into the sea (Ergin And Eker, 2019). The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental cause (IMO, 73/78). The MARPOL classifies ship-generated wastes into six main categories: i) pollution by oil. ii) pollution by noxious liquid substances in bulk. iii) pollution by harmful substances carried by sea in packaged form. iv) pollution by sewage from ships. v) pollution by garbage from ships. vi) air pollution from ships. Although MARPOL sets regulations for wastes, there are still environmental pollutions generated by ships.

Ship-generated wastes pose acute threats to the maritime and coastal environment due to the petrochemical content. For instance, sludge contains oil, asphalts and other contaminants which are very dangerous for marine habitats as well as coastal zones. Coastal management authorities are seriously concerned about the pollution of the seas and coastlines caused by discharges of waste and cargo residues from ships. Likewise, plastics another ship-generated waste may include pathogens which may cause serious disease in humans. Due to the potential impacts of ship wastes/garbage on the environment, the safety practitioners and marine environmental researchers have been concentrated on studying topics related with ship-generated wastes. Butt (2007) studied on waste management and disposal options for cruise ship and environmental effects of them. A specific study conducted on Koper Port was performed to identify and quantify the environmental impacts of ship-generated waste by evaluating life-cycle (Zuin et al., 2009). Likewise, Ng and Song (2010) presented a research on evaluation of environmental impacts of pollutants occurred by ship operations at port. Another study was performed to estimate the amount of ship-generated waste in Baltic Sea (Wilewska-Bien et al., 2017). Subası and Dogan-Saglamtimur (2011) discussed performance evaluation of Martas Port ship waste reception facilities.

Although some researchers have highlighted the importance of the issue for the maritime environment, there is a shortage of research. The literature on this topic is out of date and does not seem to cover recent advances in the control and handling of waste. Clear identification of the possible dangers of ship-produced waste, clearer knowledge about the quantity of waste created during a voyage and waste control practices in ships can result in the proper planning of waste collecting and disposal plans. Therefore, the aim of this paper is to analytically assess potential impacts of the ship-generated waste on the marine environment. As the analysis of the environmental effects of ship waste is of great concern to prevent marine environmental pollution, a robust approach can be beneficial from the point of maritime safety (Balin et al., 2019*).* It is also expected that such research can provide considerable benefits to a wide range of maritime shareholders, such as ship suppliers, shipping companies, ports and terminals, offshore terminals, and waste handlers,. In this context, the paper is organised as follows; this section introduces the aim, scope of paper and brief literature reviewing about researches performed over ship-generated waste. Section 2 describes the methodology. Section 3 evaluates the potential impacts of the ship-generated waste on the marine environment. Section 4 concludes paper and gives future remarks about research.

2. TYPE-2 FUZZY AHP METHOD

This paper is adopted analytic hierarchy process (AHP) under interval type-2 fuzzy sets (IT2FSs) environment.

2.1 IT2FSs

IT2FSs are often preferred instead of traditional fuzzy sets since it is more capable of modelling higher orders of uncertainty (Aminifar and Marzuki, 2013). Zadeh (1975) introduced type-2 fuzzy set logic as an extension of the concept of type-1 fuzzy set (Karnik and Mendel, 2001; Mendel, 2007a). The IT2FSs have been widely used in various applications (Demirel et al. 2019; Soner et al., 2017; Celik et al., 2016; Castillo and Melin, 2012) since it is capable of solving more uncertainty (Mendel and John 2002; Kahraman et al. 2014) and producing more accurate results (Akyuz and Celik, 2016; Dereli and Altun, 2013).

Some of fundamental definitions of IT2FSs are explained as follows (Celik and Akyuz, 2017; Celik and Gumus, 2015; Chen and Lee, 2010):

Definition 1: A type-2 fuzzy set $\tilde{\tilde{A}}$ in the universe of discourse *X* can be illustrated by the type-2 membership function $\mu_{\tilde{\tilde{A}}}$, noted as followings:

$$\tilde{\tilde{A}} = \left\{ ((x,u), \mu_{\tilde{\tilde{A}}}(x,u)) \middle| \begin{array}{l} \forall x \in X, \\ \forall u \in J_X \subseteq [0,1] \end{array}, 0 \le \mu_{\tilde{\tilde{A}}}(x,u) \le 1 \right\}$$

where J_X gives an interval in [0, 1]. Moreover, the type-2 fuzzy set $\tilde{\tilde{A}}$ also might be illustrated as;

$$\tilde{\tilde{A}} = \int_{x \in X} \int_{u \in J_X} \mu_{\tilde{\tilde{A}}}(x,u) / (x,u) \text{ where } J_X \subseteq [0,1] \text{ and } \iint$$

defines union entire admissible *x* and *u*.

Definition 2: Let $\tilde{\tilde{A}}$ be a type-2 fuzzy set in the universe of discourse X demostrated by the type-2 membership function $\mu_{\tilde{\tilde{A}}}$. If all $\mu_{\tilde{\tilde{A}}}(x,u) = 1$, then $\tilde{\tilde{A}}$ is named as an interval type-2 fuzzy set. An interval type-2 fuzzy set $\tilde{\tilde{A}}$ is figured out as a particular case of a type-2 fuzzy set and demonstrated as follows:

$$\tilde{\tilde{A}} = \int_{x \in X} \int_{u \in J_X} 1 / (x,u) \text{ where } J_X \subseteq [0,1]$$

Definition 3: The upper and the lower membership function of an interval type-2 fuzzy set is created by the membership functions of type-1 fuzzy sets. The upper and lower membership functions of IT2FSs are used to address type-2 fuzzy sets in order to cope with fuzzy MCDM (Multi-Criteria Decision Making) issue. Figure 1 illustrates a trapezoidal IT2FSs.

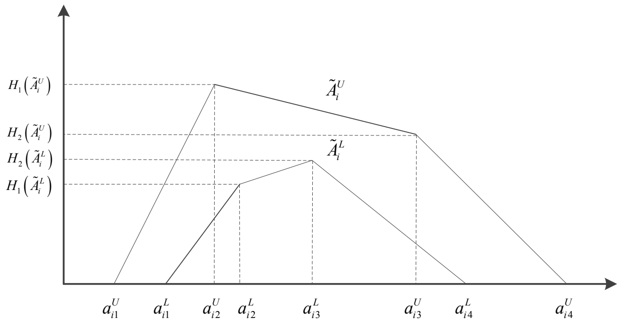

Figure 1. The membership functions.

2.2 IT2FAHP

Saaty (1980) presented AHP methodology to solve MCDM problem. It is quite practical and applicable approach for decision-maker. The method involves a couple of steps to calculate priorities: compose pair-wise comparison matrix, ranking of criteria and consistency of comparison matrix (Marhavilas et al., 2020; Mollaoğlu, 2019; Sahin, 2018; Gul et al., 2017). The AHP was extended by IT2FSs by Buckley (1985). In the literature, there is strong tendency for applying IT2FSs into AHP since it may serve a robust decision-making tool. Some of researchers presented different perspectives to IT2FSs such as Kahraman et al. (2014), Abdullah and Najib (2014), and Celik and Akyuz, (2016). In order to assess environmental impacts of the ship-generated waste, the IT2FSs are adopted. Hence, priority weight of each circumstance is analytically determined. The main steps of the IT2FSs are expressed as follows.

Step 1: Establish pair wise comparison matrix by using IT2FSs among the ship-generated waste. The linguistic terms for importance weights of factors are shown in Table 1.

$$\tilde{\tilde{M}} = \begin{pmatrix} 1 & \tilde{\tilde{a}}_{12} & \cdots & \tilde{\tilde{a}}_{1m} \\ \tilde{\tilde{a}}_{21} & 1 & \cdots & \tilde{\tilde{a}}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\tilde{a}}_{m1} & \tilde{\tilde{a}}_{m2} & \cdots & 1 \end{pmatrix} = \begin{pmatrix} 1 & \tilde{\tilde{a}}_{12} & \cdots & \tilde{\tilde{a}}_{1m} \\ \tilde{\tilde{1}}/\tilde{\tilde{a}}_{12} & 1 & \cdots & \tilde{\tilde{a}}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\tilde{1}}/\tilde{\tilde{a}}_{1m} & \tilde{\tilde{1}}/\tilde{\tilde{a}}_{2m} & \cdots & 1 \end{pmatrix} \quad (1)$$

where

$$\tilde{\tilde{1}}/\tilde{\tilde{a}}_{ij} = \begin{pmatrix} \left(\frac{1}{a_{ij4}^U}, \frac{1}{a_{ij3}^U}, \frac{1}{a_{ij2}^U}, \frac{1}{a_{ij1}^U}; H_1(a_{ij}^U), H_2(a_{ij}^U) \right), \\ \left(\frac{1}{a_{ij4}^L}, \frac{1}{a_{ij3}^L}, \frac{1}{a_{ij2}^L}, \frac{1}{a_{ij1}^L}; H_1(a_{ij}^L), H_2(a_{ij}^L) \right) \end{pmatrix}$$

Step 2: Control consistency of the fuzzy pair wise comparison. In this step, if the result of the A is consistent, then the result of the $\tilde{\tilde{A}}$ is also consistent. In case CR value is found 0.1 or less, the judgement inserted in comparison matrix is considered consistent.

Step 3: In order to get the fuzzy geometric means, the geometric mean technique is applied.

$$\tilde{\tilde{r}}_i = \left(\tilde{\tilde{a}}_{i1} \times \tilde{\tilde{a}}_{i2} \times \cdots \times \tilde{\tilde{a}}_{im}\right)^{1/m} \quad (2)$$

where $\sqrt[n]{\tilde{\tilde{a}}_{i1}} = \begin{pmatrix} \left(\sqrt[n]{a^U_{ij1}}, \sqrt[n]{a^U_{ij2}}, \sqrt[n]{a^U_{ij3}}, \sqrt[n]{a^U_{ij4}}; H_1\left(a^U_{ij}\right), H_2\left(a^U_{ij}\right)\right), \\ \left(\sqrt[n]{a^L_{ij1}}, \sqrt[n]{a^L_{ij2}}, \sqrt[n]{a^L_{ij3}}, \sqrt[n]{a^L_{ij4}}; H_1\left(a^L_{ij}\right), H_2\left(a^L_{ij}\right)\right) \end{pmatrix}$

Step 4: The fuzzy weights of each criterion is calculated with respect to the following equation.

$$\tilde{\tilde{w}}_i = \tilde{\tilde{r}}_i \times \left(\tilde{\tilde{r}}_1 + \tilde{\tilde{r}}_2 + \cdots + \tilde{\tilde{r}}_m\right)^{-1} \quad (3)$$

Step 5: In order to obtain priority weight of the criteria, defuzzification of IT2FSs is performed by applying centre of area method (Kahraman et al., 2014).

$$Defuzzified\left(\tilde{\tilde{w}}_i\right) = \frac{\frac{\left(a^U_{i4} - a^U_{i1}\right) + \left(H_1\left(\tilde{A}^U_i\right) * a^U_{i2} - a^U_{i1}\right) + \left(H_2\left(\tilde{A}^U_i\right) * a^U_{i3} - a^U_{i1}\right)}{4} + a^U_{i1} + \frac{\left(a^L_{i4} - a^L_{i1}\right) + \left(H_1\left(\tilde{A}^L_i\right) * a^L_{i2} - a^L_{i1}\right) + \left(H_2\left(\tilde{A}^L_i\right) * a^L_{i3} - a^L_{i1}\right)}{4} + a^L_{i1}}{2} \quad (4)$$

Step 6: Normalised crisp weight of criteria is determined.

$$w_i = Defuzzified\left(\tilde{\tilde{w}}_i\right) / \sum_{i=1}^{n} Defuzzified\left(\tilde{\tilde{w}}_i\right) \quad (5)$$

3. ASSESSMENT OF THE POTENTIAL IMPACTS OF THE SHIP-GENERATED WASTE ON THE ENVIRONMENT

The IT2FAHP is applied to assess potential impacts of the ship-generated waste on marine environment since it poses serious hazards to the maritime and coastal environment.

3.1 PROBLEM DEFINITION

Ships generate a large amount of wastes such as food wastes, plastics, domestic wastes, sludge, bilge, ashes, cargo residues, dunnage, etc. and many of them have negative effect on the marine environment. For instance, ashes produced by inclinator have severe effects on marine ecology and atmosphere. Likewise, plastics including drums, synthetic ropes, bags, cans, etc. are composed of major toxic pollutants and have potential to cause severe harm to the human, marine environment. Waste management systems can improve pollution prevention from ships by reducing discharges into the sea of ship-generated waste and cargo residues. This can be achieved through environmental standards and implementation of these requirements. Accordingly, compliance with environmental requirements, codes and resolutions, while conducting the analytical research concerned with waste management, is one of the most effective ways of ensuring a sustainable marine environment. Therefore, a sensitive analysis is needed to assess potential environmental impacts of ship-generated waste. The paper, in this context, analytically analyse and evaluate potential impacts of ship waste on the environment by prioritizing them.

3.2 ANALYSIS OF RESPONDENTS

The experts' judgements provide a quick evaluation of the state of knowledge about a particular aspect. Since there is lack of data, the paper utilises expert's evaluation to analyse potential impacts of ship-generated waste on the marine environment. To achieve this purpose, it was connected ship management company which has chemical tanker ship fleets. The experts profile includes DPAs (Designated Person Ashore) who have wide knowledge and experience about the management of ship-generated waste on-board ships. All of them hold ocean-going Master licences and have extensive sea-going experience. They also have appropriate knowledge about conventions, codes, regulatory penalties and violations. Marine experts were asked to compare impact of ship-generated wastes on the marine environment. Since there were three experts participated to the survey, arithmetic means of them are obtained.

3.3 POTENTIAL IMPACTS OF SHIP-GENERATED WASTE ON MARINE ENVIRONMENT

As the ship-generated wastes are an increasing threat to the health of human and marine ecosystems, potential impacts of them are figured out in Table 2. The potential impacts of the ship-generated wastes were ascertained by the consensus of marine experts and average waste generation rate were taken from EMSA report (EMSA, 2018).

Table 1. Linguistic terms for importance weights of factors.

Linguistic variables	IT2FSs	Reciprocal IT2FSs
Extremely more important (EMI)	((8;9;9;10;1;1),(8.5;9;9;9.5;0.9;0.9))	((0.1;0.11;0.11;0.13;1;1),(0.11;0.11;0.11;0.12;0.9;0.9))
Intermediate value (IV)	((7;8;8;9;1;1),(7.5;8;8;8.5;0.9;0.9))	((0.11;0.13;0.13;0.14;1;1),(0.12;0.13;0.13;0.13;0.9;0.9))
Very strong more important (VSMI)	((6;7;7;8;1;1),(6.5;7;7;7.5;0.9;0.9))	((0.13;0.14;0.13;0.14;1;1),(0.13;0.14;0.13;0.13;0.9;0.9))
Intermediate value (IV)	((5;6;6;7;1;1),(5.5;6;6;6.5;0.9;0.9))	((0.14;0.17;0.17;0.2;1;1),(0.15;0.17;0.17;0.18;0.9;0.9))
Strongly more important (SMI)	((4;5;5;6;1;1),(4.5;5;5;5.5;0.9;0.9))	((0.17;0.2;0.2;0.25;1;1),(0.18;0.2;0.2;0.22;0.9;0.9))
Intermediate value (IV)	((3;4;4;5;1;1),(3.5;4;4;4.5;0.9;0.9))	((0.2;0.25;0.25;0.33;1;1),(0.22;0.25;0.25;0.29;0.9;0.9))
Moderately more important (MMI)	((2;3;3;4;1;1),(2.5;3;3;3.5;0.9;0.9))	((0.25;0.33;0.33;0.5;1;1),(0.29;0.33;0.33;0.4;0.9;0.9))
Intermediate value (IV)	((1;2;2;3;1;1),(1.5;2;2;2.5;0.9;0.9))	((0.33;0.5;0.5;1;1;1),(0.4;0.5;0.5;0.67;0.9;0.9))
Equally important (EI)	((1;1;1;1;1;1),(1;1;1;1;0.9;0.9))	((1;1;1;1;1;1),(1;1;1;1;0.9;0.9))

Table 2. Ship-generated waste potential impacts and average generation rate.

	Type of waste	Potential impacts on the environment	Effected area	Generation rate (EMSA, 2016)
Type1	Bilge water	Gasoline, solvents, detergents, chemicals.	Soil	0.01-13 m3 per day, larger ships generate larger quantities.
Type2	Sludge (oil residues)	Oil, pathogenic organisms, organic compounds, heavy metals, nitrogen	Soil	0.01 to 0.03 m3 of sludge per tonne of HFO. 0 and 0.01 m3 per tonne of MGO.
Type3	Sewage	Harmful bacteria, parasite	Sea water, Marine habitat	0.01 to 0.06 m3 per person per day. Sewage is sometimes mixed with other waste water. The total amount ranges from 0.04 to 0.45 m3 per day per person.
Type4	Plastics	Toxic chemicals	Soil, air	0.001 to 0.008 m3 of plastics per person per day.
Type5	Slop (tank cleaning water)	Solvents, detergents, chemicals	Soil	20 to hundreds of m3.
Type6	Food waste	Methane, CO2 and chlorofluorocarbons	Sea water, marine habitat, Air	0.001 to 0.003 m3 per person per day
Type7	Cargo residues	Toxic, chemical products	Soil	0.001–2 % of cargo load.
Type8	Dunnage	Toxic substances	Sea water, Marine habitat	0.1 to 1.5 m3 of dunnage disposal per voyage.
Type9	Ashes	Toxic substances	Air	0.004 and 0.06 m3 per month.
Type10	Ballast water residues	Oil contaminants, non-native marine animals and plants,	Soil	0.04 and 0.5 m3 per year.
Type11	Cooking oil	Heavy metals, green gas emissions	Soil	0.01 to 0.08 litres per person per day.

3.4 EMPRICAL ANALYSIS

IT2FAHP is applied to analytically assess potential impacts of the ship-generated waste on the marine environment by using evaluation of three experts. The result of the pair wise comparisons of the expert evaluations are performed by using Eq. (1). The aggregated type-2 fuzzy evaluation matrix for the type of wastes weights are obtained (Table 3).

The type-2 fuzzy geometric means of the type of ship-generated wastes are obtained in step 3 by using Eq. (2). For example, the geometric mean of the first row is calculated as follows:

$$\tilde{\tilde{r}}_1 = \left(\tilde{\tilde{a}}_{11} \times \tilde{\tilde{a}}_{12} \times \tilde{\tilde{a}}_{13} \times \tilde{\tilde{a}}_{14} \times \tilde{\tilde{a}}_{15} \times \tilde{\tilde{a}}_{16} \times \tilde{\tilde{a}}_{17} \times \tilde{\tilde{a}}_{18} \times \tilde{\tilde{a}}_{19} \times \tilde{\tilde{a}}_{110} \times \tilde{\tilde{a}}_{111}\right)^{1/11}$$

$$= \begin{pmatrix} ((1;1;1;1;1;1),(1;1;1;1;0,9;0,9))\times \\ ((0,53;0,61;0,61;0,83;1;1),(0,56;0,61;0,61;0,69;0,9;0,9))\times \\ ((2,67;3,67;3,67;4,67;1;1),(3,17;3,67;3,67;4,17;0,9;0,9))\times \\ ((0,22;0,29;0,29;0,42;1;1),(0,25;0,29;0,29;0,34;0,9;0,9))\times \\ ((0,28;0,39;0,39;0,67;1;1),(0,32;0,39;0,39;0,49;0,9;0,9))\times \\ ((2,67;3,67;3,67;4,67;1;1),(3,17;3,67;3,67;4,17;0,9;0,9))\times \\ ((1;1,67;1,67;2,33;1;1),(1,33;1,67;1,67;2;0,9;0,9))\times \\ ((2,33;3,33;3,33;4,33;1;1),(2,83;3,33;3,33;3,83;0,9;0,9))\times \\ ((0,25;0,34;0,34;0,58;1;1),(0,29;0,34;0,34;0,43;0,9;0,9))\times \\ ((1,33;2;2;2,67;1;1),(1,67;2;2;2,33;0,9;0,9))\times \\ ((1,67;2,67;2,67;3,67;1;1),(2,17;2,67;2,67;3,17;0,9;0,9)) \end{pmatrix}^{1/11}$$

$$= ((0,9;1,23;1,23;1,67;1;1),(1,06;1,23;1,23;1,42;0,9;0,9))$$

Table 3. The aggregated IT2F comparison matrix.

	T1
T1	((1;1;1;1;1;1),(1;1;1;1;0.9;0.9))
T2	((1.33;2;2;2.67;1;1),(1.67;2;2;2.33;0.9;0.9))
T3	((0.22;0.29;0.29;0.42;1;1),(0.25;0.29;0.29;0.34;0.9;0.9))
T4	((2.67;3.67;3.67;4.67;1;1),(3.17;3.67;3.67;4.17;0.9;0.9))
T5	((1.67;2.67;2.67;3.67;1;1),(2.17;2.67;2.67;3.17;0.9;0.9))
T6	((0.22;0.29;0.29;0.42;1;1),(0.25;0.29;0.29;0.34;0.9;0.9))
T7	((0.56;0.67;0.67;1;1;1),(0.6;0.67;0.67;0.78;0.9;0.9))
T8	((0.23;0.31;0.31;0.44;1;1),(0.26;0.31;0.31;0.36;0.9;0.9))
T9	((2.33;3.33;3.33;4.33;1;1),(2.83;3.33;3.33;3.83;0.9;0.9))
T10	((0.53;0.61;0.61;0.83;1;1),(0.56;0.61;0.61;0.69;0.9;0.9))
T11	((0.28;0.39;0.39;0.67;1;1),(0.32;0.39;0.39;0.49;0.9;0.9))
	T2
T1	((0.53;0.61;0.61;0.83;1;1),(0.56;0.61;0.61;0.69;0.9;0.9))
T2	((1;1;1;1;1;1),(1;1;1;1;0.9;0.9))
T3	((0.16;0.19;0.19;0.23;1;1),(0.17;0.19;0.19;0.21;0.9;0.9))
T4	((2;3;3;4;1;1),(2.5;3;3;3.5;0.9;0.9))
T5	((1;1.67;1.67;2.33;1;1),(1.33;1.67;1.67;2;0.9;0.9))
T6	((0.16;0.2;0.19;0.24;1;1),(0.18;0.2;0.19;0.21;0.9;0.9))
T7	((0.28;0.39;0.39;0.67;1;1),(0.32;0.39;0.39;0.49;0.9;0.9))
T8	((0.22;0.29;0.29;0.42;1;1),(0.25;0.29;0.29;0.34;0.9;0.9))
T9	((2.67;3.67;3.67;4.67;1;1),(3.17;3.67;3.67;4.17;0.9;0.9))
T10	((0.28;0.39;0.39;0.67;1;1),(0.32;0.39;0.39;0.49;0.9;0.9))
T11	((0.26;0.36;0.36;0.61;1;1),(0.3;0.36;0.36;0.45;0.9;0.9))
	…………………………………………………………..
	T11
T1	((1.67;2.67;2.67;3.67;1;1),(2.17;2.67;2.67;3.17;0.9;0.9))
T2	((2;3;3;4;1;1),(2.5;3;3;3.5;0.9;0.9))
T3	((0.5;0.56;0.56;0.67;1;1),(0.52;0.56;0.56;0.6;0.9;0.9))
T4	((3;4;4;5;1;1),(3.5;4;4;4.5;0.9;0.9))
T5	((3.33;4.33;4.33;5.33;1;1),(3.83;4.33;4.33;4.83;0.9;0.9))
T6	((0.26;0.36;0.36;0.61;1;1),(0.3;0.36;0.36;0.45;0.9;0.9))
T7	((1.11;1.83;1.83;2.67;1;1),(1.47;1.83;1.83;2.22;0.9;0.9))
T8	((0.53;0.61;0.61;0.83;1;1),(0.56;0.61;0.61;0.69;0.9;0.9))
T9	((4.33;5.33;5.33;6.33;1;1),(4.83;5.33;5.33;5.83;0.9;0.9))
T10	((0.53;0.61;0.61;0.83;1;1),(0.56;0.61;0.61;0.69;0.9;0.9))
T11	((1;1;1;1;1;1),(1;1;1;1;0.9;0.9))

The type-2 fuzzy weights are calculated using Eq. (3). For example, the type-2 fuzzy weight of the first row (I1) is calculated as follows:

$$\tilde{\tilde{w}}_1 = \tilde{\tilde{r}}_1 \times \left(\tilde{\tilde{r}}_1 + \tilde{\tilde{r}}_2 + \tilde{\tilde{r}}_3 + \tilde{\tilde{r}}_4 + \tilde{\tilde{r}}_5 + \tilde{\tilde{r}}_6 + \tilde{\tilde{r}}_7 + \tilde{\tilde{r}}_8 + \tilde{\tilde{r}}_9 + \tilde{\tilde{r}}_{10} + \tilde{\tilde{r}}_{11}\right)^{-1}$$

$$= ((0{,}9;1{,}23;1{,}23;1{,}67;1;1),(1{,}06;1{,}23;1{,}23;1{,}42;0{,}9;0{,}9)) \times \begin{pmatrix} ((0{,}9;1{,}23;1{,}23;1{,}67;1;1),(1{,}06;1{,}23;1{,}23;1{,}42;0{,}9;0{,}9))+ \\ ((1{,}26;1{,}7;1{,}7;2{,}28;1;1),(1{,}47;1{,}7;1{,}7;1{,}95;0{,}9;0{,}9))+ \\ ((0{,}37;0{,}46;0{,}46;0{,}63;1;1),(0{,}41;0{,}46;0{,}46;0{,}53;0{,}9;0{,}9))+ \\ ((1{,}89;2{,}6;2{,}6;3{,}3;1;1),(2{,}25;2{,}6;2{,}6;2{,}95;0{,}9;0{,}9))+ \\ ((1{,}47;2{,}03;2{,}03;2{,}61;1;1),(1{,}75;2{,}03;2{,}03;2{,}3;0{,}9;0{,}9))+ \\ ((0{,}29;0{,}37;0{,}36;0{,}51;1;1),(0{,}32;0{,}37;0{,}36;0{,}42;0{,}9;0{,}9))+ \\ ((0{,}69;0{,}98;0{,}98;1{,}44;1;1),(0{,}83;0{,}98;0{,}98;1{,}17;0{,}9;0{,}9))+ \\ ((0{,}38;0{,}5;0{,}5;0{,}71;1;1),(0{,}44;0{,}5;0{,}5;0{,}59;0{,}9;0{,}9))+ \\ ((2{,}49;3{,}3;3{,}3;4{,}09;1;1),(2{,}9;3{,}3;3{,}3;3{,}69;0{,}9;0{,}9))+ \\ ((0{,}61;0{,}8;0{,}8;1{,}1;1;1),(0{,}7;0{,}8;0{,}8;0{,}92;0{,}9;0{,}9))+ \\ ((0{,}55;0{,}76;0{,}75;1{,}04;1;1),(0{,}65;0{,}76;0{,}75;0{,}88;0{,}9;0{,}9)) \end{pmatrix}^{-1}$$

$$= ((0{,}05;0{,}08;0{,}08;0{,}15;1;1),(0{,}06;0{,}08;0{,}08;0{,}11;0{,}9;0{,}9))$$

Following the same process, the type-2 fuzzy weights of the type of waste are calculated as shown in the second row of Table 4. The IF2FSs is defuzzified by using centre of area method (Kahraman et al., 2014; Celik and Akyuz, 2016) in order to obtain weights of ship-generated waste. At this point, Eq. (4) is applied. The crisp weights ship-generated waste are normalized by using Eq. (5). The results of the IT2FAHP are presented in Table 4.

Table 4. The importance weights of the ship-generated waste.

	IT2F geometric mean	IT2F weights	Crisp weights	Normalized weights
T1	((0.9;1.23;1.23;1.67;1;1),(1.06;1.23;1.23;1.42;0.9;0.9))	((0.05;0.08;0.08;0.15;1;1),(0.06;0.08;0.08;0.11;0.9;0.9))	0.086	0.084
T2	((1.26;1.7;1.7;2.28;1;1),(1.47;1.7;1.7;1.95;0.9;0.9))	((0.06;0.12;0.12;0.21;1;1),(0.09;0.12;0.12;0.15;0.9;0.9))	0.119	0.116
T3	((0.37;0.46;0.46;0.63;1;1),(0.41;0.46;0.46;0.53;0.9;0.9))	((0.02;0.03;0.03;0.06;1;1),(0.02;0.03;0.03;0.04;0.9;0.9))	0.033	0.032
T4	((1.89;2.6;2.6;3.3;1;1),(2.25;2.6;2.6;2.95;0.9;0.9))	((0.1;0.18;0.18;0.3;1;1),(0.13;0.18;0.18;0.23;0.9;0.9))	0.179	0.175
T5	((1.47;2.03;2.03;2.61;1;1),(1.75;2.03;2.03;2.3;0.9;0.9))	((0.08;0.14;0.14;0.24;1;1),(0.1;0.14;0.14;0.18;0.9;0.9))	0.140	0.137
T6	((0.29;0.37;0.36;0.51;1;1),(0.32;0.37;0.36;0.42;0.9;0.9))	((0.02;0.02;0.02;0.05;1;1),(0.02;0.02;0.02;0.03;0.9;0.9))	0.026	0.025
T7	((0.69;0.98;0.98;1.44;1;1),(0.83;0.98;0.98;1.17;0.9;0.9))	((0.04;0.07;0.07;0.13;1;1),(0.05;0.07;0.07;0.09;0.9;0.9))	0.070	0.069
T8	((0.38;0.5;0.5;0.71;1;1),(0.44;0.5;0.5;0.59;0.9;0.9))	((0.02;0.03;0.03;0.07;1;1),(0.03;0.03;0.03;0.05;0.9;0.9))	0.036	0.035
T9	((2.49;3.3;3.3;4.09;1;1),(2.9;3.3;3.3;3.69;0.9;0.9))	((0.13;0.22;0.22;0.37;1;1),(0.17;0.22;0.22;0.29;0.9;0.9))	0.227	0.221
T10	((0.61;0.8;0.8;1.1;1;1),(0.7;0.8;0.8;0.92;0.9;0.9))	((0.03;0.05;0.05;0.1;1;1),(0.04;0.05;0.05;0.07;0.9;0.9))	0.057	0.055
T11	((0.55;0.76;0.75;1.04;1;1),(0.65;0.76;0.75;0.88;0.9;0.9))	((0.03;0.05;0.05;0.1;1;1),(0.04;0.05;0.05;0.07;0.9;0.9))	0.053	0.052

3.5 FINDINGS AND DISCUSSION

In the view of findings, ashes are found the most harmful ship-generated waste since toxic substance are severely affecting environment, in particular air. Considering average ashes generation rate, obtained from EMSA (2018) report, the ashes are produced quite more and drastically affects the environment. The toxic substances such as NOx, CO_2, sulphur dioxide, particle emissions contaminate to air. Plastics apparently is the second most hazardous waste produced by ships since the average generation rate is above the normalised value. Toxic chemicals, which is combustion residues of the plastics, have serious impacts on the soil and air. Plastic wastes are prohibited to be discharged at sea. Therefore, they either deliver to port facilities or burn in inclinator.

Tank cleaning water (slop) is another harmful ship-produced waste as it placed on the third. The average generation rate of slop is above the normalised value. The finding, in this context, shows that ships are producing more wastes than expected. Slop is generating solvent, detergents and chemical which are considerable affecting environment, in particular soil where slop waste contaminates. The other wastes such as bilge water, sewage, food waste, ballast water residues, cooking oil, cargo residues and dunnage have also serious impact on the environment by considering of average generation rate. However, their average generation rates are not beyond acceptable limits as compared to ashes, plastics and slops.

4. CONCLUSIONS

Maritime transportation has negative impacts on the environment since a large amount of wastes and pollutants emerge. Ships produce a wide range of wastes such as plastics, ashes, sludge, sewage, slop, dirty ballast water, etc. which represents a major environmental problem. This paper is aimed at highlighting the significant of the potential environmental impacts of ship-generated waste. Hence, safety awareness of marine environment can be enhanced. The IT2FSs AHP method is used to conduct an analytic analysis for evaluating potential impacts of ship-generated waste. Since AHP method is employed for prioritizing the potential ship-generated waste, the IT2FSs tackle with uncertainty and vagueness during decision-making process. The average generation of rate ship waste is included into studies to increase consistency of findings. In the light of findings, the analytic analysis shows that ash, plastic and slop (tank cleaning water) have serious impacts and consequences on maritime and coastal environment. The potential impacts of ship-generated wastes seriously pollute the marine habitat and threaten the health of human. The findings of the study thus underline that the construction of a modern ship design process should be based in particular on promoting waste management and reducing cargo retention. Similarly, ship provision innovations are stressed in order to mitigate the generation of waste. In addition, improving shipboard waste management systems is also highlighted. In the view of coastal management, it is also underlined that providing adequate reception facilities in ports and terminals is crucial in order to reduction of the pollution of the seas and coastal areas.

Consequently, the paper aims to transform the linguistic evaluations of experts into practical contributions. Maritime safety engineers, professionals and marine environment protection agencies can take benefits of the research since it enables to enhance safety control level and minimize potential environmental impacts caused by ship-generated wastes. The article also aims to increase the environmental awareness regarding the probable causes leading to pollution.

5. REFERENCES

1. ABDULLAH, L. and NAJIB, L. (2014). *A new type-2 fuzzy set of linguistic variables for the fuzzy analytic hierarchy process*. Expert Systems with Applications, 41(7), 3297-3305.
2. AKYUZ, E. and CELIK, E. (2016). *A modified human reliability analysis for cargo operation in single point mooring (SPM) off-shore units*. Applied Ocean Research. 58, 11- 20.
3. AMINIFAR, S. and MARZUKI, A. (2013). *Uncertainty in Interval Type-2 Fuzzy Systems.* Mathematical Problems in Engineering, Vol. 2013: 01-16.
4. BUCKLEY, J.J. 1985. *Fuzzy Analytic hierarchical analysis*, Fuzzy Sets and Systems 17:233–247. http://dx.doi.org/10.1016/0165-0114(85)90090-9
5. BUTT, N. (2007). *The impact of cruise ship generated waste on home ports and ports of call: A study of Southampton*. Marine Policy, Vol. 31, issue 5: 591 – 598.
6. CASTILLO, O. and MELIN, P. (2012). *A review on the design and optimization of interval type-2 fuzzy controllers.* Applied Soft Computing, 12(4), 1267-1278.
7. CHEN, S.M, and LEE, L.W. (2010). *Fuzzy multiple attributes group decision-making based on the interval type-2 TOPSIS method*. Expert systems with applications, 37(4), 2790-2798
8. CELIK, E. and AKYUZ, E. (2016*). Application of interval type-2 fuzzy sets DEMATEL methods in maritime transportation: the case of ship collision.* International Journal of Maritime Engineering, Vol 158, Part A4, doi: 10.3940/rina.ijme.2016.a4.392.
9. CELIK, E. and GUMUS, A.T. (2015). *An assessment approach for non-governmental organizations in humanitarian relief logistics and an application in Turkey.* Technological and Economic Development of Economy, 1-26.DOI:10.3846/20294913.2015.1056277.

10. CELIK, E. GUMUS, A. T. and ERDOGAN, M. (2016). *A new extension of the ELECTRE method based upon interval type-2 fuzzy sets for green logistic service providers evaluation*. Journal of Testing and Evaluation 44 (5), 1-15.
11. DEMIREL, H. AKYUZ, E. CELIK, E. & ALARCIN, F. (2019). *An interval type-2 fuzzy QUALIFLEX approach to measure performance effectiveness of ballast water treatment (BWT) system on-board ship*. Ships and Offshore Structures, 14(7), 675-683.
12. DERELI, T. and ALTUN, K. (2013). *Technology evaluation through the use of interval type-2 fuzzy sets and systems*. Computers & Industrial Engineering, 65(4): 624 - 633.
13. EMSA. (2018). *The Management of Ship-Generated Waste On-board Ships*. European Maritime Safety Agency. Delft, CE Delft, January 2017.
14. GUL, M. CELIK, E. AND AKYUZ, E. (2017). *A hybrid risk-based approach for maritime applications: The case of ballast tank maintenance*. Human and Ecological Risk Assessment Volume: 23 Issue: 6: 1389 – 1403.
15. IMO. (1973/1978). International Convention for the Prevention of Pollution from Ships (MARPOL). London.
16. KAHRAMAN, C. ÖZTAYŞI, B. SARI, İ. U. and TURANOĞLU, E. (2014). *Fuzzy analytic hierarchy process with interval type-2 fuzzy sets*. Knowledge-Based Systems, 59: 48-57.
17. KARNIK, N.N. and MENDEL, J.M. (2001). *Operations on type-2 fuzzy sets*. Fuzzy sets and systems, 122(2), 327-348.
18. MARHAVILAS, P.K. FILIPPIDIS, M. KOULINAS, G. K. & KOULOURIOTIS, D. E. (2020). *An expanded HAZOP-study with fuzzy-AHP (XPA-HAZOP technique): Application in a sour crude-oil processing plant.* Safety Science, 124, 104590.
19. MENDEL, J. M. (2007). *Type-2 fuzzy sets and systems: an overview*. Computational Intelligence Magazine, IEEE, 2(1), 20-29.
20. MENDEL, J. M. and JOHN, R. I. B. (2002). *Type-2 fuzzy sets made simple*. Fuzzy Systems, IEEE Transactions on, 10(2): 117-127.
21. MOLLAOĞLU, M., BUCAK, U., & DEMIREL, H. A. (2019). *Quantitative analysis of the factors that may cause occupational accidents at ports*. Journal of ETA Maritime Science, 7(4): 294-303.
22. NG, A.K.Y. and SONG, S. (2010). *The environmental impacts of pollutants generated by routine shipping operations on ports*. Ocean & Coastal Management, vol. 53, issue 4-6: 301 – 311.
23. SAATY, T. L. 1980. *The analytic hierarchy process*, New York: McGraw-Hill.
24. ŞAHIN, B. (2019). *Route Prioritization by using Fuzzy Analytic Hierarchy Process extended Dijkstra Algorithm*. Journal of ETA Maritime Science, 7(1): 3-15.
25. SONER, O. CELIK, E. and AKYUZ, E. (2017). *Application of AHP and VIKOR methods under interval type 2 fuzzy environment in maritime transportation.* Ocean Engineering 129: 107 – 116.
26. SUBASI, E. and DOGAN-SAGLAMTIMUR, N. (2011). *Performance evaluation of the Martaş Port Waste Reception Facility Treatment Plant*. Desalination and Water Treatment, vol. 51, issue: 13 – 15.
27. WILEWSKA-BIEN, M. GRANHAG, L. and ANDERSON, K. (2016). *The nutrient load from food waste generated onboard ships in the Baltic Sea*.Marine Pollution Bulletin, vol. 105, issue1: 359 – 366.
28. ZADEH, L. A. (1975). *The concept of a linguistic variable and its application to approximate reasoning - II*. Information Sciences, 8(4), 301-357.
29. ZUIN, S. BELAC, E. and MARZI, B. (2009*). Life cycle assessment of ship-generated waste management of Luka Koper*. Waste Management, vol. 29, issue 12: 3036 – 3046.
30. ERGIN, A. And EKER, I. (2019). "*Application of Fuzzy Topsis Model for Container Port Selection Considering Environmental Factors.*" International Journal of Maritime Engineering, vol.161.
31. BALIN, A. ŞENER, B. And DEMIREL, H. (2019). "*An Integrated Fuzzy MCDM Model for Evaluation and Selection of a Suitable Tugboat*." International Journal of Maritime Engineering, vol.161.