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Analysing influencing factors of accidental oil spills under the IOPC Fund

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ABSTRACT

Despite technological advancements and enhanced safety regulations by the International Maritime Organization, oil spill accidents continue to happen and pose a serious problem. For the prevention of these accidents, hence, it is of utmost importance to analyse them from different aspects exhaustively. Taking oil spill accidents falling into the International Oil Pollution Compensation Fund (IOPC Fund) scope into account, this paper attempts to investigate the influencing factors of spill accidents for tanker vessels comprehensively. For this goal, this paper utilizes the combination of the Classification and Regression Tree (CART) method and entropy-weighted Grey Relational Analysis (GRA) approach. The outcomes of this paper indicate that accident type and the flag of a vessel are the most influential variables that affect the size of oil spills. Shipowners, petrol importing companies and IOPC Fund officials can utilize the outcomes of this paper for mitigating oil spill risks stemming from tanker vessels.

1. Introduction

Rapid worldwide economic expansion has increased oil demand and the volume of trading oil in many countries, which has led to unprecedented growth in the maritime oil transportation business (Chen et al., 2019b). Oil tanker safety has therefore become more and more important (Yu et al., 2021). Oil spillages from tanker ships are one of the riskiest forms of marine contamination. For instance, the oil spill could prevent the photosynthesis of marine phytoplankton or cause a switch of air-sea, which would reduce the dissolved oxygen amount inside the water and further cause drastic changes in the content of oxygen and other elements' temperature in the sea, which could consequently kill phytoplankton (Jafarinejad, 2016). Intense oil shipping puts the ecosystem at risk, and oil tanker accidents that result in the spilling of oil impact not only the marine environment but also structures in coastal regions and the people who live there (Brekke and Solberg, 2005; Kollo et al., 2017; Kamal and Çakır, 2022). These occurrences frequently have an impact on fishing, tourism, and other associated economic industries. The severity of this detriment has been culminated by different impact evaluation research executed following catastrophic spills, such as the accident of Amoco Cadiz (Grigalunas et al., 1986), Exxon Valdez (Peterson et al., 2003) and (Carson et al., 1992), Erika (Bonnieux and Rainelli, 1993), among others (Alló and Loureiro, 2013).

Some initiatives have been taken in the international arena to eliminate the grievances of victims of the parties affected by the pollution incident that stems from oil tanker vessels. These are the International Convention on Civil Liability for Oil Pollution Damage (1969 CLC) and the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (FUND 1971), which resulted from the intensive work carried out under the leadership of the International Maritime Organization (IMO) after the Torrey Canyon maritime accident that occurred in 1967. Later, the 1992 Civil Liability Convention (CLC 92) and the 1992 Fund Convention (Fund 92), along with the Supplementary Fund Protocol (2003), replaced these conventions and created the third-tier compensation system. Fund 92, which is a supplement to the CLC 92, establishes a regime of compensation for the victims when the amount of compensation under the CLC 92 is not available or is insufficient. In line with this, the International Oil Pollution Compensation Fund (IOPC Fund) was founded under Fund 92 to ensure that the victims are compensated (Kamal and Çiloğlu, 2020; IOPC, 2022a).

Although the International Tanker Owners Pollution Federation Limited (ITOPF) database, which covers data on spills of oil going back to the 1970s, shows that there has been a dramatic decline in the frequency of accidents and the overall volume spilled over time (ITOPF, 2022), accidents that fall within IOPC Fund nevertheless continue to take place (IOPC, 2022b). This remains a serious financial burden on tanker vessel shipowners and oil importing companies as the financing

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parties of the IOPC Fund since accidents covered by the IOPC Fund are costly accidents (Alló and Loureiro, 2013).

Furthermore, it should be noted that the magnitude of the oil's environmental harm is not just determined by the volume of spilt oil, though. A smaller amount of spill that occurs at the incorrect time or season and in an environmentally susceptible area may prove to be much more ecologically detrimental than a greater spill that occurs at a different period of the year in a different, or even the same, environment even though a larger spill carries inherently a greater risk for the environment to a large extent (European Environment Agency, 2022). In this line, although the accidents covered by the IOPC fund are low frequency, the financial burden can be high. The ultimate aim, bringing oil spills covered by the IOPC Fund to zero point, has not been achieved yet, hence efforts to stop these tanker vessel spills deserve special attention and are still in need of research. Therefore, the research questions of this study are as in the following. (1) What are the dominant factors of the oil spill accidents under the scope of the IOPC Fund? (2) To what extent does each accident type contribute to the occurrence of different oil spill sizes? To respond to these questions, this paper employs the Classification and Regression Tree (CART) method and entropy-weighted GRA combination approach to analyse the dominant factors of spill accidents. CART has proven to be a strong tool, especially for dealing with prediction and classification issues, and does not require any pre-defined underlying link between the target (dependent) variable and predictors (independent variables). On the other hand, when there is limited knowledge and a lot of uncertainty, the GRA method is a potent alternative approach that can be used to reveal the relationships among the variables in the ship accident databases. Therefore, while the CART is used to reveal the most influential factors on oil spill size, the entropy-weighted GRA method is exploited to further examine the correlation between the most influential variable and oil spill size.

This paper is considered as preliminary research that exhaustively

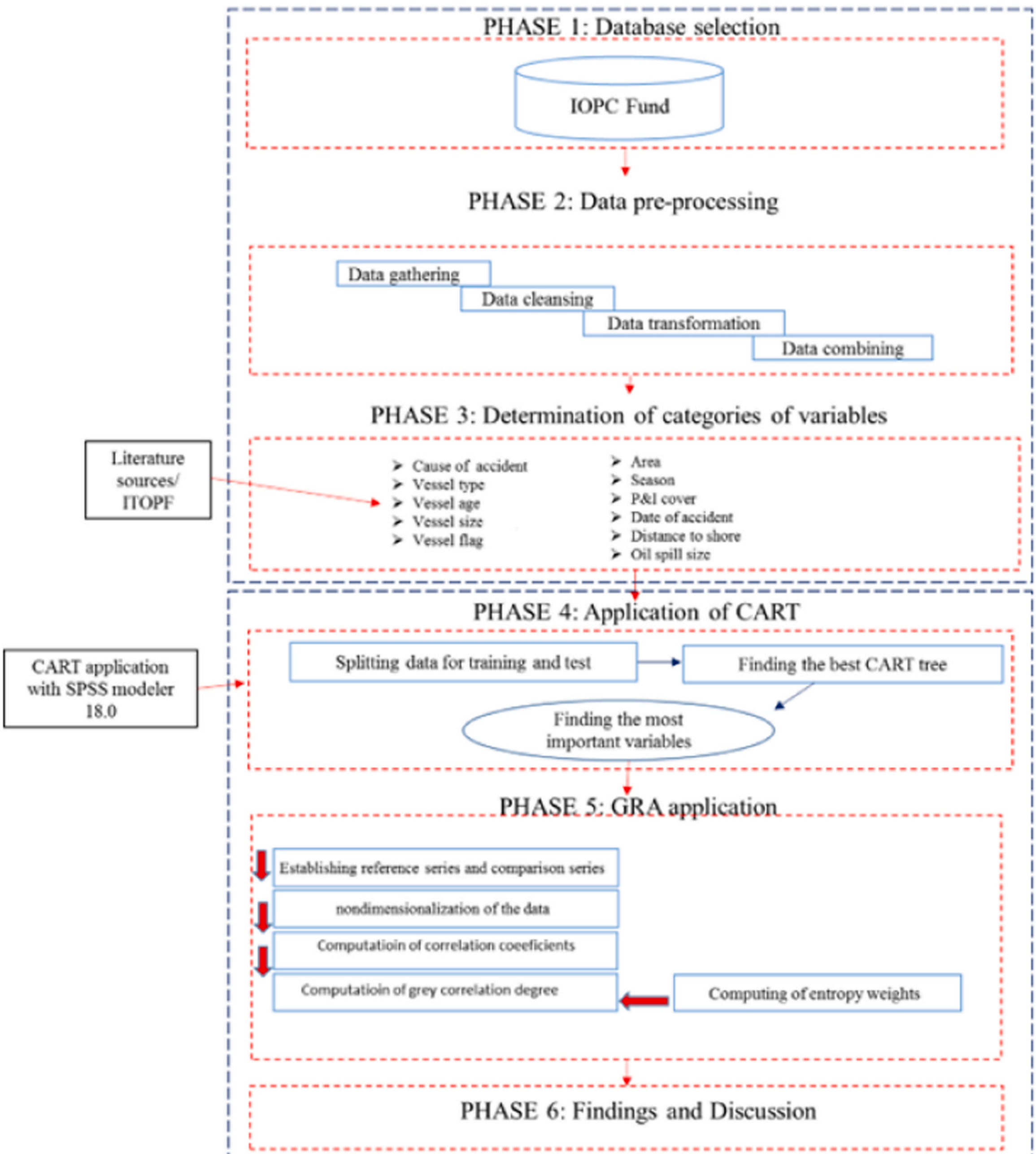

Fig. 1. The flowchart of the study.

investigates the accident influencing factors for the tanker vessels under IOPC Fund. Furthermore, it should also be noted that this is one of the pioneering studies contributing to the limited literature examining tanker vessel accidents with regard to size of spill. Analysing scientifically these dominant leading factors and oil spill size, we are required to systematically examine these factors and assess their effects on oil spill size. In this regard, this study is structured as in the following. After presenting literature regarding oil spill accidents in Section 2, the CART and Entropy-Weighted GRA approaches are explained in Section 3 with the brief implementation of Entropy-Weighted GRA stages. Following this, the outcomes of the adopted methodologies are provided and discussed in Section 4. In the concluding section, a summary of the study and some further suggestions are illustrated. For convenience, Fig. 1 provides the flowchart of the study to accomplish objectives of the research.

2. Literature review

Earlier academic study findings have largely concentrated on the use of various models and approaches to assess the risks of vessel oil spills to suggest the technologies of oil spill prevention, crucial precautions, overcoming mechanisms, and managerial aspects (Chen et al., 2018). Boehm and Page (2007) evaluated the exposure factors in spillage risk and the adverse effects on natural resources. Oil spill risk management that integrates accident data gathering, elicitation of expert view, and simulation of maritime transportation system were investigated by van Dorp and Merrick (2011). According to empirical research by Yip et al. (2011), double hulls can, on average, decrease the number of accidental spills on tank barges and tanker ships by 20% and 62%. Talley et al. (2012) empirically investigated bunker-sourced spillages arising from ships with non-oil-cargo. Frazão Santos et al. (2013) examined frameworks of the oil spill risk assessments and marine spatial planning for identification of commonalities. Xiong et al. (2015) examines the evolution and growth of China's management of oil spills from ships, assess the status quo and concerns with China's marine oil spill management, and offer important information to improve marine oil spill management in China. Zhang et al. (2021) suggest a strategy for improving the governance of oil pollution from vessels, particularly refining the prevention technology of fire and explosion for oil tanker vessels, improving the oil spill emergency response, improving the spill pollution compensation mechanism, giving more importance to the human element, and advancing the management of open registries. Kamal and Kutay (2021) present the causal elements of the bunkering operation-sourced oil spills. Sevgili et al. (2022) developed a framework that depended on a Bayesian Network approach to predict whether an oil spill might occur after tankship accidents utilizing non-US flagged ships' data compiled from the database of the Coast Guard of the United States. Bayazit and Kaptan (2023) investigate the marine pollution that stems from vessel operations with their steps and relationships among them utilizing expert opinions. Some academics also investigated how oil spillages affect the ecological environment, society and health of human beings among other effects. In this regard, the ecosystem's response to the catastrophic spill incident of Exxon Valdez was investigated by Peterson et al. (2003). Considering the case of the Hebei Spirit spill disaster, Ha et al. (2012) analysed urine metabolites of the volunteer participants before and following the clean-up process. The geographical scope of pollution of petroleum hydrocarbon in some structures such as sediment, and seawater before and following the oil drilling rig accident of Deepwater Horizon was investigated by Sammarco et al. (2013). These research primarily focused on the severe consequences of catastrophic spill incidents and presented evidence in the context of ecological solutions for government and stakeholders.

Additionally, numerous academics have examined numerous spill factors and evaluated their effects using a range of methodologies. Burgherr (2007) examined the trends and primary causes of all oil spills that occurred between 1970 and 2004. Martins and Maturana (2010) conducted a quantitative investigation of how human error contributed to oil tanker accidents considering collision and grounding. Yip et al. (2011) compared the designs of the vessels (single/double hull) statistically in terms of oil spills. Chen et al. (2018) employed some contributory factors to spills for assessment and developed an analytical scheme for spillage factors for tanker vessels. However, rather limited studies among them focused on spill size. In this regard, considering the accidents of tanker and tank barge that occurred in US seas, Anderson and Talley (1995) evaluated the amount of oil spilt following the Oil Pollution Act (OPA) period. Utilizing the decision tree and Bayesian Network approach, Cakir et al. (2021) investigated the prediction of spill severity in possible ship accidents through analysing the data set of the vessel accidents that lead to sea contamination.

Specifically, considering previous studies under the scope of IOPC Funds, the majority of the studies carried out fall within the clean-up expenses, spill cost and economic aspects. In this regard, a regression model for clean-up expenses was created by Shahriari and Frost (2008) using data from 80 oil spill incidents that were reported to IOPC. Utilizing the spill database of the IOPC Funds, a regression analysis was performed by Yamada (2009) to determine the relationship between spill costs and volume of the oil spilled. A regression analysis was provided by Kontovas et al. (2010) utilizing knowledge on the total cost of IOPC funds and the cost of clean-up. Schmitt and Spaeter (2009) outline the key elements of such a fund compensation structure and discuss the advantages of oil companies hedging their payments to the Funds through conventional insurance and capital market investments. Hay (2010) examines whether the voluntary nature of international regimes affects their ability to serve as an incentive in the prevention of accidents to examine the effectiveness of these regimes. The study by Dong et al. (2015) examines the logical and statistical linkages between the high acceptance levels of the international compensation scheme (IOPC Fund) for damage caused by tanker oil spills in some countries as well as the key determinants of such an acceptance level. Yang (2017) concentrates on China's execution of the international liability and compensation regime for oil pollution and considers whether the international regime and domestic Chinese laws together could provide a sufficient mechanism for holding offshore oil operators accountable for mishaps and ensuring adequate compensation for harmed parties. Claim amounts owing to accidental oil spills from tanker vessels were evaluated by Ching and Yip (2022) by analysing the claim data set of the IOPC Fund. The goal of Soto-Oñate and Torrens (2022) is to comprehend the reasoning processes that nations use to choose the type of responsibility distribution they desire and, consequently, the agreements they should sign. They offer a model that suggests that policymakers compare the expenses of both systems (international compensation regime and national compensation regime) and select the least expensive option based on cost-benefit analysis. However, there has been a gap in the literature on studies examining the factors affecting spill accidents covered by the IOPC fund, and on studies that consider accidents about spill size. To address this gap, this research aims to investigate comprehensively of influencing factors of spill accidents. For this goal, this study utilizes the CART method combined with the entropy-weighted GRA approach, which is explained in the methodology section.

3. Methodology

3.1. Data and categories of variables

In this study, data including 150 oil spill accidents that occurred between the years of 1978 and 2022, was obtained from the IOPC website. However, some information related to accidents was missing and therefore after the data cleansing transaction, a total of 129 accidental oil spill cases were considered for analysis of the relationship between contributing risk factors and oil spill size. Accidents which are in the scope of the IOPC Fund, contain information related to accident cause, vessel type, vessel age, vessel size, region, season, information about the P&I cover, year phase, nearest distance to shore of the accident and oil spill amount. The vessel age variable was divided into 3 categories (0−10), (11−20), and over 20 years of age, taking into consideration the related literature. In addition, frequency values of vessel age were also taken into consideration while determining this category. The year phase variable was categorised considering the IMO's phasing out of the single-hulled tankers schedule. The oil spill size variable, which is the dependent variable in the study, consists of large spills (>700 tonnes), medium spills (7–700 tonnes) and small spills (<7) categories created by ITOPF. Other categories of each variable employed in this research and literature references for the establishment of categories are presented in Table 1:

3.2. Decision trees (DT)

A decision tree (DT) is an efficient method to classify problems and create decision rules. One root, branches, nodes, and leaves form an ordinary tree. In the same manner, the decision tree consists of nodes which purport circles, the branches represent segments connecting the nodes (Zhao and Zhang, 2008). DTs are types of trees that categorize instances by sorting them according to the values of their features. In decision tree illustration, each node represents a feature in an instance that needs to be classified, and each branch represents a possible value for the node. The "divide and conquer" technique is used to create a decision tree from a collection of training objects. A tree only has one node—a leaf with the correct decision—when all objects belong to the same decision class. Otherwise, a set of objects is separated into groups according to the category of the chosen attribute and an attribute is chosen whose value is drawn from at least two distinct choice classes. In a decision tree that is expanding, the chosen attribute creates an attribute node. For each branch from that node, the inciting procedure is repeated on the remaining objects relating to the division until a leaf is encountered.

DT employs a high variety of algorithms during the construction process of the tree, including QUEST, CART, CHAID, C0.5, etc. The classification and regression tree (CART) algorithm is selected for this study due to its more accurate predictions than other DT algorithms (Ghiasi et al., 2020). CART also yields better results than other statistical approaches in terms of overcoming the over-fitting problem which leads to poor classification problems (Waheed et al., 2006). Furthermore, CART handles both continuous and nominal variables. It may create interactions between variables and also automatically manage missing values (Gupta et al., 2017). Finally, like other decision trees, the CART tree is very easy to interpret and understand (Podgorelec et al., 2002; Zhao and Zhang, 2008).

3.3. Entropy-weighted grey relational analysis (GRA)

Developed by Deng (1982), grey system theory is commonly used for dealing with uncertain and inadequate knowledge and is the foundation for Grey Relational Analysis (GRA), also known as grey incidence analysis. The fundamental goal of the GRA is to disclose previously unrecognized relationships among system components and to analyse the system utilizing limited data. In other words, the GRA approach is used for evaluating the strength of links between two digits by utilizing the departing and scattering measurement technic for actual distance measurements (Julong, 1989). The GRA examines, models, predicts, and controls the systems' inherent properties, thus it has been extensively employed in a variety of disciplines, including industrial, social systems, engineering, management, transportation etc. (Liu and Lin, 2010; Uzun, 2019).

The theory of entropy is generally applied to the computation of weights (Hsu et al., 2015). The entropy weighting approach fairly reflects the real importance of any systemic factors when choosing weights

Table 1
States of variables in the model.

Variables	Categories	Sources
Cause of accident	S1: collision, S2: grounding, S3: sinking, S4: loading-discharging, S5: other	Chen et al. (2018);Chen et al. (2019b);Sevgili et al. (2022)
Vessel type	S1: coastal tanker, S2: crude oil tanker, S3: oil product tanker, S4: other	Sevgili et al. (2022)
Vessel age (years)	S1: (0–10), S2: (11–20), S3: (>20) S4: unknown	Wang et al. (2020);Kamal and Çakır (2022)
Vessel size (GT)	S1: (<500), S2: [500–25000], S3: (>25000)	Silos et al. (2013)
Vessel flag	S1: FoC, S2: non-FoC	Burgherr (2007);Alló and Loureiro (2013)
Regions	S1: Asia-Pacific, S2: Europe, S3: Middle East, S4: North/South America	Wang et al. (2022)
Season	S1: autumn, S2: spring, S3: summer, S4: winter	Jin (2014);Kamal and Çakır (2022);Cakir et al. (2021)
P&I Cover	S1: Insured, S2: Not insured	Psarros et al. (2011);Soto-Onate and Caballero (2017)
Year phase	S1: (1970–2004), S2:(2005–2020)	Burgherr (2007)
Distance to shore (Nm)	S1: (≤1), S2: (>1)	Cakir et al. (2021);Sevgili et al. (2022)
Oil spill size (tonnes)	S1: (<7), S2: (7–700) S3: (>700).	ITOPF (2022)

for individual elements (Akyurek and Bolat, 2020). Thus, it has largely been used to assess the level of disorder and information effectiveness in a system. The entropy method is particularly functional for computing weights from secondary data (Zou et al., 2006). Oil spills' influencing elements for tanker vessels belong to a grey system with insufficient known information that is only partially available. Therefore, the GRA approach is applicable for assessment. The employed method can compute comprehensive correlation degrees among the influencing factors and present the whole and intuitive contribution of several factors to oil spillages stemming from tanker vessels. Based on this, this study chooses the indicated approach to investigate the influencing factors. Particularly, the weights of different oil spill amounts are determined through the entropy-weighted approach since these weights are well-justified and objective, computation outcomes are more objective and efficient.

The computation procedure is presented in the following.

Step 1: The oil spill factors, and spill amounts have been determined. As provided in the previous section, in this paper, 5 dominant spill influencing factors have been chosen and three spill amount segments in accordance with ITOPF classification (Table 2).

Step 2: The decision matrix is constructed after collecting the raw data. The decision matrix consists of the main factors of the system. As shown in the first equation below, x_{ij} represents the value of the j-th spill amount category indicator for the i-th accident factor and i = 1,2,….n.

$$x_{mn} = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{1}$$

Step 3: The weight of spill amounts is calculated utilizing the entropy weighted approach. To carry out this, the data is normalized initially exploiting the method of averaging. Following the normalization transaction, j-th spill amount category indicator of the i-th accident type factor is illustrated by P_{ij}, and i = 1,2…m, j = 1,2…n. The computation equation is as in the following:

$$Pij = \frac{x_{ij}}{\sum_{i=1}^{m} X_{ij}}, i = 1, 2, \ldots n \tag{2}$$

Then, using information theory's definition of information entropy, information entropy E_j of different oil spill amounts can be calculated, and, j = 1,2…n. Computation formula is as in the following:

$$E_j = -k\sum_{i=1}^{m} p_{ij} lnp_{ij}, k = \frac{1}{\ln(m)} \tag{3}$$

Ultimately, we can compute the entropy weight W_j of different oil spill amounts, and j = 1,2…n. The equation is:

$$Wj = \frac{1 - E_j}{\sum_{j=1}^{n} 1 - E_j} \tag{4}$$

In the equation (4), 1 $-E_j$ represents coefficient of deviation that indicates the significance of the indicator within the system. The significance of the indicator's function increases with value.

Step 4: In this stage, the GRA approach is implemented above the factors that influence spills and four processes are included in the stage as given below:

Firstly, reference series which reflect the spill influencing elements and the comparison series are identified. The data series which reflect the spill cause characteristics is attributed as the reference series that points out frequency of spill accidents overall in the research. The data series that consists of spill influencing components is named comparison series that points out the certain number of spill accidents caused by certain spill-influencing component. Reference series are set to X_0 and the comparison series are set to X_i, where

$$X_0 = \{ \mathrm{x}_0(\mathrm{k}) | \mathrm{k} = 1, 2, \ldots, \mathrm{n} \} , X_i = \{ \mathrm{x}_\mathrm{i}(\mathrm{k}) | \mathrm{k} = 1, 2, \ldots, \mathrm{n} \} , (\mathrm{i} = 1, 2 \ldots \mathrm{m}) \tag{5}$$

Secondly, data is nondimensionalized. In the GRA model, individual elements may have different physical meanings, which causes the data to have different dimensions and orders of magnitude and makes direct comparisons of the data impossible. Because of this, the raw data is needed to be normalized for ensuring the reliability and scientificity of the assessment outcomes and the dimensionless value can then be obtained as $Y_i(k) = \{ i = 1, 2..m, \mathrm{k} = 1, 2, \ldots, \mathrm{n} \}$. Specific equation as in the following:

$$Y_i(k) = \frac{x_i(k) - \min_i x_i \quad (k)}{\max_i x_i \quad (k) - \min_i x_i \quad (k)} \tag{6}$$

Following that the correlation coefficient between oil spill influencing factors and spil amounts are calculated. Based on grey system theory, following the nondimensionalization, the reference series is $Y_0 = \{ \mathrm{Y}_0(\mathrm{k}) | \mathrm{k} = 1, 2, \ldots, \mathrm{n} \}$, and for the comparison series,

$Y_i = \{ \mathrm{Y}_\mathrm{i}(\mathrm{k}) | \mathrm{k} = 1, 2, \ldots, \mathrm{n} \}$, $\{ i = 1, 2, \ldots, \mathrm{m} \}$. The correlation coefficient between the k-th optimal indicator and k-th spill amount indicator of the i-th influencing factor can be computed as $\xi_\mathrm{i}(\mathrm{k})$ (i = 1,2…m, k = 1,2,…n) utilizing the GRA model, that is:

$$\xi_\mathrm{i}(\mathrm{k}) = \frac{\min_i \min_k |\mathrm{y}_0(\mathrm{k}) - \mathrm{y}_\mathrm{i}(k)| + \rho \quad \max_i \max_k |\mathrm{y}_0(\mathrm{k}) - \mathrm{y}_\mathrm{i}(k)|}{|\mathrm{y}_0(\mathrm{k}) - \mathrm{y}_\mathrm{i}(k)| + \rho \quad \max_i \max_k |\mathrm{y}_0(\mathrm{k}) - \mathrm{y}_\mathrm{i}(k)|} \tag{7}$$

In the equation, ρ represents the resolution coefficient, and $\rho \epsilon [0,1]$. The ρ resolution coefficient value is generally set to 0.5.

Ultimately, grey correlation degree of oil spill influencing factors are calculated. The grey relational degree between the reference series and various influencing factors' comparison series is r_i (i = 1,2,.m) according to the weights of spill amounts which were determined by the entropy weighted approach:

$$\Gamma_i = \sum_{k=1}^{n} w_k \times \xi_\mathrm{i}(\mathrm{k}) \tag{8}$$

At this point, it should be indicated that if the grey correlation degree Γ_i of any influencing factor appears as the highest, this points out the fact that the factor carries the highest impact above the spill. In line with this, all influencing factors can be sorted by their extent of influence.

Step 5: Empirical investigation and analyses are carried out. Historical data of the IOPC Fund spill accidents can then be collected, the spill contributing factors are assessed, and characteristics of the tanker spills that fall within the scope of IOPC Fund can be analysed utilizing the models and methods indicated above to propose suggestions for oil spill treatment.

3.4. Implementation of GRA

3.4.1. Computation of weights of spill amounts utilizing the entropy weighted method

Employing formula (1), we can establish the numerical matrix X_{53} that corresponds to five major contributing factors and three spill amount types during the targeted period. Based on this, we can further execute Eq. (2) for calculation of the normalized data *Pij*, which is presented in Table 2.

Following that for the calculation of the entropy weights of different spill amounts, obtained normalized data is applied on the Eq. (3) and Eq. (4). The $p_{ij} lnp_{ij}$ value is computed as presented in Table 3.

Subsequently, values of the information entropy (E_j) and the values of entropy weight (*Wj*) are given in Table 4.

Table 2
Normalization values of numerical matrix (*Pij*).

	< 7 tonnes	7–700	> 700
Collision	0.1250	0.3768	0.3333
Grounding	0.1250	0.2318	0.2222
Sinking	0.0416	0.1884	0.1666
Loading/Discharging	0.6250	0.1594	0.0277
Others	0.0833	0.0434	0.2500

Table 3
Transformed value of the normalization data ($p_{ij}lnp_{ij}$).

	< 7 tonnes	7–700	> 700
Collision	-0.2599	-0.3678	-0.3662
Grounding	-0.2599	-0.3389	-0.3342
Sinking	-0.1324	-0.3145	-0.2986
Loading/Discharging	-0.2938	-0.2927	-0.0995
Others	-0.2071	-0.1363	-0.3466

Table 4
Information entropy (E_j) and entropy weight values (Wj) of spill amounts.

	< 7 tonnes	7–700	> 700
E_j	0.7164	0.9010	0.8979
Wj	0.5851	0.2041	0.2106

3.4.2. The GRA approach on tanker oil spills influencing factors

Initially, reference series $X_0 = \{x_0(k)|k = 1, 2, \ldots, 5\}$ and comparison series $X_i = \{x_i(k)|k = 1, 2, 3\}$ are determined according to the Eq. (5). Following that the raw data is nondimensionalized based on the Eq. (6) for achieving the dimensionless value $Y_i(k)$, which is provided in Table 5.

After that correlation coefficient $\xi_i(k)$ between the range extreme values and spill factors and also between the range extreme values and spill amounts are calculated according to the Eq. (7). For instance, the range maximum value $\max_i \max_k |y_0(k) - y_i(k)$ is 1.000 and the range minimum value $\min_i \min_k |y_0(k) - y_i(k)$ is 0.000. At this point, the grey correlation coefficient of accident type of collision for spill amount less than 7 tonnes will be $\xi_i(1) = \frac{0.000+0.5\times1.000}{0.8571+0.5\times1.000} = 0{,}3684$. In a similar way, all values of grey correlation coefficients can be obtained and the computation outcomes are presented in Tables 6 and 7.

In this stage, the entropy weights of spill amount classifications provided in Table 4 together with data of correlation coefficients which are obtained through the Eq. (7) substituted into the Eq. (8) and then accordingly, grey relation degree r_i of different spill influencing parameters can be calculated considering various spill amounts, as given in Table 8.

4. Findings and discussions

4.1. CART findings

CART yielded a tree of 23 nodes (covering the root node) and 12 terminal nodes. The tree structure needed seven splitting parameters, including the flag, area, vessel size, season, vessel age, date of accident and cause of accident. The first split in node 0 was according to the vessel flag that separated the incidents into two groups: 80% of accidents occurring among vessels which had a FoC flag caused an oil spill of over 700 tonnes, compared to 16% if the vessel had a non-FoC flag. This is consistent with a recent study which found that tankers flagged with FoC countries caused significantly higher volume oil spills (Burgherr, 2007). In addition, those vessels can cause more damage to the environment and higher clean-up costs than other vessels (Alló and Loureiro, 2013). The reason why vessels sailing under FoC flags cause high-volume spills can be that these vessels are classified as substandard vessels with a worse detention history (Alderton and Winchester, 2002) and have a lack of compliance with safety standards in terms of crew competence, certificate, and equipment (Li, 1999; Zhang et al., 2021).

Table 5
Computation outcomes of the dimensionless $Y_i(k)$ values.

	< 7 tonnes	7–700	> 700
Collision	0,1429	1,0000	1,0000
Grounding	0,1429	0,5652	0,6364
Sinking	0,0000	0,4348	0,4545
Loading/Discharging	1,0000	0,3478	0,0000
Others	0,0714	0,0000	0,7273

Table 6
Calculation outcomes of range values.

	< 7 tonnes	7–700	> 700
Collision	0,8571	0,0000	0,0000
Grounding	0,8571	0,4348	0,3636
Sinking	1,0000	0,5652	0,5455
Loading/Discharging	0,0000	0,6522	1,0000
Others	0,9286	1,0000	0,2727

Table 7
Computation outcomes of correlation coefficient of oil spill accident types and spill amount types.

	< 7 tonnes	7–700	> 700
Collision	0,3684	1,0000	1,0000
Grounding	0,3684	0,5349	0,5789
Sinking	0,3333	0,4694	0,4783
Loading/Discharging	1,0000	0,4340	0,3333
Others	0,3500	0,3333	0,6471

Table 8
Calculation outcomes of the correlation degrees.

Oil spill accident types	Grey correlation degree	Ranking
Collision	0,2101	2
Grounding	0,1489	3
Sinking	0,1305	5
Loading/Discharging	0,2480	1
Others	0,1363	4

There is a close relationship between the flag of the ship and the quality and competence of the seafarers employed on that ship. Many countries (e.g., the United States, Germany, and the United Kingdom) impose restrictions and strict requirements on the recruitment of seafarers for ships flying their flag. On the contrary, the FoC-flagged ships have flexibility in terms of seafarer employment, and seafarers of any nationality can be employed on these ships. Consequently, the quality of the crew recruited by Flag of convenience vessels is not guaranteed, they lack the necessary technical training and have poorer language skills (Zhang et al., 2021). Moreover, the minimum safe manning varies according to the countries' domestic laws. Shipowners and shipping companies wishing to employ fewer seafarers on board their ships which hoisted FoC flags, increasing the workload on seafarers and leading to unsafe conditions. Although the Maritime Labour Convention, 2006 (MLC 2006) issued by the International Labour Organisation in 2006 has made significant improvements in the working conditions of seafarers and standardising seafarer qualifications, it is still of great importance to improve the working conditions and monitor the qualifications of seafarers employed on FoC flagged ships. Therefore, frequent and stringent port state controls for these ships will help eliminate substandard vessels and contribute to the safety of navigation.

The IOPC Funds are financed by contributions from entities that import certain types of oil through maritime transport, and these contributions are calculated based on the amount of oil imported during the relevant calendar year (IOPC, 2022c). Considering the relationship between ship specifications and IOPC Fund, not only the amount of oil imported is important, but also the age, and flag of the vessels used for transportation. The results of this paper imply prioritizing and increasing the contribution amounts to be paid by the companies (entities) carrying the flag of convenience as a deterrent element to ensure spill-free vessel operations. Therefore, changing the criteria for making financial contributions to the fund will lead oil-importing countries/companies to be more prudent in the selection of ships, fleets, and companies to be used for oil transportation.

At the second level of the DT, the group for accidents among the vessels hoisting a FoC flag (node 1) was split by area: all the accidents that occurred in North-South America led to an oil spill of fewer than 7 tonnes (node 4). At the third level, the group of accidents that occurred in Asia-Pacific, Europe and the Middle East was again split by area generating node 7 and terminal node 8: all accidents that occurred in Asia-Pacific or Europe caused an oil spill of over 700 tonnes compared to 50% of accidents occurred in Middle East area. In particular, all of the FoC-flagged tanker accidents that occurred in the Asia-Pacific region caused an oil pollution of over 700 tonnes. It is also observed that 60% of all accidental oil spills which were under the IOPC fund, occurred in this region. The Strait of Malacca & Singapore Strait, China, Japan & Korea, and the Gulf Area, are dangerous waterways because of the intense transport routes and adverse geographical conditions (Wang et al., 2022). Oil transportation in coastal areas also requires more frequent port visits and loading-discharging operations which leads to more shipping accidents and accidental oil spills (Hsu et al., 2015). Furthermore, collision and grounding accidents which cause severe hull structure failure and thus lead to severe accidental oil spills, are more frequent in coastal waters (Youssef and Paik, 2018; Yu et al., 2021). The "inappropriate manoeuvre of the captain" or "Bridge Team Management (BTM)" and "violation of Convention on the International Regulations for Preventing Collisions at Sea (COLREG)" are found to be unsafe behaviours that contribute to the occurrence of collision accidents (Uğurlu et al., 2020a, 2020b). Preventing ship collisions and the resulting oil spills requires a combination of advanced technology, adherence to regulations, effective communication, and a strong commitment to safety and environmental protection. Continuous training and vigilance are essential to reduce the risk of accidents at sea.

Returning to the second level of DT, accidents among vessels hoisting non-FOC flag was split by vessel size generating two subgroups as node 5 and 6: 57% of accidents of the vessels over 25000 GT resulted in an oil spill of over 700 tonnes compared to 8% for accidents of the vessels fewer than 25000 GT, respectively. At the fifth level, node 9 was split season, forming terminal node 15 and terminal node 16. All accidents involving vessels over 25000 GT in case of a collision and grounding accident in the summer or spring season led to an oil spill of over 700 tonnes while other accidents caused an oil spill between 7 and 700 tonnes. In short, large vessels were found more prone than small vessels to lead the severe oil spills. Collision and grounding accidents further augment severe accidental oil spill risk from these vessels. The reason for a high volume of oil spills can be attributed to the vessel's damage severity in case of an accident. In line with this finding, Cakir et al. (2021) revealed that grounding, collision and sinking accidents involving tankers and barges increase the severity of oil spills. Some studies (Chen et al., 2019a; Uğurlu et al., 2020a, 2020b) suggested that grounding and sinking are the most dominant type variables of catastrophic accidents. Furthermore, in a grounding event, a larger vessel is more likely to be exposed to relatively larger damage compared to a smaller vessel (Pedersen and Zhang, 2000).

Considering the right branch of DT structure, cause of incident divided the node 6 into two subgroups to form node 11 and node 12: % 70 of accidents involving the vessels under 25000 GT in case of a collision, grounding, loading-discharging, or sinking caused to an oil spill between 7 and 700 tonnes while other accidents caused an oil spill over 700 tonnes with probability of 67%. At sixth level of DT, cause of incident caused another split into terminal nodes 21 and 22: the vessels under 25000 GT caused an oil spill under 7 tonnes with 71% probability during the loading-discharging operations while the vessels with the same size involving a collision, grounding, or sinking accident caused an oil spill between 7 and 700 tonnes with 71% probability. According to findings of CART, like accidents of large vessels, collision, grounding and sinking accident types were the primary causes of severe oil spillages for relatively smaller vessels. However, small tankers caused less severe oil spills than larger tankers as expected. On the other side, some studies which proposed that there is no significant correlation between vessel size in gross tons and oil spill size (Anderson and Talley, 1995; Cakir et al., 2021).

The normalized significance of the predictor variables employed in the CART analysis is shown in Figs 2 and 3. A total of 9 predictors were disclosed to have the greatest influence on spill size stemming from vessel accidents, with percentages varying from 12% to 100%. The two parameters that carry the largest influence on the extent of the oil spill size in the CART model are the cause of the accident (100%) and the vessel flag (64%). In decreasing order of importance, other predictors that have been identified are, area (42%), vessel type (30%), season (24%), and four other predictors with a 12% degree of importance which are date of accident, vessel age, P&I cover, vessel size. Like the findings of this study, some studies (Cakir et al., 2021; Sevgili et al., 2022) revealed that accident type is the most important variable in the severity of an oil spill and has the highest influence on the probability of an oil spill. Also, a recent study (Wang et al., 2021) found that accident types are one of the most critical parameters affecting the severity of marine accidents. Therefore, to examine the correlation between accident types and oil spill size comprehensively, the GRA approach which is successful in addressing the root of a problem was employed in this study.

4.2. GRA findings

Based on CART findings, the cause of the accident was found as the most influential factor in determining the size of the oil spill. Hence, we concentrated on the relationship between accident cause and spill amount types by utilizing Entropy weighted GRA approach. In this line, it is seen from Fig. 4 that the correlation of the causal factors of the petrol tanker in the final computation outcome proposes that correlation degrees are respectively: loading/discharging, 0.2480; collision, 0.2101; grounding, 0.1489; others, 0.1364 and sinking, 0.1305. Loading/Discharging includes accidents stemming from overflow, mishandling of cargo etc., and other segments include fire/explosion, hull failure such as breaking and unknown etc. Specifically, the loading/unloading operation has the highest impact among the accident types, followed by the collision and grounding accident types, respectively. The sinking accident type delivers the least correlation value that indicates the lowest effect on tanker accidents.

It is obvious that loading/discharging and collision accident types have a higher impact among tanker accident types and these outcomes are confirmed in the previous studies as well (Alló and Loureiro, 2013; Chen et al., 2018; Su et al., 2019). The most crucial cause of oil pollution incidents during loading and unloading operations is human error. Cargo calculation error, inaccurate measurement of cargo density and controlling hose and manifold connections during loading and unloading of oil cargo are considered to be the main causes of spills caused by human error. To maintain safe operations for tanker ships, it is essential to have routine supervision and monitoring of cargo operations (Aydin et al., 2021). As a result, it is necessary to deploy sufficient staff and clearly define each person's role. In addition, the crew and operators involved in loading and discharging operations should have ongoing training and instruction to reduce the possibility of human error during these operations. Another influential cause of spills during loading and discharging of crude oil at offshore oil terminals are pipe ruptures, and pump/valve malfunctions (Iduk and Samson, 2015). In this line, it is emphasized that as a contributory factor, failure of the equipment is more probable to incur an oil spill during loading/discharging of the cargo (Chen et al., 2018). Regular maintenance and calibration of equipment used in loading and discharging operations would help reduce the risk of oil spills.

When the sub-correlation coefficients between accident types and spill amounts are examined (Fig. 5), it is seen that spill amounts of less than 7 tons are most likely to occur due to loading/discharging

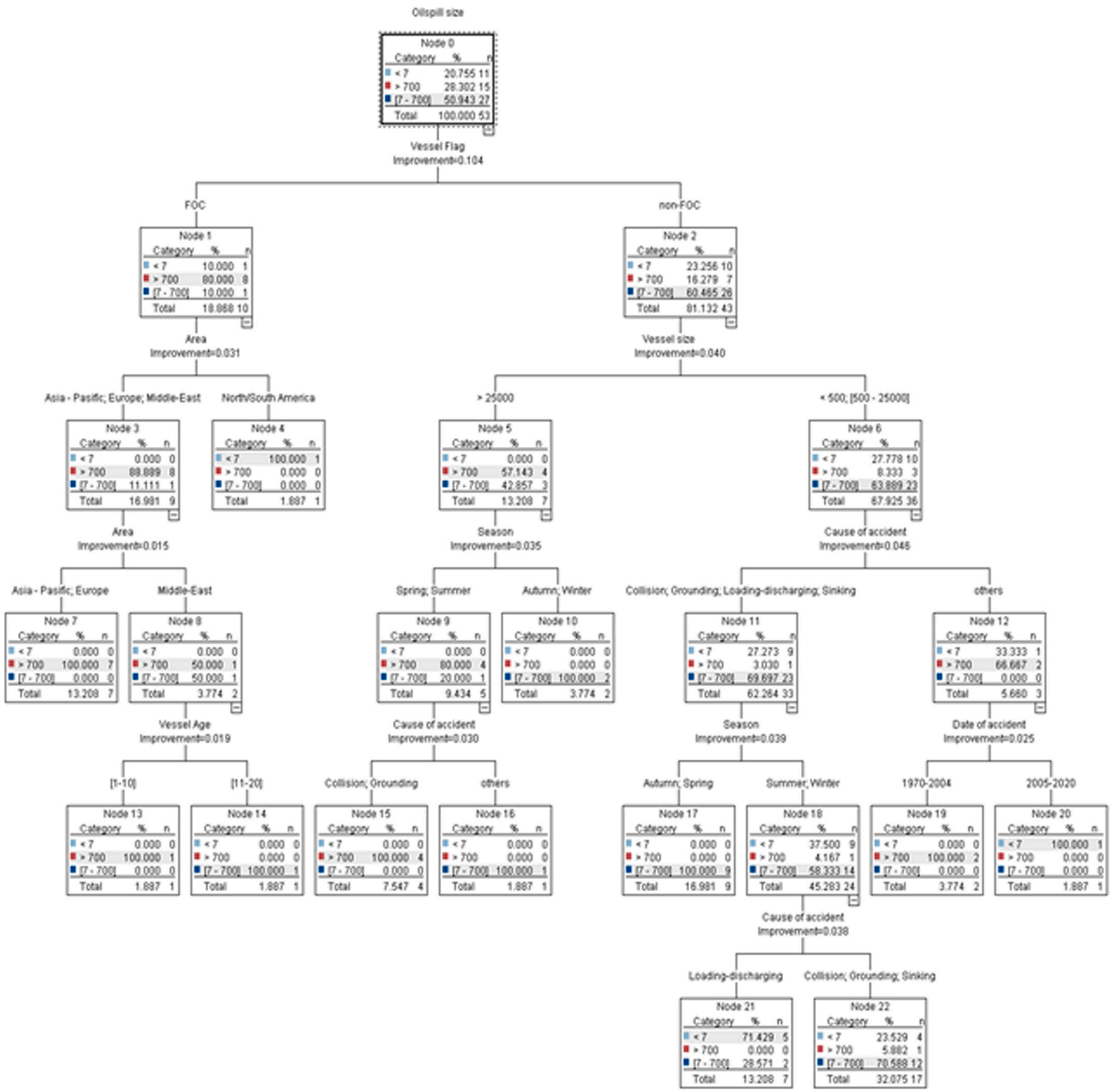

Fig. 2. CART Tree.

operation and the rest of the spill-incurring factors have almost equal impact to account for this spill amount segment. The severity of the oil's environmental devastation is decided by more than just the amount of oil spilt. A smaller spill that occurs at the wrong time or season and in an environmentally vulnerable area may prove to be much more ecologically detrimental than a larger spill that occurs at a different time of year in a different, or even the same, environment, even though a larger spill carries a greater risk for the environment. In this regard, it has been indicated by the Shipowners' Mutual Protection& Indemnity Club (P&I) that the Club has lately been made aware of many cases where standard procedures are not followed while loading, resulting in overflowing of cargo tanks, eventually leading to the pollution of the marine environment (The Shipowners' P&I Club, 2016). Therefore, it should be ensured that the International Safety Guide for Oil Tankers and Terminals (ISGOTT) is strictly followed by the vessel crew, particularly for loading/discharging operations to prevent relatively smaller spills. Also, it should be noted that since the cargo loading/discharging operation takes place in the terminal or a region close to the terminal area as a ship-to-ship (STS) operation, it can be said that the intervention to the pollution incident may be early, and this ultimately plays a role as a reducing factor on the amount of spillage.

Considering that spills of less than 7 tonnes occur in the port area or near the shore, emergency response plans are of critical importance. Because the pollution occurring in these areas has a high destructive power as they are places with high populations. In addition, pollution in these areas leads to very high clean-up costs. However, the clean-up contamination rate of spill accidents on a global scale has not yet reached the desired level and for instance, it is indicated as only 7% in

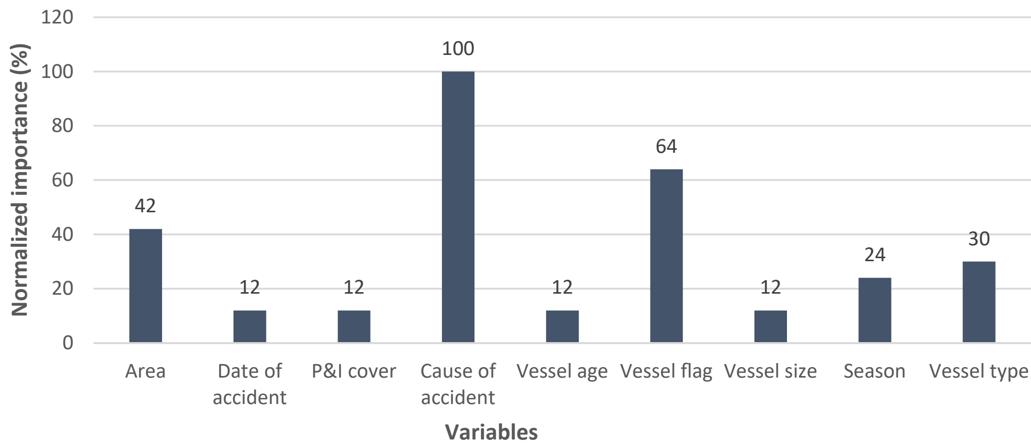

Fig. 3. Importance of the variables with CART.

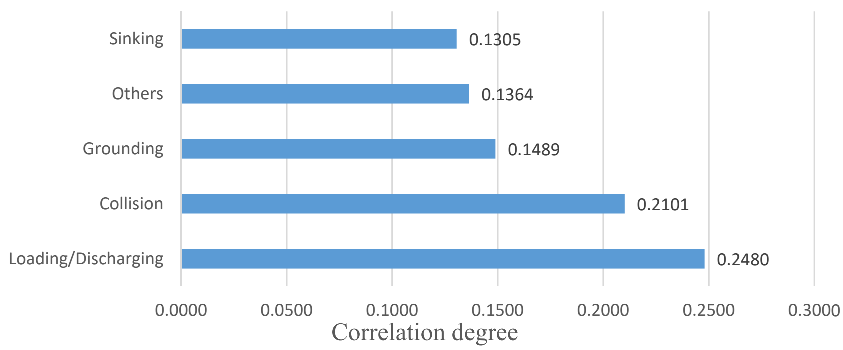

Fig. 4. Correlation of different accident types of spills.

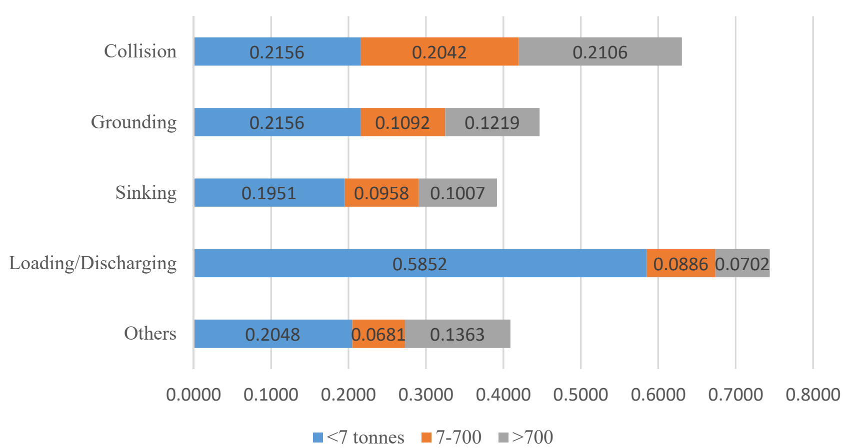

Fig. 5. Correlation coefficient between accident types and various spill amounts.

China (Xiong et al., 2015). In this regard, port facilities of states parties to the IOPC Fund, which frequently witness loading and unloading operations, should improve their capability for fast responding to emergencies, which mostly entails allocating resources, training response personnel, and conducting emergency response drills. For instance, several small-scale equipment stockpiles should be provided in these port structures to cope with this size of spill.

Considering spills between 7 and 700 tons, it appears that collision accident type has the highest impact to explain the spill amount for this segment. The remaining accident types carry approximately similar effects to account for the spill occurrences for this segment. In addition, accidents resulting in spills of more than 700 tons occur mostly as a result of collision accidents and with the least probability during the loading/unloading operation. These findings are in parallel with the outcomes of the CART approach which implies that large vessels are more likely than small vessels to cause significant oil spills.

5. Conclusion

One of the biggest problems the maritime industry faces is oil spills from tanker vessels. Despite technical breakthroughs and safety standards which are continuously improved by practitioners and regulatory authorities, accidental oil spills continue to be a major concern for the maritime industry. Particularly, the accidents covered by the IOPC Fund are even more destructive in terms of environmental damage and oil spills caused by these accidents also cause enormous clean-up costs. Therefore, this paper aimed to reveal the influencing factors of accidental oil spill size by combining of Classification and Regression Tree (CART) method and entropy weighted Grey Relational Analysis (GRA) approach for tanker accidents causing oil spills which are in the scope of the IOPC Fund. P&I Clubs, regulatory authorities, IOPC Fund officials and tanker vessel owners might utilize the outcomes of the study to lessen the risk of oil pollution caused by tanker vessels.

In this study, CART analysis showed that the cause of the accident and vessel flag were found as the most important variables affecting the oil spill size. Collision and grounding types of accidents highly augment the risk of severe accidental oil spills from tanker vessels, as expected. On the other hand, the GRA method was used to analyse the relationship between the cause of accidents and oil spill size comprehensively. Despite the loading/discharging operations causing relatively fewer oil spills (under 7 tons), it has the highest impact among the accident types on accidental oil spills considering all accidents. Therefore, the parties involved in the tanker transportation industry (shipowners, oil importers, the IOPC Fund, government agencies, etc.) should focus more on loading/discharging operations resulting in oil spills of less than 7 tons compared to other spill amount categories and accidental spills caused by these operations need to be examined in-depth to identify the causal mechanism.

This research has implications for practice in addition to theoretical insights. Considering that the majority of the loading/discharging operations occur at berth alongside or in an anchorage zone, locations and premises close to the coast are at significant risk of an oil spill due to the high impact of such an event. A spill in these areas might have a larger impact on the environment and can quickly reach the shore. Therefore, rapid first response, clean-up strategies, and equipment usage gain importance for preventing spillage from reaching the shore. The first response speed and equipment to be utilized should be prioritized for designing response methods and developing strategies, and countermeasures, especially for such regions. The major limitation of this study is that the information related to some accidents was missing due to a lack of detailed accident reports, and therefore, we particularly excluded some outdated accidents. This study is concentrated on some major parameters and in a future study as a significant variable, the compensation amount paid for each accident can be incorporated into our model. Also, this research is limited to the IOPC data and to obtain a broader perspective about spill influencing variables and spill sizes, a further study can focus on a large historical database of ITOPF.

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CRediT authorship contribution statement

Erkan Çakır: Visualization, Supervision, Writing- Reviewing and Editing, Methodology, Software. **Bunyamin Kamal**: Conceptualization, Investigation, Data curation, Writing- Reviewing and Editing.

Declaration of Competing Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed.

We further confirm that the order of authors listed in the manuscript has been approved by all of us. We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office).

Bunyamin Kamal is responsible for communicating with the another author about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author.

Data availability

Data will be made available on request.

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