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A Risk Assessment of Ships Groundings in Rivers: The Case of Parana River

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A ship's grounding appears to be a significant threat to the safety of its crew, marine environment and the local ports economy. The risk of such incidents is higher in rivers since weather conditions can significantly alter the depths of channels from those shown on navigation charts. By means of a fuzzy analytic hierarchy process, a new methodology is proposed, capable of evaluating the hazards of a ship's grounding in a river. The proposed method contributes to safe navigation in rivers. Navigators are able to assess grounding risk in a river passage based on local information of past incidents. The proposed methodology is used to evaluate commercial risks from groundings in the Parana River. A case study was carried out using data from 118 cases, as provided by local agencies for the period 2008–2017.

KEYWORDS

1. Navigation. 2. Fuzzy Analytic Hierarchy Process. 3. Coastal Navigation.

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1. RISKS ASSOCIATED WITH SHIP GROUNDINGS. In some geographical regions, transport of commodities through rivers has grown as it is beneficial in terms of environmental, economic and ship safety, in contrast to road transport (Buldgen et al., 2015). However, river navigation is not a simple operation. In the case of the Boca Grande River, vessel traffic is sometimes limited to one-way passage, which in the case of a grounding can cause transition delays and dangerous situations for subsequent ships (Kowalski, 2013). Furthermore, in some geographical locations, a rapid slowdown in the current can generate the deposition of heavier fractions of sediment, requiring ships to make turns of about 45° just before the entrance to the river track (Kowalski, 2013). In some areas such as the Amazon delta, due to meteorological conditions, the river's depth fluctuates leading to groundings, notwithstanding navigational warnings being issued (Kowalski, 2013).

Despite technological advances in ship design, ship structures are vulnerable to accidents, which may result in fatalities, commercial losses and environmental disasters (Yu et al., 2015). Collisions and groundings are generally considered the greatest hazards for vessels (Fenstad et al., 2016). An analysis of accidents arising in the Turkish Straits from 2001–2010 reveals that the second most frequent type of accident is grounding (Erol and Başar, 2015; Uğurlu et al., 2016). The grounding of a ship on seabed obstacles is a well-known hazard potentially leading to structural damage and breaches of the hull's integrity

(Yu et al., 2015). The breach of a ship's hull can lead to uncontrolled flooding of its compartments causing loss of stability and endangering crewmembers (Mazaheri et al., 2014). Adverse weather conditions can cause severe loss of stability and listing, which in turn can contribute to a ship sinking (Łozowicka and Kaup, 2015). Furthermore, ships travelling at high speeds can incur structural damage to the hull if required to slow down in muddy areas (Kowalski, 2013).

Typically, the costs incurred by a grounding are associated with ship repairs and operational delays, which might include steelwork repairs, outfitting harbour fees and additional fuel consumption (Papanikolaou et al., 2013). Costs may be excessive when a grounding occurs on a reef; damages potentially including reef restoration, structural solutions to repair natural breakwaters for the protection of coastlines sensitive to erosion, and restoration of the structural integrity and topographical complexity of reefs (Young et al., 2012).

A common practice for determining environmental costs involves dealing with several authorities, and demanding a combined effort from lawyers, economists, policymakers and insurance experts (Mondragon and Escofet, 2013). An offender's liabilities depend on the accuracy of the economic losses calculation, including claims, potential delays in the administrative process, and environmental injuries (Mondragon and Escofet, 2013). A ship's operator should be aware that in a grounding incident, local government assistance may be delayed for several hours, which in the case of pollution may cause an inadequate response to oil spill cleanup (Morgan et al., 2014).

The Exxon Valdez grounding (Alaska 1989), widely acknowledged as the worst human-made environmental disaster ever, led to a major oil spill of nearly 40,000 tons (Yu et al., 2013). In the aftermath of this and similar incidents, technical and regulatory initiatives have made ships safer; however groundings still occur, and are particularly significant causes of marine pollution. Regulators are particularly concerned regarding crude oil carriers and chemical tankers (Choung et al., 2014). Another area of improvement concerning dry cargo and passenger ships was the introduction of standard international rules in January 2009 (Papanikolaou et al., 2013). Furthermore, requirements related to probabilistic damage stability requirements for ships in a grounding have been enforced by leading classification societies and the International Maritime Organization (IMO) (Choi et al., 2014).

From the literature, it appears that river groundings have severe environmental, safety and commercial consequences. It is therefore essential that ship operators are be able to assess existing hazards as part of a ship's navigation risk assessment and contingency planning. However, researchers wanting to study shipping accidents in rivers can sometimes find the authorities restrict access to the shipyards, precluding physical inspection of the damaged ships (Yu et al., 2013). To contend with such challenges, analysis of marine casualties involving structural damage was categorised into experimental non-linear finite elements, and simplified analytical methods (Sun et al., 2015). However, both categories involve high costs and are difficult to interpret. Furthermore, with respect to maritime accident analyses, there are several conflicting opinions regarding the statistical distribution of possible causes. Celik (2009) argued that the variety of investigation techniques employed in investigating marine casualties is a significant barrier to statistical analysis. As an alternative, an analysis could be carried out that involves the development of an accident model to examine the causes, to eliminate similar accident (Uğurlu et al., 2016).

As an addition to existing research approaches, the principal aim of this study was to suggest a comprehensive methodology for evaluating ship grounding risk when navigating a river. This was achieved by utilising a model-based approach, integrating fuzzy sets and an analytic hierarchy process (AHP). Within this framework, the combined methodologies produce a ranking tool capable of measuring the consequenses of a maritime casualty. For ease of presentation, this paper comprises five sections. Following the literature review, Section 2 presents the proposed methodology. In the third section, the framework for measuring the burden of hazards when a ship grounds in a river is introduced. The proposed methodology is used in the fourth section to analyse data from 118 grounding cases in the Parana River. In Section 5 conclusions and the potential benefits of the proposed methodology are presented.

2. RESEARCH METHODOLOGY.

A ship master's obligation to execute safe navigation in rivers and other narrow channels by utilising safety information and contingency planning is paramount. The proposed methodology takes into account the potential consequences of grounding in a river. The weight of the consequences (severity of injuries, pollution, delays) is evaluated from an economic perspective. The methodology should be useful to a ship's master and ship operators to assess both physical and commercial losses. Therefore, the objectives of the proposed methodology are to:

1. classify the hazards of a ship's grounding in a river; and
2. rank the hazards for burden in a ship's grounding

2.1. *Classification of the hazards of a ship's grounding in a river.*

The evaluation of consequenses caused by a ship's grounding can be measured both in financial and managerial terms. One successfully applied tool to similar studies is the Balance Scorecard (BSC) (Punniyamoorthy and Murali, 2008; Shafia et al., 2011; Tung et al., 2011). The BSC has proven very useful in several business sectors by adopting four critical perspectives, as introduced by the founders of the method,Kaplan and Norton (1996, 2004, 2005). The two perspectives related to commercial issues are finance and customer satisfaction. The remaining perspectives are associated with organisational issues: internal business and knowledge growth. A list of successful applications in the maritime industry can be found in Table 1.

2.2. *Ranking hazards for their burden in a ship's grounding.*

Each perspective and indicator of a BSC should be weighted for its severity in a grounding incident. Quantification of the scorecard element weights can be achieved by means of AHP (Vinodh et al., 2012). One strength of AHP is that decision makers can utilise their experience and knowledge in judgements to obtain an objective and realistic result for a given problem (Park and Lee, 2008). A recent study presented a list of 190 research applications using AHP between 2004 and 2016 (Kubler et al., 2016). The variety of these studies proves the applicability of AHP across a wide range of research fields.

The first step when applying AHP is to rank the scorecard elements: the construction of a hierarchy to stratify a problem into its sub-problems for independent analysis (Asgari et al., 2015). Subsequently, multiple comparisons of the criteria can be undertaken to provide ranking weights according to priority (Zheng et al., 2012). Eventually, a weighting list and, consequently, a breakdown of the relative significance of each element in the hierarchy is determined (Tavana and Hatami-Marbini, 2011).

Table 1. Notable applications of the Balanced Scorecard in maritime-related studies.

Havold and Nesset (2009)	Performance of ship operators
Perepelkin et al. (2010)	Performance of flags states
Wu and Liu (2010)	Performance measurement of ISO certified companies
Havold and Nesset (2009)	Evaluation of safety culture
Karahalios et al. (2011)	Regulatory performance of various maritime stakeholders
Akyuz et al. (2015)	MLC 2006 compliance

Table 2. Random index values.

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0·58	0·90	1·12	1·24	1·32	1·41	1·45	1·49

Note: RI: random index

From a mathematical point of view, in an arbitrary, random reciprocal matrix, A, shown in Equation (1), the criterion a_{ij} (where $i, j = 1, 2, 3, \ldots n$) represents the preference of a_i over a_j. Consequently, when two elements are of equal importance in the matrix, a_{ij} will have a value equal to 1 when $i = j$ and $a_{ji} = 1/a_{ij}$ (Akyuz et al., 2015).

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \qquad a_{ii} = 1,\ a_{ji} = 1/a_{ij},\ a_{ij} \neq 0 \tag{1}$$

After completing the matrix, calculation of the relative weights of the criteria is required. This can be achieved by using Equation (2). The value $\lambda_{\max}$ is defined as the principal eigenvalue of an $n \times n$ comparison matrix (Vargas, 1982) and is calculated by

$$\sum_{j=1}^{n} \alpha_{ij} w_i = \lambda_{\max} w_j \tag{2}$$

By carrying out multiple pairwise comparisons it is possible for a decision maker to rank and weight the burden of each element against the objective (Veisi et al., 2016). However, in AHP calculations, consistency of pairwise comparisons must be ensured. To this end, the consistency index (CI) is measured using Equation (3) (Ung et al., 2006). Saaty (1994) suggested that the CI should be compared with the defined values of a random index (RI) of a matrix, which are shown in Table 2. The ratio of these two values measures the consistency ratio (CR) of a matrix, as shown in Equation (4). In the literature, the accepted value of CR is 0·2 or less (Wedley, 1993). Otherwise, the AHP study should be repeated including new information, or the validity of the available data should be reviewed.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{3}$$

$$CR = \frac{CI}{RI} \tag{4}$$

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2.3. *Fuzzy set theory.* The application of AHP has been criticised for the uncertainty of its results; the main reason being vagueness during pairwise comparisons (Zheng et al., 2012). A further limitation is that its users use a nine-number scale, which may not adequately map their judgements to a number, negatively affecting certainty (Ayag and Özdemir, 2006). However, the combination of AHP with fuzzy sets has been proven beneficial in literature in reducing uncertainty when there is a lack of data (Celik, 2009; Beikkhakhian et al., 2015; Guo and Zhao, 2015; Ren and Lützen, 2015; Uğurlu, 2015; Joshi and Kumar, 2016). Fuzzy sets are valuable when dealing with problems involving incomplete, imprecise data – as in most real-world systems involving human intuitive thinking (Ebrahimnejad et al., 2010).

Fuzzy AHP was applied in this methodology for expert weighting of the BSC indicators using linguistic variables. The five chosen linguistic terms used in a scale ranging from equal- to absolute importance are shown in Table 3 (Pak et al., 2015). The linguistic variables used in this research were triangular numbers that assisted the experts in making comparisons (Zadeh, 1965). For each triangular fuzzy number, a special fuzzy set $M = \{(\chi, \mu_M(\chi)), \chi, \in R\}$, was defined. The values of χ were taken from the real line $R : -\infty < \chi < +\infty$ and, $\mu_M(\chi)$, which was a continuous mapping from R to the closed interval [0, 1] (Cheng et al., 1999; Wang and Parkan, 2006):

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & x < a \\ \dfrac{x-a}{b-a} & a \le x \le b \\ \dfrac{c-x}{c-b} & b \le x \le c \\ 0 & x > c \end{cases}$$

Each linguistic term used by the experts was represented by a triangular number. As suggested by Ung et al. (2006) when several experts participate in a study, the average value of their judgements represented in fuzzy numbers should be used. The operations of fuzzy numeration are presented in Equations (5)–(7) (Cheng et al., 1999; Wang and Parkan, 2006):

1. Fuzzy number addition

$$(a_1, b_1, c_1) + (a_2, b_2, c_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \tag{5}$$

2. Fuzzy number multiplication

$$(a_1, b_1, c_1) \times (a_2, b_2, c_2) = (a_1 a_2, b_1 b_2, c_1 c_2) \tag{6}$$

3. Reciprocal fuzzy number

$$(a_1, b_1, c_1)^{-1} = \left(\frac{1}{c_1}, \frac{1}{b_1}, \frac{1}{a_1}\right) \tag{7}$$

Although fuzzy numbers are very useful in measuring linguistic terms, it is convenient to defuzzicate them in order to find crisp values (M_crisp). Equation (8) presented by

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Table 3. Triangular conversion scale.

Linguistic scale	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Equal importance	(1,1,1)	(1,1,1)
Slightly more important	(1,3/2,2)	(1/2,2/3,1)
Strongly more important	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more important	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more important	(5/2,3,7/2)	(2/7,1/3,2/5)

Wang and Parkan (2006) is an acceptable simplification method where the three values of a triangular fuzzy number are averaged to find the centre of a triangular area, as shown:

$$M_{\text{crisp}} = \frac{(b + a + c)}{3} \tag{8}$$

3. PROPOSED MODEL. Dealing with ship grounding incidents is a complicated task. For this reason, the approach adopted in this research is similar to the one suggested by Karahalios et al. (2011): critical shipboard operations were monitored according to the following steps:

1. Problem declaration.
2. Identification of the indicators for evaluating the consequences of a grounding incident.
3. Weighting of indicators for burden in the grounding of a ship.

3.1. *Problem declaration.* The literature review confirmed that the grounding of a ship causes financial and commercial losses to several parties, but particularly to the liable ship operator. At the same time, the risk of pollution and crew injury is also possible. Therefore, the risk assessment for a river grounding should combine financial, safety and environmental hazards. The results of this study have revealed weighted indicators for the consequences of a river grounding. The indicators could prove useful for port authorities in evaluating the severity of a grounding in certain locations; such data could enable authorities to adjust their contingency plans specifically based on river-grounding scenarios. Similarly, ship operators and navigators could benefit from the findings when undertaking risk assessments for navigation hazards and when devising applying contingency plans.

3.2. *Identification of indicators for evaluating the consequences of a grounding incident.* By adopting the BSC approach, a scorecard can be prepared with the hazards described in the literature (Table 4). Beginning with financial indicators, the delays incurred until a ship is refloated should be measured. As a reference point, the ideal cost-saving scenario is a ship that can be refloated by its own means. Another perspective is customer satisfaction, which includes the cargo damages and marine pollution caused by a grounding incident. From a safety perspective, crew injuries will complicate an incident, since more authorities will be need to be involved. The third perspective is know-how, used in this study to show how fast a ship operator and crew can react in a grounding, minimising its consequences. This will include indicators such as canal block days and preventing

Table 4. Proposed scorecard.

Perspectives	Indicators
Financial	Tugboat cost
	Days lost
Customer satisfaction	Pollution
	Cargo loaded at risk
	Crew injuries
Know-how	Days the canal is blocked
	Navigation hazards
Internal business	Poor voyage planning

the grounded ship becoming a navigation hazard. The last perspective comprises measuring the internal procedures of a ship operator's company. Poor voyage planning could be eliminated by assessing excessive sailing drafts depending on the geographical area.

3.2.1. *Evaluation of the scorecard.* The proposed scorecard required validation; for this reason, experts from the maritime industry with formal professional and academic qualifications were appointed to this study. Ideally, experts would have experience of ship operations either as managers or marine surveyors for classification societies or government authorities. However, inclusion of several individuals, without prior evaluation of their expertise, could have led to a ranking of priorities that may not necessarily have appeared rational. For this reason, the CR method was chosen to evaluate expert knowledge (Karahalios, 2017).

The criteria for experts therefore were

1. academic background and
2. industrial experience as safety and operation managers.

A survey was undertaken applying the Delphi method. Three rounds of the survey were required for the groups of experts to achieve a CR value smaller than 0.2, which indicates insignificant levels of uncertainty.

3.3. *Indicators weighted for burden in the grounding of a ship.* To evaluate the severity weight of BSC indicators in a grounding incident, the experts were requested to make pairwise comparisons with the chosen indicators (see Table 4). The evaluation was carried out with fuzzy numbers forming a pairwise comparison matrix, as described in Section 3.2. The mathematical operations of fuzzy numbers were carried out with Equations (5) and (6). In order to defuzzicate the numbers, Equation (8) was used. A new matrix was then formed with crisp indicator values, as shown in Table 5. To evaluate inconsistency issues, the CR value was calculated for the crisp matrix, as suggested in Section 3.2, and was found to be 0·2, an acceptable value.

By means of Equation (2) the weights of the indicators were found (Table 6). Expert judgement revealed that the most significant indicator was crew safety with value 0·24. Pollution was the second highest indicator, ranked with a weight 0·21, followed by navigation hazards. Ranked fourth and fifth were cargo damage and canal blocking, which relate to losses to other parties. Subsequent weighted rankings were assigned to the cost associated with delays and use of tugboats listed sixth and seventh accordingly. Notably, the lowest weighted indicator was voyage planning; if carried out correctly, groundings should not happen.

Table 5. Matrix of indicators.

	Navigation hazard	Days lost	Days the canal is blocked	Crew injuries	Pollution	Cargo loaded at risk	Poor voyage planning	Tugboat cost
Navigation hazards	1·000	2·000	2·000	0·722	0·411	1·500	2·500	1·500
Days lost	0·522	1·000	2·000	0·340	0·340	0·411	2·000	1·500
Days the canal is blocked	0·522	0·522	1·000	0·411	0·411	0·722	2·500	1·500
Crew injuries	2·000	3·000	2·500	1·000	2·000	2·500	3·000	3·000
Pollution	2·500	3·000	2·500	0·522	1·000	2·500	3·000	3·000
Cargo loaded at risk	0·722	2·500	1·500	0·411	0·411	1·000	2·500	2·500
Poor voyage planning	0·411	0·522	0·411	0·340	0·340	0·411	1·000	0·411
Tugboat cost	0·722	0·722	0·722	0·340	0·340	0·411	2·500	1·000

Table 6. Weighting according to expert validation.

Indicator	Weight
Crew safety	0·242
Pollution	0·210
Navigation hazard	0·136
Cargo damage	0·122
Delays	0·084
Canal block	0·082
Tugboat cost	0·072
Voyage plan	0·048

By following a similar process, the calculated values of the expert perspectives from an operational point of view were identified in terms of their impact in a grounding incident. The weights were as follows: finance 0·438; customer satisfaction 0·349; internal business 0·164; and know-how 0·049.

4. CASE STUDY FOR THE PARANA RIVER.

4.1. *Frequency analysis.* A principal aim of this study was to investigate the severity of consequences caused by a grounding incident with respect injury, loss of life, and environmental and commercial losses. Therefore, in this section, the applicability of the tool is shown by means of a case study. Local agencies provided the data from ships' groundings that occurred in the Parana River. From the total 118 groundings that were examined, 88 referred to dry cargo ships. Examination of the period in which the casualties occurred showed that there was an average of 11·8 cases annually with significant variations, as shown in Table 7. The data indicates that this phenomenon is repeated over several years without any change in the trend. Ships of various sizes were grounded, however, many of the incidents were incurred by ships with cargo loading capacity of more than 10,000 tons. Analysis of the cargo loading capacity of ships involved in the incidents showed that ships of 30,000, 40,000 and 50,000 tons were involved in groundings in 12, 18 and 17 cases respectively. The maximum draft of the ships grounded was more than 9 m and several ships had a draft of 10–11 m in 62 of the incidents. It appears that although in the majority of cases ships were loaded to their permitted draught, they still experienced groundings. In contrast, 12 ships were found to be overloaded; an aspect that raises several questions for authority control over cargo operations.

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Table 7. Annual grounding distribution in the Parana River.

2008	7
2009	9
2010	17
2011	10
2012	15
2013	12
2014	9
2015	15
2016	10
2017	14

Table 8. Distance from the river's open sea entrance.

Location	Km	Frequency
Emilio Mitre Channel	5–40	6
Canal Nuevo	98	3
Cancha Larga	152	4
Bifurcación	180	3
Punta Indio Channel	206	7
EP Bifurcación/Abajo Los Ratones	245	4
Abajo Los Ratones	287	5
Las Hermanas Bifurcación	322	5
Tonelero Isla Nueva	333	4
Abajo San Nicolás	343	4
Paraguayo	392	3
Alvear	406	11
Bella Vista	451	3
Other		34

A significant threat from a ship's grounding is pollution caused by bunker- or cargo spillage. However, a notable finding from the data analysis was that no pollution incidents were reported. This may be due to the fact that in 88 cases the cargo was grain, which could have a relatively low impact on the marine environment in cases of spillage. Nevertheless, there were incidents involving liquefied natural gas, gas oils and naphtha, which could damage the environment.

Another navigational/commercial hazard examined was the blockage of a canal. In 25 cases ships blocked the canal for less than a day; in 45 cases the ships were delayed for at least 1 day; whereas in 46 cases the delay was up to 8 days. Most incidents were reported in a range between 350 and 450 km of the river's entrance. In 58 cases the ships were able to move by their own means. However, in 18 cases the use of a tugboat was necessary and in 16 cases two tugboats were required. There were also four cases where more tugboats were employed.

The geographical distribution of incidents that occurred in the Parana River is shown in Table 8. It appears that ships are more vulnerable to grounding when navigating between 350 km and 400 km from the river's open sea entrance. However, incidents did occur at other passage legs with an average of seven groundings every 50 km.

4.2. *Calculate the risk.* Following the process described in Section 3.1, the experts determined the severity of each hazard. The frequencies of each hazard were multiplied by

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Table 9. Completed scorecard.

Hazard	Weighting	Probability	Severity	*Rank*
Cargo loaded at risk (more than 30,000)	0·094	0·521	0·048	1
Days lost	0·049	0·948	0·046	2
Days the canal is blocked	0·051	0·542	0·027	3
Pollution	0·235	0·102	0·024	4
Tugboat cost	0·042	0·396	0·016	5
Voyage plan – actual draft (more than 9 m)	0·005	0·906	0·004	6
Voyage plan – distance (distance 350–450 km)	0·005	0·458	0·003	7
Voyage plan – maximum draft 100% draft to ship design	0·005	0·635	0·002	8
Crew injuries	0·390	0	0	9
Navigation hazards	0·122	0	0	10

the weighting allocated by the experts, which produced the severity values. The hazards are presented in rank order with respect to severity in Table 9. For a ship operator, analysis of the rankings shows that, from a commercial point of view, the worst-case scenarios are cargo damage when ships have a larger capacity than 30,000 tons, followed by delays, canal block, pollution, and tugboat cost. The internal business perspective is represented by the voyage plan. Voyage plan was separated into three parts for better analysis: draft, distance from canal entry, and maximum draft at ship design. It appears that draft was a more determinant factor of grounding than voyage leg.

4.3. *Benefits in the application of the proposed model.* A ship's master's ultimate legal obligation is to navigate a ship properly following best practices and their company's instructions. However, any oversights by navigation officers that may lead to a grounding will have severe financial consequences for the responsible company. Analysis of the literature shows that economic losses include, but are not limited to, ship repairs, pollution cleanup and compensation to third parties. The financial perspective was found to have the highest weightings on the scorecard. However, from a customer perspective, the port and flag authorities were very concerned about safe navigation. Where a ship cannot refloat by its own means, a salvage operation may be necessary, which further increases costs and delays. Several other parties including charters and insurers are also affected by any delay.

A major incident such a grounding is highly likely to expose a ship's operating company to third-party investigations. In such cases, the company's procedures related to risk assessment and resources are expected to be thoroughly examined. The typical causes of a grounding are poor voyage preparation and execution. However, in the case of the Parana River it appears that there is an additional factor, related to weather conditions, which make chart information unreliable in certain cases. Consequently, the ship operators should ensure that their ships have all available navigation information and that this is reflected in the voyage plans. In the case of river navigation, information and lessons learned from previous accidents should be available to a ship's master regarding depth fluctuations.

It appears that local agencies provide invaluable information regarding local marine casualties and incidents. Navigators should be provided with this information to prepare accurate passage plans. For instance, it is crucial for a navigator to know which geographical areas in the river incur most of the groundings, as shown in Table 9. Ships with a draft of more than 9 m are more vulnerable in these locations. Consequently, during passage execution, navigation officers need to stay alert, paying more attention at particular legs of the voyage. A ship's master could also prepare contingency plans and train their crew for grounding incidents, salvage, towage and pollution elimination jointly with head office.

5. CONCLUSIONS. A marine casualty such as the grounding of a ship could have devastating results concerning injuries to crew members, pollution and damage to nearby ships. Of course, greater severity damages will increase the financial losses of the liable operating company. In this paper, it has been suggested that a risk assessment could include financial and non-financial consequences in the case of a grounding. With this approach, ship operators could measure the impact of a third-party grounding on their company.

The data analysed in this study, as provided by local agencies, revealed that in 88 cases the groundings involved bulk carriers loaded with grain. Therefore, the risk of pollution due to cargo spillage was limited since grain is not hazardous. On the other hand, the most catastrophic damages for ship operators were incurred by delays when the canal was blocked. Such blockages of a duration of more than a day occurred in 49 cases. It appears necessary therefore, for the masters and operators of a ship sailing in the geographical area between 350 and 450 km from the river's entrance to ensure that voyage planning is carefully undertaken, bearing in mind potiential depth inaccuracies. In terms of the availability of local tugboat services, contingency plans should be in place.

Fuzzy AHP appears to be useful in calculating weighting for a river-grounding incident. The contribution of experts reduced the level of uncertainty in the proposed methodology. The preparation, appraisal and execution of a voyage plan when a ship is trading in the Parana River should include theh results provided by this study. Ship operators should provide navigators with updated information about relevant incidents. This also assists ship operators in fulfilling their obligations concerning IMO guidelines that require all available navigation information for their ships.

The proposed tool was tested using cases from the Parana River because a significant number of groundings have been reported in this waterway. In this paper, it is suggested that navigation planning by a ship operator should include local information regarding incidents. The proposed tool could therefore be useful if applied in analyses of other geographical regions. The research could also be repeated with a focus on other types of ships such as gas carriers that could cause additional damage to the environment.

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