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ANALYSIS OF GROUNDING ACCIDENTS CAUSED BY HUMAN ERROR

Özkan Uğurlu, Umut Yıldırım, and Ersan Başar

Key words: marine accident, grounding accident, human factor, accident analysis.

ABSTRACT

Despite modern bridge equipment, new technologies, and improved safety measures, maritime accidents still occur, and an analysis of their causes is essential in preventing future accidents. Ship groundings are one of the more frequent types of accidents encountered, and this study examines the maritime accident reports issued for grounded ships between 1993 and 2011. These were sourced using the International Maritime Organization's Global Integrated Shipping Information System and the reports published by the countries and relevant institutions that investigated the accidents.

The grounding accidents are analysed using the Analytic Hierarchy Process, and the objective of this study is to act as an advisory paper on the prevention of grounding accidents involving human error. The results suggest that the most significant causes of these types of accidents are, lack of communication and coordination in Bridge Resource Management, position-fixing application errors, lookout errors, interpretation errors, use of improper charts, inefficient use of bridge navigation equipment, and fatigue. It is suggested that providing more education and training opportunities to seafarers, promoting widespread use on board of Electronic Chart Display and Information Systems, and improving seafarers' working hours and rest breaks would help to reduce grounding accidents significantly.

I. INTRODUCTION

Maritime accidents adversely affect both human and marine environments. The effects range from minor injuries to fatalities and from insignificant to very severe damage to the environment and property (O'Neil, 2003). Accidents serve as an operational measure of marine safety, specifically that of vessels, crews, and cargoes (Hashemi et al., 1995). Preventing accidents at sea depends upon implementing effective safety measures; and safety at sea ranks highly in all risk assessments, including those for vessel and cargo loss or damage, and crew injuries or fatalities (Lu and Tsai, 2008).

Many studies that have conducted analyses of marine accidents, frequently reveal the root causes to be associated with human error (O'Neil, 2003; Antoa and Soares, 2006; Hetherington et al., 2006; Eliopoulou and Papanikolaou, 2007; Tzannatos and Kokotos, 2009; Celik et al., 2010; Martins and Maturana, 2010; Mullai and Paulsson, 2011). Consequently, understanding the human and organisational factors underlying major shipping accidents is of key importance for maritime policy and management (Macrae, 2009).

Collisions and groundings represent 71% of accidents in European waters: ship groundings being one of the most prevalent. Furthermore, human error is the most significant factor in all types of accidents, not just groundings (Soares and Teixeira, 2001; Eliopoulou and Papanikolaou, 2007; Mullai and Paulsson, 2011; Uğurlu et al., 2013; Uğurlu et al., 2015a, 2015b). Thus, this study examines human error as a factor in ship groundings and uses the AHP method to investigate and prioritise alternative solutions for accident prevention.

II. LITERATURE REVIEW

A maritime accident, whether caused by meteorological events – such as storms, waves, or currents – or related to the ship or seafarer, is a term used for incidents causing financial losses and/or physical damages. Several studies in this field have concluded that between 80 and 90% of the causes of maritime accidents are attributable to human error (Moore and Bea, 1993; Rasmussen, 1997; Harrald et al., 1998; Antoa and Soares, 2006; Uğurlu et al., 2015a). Some of the research is also based on type of vessel, type of accident, and nationality of ship.

A study by Tzannatos (2010), which examined the maritime accidents of Greek ships during the pre-ISM (International Safety Management Code) and post-ISM periods, concluded that collisions and groundings involving Greek ships were closely associated with the shipmaster.

Macrae (2009) reviewed 30 maritime accident reports filed with the Australian Transport Safety Bureau (ATSB) and found human- and organisation-related errors to be the causes of collisions and groundings. The study revealed that, in gen-

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eral, groundings were caused by passage plan errors, failure of position-fixing, or lack of communication among the bridge team, whereas collisions were caused by errors in determining the speed, or even presence, of another ship and errors in collision prevention plans.

Antoa and Soares (2006) determined the causes for collisions and groundings involving Ro-Pax ships by using the Formal Safety Assessment methodology of the International Maritime Organization (IMO), and demonstrated the importance of initial incidents in causing accidents by using the Fault Tree Analysis (FTA) method. Their study concluded that failing to use navigational aids effectively, failures in manoeuvring, and system errors were common factors behind collisions, whereas radar, engine and rudder failures, and inadequate lookout were the common factors behind groundings.

Mullai and Paulson (2011) reviewed the groundings registered on the database of the Swedish Maritime Administration, examining the factors that caused these accidents under 8 main categories and 94 headings, including human, technical, operational, managerial, organisational, and external factors. They concluded that 54% of the accidents that took place in the Baltic Sea were collisions and groundings, generally caused by bad weather conditions and navigational hazards in regions with intense shipping.

In its statistics based on types of accidents involving British ships between 1998 and 2010, the Marine Accident Investigation Branch (MAIB, 2012) of the United Kingdom concluded that groundings were a significant type of accident frequently observed on dry cargo ships and tanker ships.

There are several studies on grounding accidents, most of which focus on the causes. Determining the causes of accidents is extremely important in preventing or minimising the possibility of future accidents, because the cause is a major factor in determining how to prevent accidents. In the present study, unlike in other studies in literature, the causes of accidents and preventive measures have been evaluated in hierarchically same way, with preventive measures for each accident identified.

III. WHY THE ANALYTIC HIERARCHY PROCESS?

Maritime accident analyses aim to determine the root causes of accidents and recommend effective ways to prevent similar accidents. Maritime accidents may involve more than one factor, such as human errors, mechanical failures, adverse weather conditions, and traffic density. Safety measures are therefore essential in preventing accidents; it is vital to learn lessons from previous accidents to safeguard life, property, and the environment at sea. The IMO takes previous maritime accidents into account when setting rules for ensuring safety at sea. Maritime accident analyses must therefore be conducted meticulously.

A number of methods have been employed in studies on accident analysis and safety assessment, including the following:

- FTA (Antoa and Soares, 2006; Kose et al., 2007; Doytchev and Szwillus, 2009; Celik et al., 2010; Martins and Maturana, 2010; Uğurlu et al., 2015a)
- Geographic Information System (Sigua and Aguilar, 2003; Akten, 2004; Anderson, 2009; Uğurlu et al., 2013, Uğurlu et al., 2015c)
- Event Tree Analysis (Goossens and Glansdorp, 1998; Ronza et al., 2003; Wang et al., 2010)
- AHP (Cheng et al., 1999; Arslan, 2009; Uğurlu et al., 2015)
- SWOT-AHP (Arslan and Er, 2008; Arslan and Turan, 2009)
- Human Factor Analysis and Classification System (Celik and Cebi, 2009; Xi et al., 2009; Xi et al., 2010)
- FSA (Formal Safety Assessment) (IMO, 2002)
- PAWSA (Ports and Waterways Safety Assessment) (Merrick and Harrald, 2007)
- IWRAP (IALA Waterway Risk Assessment Programme) (Kim et al., 2011a, 2011b)
- ES model) (Kim et al., 2011a)
- PARK model (Potential Assessment of Risk) (Park et al., 2013)

This study is based on the AHP method, which is widely used in activity analysis, productivity analysis, performance measuring problems, selection of port areas, and safety assessment (Peters and Zelewski, 2008).

The AHP method has a structure that simplifies complex problems, and is often applied to decision-making problems. As this method addresses the uncertainty in the humanistic way of thinking, it is effective in solving multi-criteria decision-making problems (Chan and Kumar, 2007; Dağdeviren and Yüksel, 2008; Kilincci and Onal, 2011).

The main advantage of AHP is its capability to check and minimise inconsistencies in expert judgements. While minimising bias in the decision-making process, this method enables group decision-making through consensus, by using the geometric mean of the individual judgements (Aminbakhsh et al., 2013). AHP has also been used to compare risk factors associated with human error and with the causes of maritime accidents (Zhang et al., 2009) to identify an appropriate management tool for improving the safety of chemical tankers during cargo operations at terminals (Arslan, 2009), for human factors analysis in aircraft-icing accidents (Lijuan and Shinan, 2011), and to identify priorities in the ship safety management system (SMS) (Chan et al., 2004), and to evaluate road traffic safety (Cheng et al., 2011). Using a single hierarchical structure, this method helps to assess both the causes of accidents and preventive measures, which is the main reason why it is employed in this study.

IV. ANALYTIC HIERARCHY PROCESS

AHP, developed by Saaty (1977, 1980, 1990), is one of the methodological approaches that may be applied to the decision-making process in highly complex problems involving multiple scenarios, criteria, and actors (Altuzarra et al., 2007).

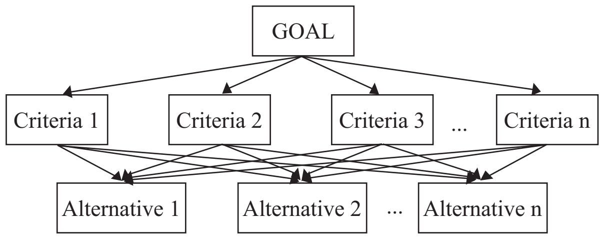

Fig. 1. Hierarchical structure.

It uses a hierarchical model comprising the overall goal, a group of falternatives, and a group of criteria linking the alternatives to the goal, and calculates the relative importance of criteria and alternatives by making paired comparisons (Vidal et al., 2011).

With the aim of improving the effectiveness of the decision-making process, AHP is in high demand for multi-criteria decision-making problems (Saaty and Vargas, 2001). The methodology incorporates the following stages:

First, the goal is determined, after which, each criterion is set in line with that goal, and then alternatives for each criterion are developed, so creating a hierarchical structure (see Fig. 1).

It is important to note that when comparing elements at each level, the decision-maker only considers the contribution of the lower-level elements to the upper-level one.

Once the hierarchical structure is created, a nxn-sized square comparison matrix is formed, as shown below:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix}_{n \times n} \tag{1}$$

n = the number of criteria to be rated
a_{ij} = the importance of criterion i compared to criterion j

If $i = j$ on the comparison matrix, then the value will be 1, because in this case, the related factor is compared with itself. Thus, due to the interrelated nature of the criteria on the matrix:

$$a = \frac{1}{a_{ji}} \quad a_{ji} \neq 0 \quad i, j = 1, 2, \ldots n \tag{2}$$

The importance scale shown in Table 1 is used for comparing factors with each other. Importance is rated from 1 to 9, not including even numbers, which are intermediate values. For example, if the decision-maker cannot choose between 1 and 3, then they might use 2. Bilateral comparisons are the most important stage in AHP.

If the decision-maker's judgement is perfect in all comparisons, then

Table 1. Pairwise comparison scale.

Inten. Import.	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favour one activity over another
4	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of tile highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgment	When compromise is needed

$$a_{ik} = a_{ij} \times a_{jk} \tag{3}$$

stands for all i, j, k, and matrix A is said to be consistent. An obvious instance of a consistent matrix A has the elements:

$$a_{ij} = \frac{w_i}{w_j}, i, j = 1, 2, \ldots\ldots, n \tag{4}$$

Thus, when matrix A is multiplied by the vector formed by each weighting,

$$w = (w_1, w_2, \ldots\ldots, w_n)^{\mathrm{T}} \tag{5}$$

one gets the following:

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_j & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_j & \cdots & w_2/w_n \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ w_i/w_1 & w_i/w_2 & \cdots & w_i/w_j & \cdots & w_i/w_n \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_j & \cdots & w_n/w_n \end{bmatrix}_{n \times n} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix}_{n \times 1}$$

$$A = n \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_j \\ \vdots \\ w_n \end{bmatrix} = nw \tag{6}$$

Table 2. Random Index.

Queue	1	2	3	4	5
RI	0	0	0.58	0.90	1.12
Queue	6	7	8	9	10
RI	1.24	1.32	1.41	1.45	1.49
Queue	11	12	13	14	15
RI	1.51	1.48	1.56	1.57	1.59

As a_{ij} is the subjective rating given by the decision-maker, there must be a distance between it and the actual values w_i/w_j. Thus, $A_w = nw$ cannot be calculated directly, and Saaty suggested using the maximum eigenvalue,

$$\lambda_{\max} = \frac{1}{n}\left(\frac{\acute{w}_1}{w_1} + \frac{\acute{w}_2}{w_2} + \cdots\cdots + \frac{\acute{w}_n}{w_n}\right), \quad (7)$$

of the solution from matrix A to replace n, then,

$$Aw = \lambda_{\max} w \quad (8)$$

This method produces the characteristic vector, referred to as the priority vector. In addition, Saaty suggested the Consistency Index (CI):

$$C.I. = \frac{\lambda_{\max} - n}{n-1} \quad (9)$$

In the final stage, the CI is divided into the standard correction value, shown in Table 2 as the Random Index, to obtain the Consistency Ratio (CR).

$$\text{CR} = \frac{\text{CI}}{\text{RI}} \quad (10)$$

The Random Index is prepared for matrixes with a maximum of 15 dimensions. The greater number of criteria in the process, the less the possibility of obtaining consistent results when taking into consideration all of the criteria. If the CR is ‘0’, then all the decisions of the decision-maker are consistent; but a Ratio of 10% or less is generally acceptable (Saaty, 1980; Saaty, 1990; Saaty and Vargas, 2001).

V. METHOD

This study evaluated data relating to grounding accidents caused by human error. The accident data used in this study were based on the grounding accident reports prepared by institutions and organizations that perform accident studies, such as GISIS, MAIB and ATSB. The GISIS accident module includes country reports analysed by experts and presented to the IMO (IMO, 2015). The Marine Accident Investigation Branch (MAIB) examines and investigates all types of marine accidents to or on board UK ships worldwide, and other ships in UK territorial waters (MAIB, 2015). The Australian Transport Safety Bureau (ATSB) is Australia’s national transport safety investigator. The ATSB’s function is to improve safety and public confidence in the aviation, marine and rail modes of transport. The ATSB is Australia’s prime agency for the independent investigation of civil aviation, rail and maritime accidents, incidents and safety deficiencies (ATSB, 2015).

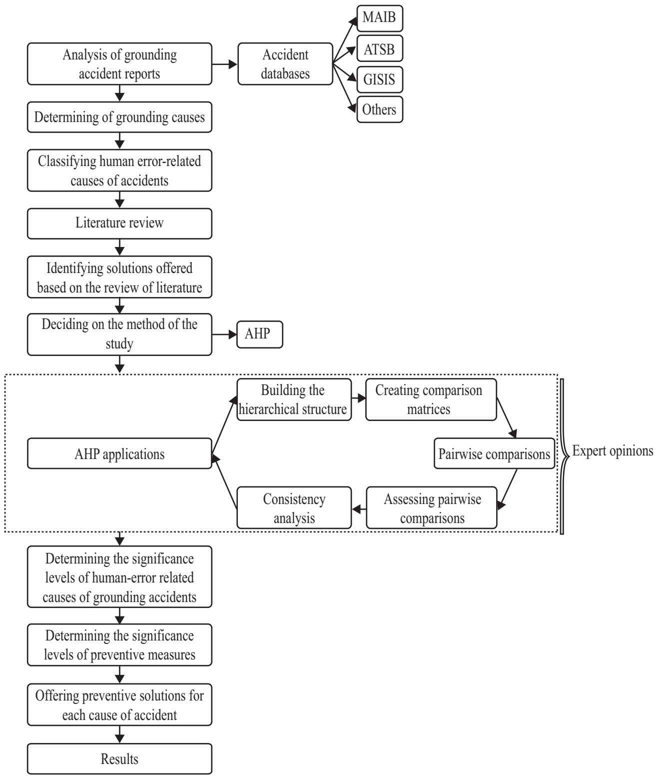

Fig. 2. Hierarchical structure.

The main purpose of this study was to identify the human error-related root causes of grounding accidents, and to propose preventive measures for each one of them. The AHP method was employed to assess both the root causes of grounding accidents and the proposed preventive measures. Fig. 2 summarises the stages of this study.

A group of five decision-makers was selected to assess the numerical data from the accident reports against the criteria and sub-criteria within the AHP hierarchy. This expert group comprised specialists from the maritime sector who possessed master’s certificates, had participated in an IMO-approved accident analysis workshop, and were currently working on maritime accidents. Possible preventive measures were derived from articles and conference papers published recently, as well as national and international maritime contracts and regulations and the rules and demands they imposed.

VI. GROUNDING ACCIDENTS

This study reviewed 131 maritime accident reports related

Table 3. Causes and frequency of groundings caused by human error.

Causes of grounding accidents		Abbreviations	Frequency
1. Voyage Management Errors	1.1 Faulty or inadequate passage plan	VME-1	18
	1.2 Inappropriate route selection	VME-2	10
	1.3 Use of improper chart	VME-3	24
2. Team Management Errors	2.1 Lack of communication and coordination in bridge resource management	TME-1	62
	2.2 Lack of external communication	TME-2	5
	2.3 Improper look-out	TME-3	20
	2.4 Deficiency in safety management system	TME-4	11
	2.5 Failure of watch arrangements	TME-5	3
3. Application Errors	3.1 Position Fixing Application Errors	AE-1	30
	3.2 Inefficient usage of bridge navigation equipment	AE-2	31
	3.3 Faulty maneuvering	AE-3	14
	3.4 Interpretation Errors	AE-4	41
	3.5 Unsafe speed	AE-5	4
4. Individual Errors	4.1 Fatigue	IF-1	35
	4.2 Alcohol	IF-2	8
	4.3 Stress	IF-3	7
	4.4 Lack of training & education	IF-4	12
	4.5 Watchkeeping officer who is unfamiliar with bridge	IF-5	10

to groundings caused by human error, and the causes were categorised to enable interpretation (Mullai and Paulsson, 2011). The causes of grounding accidents attributable to human error are defined by four main categories: team management errors, voyage management errors, application errors, and individual errors. Table 3 illustrates the causes of groundings and their frequency.

1. Preventive Measures

Determining the causes of accidents is as important as determining preventive measures against future incidents. Moreover, categorising the causes assists in determining and assessing preventive measures. Therefore, this study began with identifying and categorising the causes of accidents, and then tried to determine appropriate preventive measures for the types of accident investigated.

Thus, the overall goal was to produce accident prevention measures derived from maritime accident reports, similar studies, and new applications developed in the Standards of Training, Certification and Watchkeeping (STCW; 2010). The following are examples of preventive measures suggested for grounding accidents (Mccarter, 1999; Pillich and Buttgenbach, 2001; Macrae, 2009; IMO, 2011; Mullai and Paulsson, 2011; Størseth and Tinmannsvik, 2012; Uğurlu et al., 2013; Uğurlu et al., 2015a):

a. Obligation to have Electronic Chart Display and Information Systems (ECDIS) and compulsory ECDIS training for watchkeeping officers.
b. Compulsory Bridge Resource Management (BRM) training for watchkeeping officers, captains, and pilots.
c. Increasing the number of seafarers, especially the number of watchkeeping officers.
d. Amending the working hours of watchkeeping officers in accordance with STCW, not only on records but also in practice (improvements in seafarers' hours of work and rest).
e. Improvement of education and training.
f. Improvements in the SMS.

1) ECDIS

ECDIS is an advanced navigation device developed to optimise ship routing (Pillich and Buttgenbach, 2001; Zang et al., 2007): an electronic chart displays explanatory information on various aspects such as a ship's position, speed, course, leeway, depth of water, proximity to hazards, names and movements of the ships in the vicinity, and collision risks. It is connected to other bridge equipment such as radar, GPS, AIS, and Gyro.

ECDIS, with its automatic positioning updates, reduces both the workload in and time taken on the navigation component of the task, while increasing the amount of time available for collision avoidance without changing the workload of that component (Donderi et al., 2004). The 2010 Manila Amendments to the STCW Convention recommend the use of ECDIS on board to prevent collisions and groundings.

2) BRM

Poor bridge organisation and management is a major factor in maritime accidents (Harrald et al., 1998; Chauvin and Lardjane, 2008; Macrae, 2009; Uğurlu et al., 2015a) BRM, also known as Bridge Team Management (BTM), is the effective management and utilisation of all the human and technical resources available to the bridge team to ensure the safe completion of the vessel's voyage. It reduces the risk of marine casualties by helping the bridge team anticipate and correctly respond to their ship's changing situation (Lynch, 2009). The main purpose of good BTM is to ensure the safe and timely arrival at a destination. A secondary purpose is to avoid the losses that can occur as a consequence of collisions or stranding (Swift, 1993). BRM is a first step towards improving communication (Rothblum, 2000), and training is a recommended aspect of the ISM Code and the STCW 2010 Manila Amendments; thus, many companies are adopting it (Hetherington et al., 2006; IMO, 2011).

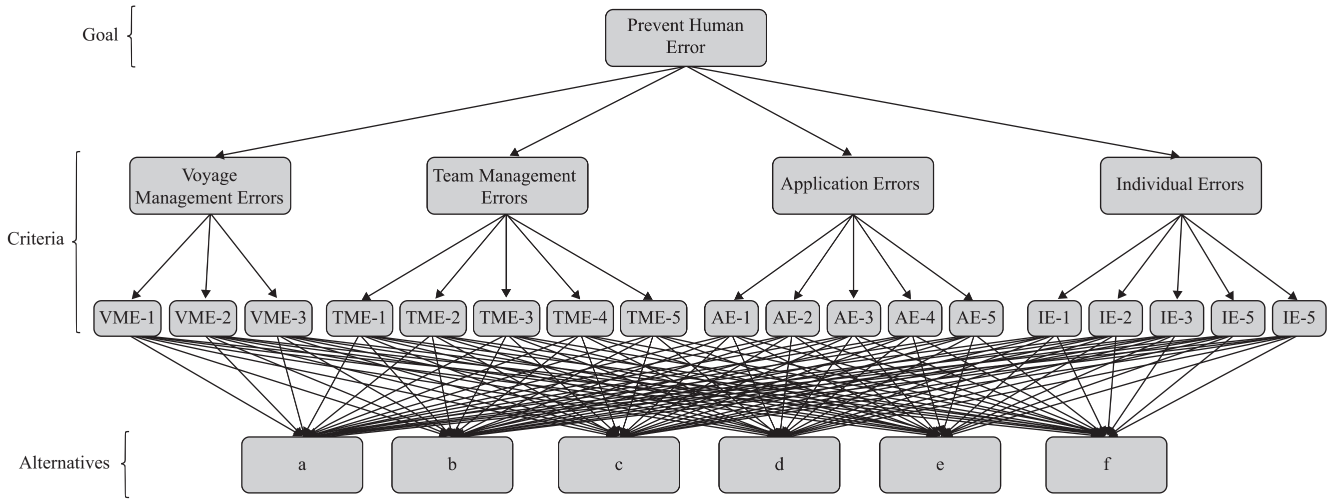

Fig. 3. Hierarchical structure of grounding accidents.

3) The Number of Seafarers and Fatigue

Maritime Labour Convention 2006 (MLC 2006) is an important international labour Convention that was adopted by the International Labour Conference of the International Labour Organization (ILO), under article 19 of its Constitution at a maritime session in February 2006 in Geneva, Switzerland. It sets out seafarers' right to decent conditions of work and helps to create conditions of fair competitions for ship owners (Garcia et al., 2011). The number of seafarers and their working conditions are important factors in fatigue, which is a major concern for health and safety at sea, leading inevitably to human error. It has been widely believed that the majority of human casualties and damage to vessels is related to human error; but recently it has been suggested that the link in the chain of events that directly leads to injury is fatigue (Baulk and Reyner, 2002). The literature includes several studies on the working conditions of seafarers (McNamara et al., 2000; Bloor et al., 2004; Jones et al., 2005; Smith et al., 2006; Andresen et al., 2007; Mitroussi, 2008; Orosa et al., 2011; Uğurlu et al., 2012), which discuss problems such as poor working and environmental conditions, work and rest hours, insufficient social opportunities, fatigue, and the relationship between fatigue and maritime accidents.

Globally, more research is revealing fatigue as a significant problem in the seafaring industry (Smith et al., 2006) and especially in the occurrence of maritime accidents. In order to minimise this effect, the intense workload of the officer on watch must not be reflected in the voyage's shifts, inconvenient working hours must be avoided (Uğurlu et al., 2015a), and the number of seafarers should be increased.

4) Training and Education

The STCW Convention was the first to establish the basic requirements of training, certification, and watchkeeping for seafarers on an international level (IMO, 2011). According to maritime accident reports, and research into such accidents, poor or inadequate education and training is a contributory factor. Therefore, one of the most effective methods in minimising human error-related risks is to provide the highest standards in education, training, certification, and competency (Barnett, 2005; Davy and Noh, 2011; IMO, 2011; Uğurlu et al., 2015a); and the IMO is a United Nations' agency that promotes safety at sea through education (Davy and Noh, 2011).

5) Safety Management System

In 1993, the IMO adopted the ISM code, the objectives of which are to ensure safety at sea, prevention of injury or loss of life, and avoidance of damage to the environment, particularly the marine environment, and to property (IMO, 2010). The IMO encouraged an SMS to be established in accordance with the ISM Code – a critical milestone in maintaining legislative control in shipping (Celik et al., 2010). Tzannatos (2010) concluded that the number of accidents reduced in the post-ISM period: the full implementation of the ISM Code and SMS could prevent maritime accidents.

2. Applying AHP to Grounding Accidents

After categorising the causes of accidents and determining alternative solutions, the decision-making process started by forming the hierarchical structure of the problem, as shown in Fig. 3.

A comparison matrix of human error criteria was produced, in consultation with experts (see Table 4). The normalisation process started once the comparison matrix was completed, and involved each element of the matrix being divided by the total of its column to achieve a normalised matrix.

The arithmetic mean of each line in the normalised matrix was used to calculate the priority vector (w). The normalised status of the human error comparison matrix and the priority vector are illustrated in Table 5.

Thus, the priorities in human error factors behind grounding

Table 4. Comparison matrix of human errors.

	VME	TME	AE	IE
VME	1	1/3	1/3	1
TME	3	1	1	3
AE	3	1	1	3
IE	1	1/3	1/3	1
Total	8	2.66	2.66	8

Table 5. Normalised status of human error comparison matrix and weights.

a	VME	TME	AE	IE	w
VME	0.125	0.125	0.125	0.125	0.125
TME	0.375	0.375	0.375	0.375	0.375
AE	0.375	0.375	0.375	0.375	0.375
IE	0.125	0.125	0.125	0.125	0.125

Table 6. Weighted aggregate matrix.

VME	TME	AE	IE	Aw	Aw/w
0.125	0.125	0.125	0.125	0.500	4
0.375	0.375	0.375	0.375	1.500	4
0.375	0.375	0.375	0.375	1.500	4
0.125	0.125	0.125	0.125	0.500	4

accidents were achieved, and confirmed that application errors were the most common type. After producing the normalised matrix, its CR was calculated. To do this, each column of the comparison matrix is multiplied to calculate the weighted aggregate matrix (Aw):

$$Aw = 0.125 * \begin{bmatrix} 1 \\ 3 \\ 3 \\ 1 \end{bmatrix} + 0.375 * \begin{bmatrix} 1/3 \\ 1 \\ 1 \\ 1/3 \end{bmatrix} + 0.375 * \begin{bmatrix} 1/3 \\ 1 \\ 1 \\ 1/3 \end{bmatrix} + 0.125 * \begin{bmatrix} 1 \\ 3 \\ 3 \\ 1 \end{bmatrix} \tag{11}$$

Then, each element of the weighted Aw is divided by the priority vector element to calculate the Aw/w value.

The $\lambda_{\max}$ value is determined by calculating the arithmetic mean of values:

$$\lambda = \frac{(4+4+4+4)}{4} = \frac{16}{4}$$

$$\lambda = 4 \tag{12}$$

The CI was then calculated:

$$\text{CI} = \frac{\lambda - n}{n-1} = \frac{4-4}{4-1} = 0 \tag{13}$$

Table 7. Comparison matrices of sub-criteria.

Voyage Management Errors CR = 0.033				
	VME-1	VME-2	VME-3	w
VME-1	1	3	1/3	0.260
VME-2	1/3	1	1/5	0.106
VME-3	3	5	1	0.633

Team Management Errors CR = 0.067						
	TME-1	TME-2	TME-3	TME-4	TME-5	w
TME-1	1	7	3	5	7	0.500
TME-2	1/7	1	1/5	1/3	3	0.075
TME-3	1/3	5	1	3	5	0.255
TME-4	1/5	3	1/3	1	3	0.125
TME-5	1/7	1/3	1/5	1/3	1	0.046

Application Errors CR = 0.055						
	AE-1	AE-2	AE-3	AE-4	AE-5	w
AE-1	1	3	7	3	7	0.458
AE-2	1/3	1	5	1/3	5	0.181
AE-3	1/7	1/5	1	1/5	1	0.050
AE-4	1/3	3	5	1	5	0.263
AE-5	1/7	1/5	1	1/5	1	0.050

Individual Errors CR = 0.009						
	IE-1	IE-2	IE-3	IE-4	IE-5	w
IE-1	1	5	5	3	5	0.496
IE-2	1/5	1	1	1/3	1	0.089
IE-3	1/5	1	1	1/3	1	0.089
IE-4	1/3	3	3	1	3	0.238
IE-5	1/5	1	1	1/3	1	0.089

Finally, the CR was calculated by dividing the CI by the standard correction value, shown in Table 6 as the Random Index:

$$n = 4, \text{RI} = 0.90$$

$$\text{CR} = \frac{\text{CI}}{\text{RI}} = \frac{0}{0.9} = 0 \tag{14}$$

This matrix is considered to be consistent since the CR = 0 is less than the 0.1 rate. The comparison matrices for the other sub-criteria in the hierarchical structure of human errors were produced and the same process applied (see Table 7).

Matrices were then produced to determine preventive measures for each cause of accidents. Their weights and CRs are given in Table 8.

VII. RESULTS AND DISCUSSION

This section presents the general priority levels of the causes of accidents and their alternative preventive measures. To this purpose, the general priorities of the preventive measures are synthesised. The synthesising process for the a-coded alternative (obligation to have ECDIS and compulsory ECDIS training for watchkeeping officers) is shown below:

Table 8. Weights and Consistency Ratios of sub-criteria.

VME-1 CR = 0.016							
	a	b	c	d	e	f	w
a	1	1/3	3	3	1/5	1/3	0.090
b	3	1	5	5	1/3	1	0.194
c	1/3	1/5	1	1	1/9	1/5	0.039
d	1/3	1/5	1	1	1/9	1/5	0.039
e	5	3	9	9	1	3	0.445
f	3	1	5	5	1/3	1	0.194
VME-2 CR = 0.060							
	a	b	c	d	e	f	w
a	1	5	7	7	3	5	0.426
b	1/5	1	5	5	1/3	3	0.149
c	1/7	1/5	1	1	1/7	1/3	0.038
d	1/7	1/5	1	1	1/7	1/3	0.038
e	1/3	3	7	7	1	5	0.268
f	1/5	1/3	3	3	1/5	1	0.082
VME-3 CR = 0.065							
	a	b	c	d	e	f	w
a	1	5	9	9	5	7	0.488
b	1/5	1	5	5	1/3	3	0.138
c	1/9	1/5	1	1	1/7	1/3	0.034
d	1/9	1/5	1	1	1/7	1/3	0.034
e	1/5	3	7	7	1	5	0.234
f	1/7	1/3	3	3	1/5	1	0.073
TME-1 CR = 0.063							
	a	b	c	d	e	f	w
a	1	1/5	1	1	1/5	1/3	0.058
b	5	1	5	5	1/3	3	0.263
c	1	1/5	1	3	1/5	1/3	0.077
d	1	1/5	1/3	1	1/5	1/3	0.051
e	5	3	5	5	1	5	0.416
f	3	1/3	3	3	1/5	1	0.135
TME-2 CR = 0.049							
	a	b	c	d	e	f	w
a	1	1/5	1/3	1/3	1/7	1	0.045
b	5	1	3	3	1/3	5	0.233
c	3	1/3	1	1/3	1/5	3	0.096
d	3	1/3	3	1	1/5	3	0.134
e	7	3	5	5	1	7	0.447
f	1	1/5	1/3	1/3	1/7	1	0.045
TME-3 CR = 0.058							
	a	b	c	d	e	f	w
a	1	1/5	1/9	1/7	1/3	1/5	0.028
b	5	1	1/7	1/5	1	1/3	0.071
c	9	7	1	3	9	5	0.470
d	7	5	1/3	1	5	3	0.245
e	3	1	1/9	1/5	1	1/3	0.057
f	5	3	1/5	1/3	3	1	0.129

TME-4 CR = 0.004							
	a	b	c	d	e	f	w
a	1	1	1	1	1/5	1/9	0.054
b	1	1	1	1	1/5	1/9	0.054
c	1	1	1	1	1/5	1/9	0.054
d	1	1	1	1	1/5	1/9	0.054
e	5	5	5	5	1	1/3	0.251
f	9	9	9	9	3	1	0.531
TME-5 CR = 0.015							
	a	b	c	d	e	f	w
a	1	1	1/7	1/3	1	1/9	0.043
b	1	1	1/7	1/3	1	1/9	0.043
c	7	7	1	3	7	1/3	0.274
d	3	3	1/3	1	3	1/5	0.114
e	1	1	1/7	1/3	1	1/9	0.043
f	9	9	3	5	9	1	0.482
AE-1 CR = 0.034							
	a	b	c	d	e	f	w
a	1	7	9	7	5	9	0.536
b	1/7	1	3	1	1/3	3	0.094
c	1/9	1/3	1	1/3	1/5	1	0.039
d	1/7	1	3	1	1/3	3	0.094
e	1/5	3	5	3	1	5	0.198
f	1/9	1/3	1	1/3	1/5	1	0.039
AE-2 CR = 0.068							
	a	b	c	d	e	f	w
a	1	1/3	1/5	1/7	1/9	1/9	0.025
b	3	1	1/3	1/5	1/7	1/7	0.046
c	5	3	1	1/3	1/5	1/5	0.087
d	7	5	3	1	1/3	1/3	0.164
e	9	7	5	3	1	3	0.400
f	9	7	5	3	1/3	1	0.278
AE-3 CR = 0.045							
	a	b	c	d	e	f	w
a	1	3	5	1/3	1/5	5	0.140
b	1/3	1	3	1/5	1/7	3	0.074
c	1/5	1/3	1	1/7	1/9	1	0.034
d	3	5	7	1	1/3	7	0.255
e	5	7	9	3	1	9	0.463
f	1/5	1/3	1	1/7	1/9	1	0.034
AE-4 CR = 0.058							
	a	b	c	d	e	f	w
a	1	3	5	1/3	3	5	0.227
b	1/3	1	3	1/5	1/3	3	0.092
c	1/5	1/3	1	1/7	1/5	1	0.041
d	3	5	7	1	5	7	0.439
e	1/3	3	5	1/5	1	5	0.160
f	1/5	1/3	1	1/7	1/5	1	0.041

Table 8. (Continued)

AE-5 CR = 0.036							
	a	b	c	d	e	f	w
a	1	1/7	1/3	1/3	1/9	1/9	0.027
b	7	1	5	5	1/3	1/3	0.177
c	3	1/5	1	1	1/7	1/7	0.053
d	3	1/5	1	1	1/7	1/7	0.053
e	9	3	7	7	1	1	0.345
f	9	3	7	7	1	1	0.345
IE-1 CR = 0.030							
	a	b	c	d	e	f	w
a	1	1	1/7	1/9	1	1/3	0.042
b	1	1	1/7	1/9	1	1/3	0.042
c	7	7	1	1/3	7	5	0.285
d	9	9	3	1	9	7	0.488
e	1	1	1/7	1/9	1	1/3	0.042
f	3	3	1/5	1/7	3	1	0.100
IE-2 CR = 0.047							
	a	b	c	d	e	f	w
a	1	1/3	1	1	1/5	1/9	0.045
b	3	1	3	3	1/3	1/7	0.110
c	1	1/3	1	1	1/5	1/9	0.045
d	1	1/3	1	1	1/5	1/9	0.045
e	5	3	5	5	1	1/7	0.200
f	9	7	9	9	7	1	0.556

IE-3 CR = 0.041							
	a	b	c	d	e	f	w
a	1	1/3	1/7	1/9	1/3	1/5	0.030
b	3	1	1/5	1/7	1	1/3	0.062
c	7	5	1	1/3	5	3	0.251
d	9	7	3	1	7	5	0.462
e	3	1	1/5	1/7	1	1/3	0.062
f	5	3	1/3	1/5	3	1	0.133
IE-4 CR = 0.054							
	a	b	c	d	e	f	w
a	1	1/7	1	1	1/9	1/5	0.039
b	7	1	7	7	1/5	3	0.242
c	1	1/7	1	1	1/9	1/5	0.039
d	1	1/7	1	1	1/9	1/5	0.039
e	9	5	9	9	1	5	0.494
f	5	1/3	5	5	1/5	1	0.149
IE-5 CR = 0.034							
	a	b	c	d	e	f	w
a	1	1/5	1	1	1/7	1/9	0.039
b	5	1	5	5	1/3	1/5	0.151
c	1	1/5	1	1	1/7	1/9	0.039
d	1	1/5	1	1	1/7	1/9	0.039
e	7	3	7	7	1	1/3	0.263
f	9	5	9	9	3	1	0.469

General Priority Calculation = (0.125) * [(0.260 * 0.090)
+ (0.106 * 0.426) + (0.633 * 0.488)]
+ (0.375) * [(0.500 * 0.058) + (0.075 * 0.045)
+ (0.255 * 0.028) + (0.125 * 0.054) + (0.046 * 0.043)]
+ (0.375) * [(0.458 * 0.536) + (0.181 * 0.025)
+ (0.050 * 0.140) + (0.263 * 0.227) + (0.050 * 0.027)]
+ (0.125) * [(0.496 * 0.042) + (0.089 * 0.045)
+ (0.089 * 0.030) + (0.238 * 0.039) + (0.089 * 0.039)] = 0.190

The syntheses of all six alternative measures suggested for preventing accidents, along with their resulting importance ratings, are given in Table 9.

Based on the data given in Table 9, the importance of each of the preventive measures is confirmed as e > a > d > f > b > c. This study first established the order of importance of the alternatives, and then tried to establish the order of importance of each cause of accidents and their related preventive measures. Table 10 illustrates the level of efficiency each alternative provides in terms of preventing the causes of accidents.

While determining preventive measures for each cause of accidents, those with priority values below 0.005 were disregarded. As a result, alternative solutions for each cause are suggested in Table 10. For example, e > f ≥ b-coded alternatives can be listed as preventive measures against accidents caused by faulty or inadequate passage plans (VME-1).

Table 9. General priority values and ranking of preventive measures.

Preventive Measures	General priority	Ranking
a	0.190	2.
b	0.131	5.
c	0.115	6.
d	0.159	3.
e	0.260	1.
f	0.145	4.

According to the results of this study, the most significant way to prevent grounding accidents is to improve education and training opportunities, including competency, shore-based, and onboard training, as well as training courses. The topics, in accordance with Table 10, to be addressed during these education and training sessions will now be discussed.

Competency training and training courses should focus on team management, communication and coordination on board, the effective use of bridge navigation equipment, passage planning and implementation, and risk assessment in dangerous waters (narrow canals, coastal waters, and during berthing and unberthing manoeuvres). In contrast, shore-based and onboard training should particularly address the features and

Table 10. Ranking of preventive measures.

	Total	a	b	c	d	e	f	Preventive Measures
Voyage Management Errors	0.125	0.047	0.019	0.004	0.004	0.037	0.013	a > e > b > f
VME-1	0.033	0.003	0.006	0.001	0.001	0.014	0.006	e > f ≥ b
VME-2	0.013	0.006	0.002	0.001	0.001	0.004	0.001	a
VME-3	0.079	0.039	0.011	0.003	0.003	0.019	0.006	a > e > b > f
Team Management Errors	0.375	0.018	0.066	0.069	0.041	0.108	0.072	e > f > c > b > d >a
TME-1	0.187	0.011	0.049	0.014	0.010	0.078	0.025	e > b > f > c > a > d
TME-2	0.028	0.001	0.007	0.003	0.004	0.013	0.001	e > b
TME-3	0.096	0.003	0.007	0.045	0.023	0.005	0.012	c > d > f > b > e
TME-4	0.047	0.003	0.003	0.003	0.003	0.012	0.025	f > e
TME-5	0.017	0.001	0.001	0.005	0.002	0.001	0.008	f > c
Application Errors	0.375	0.119	0.033	0.018	0.076	0.092	0.037	a > e > d > f > b > c
AE-1	0.172	0.092	0.016	0.007	0.016	0.034	0.007	a > e > d ≥ b > c ≥ f
AE-2	0.068	0.002	0.003	0.006	0.011	0.027	0.019	e > f > d > c
AE-3	0.019	0.003	0.001	0.001	0.005	0.009	0.001	e > d
AE-4	0.099	0.022	0.009	0.004	0.043	0.016	0.004	d > a > e > b
AE-5	0.019	0.001	0.003	0.001	0.001	0.006	0.006	f ≥ e
Individual Errors	0.125	0.005	0.013	0.023	0.037	0.023	0.023	d ≥ e ≥ c ≥ f > b > a
IE-1	0.062	0.003	0.003	0.018	0.030	0.003	0.006	d > c > f
IE-2	0.011	0.000	0.001	0.000	0.000	0.002	0.006	f
IE-3	0.011	0.000	0.001	0.003	0.005	0.001	0.001	d
IE-4	0.030	0.001	0.007	0.001	0.001	0.015	0.004	e > b
IE-5	0.011	0.000	0.002	0.000	0.000	0.003	0.005	f

equipment of the ship, job definitions (roles and responsibilities), SMS, and watch arrangements.

The second most important preventive measure is to promote the use of ECDIS equipment on board and to impose an ECDIS training requirement. Indeed, the STCW 2010 Manila Amendments recommend its use and provides training on ECDIS for watchkeeping officers. ECDIS could prevent accidents involving position-fixing application errors, the use of improper charts, interpretation errors, lack of communication in BRM, and inappropriate route selection (see Table 10). ECDIS is an advanced navigational system on the bridge for ensuring safety: it displays information on a single screen for the ship's position, speed, course, leeway, depth of water, and names and movements of the ships in the vicinity, helping the bridge team (the users) easily interpret the current circumstances.

Increased investment and operating costs and fuel prices, along with decreased freight rates as a result of the recent global financial crisis, have forced shipping companies to employ the minimum number of seafarers on their vessels, which has in turn contributed to an increased workload for crews. A heavy workload is the major cause of fatigue, stress, and insufficient rest hours, and fatigue, which inevitably leads to human error, is a major concern for health and safety at sea. It was widely believed that the majority of injuries and damage to vessels were related to human error; but recently it has been suggested that the link in the chain of events that directly leads to accidents is fatigue (Baulk and Reyner, 2002). Therefore, the number of seafarers should be increased, and appropriate hours of work and rest should be ensured, in order to prevent those accidents associated with fatigue. These two factors are so closely related, and they were assessed together: the AHP results showed that c- and d-coded improvements could prevent the causes of accidents related to improper lookout, fatigue, interpretation errors, lack of communication and coordination in BRM, position-fixing application errors, inefficient use of bridge navigation equipment, stress, faulty manoeuvres, and failure of watch arrangements.

Furthermore, the aim of the SMS is to ensure the safe operation and management of a ship, and to prevent sea pollution. According to this study, passage planning and implementation, chart applications, team management, lookout, watch arrangements, safe speeds, and familiarisation should be improved in the SMS.

Additionally, the STCW 2010 Manila Amendments introduced the obligation of BRM training for shipmasters and officers, and this study concluded that BRM training can be useful for preventing VME-1, VME-3, TME-1, TME-2, TME-3, AE-1, AE-4, and IE-4 coded maritime accidents.

A general evaluation of grounding accidents revealed that the main factor in these accidents was negligent ship management. The other topics which need to be considered for ensuring safe ship management can be listed as follows:

- The constant manning of the bridge by a minimum of two people, especially on night shifts.
- Making the use of effective watch alarm systems and movement sensors obligatory in all ships in order to prevent accidents associated with fatigue and sleep.
- The implementation of procedures that will reinforce tracking mechanisms during bridge operations (reporting regime – close loop [pilot-captain, captain-officer in charge, helmsman-officer in charge, helmsman-captain] – roles and responsibility distribution).
- Effective use of bridge navigation equipment, and especially of ECDIS systems and echosounders.
- Increasing situational awareness for emergency management, and ensuring that the crew can respond in a timely and effective manner in contingency situations.
- Risk assessment training for channel navigation, berthing-unberthing maneuvering, anchorage and in other restricted waters.
- Refresher trainings for the bridge and machine teams.

VIII. CONCLUSION

Shipmasters and officers make several decisions determining the fate of people, ships, and their environment during their careers: as was recently seen with the Costa Concordia accident, wrong decisions can lead to maritime accidents causing a loss of lives. Therefore, it is vital to determine the causes of accidents in order to minimise their number. Consequently, this study determines the significance level of each cause of, and its preventive measures for, accidents, and recommends the most relevant solutions for those causes be identified. This was achieved by using the AHP method to analyse accidents and determine preventive measures, against groundings in particular.

According to the AHP results, the most significant causes of human error-related grounding accidents are, lack of communication in BRM, position-fixing application errors, lookout errors, interpretation errors, use of improper charts, inefficient use of bridge navigational equipment, and fatigue.

The alternatives proposed to prevent grounding accidents involving human errors are arranged in the following order:

e- Improvement of education and training.
a- Obligation to have Electronic Chart Display and Information Systems (ECDIS) and compulsory ECDIS training for watchkeeping officers.
d- Amending the working hours of watchkeeping officers in accordance with STCW, not only on records but also in practice (improvements in seafarers' hours of work and rest).
f- Improvements in the SMS.
b- Compulsory Bridge Resource Management (BRM) training for watchkeeping officers, captains, and pilots.
c- Increasing the number of seafarers, especially the number of watchkeeping officers.

Thus, it is concluded that improvement in education and training and ECDIS use and training are particularly important in preventing the occurrence of groundings. It is also clear that the number of seafarers "should be increased in order to prevent fatigue-related accidents, as well as improve hours of work and rest.

Encouraging watchkeepers and masters to adapt and utilise technological equipment (ECDIS, Arpa, and AIS), and to understand the causes of and preventive measures against accidents, may help eliminate the risks. Thus, competency trainings should focus on causes of accidents, preventive measures, risk assessment, and safety watchkeeping.

The ECDIS is new on ships, in terms of both use and training, but promoting its widespread use may play an important role in preventing maritime accidents. In order to verify its efficiency, therefore, changes in the number and frequency of grounding accidents after the introduction of ECDIS should be investigated.

However, neither training nor advanced technological equipment, nor even academic studies, will completely eradicate these accidents: the marine industry will always be open to risks, since it largely involves humans. Thus, only seafarers who are aware of risks can ensure the seas are safer.

REFERENCES

Akten, N. (2004). Analysis of shipping casualties in the bosphorus. Journal of Navigation 57(3), 345-356.

Altuzarra, A., J. M. Moreno-Jiménez and M. Salvador (2007). A bayesian priorization procedure for AHP-group decision making. European Journal of Operational Research 182(1), 367-382.

Aminbakhsh, S., M. Gunduz and R. Sonmez (2013). Safety risk assessment using analytic hierarchy process (AHP) during planning and budgeting of construction projects. Journal of Safety Research 4, 99-105.

Anderson, T. K. (2009). Kernel density estimation and K-means clustering to profile road accident hotspots. Accident Analysis & Prevention 41(3), 359-364.

Andresen, M., M. Domsch, and A. Cascorbi (2007). Working unusual hours and its relationship to job satisfaction: a study of european maritime pilots. Journal of Labor Research 28(4), 714-734.

Antoa, P. and C. G. Soares (2006). Fault-tree models of accident scenarios of ropax vessels. International Journal of Automation and Computing 2, 107-116.

Arslan, O. (2009). Quantitative evaluation of precautions on chemical tanker operations. Process Safety and Environmental Protection 87(2), 113-120.

Arslan, O. and I. D. Er (2008). SWOT analysis for safer carriage of bulk liquid chemicals in tankers. Journal of Hazardous Materials 154(1-3), 901-913.

Arslan, O. and O. Turan (2009). Analytical investigation of marine casualties at the strait of Istanbul with SWOT–AHP method. Maritime Policy & Management 36(2), 131-145.

ATSB (2015). Overview of the Australian Transport Safety Bureau. Retrieved January 29, http://www.atsb.gov.au/about_atsb/overview.aspx

Barnett, M. L. (2005). Searching for the root causes of maritime casualties. WMU Journal of Maritime Affairs 4(2), 131-145.

Baulk, S. and L. Reyner (2002). Fatigue In Ferry Crews: A Pilot Study. Seafarers International Research Centre (SIRC). Cardiff, U.K.

Bloor, M., D. Pentsov, M. Levi and T. Horlick-Jones (2004). Problems of global governance of seafarers' health and safety. Seafarers International Research Centre (SIRC). Cardiff, U.K.

Celik, M. and S. Cebi (2009). Analytical HFACS for investigating human errors in shipping accidents. Accident Analysis & Prevention 41(1), 66-75.

Celik, M., S. M. Lavasani and J. Wang (2010). A risk-based modelling approach to enhance shipping accident investigation. Safety Science 48(1), 18-27.
Chan, A. H. S., W. Y. Kwok and V. G. Duffy (2004). Using AHP for determining priority in a safety management system. Industrial Management & Data Systems 104(5), 430-445.
Chan, F. T. S. and N. Kumar (2007). Global supplier development considering risk factors using fuzzy extended AHP-based approach. Omega 35(4), 417-431.
Chauvin, C. and S. Lardjane (2008). Decision making and strategies in an interaction situation: collision avoidance at sea. Transportation Research Part F: Traffic Psychology and Behaviour 11(4), 259-269.
Cheng, C., Y. Chen and T. Li (2011). An AHP method for road traffic safety. Computational sciences and optimization 2011 fourth international joint conference, Yunnan, China, 305-308.
Cheng, C. H., K. L. Yang and C. L. Hwang (1999). Evaluating attack helicopters by the AHP based on linguistic variable weight. European Journal of Operational Research 11(2), 423-435.
Dağdeviren, M. and İ. Yüksel (2008). Developing a fuzzy analytic hierarchy process (AHP) model for behavior-based safety management. Information Sciences 178(6), 1717-1733.
Davy, J. G. and C. K. Noh (2011). A study on educations role in establishing strategies for improving safety at sea. The Asian Journal of Shipping and Logistics 27(3), 483-499.
Donderi, D. C., R. Mercer, M. B. Hong and D. Skinner (2004). Simulated navigation performance with marine electronic chart and information display systems (ECDIS). Journal of Navigation 57(2), 189-202.
Doytchev, D. E. and G. Szwillus (2009). Combining task analysis and fault tree analysis for accident and incident analysis: a case study from Bulgaria. Accident Analysis & Prevention 41(6), 1172-1179.
Eliopoulou, E. and A. Papanikolaou (2007). Casualty analysis of large tankers. Journal of Marine Science and Technology 12(4), 240-250.
Garcia, R., A. Castanos and I. Irastorza (2011). Progress on security of seafarers in the MLC maritime labour convention. Journal of Maritime Research 8(2), 63-74.
Goossens, L. H. J. and C. C. Glansdorp (1998). Operational benefits and risk reduction of marine accidents. Journal of Navigation 51(3), 368-381.
Harrald, J. R., T. A. Mazzuchi, J. Spahn, D. R. Van, J. Merrick, S. Shrestha and M. Grabowski (1998). Using system simulation to model the impact of human error in a maritime system. Safety Science 30(1-2), 235-247.
Hashemi, R. R., L. A. Le Blanc, C. T. Rucks and A. Shearry (1995). A neural network for transportation safety modeling. Expert Systems with Applications 9(3), 247-256.
Hetherington, C., R. Flin and K. Mearns (2006). Safety in shipping: The human element. Journal of Safety Research 37(4), 401-411.
IMO (2002). Guidelines for formal saftey (FSA) for use in the IMO rulemaking process. The MSC/Circ. 1023, MEPC/Circ. 392, IMO Publishing, London.
IMO (2010). ISM Code and guidelines on implementation of the ISM Code, IMO Publication, London.
IMO (2011). STCW including 2010 Manila Amendments STCW Conventions and STCW Code, IMO Publishing, London.
IMO (2015). Global integrated shipping information system. Retrieved January 29, http://gisis.imo.org/Public/Default.aspx
Jones, B. C., J. Dorrian, M. W. S. Rajaratnam and D. Dawson (2005). Working hours regulations and fatigue in transportation: a comparative analysis. Safety Science 43(4), 225-252.
Kilincci, O. and S. A. Onal (2011). Fuzzy AHP approach for supplier selection in a washing machine company. Expert Systems with Applications 38(8), 9656-9664.
Kim, D. W., J. S. Park and Y. S. Park (2011a). Comparison analysis between the IWRAP and the ES model in Ulsan waterway. Journal of Navigation and Port Research International Edition 35(4), 281-287.
Kim, K. K., G. K. Park and J. S. Jeong (2011b). Analysis of marine accident probability in Mokpo waterways. Journal of Navigation and Port Research International Edition 35(9), 729-733.
Kose, E., A. C. Dincer and H. F. Durukanoglu (2007). Risk assessment of fishing vessels. Journal of Engineering and Environmental Science 22, 417-428.
Lijuan, C. and C. Shinan (2011). An approach of AHP for human factors analysis in the aircraft icing accident. Procedia Engineering 17, 63-69.
Lu, C. S. and C. L. Tsai (2008). The effects of safety climate on vessel accidents in the container shipping context. Accident Analysis & Prevention 40(2), 594-601.
Lynch, M. (2009). Focus on Bridge Resource Management. Department of Ecology State of Washington, Washington.
Macrae, C. (2009). Human factors at sea: common patterns of error in groundings and collisions. Maritime Policy & Management 36(1), 21-38.
MAIB (2012). Annual Report 2010. Retrieved June 15, http://www.maib.gov.uk/publications/annual_reports/annual_report_2010.cfm.
MAIB (2015). An accident, major or serious injury, or hazardous incident? Retrieved January 29, http://www.maib.gov.uk/about_us/index.cfm
Martins, M. R. and M. C. Maturana (2010). Human error contribution in collision and grounding of oil tankers. Risk Analysis 30(4), 674-698.
Mccarter, P. (1999). STCW '95: Implementation issues - What is the pass mark? Marine Policy 23, 11-24.
McNamara, R., A. Collins and V. Matthews (2000). A review of research into fatigue in offshore shipping. Maritime Review, 118-122.
Merrick, J. R. W. and J. R. Harrald (2007). Making decisions about safety in us ports and waterways. Interfaces 37(3), 240-252.
Mitroussi, K. (2008). Employment of seafarers in the EU context: challenges and opportunities. Marine Policy 32(6), 1043-1049.
Moore, W. H. and R. G. Bea (1993). Management of human error in operations of marine systems. Department of Naval Architecture and Offshore Engineering Report, University of California, Berkeley, USA.
Mullai, A. and U. Paulsson (2011). A grounded theory model for analysis of marine accidents. Accident Analysis & Prevention 43(4), 1590-1603.
O'Neil, W. (2003). The human element in shipping. WMU Journal of Maritime Affairs 2(2), 95-97.
Orosa, J. A., R. Santos and J. A. Pérez (2011). A practical case study of the relationship between work risk prevention and fatigue at work in Spanish merchant ships. Human Factors & Ergonomics in Manufacturing & Service Industries 21(5), 484-492.
Park, Y. S., J. S. Kim and V. Aydogdu (2013). A study on the development the maritime safety assessment model in korea waterway. Journal of Navigation and Port Research 37(6), 567-574.
Peters, M. and S. Zelewski (2008). Pitfalls in the application of analytic hierarchy process to performance measurement. Management Decision 46(7), 1039-1051.
Pillich, B. and G. Buttgenbach (2001). ECDIS-the intelligent heart of the hazard and collision avoidance system. IEEE 2001, Oakland, CA, 1116-1119.
Rasmussen, J. (1997). Risk management in a dynamic society: A modelling problem. Safety Science 27(2-3), 183-213.
Ronza, A., S. Félez, R. M. Darbra, S. Carol, J. A. Vílchez and J. Casal (2003). Predicting the frequency of accidents in port areas by developing event trees from historical analysis. Journal of Loss Prevention in the Process Industries 16(6), 551-560.
Rothblum, A. R. (2000). Human error and marine safety. The National Safety Council Congress and Expo, Orlando.
Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology 15(3), 234-281.
Saaty, T. L. (1980). The Analytic Hierarchy Process, McGraw-Hill, New York.
Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. European Journal of Operational Research 48, 9-26.
Saaty, T. L. and L. G. Vargas (2001). Models, methods, concepts and applications of the analytic hierarchy process. Springer, New York.
Sigua, R.G. and G. D. Aguilar (2003). Maritime incident analysis using GIS. Journal of the Eastern Asia Society for Transportation Studies 5, 778-793.
Smith, A., P. Allen, and E. Wadsworth (2006). Seafarer fatigue: the cardiff research programme, Cardiff University Seafarers International Research Centre (SIRC), Cardiff, U.K.

Soares, C. G. and A. P. Teixeira (2001). Risk assessment in maritime transporttation. Reliability Engineering & System Safety 74(3), 299-309.
Størseth, F. and R. K. Tinmannsvik (2012). The critical re-action: Learning from accidents. Safety Science 50, 1977-1982.
Swift, A. J. (1993). Bridge team management: A practical guide. The Nautical Institute, Suffolk.
Tzannatos, E. (2010). Human element and accidents in greek shipping. Journal of Navigation 63(1), 119-127.
Tzannatos, E. and D. Kokotos (2009). Analysis of accidents in Greek shipping during the pre- and post-ISM period. Marine Policy 33(4), 679-684.
Uğurlu, Ö., E. Köse, E. Başar, E. Yüksekyıldız and U. Yıldırım (2012). Investigation of working hours of watchkeeping officers on short sea shipping: a case study in an oil tanker. IAME 2012, Taipei.
Uğurlu, Ö., U. Yıldırım and E. Yüksekyıldız (2013). Marine accident analysis with GIS. Journal of Shipping and Ocean Engineering 3(12), 21-29.
Uğurlu, Ö., E. Köse, U. Yıldırım and E. Yüksekyıldız (2015a). Marine accident analysis for collision and grounding in oil tanker with FTA method. Maritime Policy and Management 42(2), 163-185.
Uğurlu, Ö., S. Erol, and E. Başar (2015b). The analysis of life safety and economic loss in marine accidents occurring in the Turkish Straits. Maritime Policy and Management, http://dx.doi.org/10.1080/03088839.2014.1000992
Uğurlu, Ö., R. Nişancı, E. Köse, U. Yıldırım and E. Yüksekyıldız (2015c). Investigation of oil tanker accidents by using GIS. International Journal Maritime Engineering 157(2), 113-124.
Vidal, L. A., F. Marle, and J. C. Bocquet (2011). Using a delphi process and the analytic hierarchy process (AHP) to evaluate the complexity of projects. Expert Systems with Applications 38(5), 5388-5405.
Xi, Y. T., W. J. Chen, Q. G. Fang and S. P. Hu (2010). HFACS model based data mining of human factors-a marine study. The International Conference on Industrial Engineering and Engineering Management, Macao, Portegue, 1499-1504.
Xi, Y. T., Q. G. Fang, W. J. Chen and S. P. Hu (2009). Case-based HFACS for collecting, classifying and analyzing human errors in marine accidents. The International Conference on Industrial Engineering and Engineering Management, Hong Kong, 2148-2153.
Wang, W., X. Jiang, S. Xia and Q. Cao (2010). Incident tree model and incident tree analysis method for quantified risk assessment: An in-depth accident study in traffic operation. Safety Science 48(10), 1248-1262.
Zang, L. H., Q. Zhu, Y. C. Liu and S. J. Li (2007). A method for automatic routing based on ECDIS. Journal of Dalian Maritime University 33(3), 109-112.
Zhang, Y., Y. Zhan and Q. Tan (2009). Studies on human factors in marine engine accident. Knowledge Acquisition and Modeling Conference, Wuhan, China, 134-137.