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Novel Systematic Approach to Assessing Human Factor and Engineering Issues in Marine Accidents

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ABSTRACT: Human factor issues leading to poor performance and human errors are evidently the dominant and common cause for a high number of accidents in the marine transportation sector. Attempts in the last few decades to resolve and eliminate these human factor issues appears to be complex given the very unpredictable nature of humans and the tendency of being prone to making mistakes either intentionally or unintentionally. This paper proposes a novel systematic approach for analysing marine accidents and performing accident investigations. The first approach proposed in this study involves establishing a relationship between the geographical area of the marine accident with the accident types, based on which the human factor issues and navigation and infrastructure issues can be systematically identified and addressed. The second approach proposes a forensic engineering approach on marine accident investigations. The shortcomings of the accident investigations based on International Maritime Organization (IMO) guidelines from a technical perspective as well as the very high percentages of *less serious* severity accidents form the basis for adoption of this approach.

KEY WORDS: Collision, Allision, Grounding, Forensic engineering, Geographical area, Human factor, Less Serious, Cargo ship

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Nomenclature:

Symbol	***Definition***
AIS	*Automatic Identification System*
ARPA	*Automatic Radar Plotting Aid*
ECDIS	*Electronic Chart Display and Information System*
EMSA	*European Maritime Safety Agency*
GISIS	*Global Integrated Ship Information System*
HK	*Marine Department, The Government of the Hong Kong Special Admin. Dept.*
IMO	*International Maritime Organization*
ISM	*International Safety Management*
JTSB	*Japan Transport Safety Board*
MAIB	*Maritime Accident Investigation Branch*
MLC	*Maritime Labour Convention 2006*
OOW	*Officer on Watch*
TSBC	*Transportation Safety Board of Canada*

I. INTRODUCTION

The shipping industry has a fairly good safety record comparable to any other transportation mode however when maritime accidents do happen, it is typically associated with serious environmental damages and financial losses to both the ship owner and the affected society. The last few decades has seen a greater emphasis on addressing human factor and organizational issues in ship operations and manning leading to human errors and poor performance, as a result of which there has been a greater understanding on this aspect and initiatives taken at various levels by IMO, Classification societies and Flag states to alleviate it. Despite this, accidents continue to happen sometimes for the very same reasons which were identified through earlier investigations and apparently assumed to be resolved through incorporation of new rules and regulations adopted to prevent its future occurrence. In addition to human factor issues there also exists other identified factors that can contribute to the accident i.e. substandard ships, substandard class societies and poorly performing and irresponsible flag states (WWF, 2013). The global fleet has more than doubled up in the last few decades and with the decline in volume of trade as a result of recession due to low oil prices, it is very likely that many of the ships are going to be ill maintained in an attempt to save costs by the ship owner. In such circumstances even a small scale accident involving these ships in an ecologically sensitive area can have catastrophic consequences.

This paper proposes a novel systematic approach towards analysing marine accidents due to human factor issues and also introduces the need for a forensic engineering approach to performing accident investigations. The first approach in this paper involves proposing a relationship between the geographical area of the accident with the accident types. The relationship established can then be used to facilitate identifying the relevant human factor issues and navigation and infrastructure shortcomings in the particular area of marine accident. The second approach focuses on the accident investigation itself and proposes the use of forensic engineering approach to these investigations which can bring about technical improvements in the design, construction and maintenance of ships based on assessment of the damage sustained during the accident.

Forensic engineering is defined by Noon (2001) “as the application of engineering principles and methods to answer questions of fact” where the “questions of fact” refers to issues with respect to the casualty; and such an explanation matches well with the intent and focus of this study. The word ‘accident’ and ‘casualty’ is used interchangeably in this paper and for the purpose of this study refers to events or sequence of events resulting in “the death of, or serious injury to a person, loss of a person from a ship, the loss of presumed loss or abandonment of a ship, material damages to a ship, the stranding or disabling of a ship or the involvement of a ship in a collision, material damage to marine infrastructure external to a ship, that could seriously endanger the safety of the ship, another ship or an individual or severe damage to the environment, or the potential for severe damage to the environment, brought about by the damage of a ship or ships” (MAIB, 2014b). The focus in this study is on collision, allision and grounding type accidents involving cargo ships. Cargo ships include general cargo vessels, oil tankers, bulk carriers, container ships, chemical cum product tankers and gas carriers.

II. LITERATURE REVIEW

After the Titanic accident in 1912, focus was on technological improvements to make the ship more safe and robust and subsequently major shipping accidents led to some major regulatory changes impacting the design and construction of ships built. The Titanic tragedy in 1912 followed by that of SS Mohawk, Torrey Canyon, Amaco Cadiz, Andrea Doria, Herald of Free Enterprise, Exxon Valdez, Estonia, Erica, Prestige and recently Costa Concordia, have all been precursors for change in the way ships are designed, constructed and operated (Christensen *et al.*, 2012). AGCS (2012) and Butt *et al.* (2013) report chronologically the technical and regulatory developments made in respect to maritime safety over the last few decades as a result of major accidents. The last two to three decades has seen a major focus in understanding and resolving human factor issues in ship manning and operations leading to marine accidents. Hetherington *et al*. (2006) attributes this attention to reduced failure of technology as a result of improved ship design and navigational aids as reasons for bringing to focus human errors in maritime accidents. While IMO (1997) provided guidance on marine casualty investigations from a technical perspective, IMO (2000) has been structured to provide guidance on accident investigation from the human factor perspective. The causal factors identified during the investigations were then factored to make improvements in the system design or in operations such that accidents of similar nature are prevented from happening again.

Studies by Grech *et al.* (2002) brought to focus the issues of lack of situational awareness leading to human errors and poor performance and concluded that more than 75% of the accidents of ships worldwide were attributed to human and organization errors based on the IMO data of 1994.Baker and Seah (2004) and Baker and McCafferty (2005) analysed the accident reports published by a number of accident investigation agencies and concluded that around 80-85% of the accidents were as a result of human errors, and it presents a significant threat to maritime safety. McCafferty and Baker (2006) report that 70% of the accidents in this 80-85% were associated with situational awareness issues. For the period 2011-2015, EMSA (2016a) reports 62% of the accidents investigated involving cargo ships were caused due to human erroneous actions. Baker and Seah (2004) and Baker and McCafferty (2005) attributed 50% of the marine accidents to be initiated by human error while another 30% of maritime accidents occur due to failure of humans to avoid an accident. Louie and Doolen (2007) cite human errors as reason for maritime accidents in 50-96% of the cases investigated. Wang *et al.* (2013) report human error as a dominant factor contributing to accidents in restricted waters. Hollaway *et al.* (2016) reports poor human performance as the main cause of accidents and near misses, and classified it under judgment and decision making errors.

In this paper, the major human factor issues identified to contribute to human errors and diminishing performance based on the various research findings in this field over the last few decades has been listed in Table 1.

Table no 1: Major Human Factor Issues Identified Leading to Marine Accidents.
(Legend: "√" indicates applicable and "x" indicates not applicable)

Human Factor Issues	Emond (2012)	Chauvin et al. (2013)	Baker and Seah (2004)	Card et al. (2005)	Hetherington *et al*. (2006)	EMSA (2016)	Grech et al. (2002)	Rothblum (2000)
1 .Situational Awareness issues	√	√	√	√	√	√	√	x
2. Improper Lookout/ Task Omission issues	√	√	√	√	x	√	√	x
3. Risk tolerance issues	√	√	√	√	x	√	√	x
4. Substance abuse issues	√	√	√	x	x	√	√	x
5. Over reliance on Technology or Untrained to use	√	√	√	x	√	√	√	√
6. Manning & Human Fatigue issues)	√	√	√	x	√	√	√	√

In the past, the human factor issues (in table 1) have been subject to detailed investigations and research, and some of which are presumably addressed through incorporation of advanced technology, regulations and guidelines i.e. Automatic Identification System (AIS), Automatic Radar Plotting Aid (ARPA), Electronic Chart Display and Information System (ECDIS), International Safety Management (ISM) Code, Maritime Labour Convention (MLC) 2006, and so on. However, despite adoption of these advanced technologies, regulations and guidelines, collision, grounding and allision type accidents continue to happen even now and accident investigations reveal one or more of these human factor issues being responsible. A summary of some of the recent collision, allision and grounding accidents listed bears testimony of the same and highlight the complexity involved in dealing with human factor issues and the unpredictable nature of human actions and behaviour.

- Collision accident between chemical tanker "*MV Orakai*" and bean trawler "*FV Margriet*" in the North Sea on 21st December 2014 due to ineffective lookout by the Officer on Watch (OOW) on "Margriet" (MAIB, 2015b).
- Grounding of ro-ro passenger ferry *"Commodore Clipper"* in the approaches of St Peter Port, Guernsey on 14th July 2014 due to insufficient passage planning of voyage and ineffective utilization of vessels ECDIS and information systems by the crew (MAIB, 2015d).
- Collision of bulk carriers "*Shibumi*" and "*Sam Wolf*" in Singapore Straits on 23rd December 2015 due to ineffective radio watch and communication between both vessels (EMSA, 2016b).
- Collision between bulk carrier "*Maraki*" and vehicle carrier "*Ivory Arrow*" on 5th December 2015 in a crossing between Dover Strait and West Hinder due to sudden course changes by both ships i.e. Risk taking behaviour (EMSA, 2016c).
- Collision between container ship "*Kota Duta*" and cargo ship "*Tanya Karpinskaya*" in the Port of Niigata Higashi Ku, Niigata city on 07 February 2012 due to situational awareness issues and task omission issues (JTSB, 2015a).
- Collision of container ship "*Flevodijk*" with the sea wall on the northern side of the Akashi Kaikyo bridge on 19th August 2011. Japan Transport Safety Board (JTSB) investigations reveal collision accident as a result of the OOW falling asleep when on duty (JTSB, 2015b).
- Collision of container ship "*Ever Smart*" with oil tanker "*Alexandra 1*" near the entrance to approach channel in Jebel Ali, UAE on 11th February 2015. Improper lookout and task omissions contributed to this accident as per the investigation report (MAIB, 2015c).
- Grounding of general cargo vessel "*Lysblink Seaways*" into the rugged coastline near Mingary pier on 17th February 2015. Investigations revealed that the OOW had become inattentive due to the effects of alcohol consumption (Spark, 2016 & MAIB, 2015e).

Cahill (2002) document investigations on collision accidents in the 1970's and 1980's and the circumstances leading to many of the accidents were as a result of risk taking behaviour or risk tolerance of OOW, lack of situational awareness, restricted visibility, actions during fine crossing, overtaking etc., and the very same reasons appears to be relevant even now. Emond (2012), Louie and Doolen (2007), Baker and McCafferty (2005) and Hetherington *et al. (*2006) further sub classify the six human factor issues detailed in Table 1 to better understand and address the issues which leads to human errors and poor performance. Hetherington *et al*. (2006) have reported that human errors in ship operations can also result due to language and cultural diversity issues, communication issues and teamwork. Chauvin *et al.* (2013) refers to the existence of formal and informal rules as one of the causes for collision accidents. The informal rules refer to the rules shared between certain types of ships in specific waterways and when people who do not know each other communicate, these informal rules can be a reason for such uncertainties and misunderstandings, leading to accidents. AGCS (2012) highlights some of the emerging challenges that face the shipping industry in terms of ship size, training and labour, crewing levels, language barrier, new sea routes i.e. Arctic and polar region and poor enforcement and coordination. Grech *et al.* (2002) cautioned against the rampant absorption of advanced technology in an ad-hoc manner.

Cargo ships account for the highest percentage of ship types involved in accidents world over. Close to around 40-50% of the ships involved in accidents reported during the period 2011 – 2015 involve cargo ships (EMSA, 2016a; MAIB, 2015a). EMSA (2016a) alone reported nearly 1700 cargo ships being involved in marine casualties and incidents during the year 2015 and is quite an alarmingly high figure. Accident statistics presented by AGCS (2012) over a 10 year period from 2000 indicate cargo ships account for 50% of the total losses. The IMO report on casualty statistics for the period 2006 to 2011 indicates between 23 to 55% of the accidents involving cargo ships (IMO, 2012a). WWF (2013) reports 50 % of the accidents involved cargo ships based on statistics covering a 15 years period. Probable reasons for such high accident incidence involving cargo ships is because cargo ships account for the largest fleet of ships trading worldwide and because of their nature of operations (long voyage and short voyages). Furthermore in recent times there is a more conscious effort on the part of ship owners and operators to report accidents and near misses to the flag state authorities as compared to earlier days and also since these accident investigations incur no penal action.

This paper focuses on collision, allision and grounding accident types as they constitute a major portion of accidents involving cargo ships and they are all navigation related, where human factor issues are critical. Weng and Yang (2015) provides statistics comparing the frequency of different accident types in Australasia and the East Mediterranean and Black sea region. The East Mediterranean and Black sea region accounts for higher cases of collision, allision and grounding accidents when compared to Australasia region and has also over taken the North Europe and Asia region despite having low level of shipping activity (Mandryk, 2011; WWF, 2013). The number of serious casualties in this region has shown a gradual increase during the period 2006 to 2010 and reasons attributed to this increase is the presence of substandard owners, bogus registries and substandard class ships operating in these areas along with an elderly age profile (Mandryk 2011). Chauvin *et al.* 2013 reports 71% of the accidents in European waters are related to collision and grounding accidents and a majority of them are as a result of human errors. AGCS (2012) reports 62% of the total losses of ship types during the period 2000- 2010 involved cargo ships with grounding type accident accounting for 18% followed by collision at 12% and allision at 2.1%. IMO (2012a) provide statistics of casualties involving cargo ships during the period 2006 -2011, with a high of almost 55% in 2007 and low of 23% in 2011.

JTSB (2016) publishes statistics of marine accidents in its territorial water and of ships under its registry of which cargo ships account for above 20 % of the total ships involved in accidents during the period from 2010 – 2015. It is also reported that collision, allision and grounding accidents together account for over 65% of the total accident types during the period 2010 – 2015. Similarly, Transportation Safety Board of Canada (TSBC) publishes statistics of marine accidents in Canadian territorial waters and involving ships under its registry and based on the 2015 report, grounding accidents accounted for 28% and collision 26% of all the accident types (TSBC, 2015). It also reports that during the same period 16% of the ships involved in accidents were cargo ships. These percentages would be a lot higher if the number of fishing vessels and non- commercial vessels are excluded from their analysis.

III. RELATIONSHIP BETWEEN THE GEOGRAPHICAL AREA OF MARINE ACCIDENT AND ACCIDENT TYPES

A collision, grounding and allision accident types are generally associated with navigation related issues where the human element has a major contribution in the accident taking place, and is the focus of this study. A consolidated statistics of the collision, grounding and allision casualties reported by Maritime Accident Investigation Branch (MAIB), JTSB and Marine Department of The Government of Hong Kong(HK) during the period 2011- 2015 is presented in this paper. The casualty statistics of European Marine Safety Agency (EMSA) and TSBC were also referred to for this study however only the casualty statistics in MAIB (2011 -2014;

2015a), JTSB (2016) and HK (2011 - 2015) have been selected because of the similarity of their reporting style and content which allows for uniform representation of data for the purpose of this analysis. The territorial waters of United Kingdom, Japan and Hong Kong all represent shipping routes with fairly high volume of cargo movement and area of high casualties (Butt *et al*. 2013). One of the assumptions made in this analysis is that the casualty data presented in MAIB (2011-2014, 2015a) and JTSB (2016) represents the casualties involved in the territorial waters of the respective countries, as from the published reports it is not explicitly clear to confirm the same and no statistics is presented segregating the casualties within the territorial waters and outside. Furthermore this assumption is not expected to drastically influence the findings made in this study as the purpose of this analysis is more of to establish a relationship between the accident type and the geographical area of casualty. Influence of other factors such as weather condition, specific ship type, voyage details, operating period (day or night), visibility etc., at the time of the accident are also ignored from this analysis since the accident statistics presented by MAIB, JTSB and HK do not differentiate the accident data based on these criteria's.

In Figure 1 the percentage of collision accidents reported is illustrated. Around 40-60% of collision accidents involving all ship types happen in and outside the Hong Kong territorial waters and are the worst case followed by JTSB and MAIB. The high percentage of collision accidents could be attributed to the heavily congested waters and high traffic volume in this water as Hong Kong is one of major business centres in South Asia. Furthermore there is also a likelihood of high number of general cargo vessels of an elderly age profile flagged with substandard registries and which are best suited for "tramp" trade operating in this region (Butt *et al.*2013).

Figure no 1: Percentage of Collision Accidents involving all Ship Types during the Period 2011-2015.

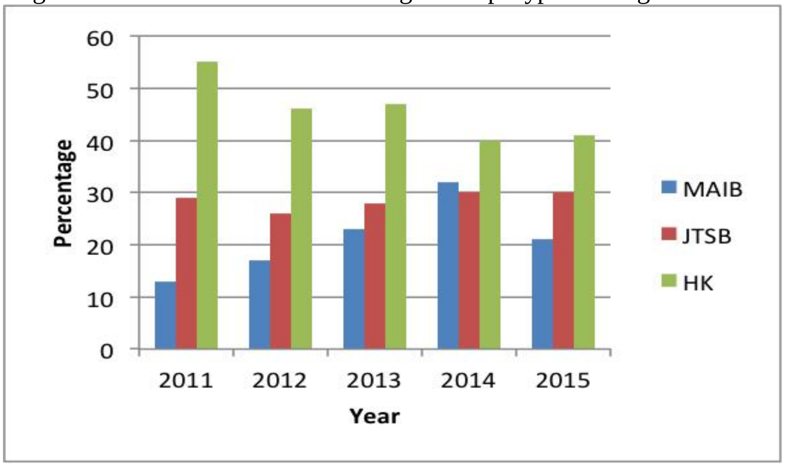


Figure 2 compares the percentage of allision accidents between HK, JTSB and MAIB and the occurrence of allision accidents are less when compared to collision accidents shown in Figure 1. Allision accidents reported by MAIB is the highest and range between 18-28%. There was no specific literature found addressing this issue and the authors presume the rough seas associated with the North Sea and North Atlantic Ocean and presence of many offshore structures and platforms in these waters contributing to the allision type casualties.

Figure no 2: Percentage of Allision Accidents involving all Ship Types during the Period 2011-2015.

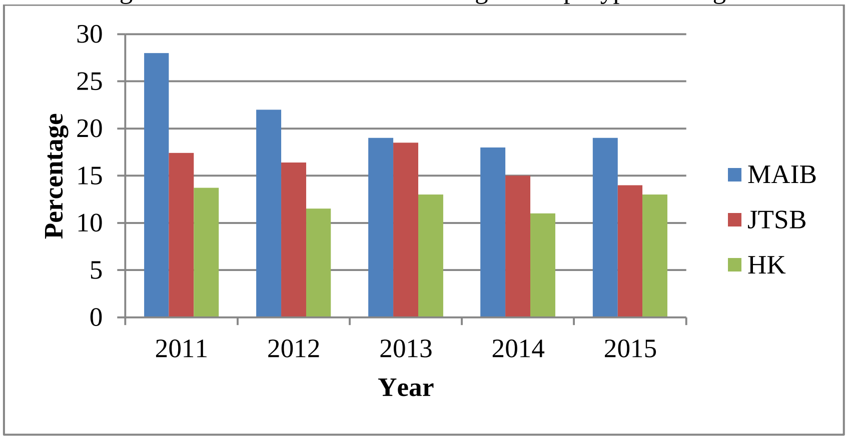
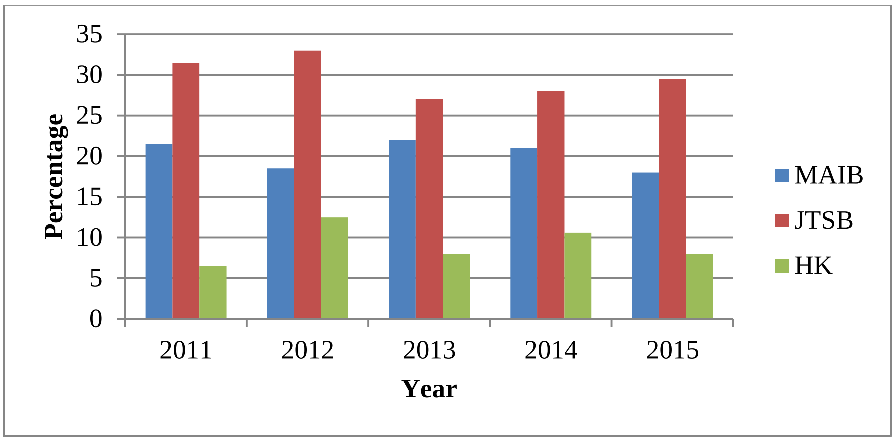


Figure 3 compares the percentage of grounding accidents between HK, JTSB and MAIB and it can be seen that the percentage of occurrence is quite similar to allision accidents but less when compared to collision accidents.

Figure no 3: Percentage of Grounding Accidents involving all Ship Types during the Period 2011-2015.



Grounding casualties reported by JTSB is the highest and range between 27-33% and the possible reason for such high number of grounding casualties could be because Japan is surrounded by the "Ring of Fire", which is a zone of frequent volcanic eruptions and earthquakes. Kery (2012b) reports that a single event is enough to raise or lower the seabed considerably as a result of such regular volcanic and earthquake activities in this region and passages assumed to be deep enough for navigation may not be safe anymore. The Pacific region of Canada also falls in the "Ring of Fire" zone and TSBC (2015) reports of majority of the bottom contact accidents (53%) in this region.

The consolidation of the accident types reported by JTSB, HK and MAIB in figures 1 to 3 in this paper indicate a predominance of particular accident type to a specific geographical area. The statistics presented in a way indicate collision accidents ranking high in Hong Kong territorial waters, grounding accidents in Japanese territorial waters and allision/ contact accidents in United Kingdom territorial waters. A relationship between the accident type and geographical area of the casualty is established in this paper. This relationship provides opportunities for research focussed on identifying and resolving the relevant human factor issues pertaining to the particular accident type in the particular area of casualty. When compared to the approach of identifying and attempting to resolve the human factor issues leading to marine accidents by reviewing it with respect to worldwide statistics or a larger geographical area, the proposed approach in this study facilitates a more focussed analysis. The relationship established in this paper can also facilitate to ascertain any navigation and infrastructure shortcomings (i.e. lack of traffic separation system, updating of charts, pilotage, navigational buoys, speed restrictions, fishing vessel activity etc.), which when addressed can mitigate or lessen the influence of human factor issues leading to the accident. Furthermore, this approach can also be extended to ascertain the human factor issues based on different ship types, environmental issues (i.e. weather conditions, sea state, daytime and night time operations etc.) and duration of voyage.

IV. FORENSIC ENGINEERING APPROACH IN MARINE ACCIDENT INVESTIGATIONS

The second important aspect discussed in this paper is on the need for a forensic engineering approach to marine accident investigations. IMO (2013) refers to the guidelines to assist investigators in the implementation of the Casualty Investigation Code and provides a common approach for flag states/ administration to adopt when conducting such investigations involving marine casualties and incidents in accordance with this Code. The guidelines include the qualifications of the investigator, step by step investigation procedure and also listed in the appendices are the areas of inquiry for investigation of human and organizational factors. The investigation ends with reporting of the findings in accordance with the reports in IMO (2008), preparation and submission of a full investigation report (if required), consultation, publication and follow up of any recommendations made. The adoption of these guidelines effectively revoked the earlier investigative guidelines in IMO (1997) and the guidelines for systematic investigation of human factors in marine casualties in IMO (2000).

IMO (2008) provides details of the accident reports that need to be submitted for reporting of marine casualties based on the severity along with the time frame for submission, to populate the Global Integrated Ship Information System (GISIS) module for each type of casualty severity. A full investigation report of the accident is mandatory for only *very serious* severity type; however detailed investigations can also be performed for accidents of lesser severity in cases where such investigations can offer scope for improvements or important lessons learnt. According to EMSA (2015a) *very serious* casualties are “marine casualties involving the total loss of the ship or a death or severe damage to the environment” while s*erious casualties* are defined as “marine casualties to ships which do not qualify as very serious casualties and which involve for example a fire, collision, grounding, contact, heavy weather damage, suspected hull defect, etc., resulting in the ship being unfit to proceed, pollution or a breakdown necessitating towage or shore assistance”. EMSA (2015a) also defines *Less Serious* casualties as “marine casualties that do not qualify as *very serious* or *serious* casualties.

An analysis of the contents of the full investigation reports of collision, allision and grounding type accidents involving cargo ships of *very serious*, *serious* and *less serious* severity has been performed (see Table 2) and it is noted that the accident investigation process involves identifying the consequences (i.e. damaged ship) and works its way backwards to identify the Casualty events leading to damage (i.e. collision, grounding etc.) followed by the Accidental Event (i.e. Human error) and the Contributing Factors (at various levels). There is very little emphasis on the structural damage sustained during the accident other than a brief description of the damage sustained and furthermore evidence of any specialized studies being performed to analyse the crashworthiness or robustness of the hull structure was also found lacking. Although the findings from such investigations may have been instrumental in highlighting the human factor issues in ship operations and manning, the fact that the damaged ship was badly maintained and operated, had imperfections i.e. cracks, fracture, dents and deformations, corrosion, was of inferior design and construction is lost due to the investigations focussed on identifying human factors and organizational issues. Such ships have a high probability of getting involved in accidents or being badly damaged at sea, the outcome of which could be loss of lives, loss of vessel and the environmental impact it causes.

Table no 2: Review of Investigation Reports of Marine Casualties

S.No	Casualty Severity	Casualty type	Ship name and type involved in the casualty	Casualty Date	Source
1	Very Serious	Collision	*City of Rotterdam* (Pure Car carrier) and *Primula Seaways* (Ro-Ro freight ferry)	03 Dec 2015	MAIB (2017)
2	Very Serious	Grounding	*Lysblink Seaways* (General Cargo)	18 Feb 2015	MAIB (2015e)
3	Very Serious	Collision	*MV Orakai* (product Tanker) with *Margriet* (Fishing vessel)	21 Dec 2014	MAIB (2015b)
4	Very Serious	Collision	*Darya Gayatri* (Bulk carrier) with *Paula C* (General Cargo)	11 Dec 2013	MAIB (2014b)
5	Serious	Collision	*British Cygnet* (Oil tanker) with *Vera* (Container ship)	02 Dec 2006	IM (2006)
6	Very Serious	Collision	*Ostende Max* (Bulk carrier) with *Formosaproduct* Brick (Oil Tanker)	19 Aug 2009	IM (2009)
7	Less Serious	Allision	*Navios Northern Star* (bulk Carrier) with Buoy	14 March 2016	GISIS (2017b)
8	Very Serious	Collision	MSC *Alexandra* (Container ship) with *Dream II* (Oil tanker-VLCC)	3 August 2016	GISIS (2017c)
9	Very Serious	Collision	*Consouth* (Cargo ship) with *Pirireis* (Dry cargo)	29 April 2013	GISIS (2015)

Wang *et al*. (2013) reports that the IMO casualty investigation guidelines are not prepared from a technical sense and argues that when investigating collision accidents, a more technical investigation approach (quantitative results) is suitable if any meaningful changes or improvements are to be made. Furthermore the investigative process does not take into account of the role of the irresponsible flag state, ship owners and operators (Butt *et al*., 2013).

This paper focuses on the *less serious* severity accidents because by definition the damage sustained on the ship hull structure is of a lesser magnitude when compared to the damages sustained under the more *serious* categories, in the event of a collision, allision or grounding type accident. Collision between two ships, contact with pier, bottom touching resulting in dent or deformations, scrapping of paint, minor punctures in the side shell etc., would presumably fall under this *less serious* accident category. The authors critically assess the relevance of *less serious* severity accidents despite it not resulting in any loss of lives, loss of asset and environmental damage, and also how a forensic engineering based investigation approach of these accidents can bring about classification rule and regulatory changes and improvements, and foster the more efficient use of advanced numerical analysis methods (i.e. finite element analysis).

In Table 3, a comparison of the number of marine accidents is presented based on the data in EMSA (2014; 2015a) and MAIB (2013; 2014; 2015a). It is noted from Table 3 that the percentage of occurrence of *less serious* accidents ranges from 66% to 85% and is alarmingly very high. Despite the emphasis provided to human factor issues in reducing human errors and poor performance issues in ship operations and manning, if such minor skirmishes and contacts continue in such high percentages, the probability that one of them turning into a *very serious* or *serious severity* casualty and that too in an environmentally sensitive area would be of catastrophic consequence.

Table no 3: Comparison of Number of Marine Accidents based on Severity.

Year &	2013				2014				2015			
Agency →	EMSA		MAIB		EMSA		MAIB		EMSA		MAIB	
Severity ↓	No	%	No	%	No	%	No	%	No	%	No	%
Very Serious	81	4	21	3.5	99	4	23	4	99	4	24	5
Serious	468	21	82	14	765	30	71	13	626	23	48	10
Less Serious	2001	78	488	82.5	1718	66	462	83	1944	73	411	85
Total	2550	100	591	100	2582	100	556	100	2669	100	483	100

The performance of a ship in an casualty has been a matter of focus by the academia for the last two decades and many studies have been performed to understand and address issues on energy dissipation i.e. external and internal mechanics, penetration depth, oil outflow, bow structure type, stability (Wang *et al*., 2002) etc., and their evaluation approaches. A *very serious* and *serious* casualty generally involves substantial damage to the ship hull covering a significant area. The investigation for such casualties would rarely bring about the inherent weakness in the structure prior to damage as the defects if any would be lost as a result of the casualty itself. Furthermore the cost of modelling and analysis of such an extensive damage would involve lot of resources, expertise, time and cost and the assumptions made on influencing parameters such as vessel speed, angle of contact, weather condition, striking vessel bow structure, material behaviour, soundness of weld etc. could distort the results significantly. Furthermore the question of whether the investigation will result in meaningful lessons learnt may lead to abandoning the idea of conducting the investigation in the first place. On the other hand, a *less serious* casualty involves a lesser area and lesser extent of damage in which the initial defects to the hull structure would not be distorted or lost to the extent as in the severe cases. Furthermore, the resources, expertise, time and cost of conducting the investigation would be far less and the results from the analysis could identify gaps or shortcomings in the existing rules and regulations, which have been written based on experience and at times do not even have engineering basis to justify it (Kery, 2012a).

Finally, a *less serious* severity accident presents a smaller damaged area of side shell or bottom plating typically associated with collision, allision and grounding type accident. Investigation of the damaged area using the numerical analysis tools (i.e. finite element analysis) would be a lot faster, easier and efficient to model and analyse the casualty to determine the forces or loads that could have caused the damage sustained. The reduced time and cost of the analysis and possibility of performing multiple simulations using such tools could prompt wider acceptance for considering the forensic engineering based investigation approach. The results derived from the analysis can assist to simulate the behaviour of the structure with different types of initial deformities i.e. side shell deflections, weld induced deflections, corrosion, cracks and fracture, etc., something that would otherwise be lost or ignored with the damage sustained, in the event of a *serious or very serious* casualty.

V. DISCUSSION

The unique work environment of the maritime industry poses additional stress on human nature and behaviour accounting for their unpredictable and inconsistent actions which may lead to accidents. Also are the many other recognized human factor issues which lead to human errors and poor performance which has been discussed in this paper. Dealing with human factor issues is extremely complex and with public perception on maritime accidents being very bad as a result of some of the major oil spills having severe environmental damage consequences, it is important that the focus should not be shifted away from technical improvements in the design, construction and maintenance of ships especially when the recent technological advancements present an opportunity to do so in an efficient and cost effective manner.

The shipping industry is set for a dramatic change in the years to come. In future, with delivery of bigger and bigger ships to ensure economies in operation, the demand for cleaner fuels for operation and transportation, opening of new sea route through harsh weather conditions and fragile ecosystems (i.e. polar region, Arctic Ocean) for year round trade etc., pose great challenges to the shipping fraternity. Accident statistics presented in this paper not only indicates a relatively high number of *very serious* and *serious* severity casualties, but also an alarmingly high number of *less serious* severity casualties, any one of which can lead to catastrophic consequences. Under these circumstances, this paper proposes a novel systematic approach to assessing human factor issues and engineering issues aimed towards preventing accidents and /or reducing the escalation of damage sustained during accidents.

The paper has established a relationship between accident types and geographical area of accident based on the accident statistics presented by MAIB, JTSB and HK. Identifying either the relevant human factor issues or navigation and infrastructure shortcomings which resulted in a particular accident type in a specific area can assist the administration in taking pre-emptive measures to mitigate the future occurrence by way of adopting or enforcing regulations, policy changes, infrastructural improvements etc. The relationship established in this paper also offers scope for future research and studies focused on addressing and resolving human factor issues leading to human errors and their diminishing performance.

The paper has also highlighted the shortcoming of the accident investigations being presently carried out based on IMO guidelines and the very high incidence of *less serious* severity accidents taking place. It is imperative from today's standpoint that marine accident investigations carried out not only identify the immediate causes i.e. human factor issues, but also understand the reasons for escalation of the damage to the ship structure as a result of the accident. A forensic engineering approach to marine accident investigations of *less serious* severity is proposed to ascertain how the ship structure reacts when subject to a sudden impact force typically associated with collision, grounding and allision accidents and transform the findings of the investigations in the way ships are designed, constructed and maintained. Unlike earlier days when such detailed investigations involved high costs and was time consuming, present day technologies address these shortcomings to a great extent and allow for meaningful investigations.

VI. CONCLUSION

Ships are manned by humans and IMO recognizes the role of human element in maritime accidents and strives to prevent them by way of adopting regulations and rules to prevent its recurrence. Present day collision, grounding and allision accidents continue to happen despite enforcement of regulations aimed at addressing many of the human factor issues plaguing the maritime industry from a navigation perspective through use of technologically advanced navigation equipment, minimum crew manning requirements, rest periods and so on. It is quite clear that many of the changes made have not worked in favour of the seafarers and adopting these changes alone cannot guarantee an accident free navigation. Any accident involving ships involve negative publicity in the media as the numbers of affected parties are many and at times the consequences of the accident to the environment catastrophic.

In the present scenario, the shipping industry has to be cautious towards casualties as there is no such insignificant leak which is acceptable anymore. In an extreme event such as collision, allision or grounding casualty as a result of human errors or not, a high level of redundancy will be crucial in limiting the extent of damage to the ship hull and the potential for further unexpected consequences. Human factor issues are many and complex to deal with and so is the presence of substandard ships, substandard class societies and poorly performing and irresponsible flag states that can contribute to the casualty. To deal with such a problem, a fundamental change is required in the way accident investigations are carried out, both from the human factor perspective and from a technical perspective using forensic engineering investigation approach. It is also recommended that recent technical advancements for structural analysis should be used to bring about improvements in the design, construction and maintenance of ships.

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