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Research Article

HUMAN FACTORS IMPLICATIONS ON SHIP BRIDGE DESIGN

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ABSTRACT

The aim of this paper is to analyse human errors in grounding accidents according to the Marine Accident Investigation Branch of UK (MAIB) Database. In the analysis it was found that 82% of grounding accidents were related to human factor. The main aim is to identify the effect of **human errors** on deterioration of **navigation safety** with a view of **improving future ship bridge design** according to the **IMO Human Centered Design (HCD)** approach.
In order to understand the role of human factors on grounding accidents; Casualty Statistics were first comparatively studied. Then, the grounding incidents in MAIB database between the years of 2006 and 2012 were broken down according to the MAIB Human Factor Taxonomy. The findings were first analysed with the user needs, gaps and anamolies which were mentioned in related International Maritime Organization(IMO) documents and consequently International Standardization Organization (ISO) Human Factor quality requirements of Information and Communication (ICT) Products were used to propose possible industrial recommendations in trial process.
Keywords: Ship bridge design, human centered design, human factors, maritime accidents.

1. INTRODUCTION

Safety has the highest priority in maritime transportation. The purpose of this study is to investigate the maritime accidents in order to understand the effects of human factors on navigational safety [1]. Seafarer Training which focuses on increasing the human performance and reliability on board is one of the most popular approaches commonly used to mitigate the human error [2]. But the main thought should be to fit the machine to the human [3].

It is believed that the outcomes of detailed investigations on **the root causes of human errors** can provide valuable input on developing and execution process of maritime regulations. Therefore many investigations aiming to identify the causes of human error in maritime accidents have been carried out by the maritime society (regulatory organizations, industrial base, academic field etc.) [4; 5; 6; 7].

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It is noted that the design factors related to the design-induced errors such as: human-machine interface design; information characteristics; workspace arrangement; procedures; environment; and training [8].

The ISM Code (2008) was introduced by IMO with the purpose of decreasing human errors in ship operations and improving the safety. The new navigational aids such as Automatic Plotting Aids (ARPA), Electronic Chart Display and Information Systems (ECDIS) , Automatic Information System (AIS), Global Maritime Distress and Safety System (GMDSS) etc, provide valuable support in the ship bridge operations [9]. The marine bridge electronics industry has a total market value of around US$3.2 billion and the market value incorporates all sales in one year of marine bridge electronics on commercial shipping, workboats of various types, fishing vessels, and recreational boats [10].

Technological advances resulting a decrease in number of crew as well as stricter navigational regulations imposed by authorities naturally increase cognitive task load for navigational crew, who rely heavily on the information provided by the bridge equipment. [11]

The human related causes, together with the negative contributions of ship design such as inadequate navigational equipment (eg. ARPA Radar, ECDIS), engine and steering failures, and the poor bridge layout, increase the probability of accidents [12].

The discipline of human factor aims for understanding the human capabilities and limitations, as well as applying this information to design equipment, that are compatible with human abilities. This kind of "**human-centred approach"** provides guidance to system design and improvement in data quality and information analysis, and to generally meet user needs and enhance safety [13].

This study attempts to identify the effect of human errors in bridge operations leading to grounding accidents which is the most frequent initial incident of the both total and serious losses for all types of ships. It is concluded that the results from such analysis can be used to improve the future ship bridge environment.

2. BACKGROUND

It was reported by United Nations Conference on Trade and Development (UNCTAD) in Review of Maritime Transport 2018; the world's commercial fleet grew by 3.31% during the year 2017 and it reached 94,171 vessels, with a combined tonnage of 1.92 billion dwt. And it was declared that the world seaborne trade grew by 4% in 2017, the fastest growth in last five years taking the total volume of goods loaded worldwide 10,7 billion tons [14].

Table 1. Total Losses By Cause, All Types of Ships, >500 GT

	2001-2005 (%)	**2006-2010 (%)**	**2011-2015 (%)**
Weather	30	44	47
Grounding	16	21	26
Fire Explosion	15	9	8
Collision/Contact	14	12	4
Hull Damage	11	5	4
Machinery	8	6	9
Other	7	3	2
TOTAL	100%	100%	100%

According to the International Union of Marine Insurance (IUMI) Casualty Statistics the general trend in reducing frequency of total losses witnessed over the past 14 years (2001-2015) reversed in 2015. Through the years 2001-2015 there is a marked increase in the frequency of total loss caused by weather and grounding. For the vessels above 500 GT Table 1 shows that the

weather (47%) and **grounding** (26%) continue to be the first two major causes of the total losses and serious casualties [1; 15].

According to former studies; in relation to grounding, collision and contacts, the main causes are usually related to human failures during the navigational operations state, [9; 12; 16]. Among the navigational accidents (collision, grounding and contacts**) grounding** is the most frequent initial incident of the total losses for all type of ships [15].

Foundering accidents are associated with the geographical area they occur in and **the extreme weather conditions** often encountered in such locations[17]. The marine insurance statistics have shown that human error is a major contributing factor in about 60% of shipping accidents. [18; 19].

The initial accidental events caused of these reported total losses for all type of ships greater than 100 GT are given by numbers and gross tonnages in Table 2[20].

Table 2. Initial Accidents, By Number and GT of The Total Losses, All Types of Ships, >100 GT

	Number	**%**	**GT**	**%**	**Age**
Grounding	25	18	273055	32	33
Fire Explosion	34	24	203781	24	28
Foundered	52	37	162306	18	30
Hull/Machinery	11	8	132647	15	22
Collision And Contact	15	10	91.417	10	26
Missing	1	1	108	1	25
TOTAL	**138**	100%	**863314**	100%	28

When we consider Table 1 and 2 together; it is observed that heavy weather has a dramatic effect on the most of the foundered accident among the vessels which they have smaller tonnage. Groundings (18%), collisions and contacts (11%) combined as navigational accidents; stands for 29% of the claims in terms of numbers but 42% in terms of GT. Similar with the IUMI Statistics among the navigational accidents (collision, grounding and contacts**) grounding** (32%) is the most frequent initial incident and the first initial incident type which **causes to the total losses by means of GT** for all type of ships.

In the light of the discussed statistics and the IMO considerations it can be said that **groundings are the most frequent navigation related initial incident of the ship losses** for all type of ships. According to the released interim reports by the Transport Accident Investigation Commission [21] and MSC 92/6/3 [22]; the issues related to the human element are at the root of the both grounding accidents. These accidents emphasizes the strong connection between human errors and the accidents [23].

The aim of the study is to investigate the maritime accidents to understand the effect of ship bridge design-induced errors on officers' ability to make operational decisions. In the light of this aim; the objective of the paper is to identify;

- The underlying reasons for **groundings** due to human error,
- The current **deficiencies in human-machine interaction** practices and
- The potential areas to improve **for better bridge design and human-machine interaction**.

3. METHODOLOGY

Analyzing the root causes of shipping accidents is important for developing strategies for reducing marine incidents and casualties. In order to understand the roles of the root causes in grounding accidents, following research methodology (Figure 1.) is used.

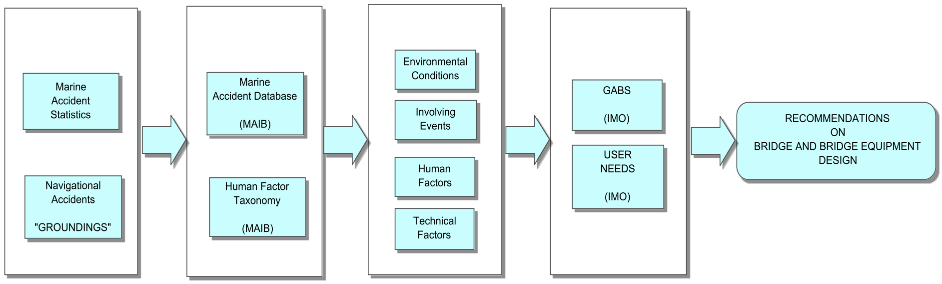

Figure 1. Research Methodology

MAIB reports frequently pointed out that the accidents are the key source of useful safety advice [24]; and every effort should be made to learn and promulgate the lessons so that a recurrence can be avoided [25].

The research set of accident data gathered from the accidents involves the UK flag ships worldwide and the ships in the UK waters from MAIB database and the MAIB root causes taxonomy was selected to be used in this study. The terms of MAIB Human Factor Taxonomy are used in MAIB Accident Investigation Process [26]. The findings were comparatively analyzed with the user needs, gaps and anomalies which were mentioned in related IMO documents to underline the role of human factors on grounding accidents. And finally the possible industrial recommendations in trial process which have been developed according to the adopted International Standardization Organization (ISO) Iterative Application Processes of Human System Integration Concept throughout the life-cycle of systems and software [27] and finally, Human Factor Quality Requirements of Information and Communication (ICT) Products [28] were used to propose possible industrial recommendations in trial process. (see Figure 2.)

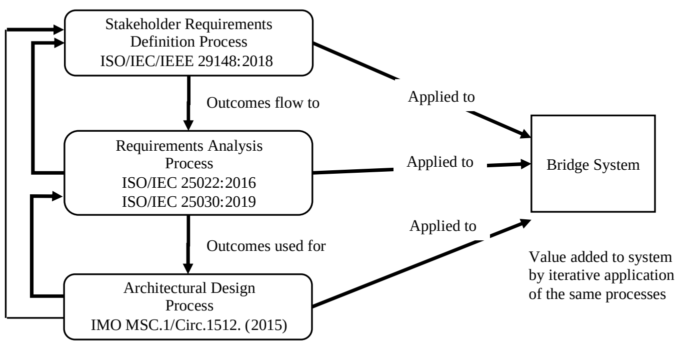

Figure 2. Adopted Application Processes (Adopted from ISO/IEC/IEEE 29148)

The **accidents and hazardous incidents** were analyzed among the **grounded ships** above **500GT** considering the carriage requirements of bridge equipments according to the SOLAS and the competence and watch keeping standards of seafarers according to the STCW [2]. The fish catching and other non-commercial vessels (mainly fishing vessels, tugs, dredgers, survey/research, associated with offshore industry, port service ships etc) were discarded, since their reduced manning requirements according to ISM Code (2014) would lead to a distortion of results with regard to the human element effect.

According to this criteria, the overall accident dataset consisted of 214 shipping accidents involving vessel categories of Dry Cargo, Passenger and Tanker/Combination Tanker . The case summaries and case notes regarding to these accidents were examined.

4. RESULTS & DISCUSSION

It was observed that 214 grounding incidents occurred during the period of 2006-2012. 706 involving events are found in these grounding incidents including accidents and hazardous incidents.

4.1. Environmental Findings

Table 3 shows **visibility, light, sea state, wind** values at the time of the examined groundings (the scale is defined in [26]):

Table 3. Environmental Findings-Groundings

Visibility	%	Light	%	Sea State	%	Wind	%
Good	78	Darkness	50	Sheltered Waters	43	Calm	56
Moderate	13	Light	44	Calm	33	Moderate	29
Poor	9	Semi-dark	6	Moderate	13	Gale	10
				Rough	11	Storm	5

It was found that most of the analyzed groundings occurred under **Good** visibility conditions, in the **darkness** and they took place in the **sheltered waters** when the wind force was **calm**. Contrary to the belief; sailing in the sheltered waters in the dark was more significant than the bad weather conditions. It is considered that these environmental conditions can be used in the bridge simulator training as part of a common grounding avoidance scenario.

4.2. Involving Events

Considering the fact that one accident or hazardous incident may have more then one related casual factor so; 706 involving events are found in 214 grounding incidents including accident (96%) and hazardous incidents (4%).

4.2.1. Involving Categories

Table 4. presents the **involving categories** of 706 involving in 214 analyzed grounding accidents.

It was found that the 83% of the involvings are related with the deck category. For that reason, the category **deck** was analyzed to identify the effect of the bridge design induced human errors in grounding accidents. According to the study regarding to the *involving* the research question was “What involves in grounding?” [26]. Some problematic areas related with the ship bridge design in involving sub-categories are Bridge Procedures and Navigation/Communication Equipments.

Table 4. Involving Sub-Categories of Groundings

Category	%	Involving	∑	%
Deck	83	Bridge Procedures	557	78.8
		Navigation and Communication Eq.	13	1.84
		General Shipboard Activities	17	2.40
Safety	6	General Management/Procedures	40	5.66
Machinery	5	Main Machinery	10	1.41
		Auxiliary Machinery	11	1.55
		Deck machinery	4	0.56
		Electrical	10	1.41
Ship	6	Manoeuvrability	35	4.95
		Stability	4	0.56
		Structural Integrity	3	0.42
		Flooding	2	0.28
	100	**TOTAL**	**706**	**100**

4.2.2. Human Factor Analysis.

The distribution of 557 involving of Bridge Procedures was given in Table 5**;**

Table 5. Involving of Bridge Procedures

Involving	%	Σ
Passage Planning/Track Monitoring	36	199
Poor Decision Making	22	120
Environmental	16	88
Manning	11	55
Communications/Orders	9	53
Look out	3	20
Rule Contravention	2	19
Bridge Environment	1	3
TOTAL	**100**	**557**

It can be observed that Passage Planning/Track Monitoring and Poor Decision Making almost make 60% of involving of Bridge Procuders. The Planning, Monitoring and Conning functions of Bridge Operations are the most negatively affected by Human Factors.

According to the database; the detailed analysis continued on the involving categories to find out how and why the Bridge Procedures and Navigation/Communication Equipments were affected negatively.

4.2.2.1. Bridge Procedures (78.8%)

Passage Planning (36%) : Inadequate Passage Planning (26%), Position Monitoring Not Frequent Enough (22%), Passage Plan Not Followed (15%), Position Monitoring Inaccurate (12%), Position Not Checked by another Method or Person (9%), Chart Incorrect (7%), No Position Fixed (6%), Chart Not Used (2%), No Passage Planning (1%), Passage Planning(Pilot to Pilot only) (1%), Passage Plan Not Understood (1%)

Poor Decision Making (22%) : Incorrect or insufficient Action Taken (64%), Speed too fast for the conditions (7%), Speed or heading not altered(risk not appreciated) (18%), Anchored in wrong position for the conditions (10%), Improper anchoring (1%)
Environmental (16%) : Conditions had greater affect than expected (75%), Conditions found to be worse than forecast (19%), No tidal height information gathered (1%), Poor visibility in fog/mist/rain/snow etc (4%), Visibility affected by lights/back scatter (1%)
Manning (11%) : Watchkeeper asleep (21%), Sole watchkeeper (27%), Watchkeeper unfit for duty (9%), Inappropriate roles allotted (6%), Lack of role monitoring (5%), No lookout posted (18%), No helmsman used (7%), Individual takes inappropriate role (5%), No watchkeeper (2%)
Communications/Others (9%) : Communication failure, master/pilot (64%), Communications failure, master/watchkeeper/rating (12%), Communication (2-way) not encouraged (4%), Communication difficult for language or cultural reasons (4%), Verbal order or instruction not understood/misinterpreted (12%), Inappropriate use of VHF (2%), No, or inadequate, company orders (2%)
Look Out (3%)
Rule Contravention (2%)
Bridge Environment (1%) : Use of chair at control station(officer fell asleep) (70%), Poor visibility from control position (20%), Noise (10%)

4.2.2.2. Navigation/Communication Equipments (1.84%)

Navigational Instruments (53%) : Instrument Not Used (25%), System Error/Failure Detected (25%), Information Misinterpreted (13%), System Error/Failure Not Detected (13%), Error check not made (6%), Error not allowed (6%), Inaccurate Data Input-Automatic (6%), Operator Error (6%)
Bridge Control Equipment (35%) : Features/Functions/Alarms Not Used or Incorrectly Used (45%), System Error/Failure Detected (33%), Operator Error (16%), Inaccurate Data Input-Automatic (6%)
Communications and Alarms (12%): Features/Functions/Alarms Not Used or Incorrectly Used (25%), System Error/Failure Detected (25%), Operator Error (25%), Inaccurate Data Input-Automatic (25%)

4.2.3. Analysis of Groundings

The grounding incidents in MAIB database were analyzed and contributory factors have been identified. It was found that 82 % of grounding accidents were attributed to the human factor. The events were associated with navigational tasks on the bridge. The underlying factor of the half of these factors are directly related with "People" .

4.2.3.1. Human Factors-Groundings

People (48%) : Situational awareness or communication inadequate (28%), Competence (21%), Inattention (18%), Complacency (13%), Perception (11%), Poor decision making and information use (7%), Over confidence (1%), Fatigue (1%)
System-Crew (16%) : Procedures inadequate (50%), Misapplication of Regulations and procedures (20%), Lack of communication and coordination of information (16%), Inadequate management of resources (14%)
System-Company and Organization (11%) : Orders and instructions are inadequate (37%), Training, skills and knowledge inadequate (32%), Complacency (19%), Inadequate resources (12%)

System-Equipment (4%) : Personnel Unfamiliar with the equipment (40%), Poor Human Factor Design (28%), Equipment not available (17%), Equipment misused (15%)
System-External Bodies Liaison (1%) : Poor Regulations
Working Environment (2%) : Visual Environment, Hazardous Natural Environment, Poor Housekeeping

These findings were compared with the results of the other researches regarding the collision accidents [18]. It was found that the maintaining the right amount of information at the right time is vital for distributed situational awareness among the Bridge Team. The system should not only integrate the officer but also **train the officer** by taking part in the operation and additionally allowing the operator to **alerting the abnormal situations**. The **familiarizing the ships' officers** with the new technologies on board is essential.

4.2.3.2 Technical Factors-Groundings

Some events were found due to technical failures related to the navigational equipments, steering, hydraulic, and propulsion systems.

External Causes : Uncharted water obstruction
Design and Construction : Design Inadequate, Characteristic Defect
Material Defect
Environment : Current (45%), Heavy Weather (38%), Visibility (17%)

Also some problematic areas among the events; related to navigational equipments such as ECDIS and BNWAS; were found.

Some recommendations on ECDIS are put forward in response to the research findings to contribute to the improvement in future bridge environment:

- Voice activated system features as the meaning of the verbal alarm phrases can be added to the system, for making officers what they do while changing settings of the device.

Alarm phrases can be displayed also in the other conning screens to alert the other members of the bridge team via by a central alarm management system [7]

- Predefined channel restrictions can be added; as an adaptive solution; to the harbour charts of ECDIS. Even if the team doesn't plan the passage on the ECDIS it should give alarm according to the position if it is in outband of the restricted channel or in the outer limits of predefined channel restrictions

Bridge Navigation Watch Alarm Systems (BNWAS): Another common reason for groundings was identified as **the watchkeeping.** It was caused by the watchkeeper falling asleep and the BNWAS was set off. BNWAS are intended as a means of preventing incidents such as collisions and groundings when there is a single OOW on the navigation bridge [29]. Accordingly, as an *interim* measure the Automatic mode is not suitable for use on a ship conforming with regulation SOLAS V/19.2.2.3 [30].

4.3. Human Factors Requirement Analysis

It is needed to design automation systems and technology that adapt to humans and maintain the human in the loop at all times also it must be seen that the environment, the machines and humans as a whole[30]. Combining engineering with human is one approach to achieve this[31].

Consideration of human systems integration (HSI) is an important concept within systems engineering. HSI focuses on the human over the system life cycle. It promotes a total system approach that includes humans, technology (hardware and software), the operational context and the necessary interfaces among the system elements to make them work in harmony. HSI brings human-centered disciplines (such as manpower, personnel, training, human factors, environment, health, safety, habitability and survivability) into the systems engineering process to improve the overall system design and performance. [27] According to this concept the possible industrial recommendations in trial process have been developed (Table 6) using with the ISO Human Factors Requirements in terms of safety, performance, effectiveness, efficiency, reliability, maintainability, health, well-being and satisfaction [28] which they were measured with the ISO Measurement of Quality In Use Guide [32]. Human Factors Requirements have been stated for the outcomes of interaction with human users (and other stakeholders affected by use) and include characteristics such as measures of usability, including effectiveness, efficiency and satisfaction; human reliability; freedom from adverse health effects.

Table 6. Industrial Recommandations in Trial Process

<table>
<tr><th>USER NEEDS</th><th>GAPS</th><th>HUMAN FACTORS</th><th>INDUSTRIAL RECOMMANDATIONS IN TRIAL</th></tr>
<tr><td>Maximize navigational safety benefits and minimize any risks of confusion or misinterpretation.</td><td>Intuitive human-machine interface for communication and navigation, Harmonized symbolization for whole potential navigation information</td><td rowspan="3">Situational awareness or communication inadequate

Inattention

Complacency

Perception

Poor decision making and information use

Over confidence

Fatigue

Poor Human Factor Design</td><td>Multifunction Workstations.
Locating primary data near center of operator’s field of view.
Minimize operator data input requirements
Voice Alarms for critical systems.</td></tr>
<tr><td>Navigation displays designed
-to optimize support for decision making.</td><td>To enhance graphical display of navigational information.</td><td>Enhanced high definition, high resolution, anti-glare, anti finger print, low illuminated monitors.</td></tr>
<tr><td>- to prevent the confusion and misinterpretation when sharing safety-related information.
- to avoid information overload by means of Human Machine Interface</td><td>To minimize light reflection.</td><td>Tilting Displays.</td></tr>
<tr><td rowspan="4">-to manage the information load of users.</td><td>To enable operations in sitting or standing configurations.</td><td rowspan="5">Situational awareness or communication inadequate

Inattention

Complacency

Perception

Poor decision making and information use

Over confidence

Fatigue

Poor Human Factor Design</td><td>Height adjustable consoles.</td></tr>
<tr><td>- Presentation of manoeuvring information/data (engine-room telegraphs) on navigational display
- Improve communication between bridge team members for planning, checking and implementing operations.</td><td>Centrally located electronic information display.</td></tr>
<tr><td>Improve communication between Pilot and bridge team members</td><td>Integration of information from Pilot Portable Units on to the bridge consoles</td></tr>
<tr><td>Improve ship to shore or ship to data centre Communication</td><td>Electronic Data Collection and Analytics</td></tr>
<tr><td>Operating procedures should be kept under review.</td><td>Most notably in relation to the human/machine interface</td><td>BNWAS eg.</td></tr>
</table>

5. CONCLUSIONS

The main findings of the results of the comperative analysis and the recommendations which are proposed accordingly can be summarized as follows: Navigational displays should be designed to make the officer focus on important information. Computers can be stored in a central, access-protected equipment room, which leaves the crew more space on the bridge or in the control room. Adaptive systems which are allowing users to store the switching states for different tasks for example, in harbours, or in an emergency, or during man-overboard manoeuvres. The functions could be transferred that were on hardware panels into the software. It improves the visibility of functions and can be adapted to user needs. New technology is sometimes implemented without caring for the OOW and it causes "information overload". The system should not only integrate the officer but also train the officer. And also allowing the operator to alerting the abnormal situations. The practice of familiarizing the ships' officers is essential, especially, for the increasingly complex technological equipment they will be required to use. Situation awareness is related to decision-making and it needs the right information at the right time. Improper situation awareness causes poor decision making. Bridge Resource Management. Failures in BRM are involved in almost every groundings investigated dealing with situational awareness. Insufficient manning causes poor lookout which occurs because several bridge tasks such as administrative, navigation, collision and grounding avoidance. Instructions/orders given to the bridge team were incorrect. They cause some difficulty for Senior Officers to adapt their instructions to a changing situation. They may also indicates a poor safety culture. ECDIS can be a powerful tool in support of safe and efficient ship operations when it is used correctly along with all other available information sources. The safety of the ship is compromised by over-reliance on a single system, no matter how effective that system might be.

An attempt was made to explore the layout of the present bridge equipments and information flow on the ship's bridge equipment influences on officers' ability to make operational decisions. Accordingly, it was aimed to explore what kind of problems took place in the interaction between officers faced on the bridge equipment caused human errors although it is usually expected that the equipment will help the officer who wants to navigate safely.

To find specific safety interventions in order to reduce the groundings due to the bridge equipment design related human errors, statistical analysis of an accident database can not be sufficient. For identifying, characterizing, quantifying and evaluating critical event occurrence; **Risk analysis** technique (eg. PRA, QRA) regarding other **Human Factor Taxonomies** (eg. HFACS) can be used.

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