Maritime Accident Analysis and AI based HCD IoOT Larch for Operator Vigilance and Cognition

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ISLAMABAD, PAKISTAN

OCTOBER, 2020

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A thesis submitted in partial fulfillment of the requirements for

the degree of *master of science* in

Robotics and Intelligent Machine Engineering

Thesis Supervisor:

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OCTOBER, 2020

Declaration

I, *Ahmed Husnain Johar* certify that this research work titled "*Maritime Accident Analysis and AI based HCD IoOT Larch for Operator Vigilance and Cognition*" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Copyright Statement

➢ Acknowledgements

I am thankful to my Creator Allah Subhana-Watala to have guided me throughout this work at every step and for every new thought which You setup in my mind to improve it. Indeed, I could have done nothing without Your priceless help and guidance. Whosoever helped me throughout the course of my thesis, whether my parents or any other individual was Your will, so indeed none be worthy of praise but You.

I am profusely thankful to my beloved parents who raised me when I was not capable of walking and continued to support me throughout in every department of my life.

I would also like to express special thanks to my supervisor Prof. Dr. Yasar Ayaz for his help throughout my thesis and also for Artificial intelligence, Mobile Robotics and Fuzzy Control courses which he has taught me. I can safely say that I haven't learned any other engineering subject in such depth than the ones which he has taught.

I would also like to pay special thanks to my precious friends for their tremendous support and cooperation. Each time I got stuck in something, they came up with the solution. Without their help I wouldn’t have been able to complete my thesis. I appreciate their patience and guidance throughout the whole thesis.

I would also like to thank Dr. Umer Asgher, Dr. Hasan Sajid, and Dr. Muhammad Jawad Khan for being on my thesis guidance and evaluation committee and express my special thanks to Dr. Salman Nazir and Dr. Mohsin Shahid for his help, support and cooperation.

Finally, I would like to express my gratitude to all the individuals who have rendered valuable assistance to my study.

Dedicated to my exceptional parents and adored sibling whose tremendous support and cooperation led me to this wonderful accomplishment

Abstract

Maritime accidents occur due to the accumulation of various contributing factors that happened in the sequence. The nature of these tributary factors can be either latent or active. The maritime accident ought to be investigated and evaluated based on some accident causation model. Approximately 80% of maritime accidents are attributed to factors that are associated with humans. Either the chain of erroneous events that eventually leads to an accident or some contributing step is factually initiated by human operator. The statistics by International Maritime Organization (IMO) depicts that the major contributing factors are either negligence of operators or violation of the standard operating procedures, thus, the study of the factors having maximum contribution will serve the principal purpose. Hence, for the elimination of these factors to avoid such misfortune events, operator vigilance for gross violations is deemed necessary. Breaches of rules by the human operator are a frequent cause of accidents, as accident evaluations show. Until now, there exists no framework for operator vigilance and cognition in their active environment. In this study, based on the fact that the primary cause of accidents in the maritime, chemical, and aviation industry is the erroneous human behavior, we have designed an AI-based Human-centered design IoOT (Internet of Operator Thing) Larch for continuous monitoring and surveillance. Various sensors constitute the Larch, which extracted the activities data and fed to the system where activities are successfully recognized and classified as either valid or invalid. An alarm will trigger by the continuous occurrence of mischievous activities by a specific human operator. Besides the rectification of malpractices by validating activities, the system also develops the profile of operator activities by creating separate log account, which can be further manipulate for behavioral and policy management in the long run.

Key Words: *Maritime, Accident, Human factor, Causation model, Statistical method, Meta-analysis, IoOT Larch, vigilance, surveillance*

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CHAPTER 1: INTRODUCTION

1.1. Overview

Waterways have as much traffic as roads. They have been in use for traveling as well as cargo transportation for a long time. From small vessels to the large leisure and cargo ships having the capacity of thousands of TEU utilize these waterways. Statistics show that 90% of the world trade occurs through maritime transportation [1]. Such figures reemphasize that maritime transportation is the backbone of the world's economy [2]. By 2018, the volume of world seaborne trade rose to a new all-time high level of 11 billion tons. The statistics given in Figure 1 shows consistent growth in the seaborne trade.

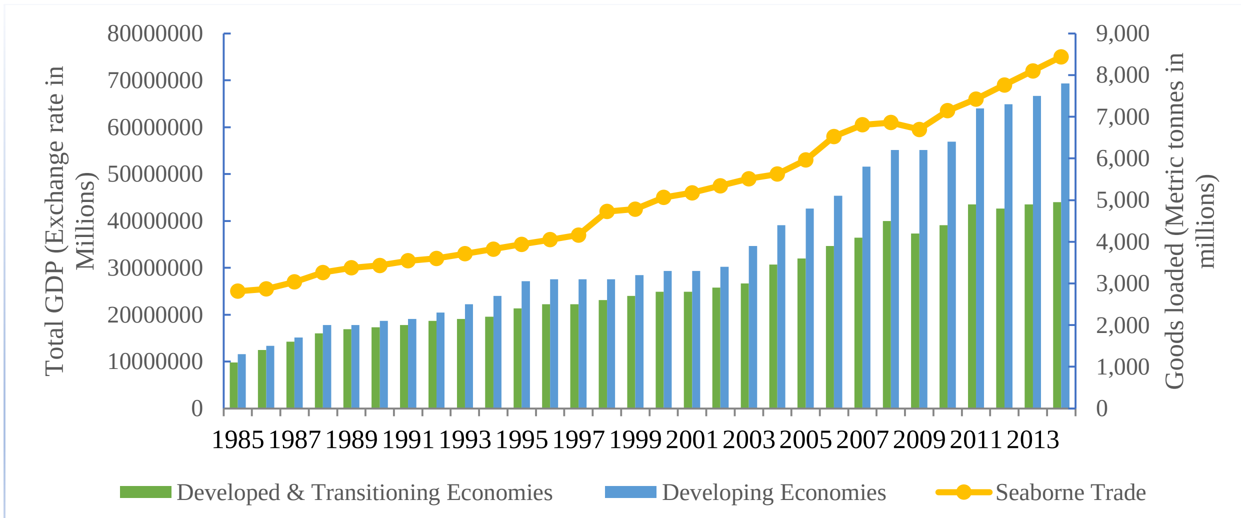

Figure 1: Statistics of world economy & seaborne trade – UNCTAD

Besides cargo vessels, passenger ships also having an equal share in waterways traffic. Korea Shipping Association data shows that millions of passengers used this mode of transportation solely in Korean waters [3]. Keeping in view the high utilization and value of maritime transportation, corporations and governments incurred huge losses due to even a single maritime accident [4] [5]. Figure 2 is the data of maritime accidents of the past 11 years provided by the IMO in 2016.

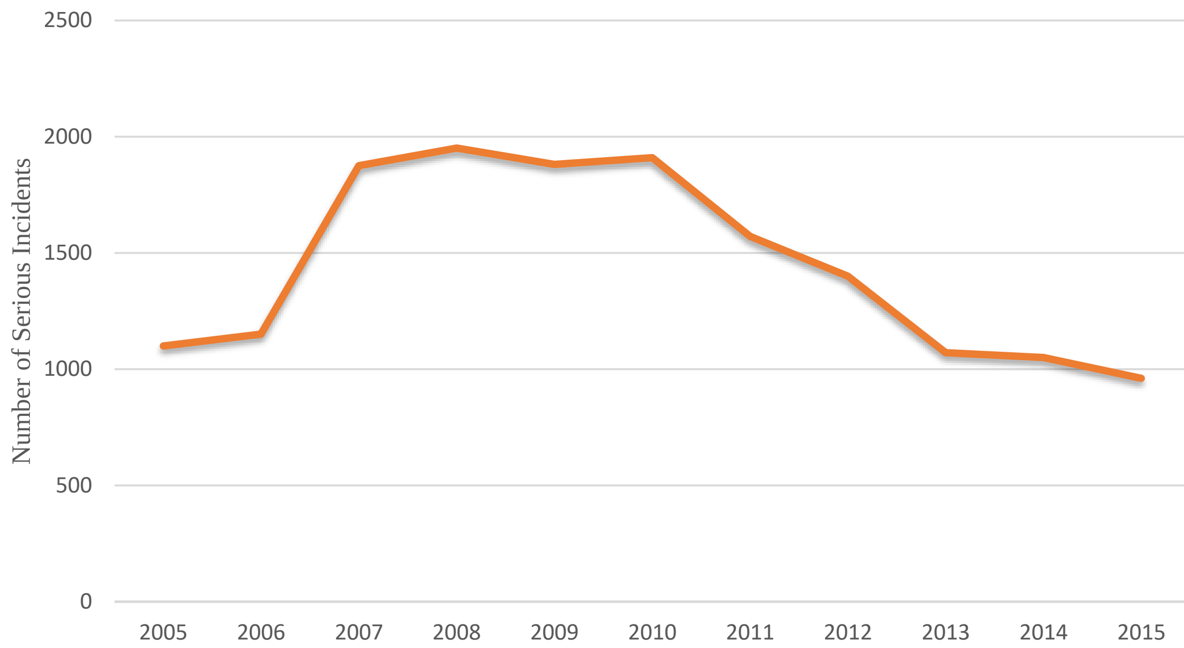

Figure 2: Marine casualties and incidents (IMO, 2016b)

To avoid any mishap, the International Maritime Organization (IMO) devised several safety standards and many research institutes developed hi-tech systems for ships. For precise automated navigation, Integrated Bridge System (IBS) and Integrated Navigation System (INS) are available and other systems like Automatic Identification System (AIS), Electronic Chart Display Integrated system (ECDIS), Central Alert Management - Human Machine Interface (CAM-HMI) etc. assist the onboard tasks [5] [6] [7]. Despite the high advancement in the guidance technologies deployed on ships, data shows that no significant decline in accident numbers. Analysis of accidents depicted that the most significant contributing factors are attributed to human errors. Human involvement in maritime accidents is so enormous that it piles up to 80% of accident causation [8] [9]. EMSA data shows that almost 415 maritime accidents already happened in 2019 as of July in its jurisdiction. The number was 828 in 2018 and the same trend goes on. KMTS data of five years depicts a consistent trend in the accident as the rate of accidents persistent at 2 percent [10].

Accidents always attributed to different factors, which caused the initiation of the accident causation chain. Experts analyze the accident to extract those causes. Yoon et. el. proposed the following generalized scheme for accident analysis as shown in Figure 3. This generalized model takes the accident-related information and after the implementation of accident causation models and techniques, outputs the actual causes, sequence chain and problems occurred. Highly sophisticated models can also suggest corrective actions [11].

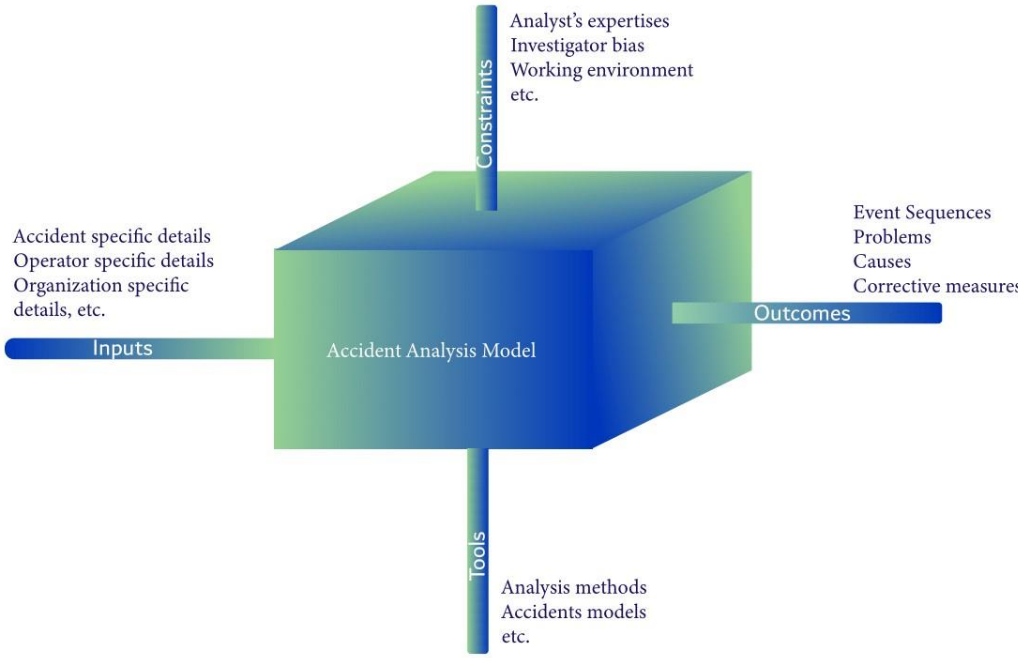

Figure 3: Generalize accident analysis model, (courtesy Yoon et. el.)

Data shows that human errors are the main contributor to each type of accident. EMSA 2016 statistics in Figure 4 show that fire & explosion accidents are mainly happened due to human errors [12] [13] [14].

The human factor is a substantial issue regarding maritime safety. The assessment of human errors is highly critical task among maritime marine engineers, safety experts and researchers. Due to the embedded limitations, an expert's judgment is the basis of many empirical techniques of this field. The technique for human error rate prediction commonly known as THERP undertake the failure definition, quantified HEP values and task analysis for the assessment of human errors [15], [16]. This technique considered the first generation method for error assessment [17].

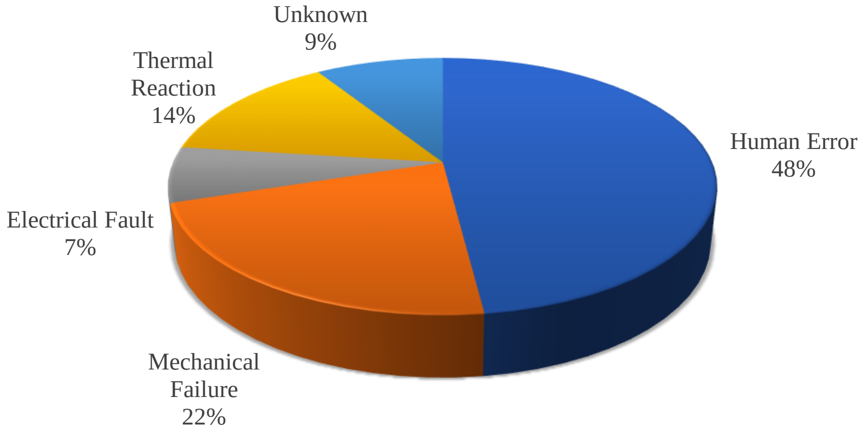

Figure 4: EMSA 2016 statistics of fire & explosion accidents

Another human factor analysis method is a cognitive event tree system known as COGENT, based on the event tree method. COGENT integrates the three prominent and potential means which blanket all human activities. These domains are event-tree approach, skill-rule knowledge paradigm, and slips-lapses-mistakes paradigm [18] [19] [20]. There is also exists a multidisciplinary framework to explain human factors [21]. By the fusion of different domains like engineering, behavioral sciences, and human factors, social scientists have designed a technique for human error analysis commonly known as ATHENA [16]. This framework has a comprehensive set of factors that include the elements beyond human activities. The prominent elements of this framework including scene definition, conditions of plant, contexts of error forces, performance shaping factors, human errors, events of human failure, error mechanisms, unsafe actions, and risk assessment models [22]. These frameworks analyze the accidents after their occurrence and respective preventive measures based on their assessments then enforced by the regulation. These incidental events developed from near-miss to catastrophic disaster while mishap, hazardous incident and accident are the intermediary stages [23]. Table 1 contains the data of some serious accidents and major regulations enforced after them [24] [25].

Table 1: Regulations derived from serious maritime accidents

Accident	Regulation
Titanic - 1912	SOLAS 1929 by IMO
SS Yarmouth - 1965	SOLAS – Fire & Safety amendments by IMO
Torrey Canyon - 1967	Intervention Convention 1969, MARPOL 1973, CLV, 1969 by IMO
Argo Merchant - 1976	MARPOL 1973 – Protocol of 1978 by IMO

Tanker Accidents - 1977	SOLAS 1974 - Protocol of 1978 by IMO
Amoco Cadiz - 1978	SOLAS 1974 – Protocol of 1978 (Introduction of remote steering gear) by IMO
European Gateway - 1982	SOLAS 1988 – SOLAS 90 Stability standards by IMO
Herald of Free Enterprises - 1987	ISM Code 1994, SOLAS 1988 amendments, SOLAS 1988 – SOLAS 90 stability standards by IMO
Scandinavian Star - 1988	SOLAS 1989 amendments (fire protection) by IMO
Bulker accidents - 1990	SOLAS Chapter X11 adopted 1997 by IMO
Exxon Valdez - 1989	OPRC 1990, MORPOL 1992 amendments (Double hull) by IMO
	OPA 1990 by USA
Estonia - 1994	SOLAS 1995 amendments, SAR convention 1998 amendments by IMO
Erika - 1999	Follow-up in MSC and MEPC by IMO
	"Erika" Package by EU
Prestige - 2002	EUR – OPA by EU
Costa Concordia - 2012	SOLAS Chapter 3 – Passenger muster requirement by IMO

The purpose of this review is to present a brief analysis of previous studies which discussed maritime accidents and also analyze those accidents preferably by the employment of accident causation models. The paper is developed as follows. Firstly, there's a brief description of a few accident causation models which utilized by the included studies to analyze the accidents. In the next section, there's a detailed description of selection criteria and Preferred Reporting Items for Systematic Review and Meta-Analysis statement is also discuss because selection of included studies is based on PRISMA. Electronic search terms along with databases have mentioned. In succeeding sections, the statistical tool is applied to the extracted data and then meta-analysis has been conducted. meta-analysis presents a unique result from the analysis of the results of different studies as accident data against different factors taken from various studies.

Finally, the review is concluded with the discussion and few validity threats are also discussed given that the novel approach for data solicitation. Other relevant material and reports are given in appendices as well.

1.2. Structure of this study

The included studies for this study were selected on the narrowly defined criteria. Those studies are preferably included in which accident were analyzed on the bases of any causation method [26]. The purpose of the analysis of accident via the prism of these methods is to expose and identify the chain of latent and active errors which have to contribute interaction to the happening of the accident [27]. Few of these models and methods which are employed in selected studies are briefly discussed in next chapter.

CHAPTER 2: RESEARCH QUESTION

2.1. Systemic techniques

In the deemed opposition of the general argument about accident occurrence that they happened as a consequence of a sequential chain of events, systematic techniques suggest that the cause of the accident deeply rooted in the chaotic relationship among the system forming components. E. Hollnagel [28] concluded that the combination of active and latent error does not become the cause of the accident. The use of unsafe equipment complemented with the erroneous human behavior results in an accident [29]. A holistic approach is required to examine the failures in the entire system [30] as merely eliminating the only root cause doesn't certify the eradication of future accidents [28], [31].

There may require sufficient technical expertise to implement systematic techniques [31], [32]. The selection of the appropriate method for analyzing the accident is the most important step for the rest of the procedure as implementation approaches are different for each method. Hollnagel et. al. Suggested that accident complexity and under observation elements are the deciding factors for the selection of the method [32]. For the eradication or minimization of the accidents occurred in the maritime industry, investigation of the underlying human factors is extremely important as they are the main catastrophic cause [33]. One of the authenticated methods for human factor analysis is HFACS among others. AcciMap, Stamp-Cast, and CREAM are the other important methods but HFACS finds its applicability in many fields [34] [35] [36] [37] therefore, maximum data for analysis in the coming sections provided by this method. All of these methods briefly describe in the next section.

2.2. Accident causation models

2.2.1. AcciMap

The conception of AcciMap is rooted in Risk Management Framework (RMF) devised by Rasmussen [38] [39]. The RMF indicated various hierarchical levels of sociotechnical systems including staff, work, company, management, regulators and government. Based on the Risk Management Framework theory, [40] charted-out a graphical representation scheme for the visualization of system-wide failures and other decisions and actions which contribute to the accident. This systematic technique is known as AcciMap. AcciMap analyzes the actions and decisions at following six organizational levels; (i) government policy and budgeting (ii) regulatory bodies and associations (iii) local area government planning and budgeting (iv) technical and operational management (v) physical processes and actor activities (vi) equipment and surroundings. This technique outputs the factors involved in accident causation and their interrelationships as well [41]. AcciMap finds its wide range of applications in safety-critical domains.

2.2.2. HFACS

The Human Factors Analysis and Classification System (HFACS) technique conceived from theory of latent and active failures i.e. the so-called Swiss Cheese modelled by Reason [38]. The basic structure is shown in Figure 5. Latent failures are invisible and lie deep inside the system. They may include inadequate resources, flawed organizational management practices, inadequate equipment design, supervisory violations, insufficient staff training, and lack of protocols. On the contrary, failures occur closer to the moment at which accidents about to happen are active failures. Unsafe acts usually turned into active failures. Reason's Swiss cheese model lacks the classification system of factors that contribute to the accident as it is purely theoretical [42].

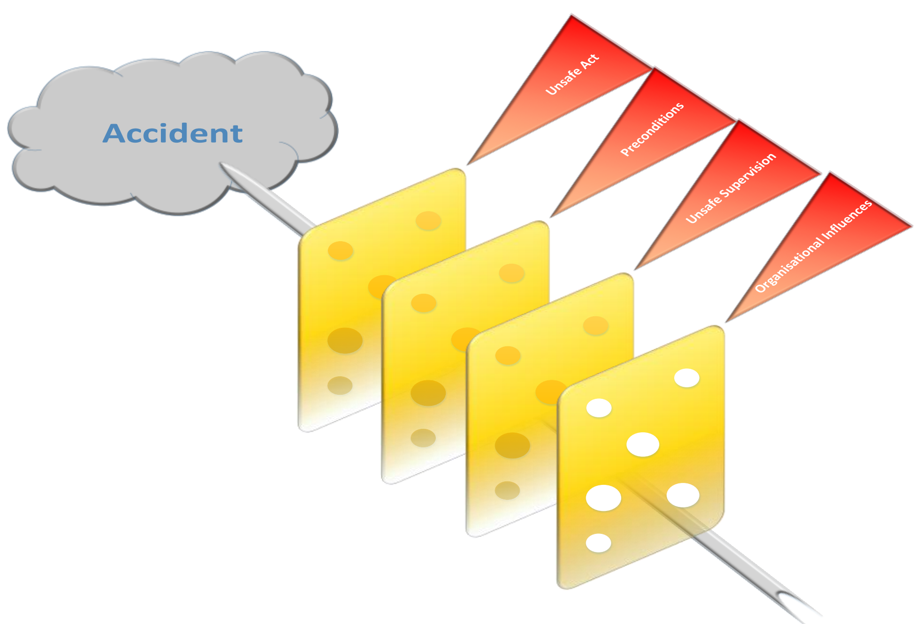

Figure 5: Basic Swiss-Cheese model, (courtesy James Reason, 2000)

To counter this deficiency, [36] a systematic approach has devised that has the embedded capacity of factor classification among the four classes; (a) unsafe acts, (b) preconditions for unsafe acts, (c) unsafe supervision, (d) organizational influences as shown in Figure 6. An additional layer of external factors can also be incorporated in this model. The proposed system also has sub-classes at each level and originally has 17 categories which are extended up to 19 [37] [43] [44].

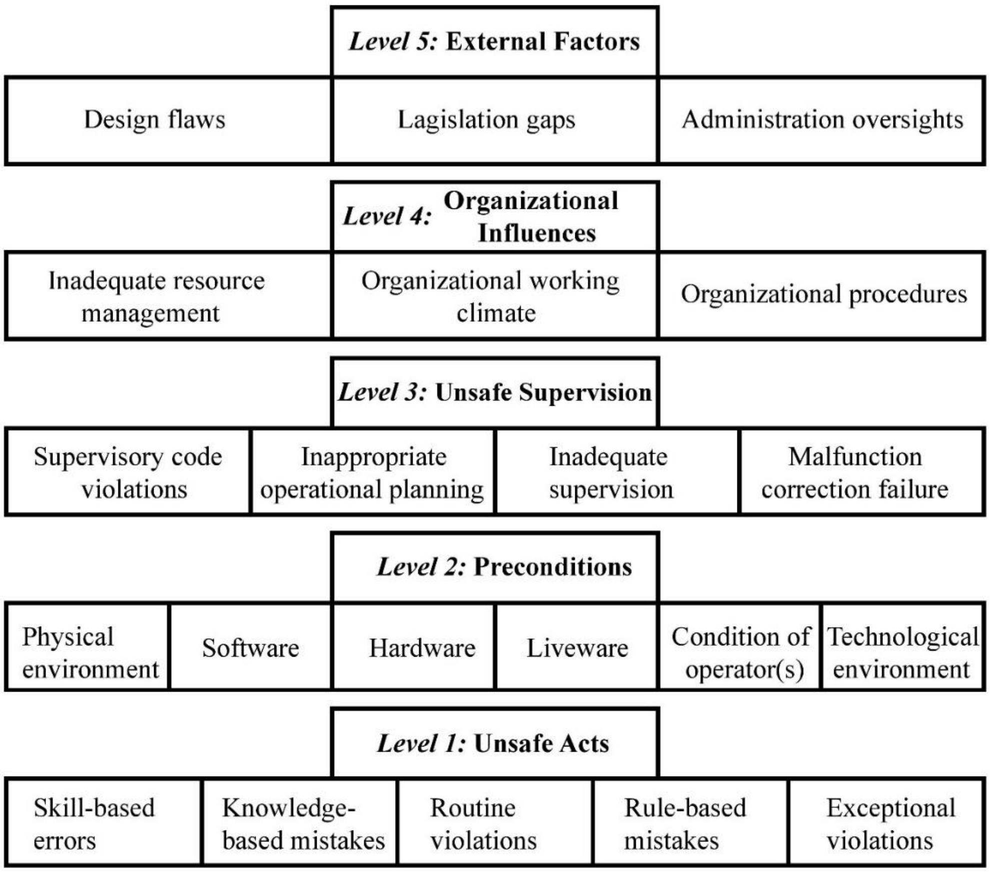

Figure 6: Human Factors Analysis and Classification System

2.2.3. STAMP-CAST

The STAMP model proposed and revised by Leveson, analyze the accident by keeping in view the enforcement of safety-related constraints when system's control fails to take control during chaotic situations [45]. STAMP focuses on the safety constraints across the sociotechnical system by considering safety as a control issue [46] [47]. Control at different levels may be considered, e.g. managerial level, organizational level, operational level, manufacturing-based, or even social controls [48]. Same as AcciMap, the STAMP model also takes a holistic approach of the entire system by incorporating government level i.e. Congress and legislatures.

The STAMP model composed of STPA (Systems Theoretic Process Analysis) and CAST (Causal Analysis based on STAMP) methods as it has both risk & hazard assessment and accident analysis. The CAST analysis has different classification taxonomy categories for the assessment of human factors as this method was originated from the engineering domain. These categories may include context, mental model flaws, and coordination [45].

2.2.4. CREAM

Hollnagel proposed an HEI/HRI method in 1998 known as CREAM i.e. Cognitive Reliability and Error Analysis Method. CREAM employed both predictively and retrospectively to predict, quantify and analyze the potential human errors [49] [50]. This model capable of achieving the following:

- How variation of cognitive reliability affects the actual work
- Determination of cognitive reliability reduction condition
- Ascertain the human performance effects on the safety of the system by implementing PRA/PSA
- Development of cognitive reliability enhancement and risk reduction modifications

The CREAM model employs a classification scheme through which an analyst can predict and explain the occurrence of potential errors. That classification scheme also can provide linkage between causes and their potential consequences. The Contextual Control Model (COCOM) is the variant of CREAM which focuses on the choices of actions.

2.3. Study Design

For the review article, only electronic databases have been searched. For the accident data, different maritime agencies' databases have also been searched.

2.3.1. Electronic Search

Six databases searched for the relevant articles to be included in this study. Table 2 contains the appropriate terms which used as a filter in search;

Table 2: Electronic search terms

Databases	Search terms and applied filters
PubMed	Search (((((“Maritime accidents attributed to human factors”)) OR “HFACS”) OR AcciMap) OR (“Accident causation models”)) OR “STAMP, STAMP-CAST, FRAM,

	SHEL, SHELL, AcciMap, Swiss Cheese, HPES, CREAM" Recent Publication; Any Language
Scopus	TITLE-ABS-KEY ("Maritime accidents attributed to human factors" OR "Accident causation models" OR HFACS OR "STAMP, STAMP-CAST, FRAM, SHEL, SHELL, AcciMap" OR "Swiss Cheese, HPES, CREAM") All Documents; Recent Publications; Any Language
web of science	TOPIC: ("Maritime accidents attributed to human factors") OR TOPIC: ("HFACS") OR TOPIC: (AcciMap) OR TOPIC: ("Accident causation models") OR TOPIC: ("STAMP, STAMP-CAST, FRAM, SHEL, SHELL, AcciMap, Swiss Cheese, HPES, CREAM") All Documents and Language
IEEE Explore	"Maritime accidents attributed to human factors" OR "Accident causation models" OR "Maritime operational accidents analysis" OR "HFACS, STAMP, STAMP-CAST, FRAM, SHEL, SHELL, AcciMap, Swiss Cheese, HPES, CREAM"
ScienceDirect	"Maritime accidents attributed to human factors" OR "Accident causation models" OR HFACS OR "STAMP, STAMP-CAST, FRAM, SHEL, SHELL, AcciMap, Swiss Cheese, HPES, CREAM"
Google Scholar	"Maritime accidents attributed to human factors" OR "Accident causation models" OR "Maritime operational accidents analysis" OR "HFACS, STAMP, STAMP-CAST, FRAM, SHEL, SHELL, AcciMap, Swiss Cheese, HPES, CREAM"

2.3.2. Selection of studies

Diverse range of studies selected for this review, including;

- Research Article databases
- Maritime Agencies databases
- Reports
- Thesis work of different maritime Universities
- Pre-print research work

2.3.3. Eligibility criteria

Studies should comply with and qualify the following criteria to be eligible to include in the review paper;

- Maritime accidents e.g. grounding/stranding, Flooding/Foundering, Fire/Explosion, Contact, Collision or Capsizing/Listing
- During operation
- Attributed to the Human factor(s) or error(s)
- Analyzed on the bases of any accident causation model i.e. HFACS, CREAM, LMQ HF Model, FRAM, PEAR Model, RCA, STAMP, James Reason HF Model, CAST, GEMS, Heinrich Pyramid, or ICAO SHELL Model

2.4. PRISMA

Preferred Reporting Items for Systematic Reviews and Meta-Analyses widely mentioned as PRISMA strategy is employed for the reporting of evidence-based items for systematic review and also for implementation of any statistical procedure, e.g. the Meta-analysis. PRISMA statement is a set of protocols for the evaluation and extraction of the data from the literature for further analyses under the precise PICO based research question. It is a development ground of systematics review and then further processed.

PRISMA statement based selection of studies as following in Figure 7.

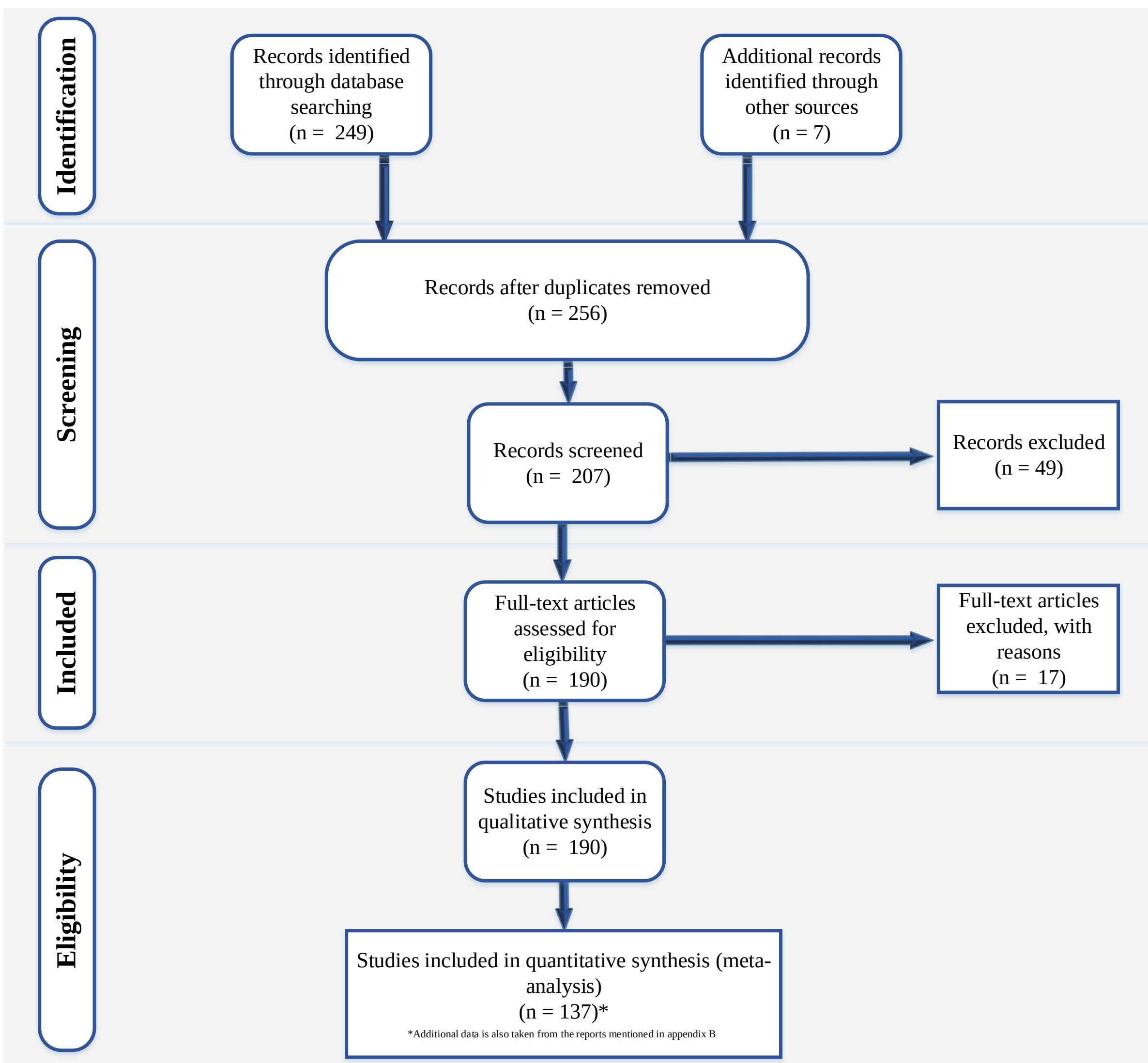

Figure 7: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) based selection

Complete PRISMA statement and checklist are available in Appendix A.

2.5. Databases

The incidents reported in this study are collected by examining various literature studies and reports and about 41 prominent databases of maritime accidents were scrutinized in these studies [51]. In Table 3, the list of accident investigative agencies dealing with maritime affairs is given [52] [53] [34] [54] [34] [55].

Table 3: Maritime accident investigation organizations

Country	Maritime Agency
United Kingdom	Marine Accident Investigation Branch (MAIB)
Norway	Accident Investigation Board Norway (AIBN)
Ireland	Marine Casualty Investigation Board (MCIB)
Cyprus	Marine Accident Investigation Committee Cyprus (MAIC)
Portugal	European Maritime Safety Agency (EMSA)
United Nations	International Search and Rescue Advisory Group
Australia	Australian Transport Safety Bureau (ATSB)
Bahamas	Bahamas Maritime Authority (BMA)
USA, Canada, Sweden, Netherlands	International Transportation Safety Association (ITSA)
UK	Lloyd's Register Marine and Shipping
USA	American Bureau of Shipping (ASB)
United Kingdom	Isle of Man Ship Registry (IOMSR)
New Zealand	Transport Accident Investigation Commission (TAIC)
Turkey	KAIK Accident Investigation Board (KAIK)
USA	Countryman & McDaniel (C&M)
France	French marine casualties investigation board
United Kingdom	Confidential Hazardous Incident Reporting Programme (CHIRP)
Denmark	Danish Maritime Accident Investigation Board (DMAIB)
Netherlands	Dutch Safety Board (DSB)
Canada	Transportation Safety Board of Canada (TSB)
SIPRI	Vessel and Maritime Incident Database
United Kingdom	Global Integrated Shipping Information System (GISIS)
Germany	Federal Bureau of Maritime Casualty Investigation (BSU)
Japan	Japan Transport Safety Board (JTSB)
USA	United States National Transportation Safety Board (NTSB)
Philippines	Philippine Coast Guard (PCG)
Sweden	Swedish Transport Agency (STA)
China	Maritime Safety Administration of the People's Republic of China (MSA)
Finland	Safety Investigation Authority (SIA)
Antique and	Department of Marine Services and Merchant Shipping

Barbuda	(ADOMS)
United Kingdom	Marine Accident Investigators' International Forum (MAIF)
China	Marine Department-Hong Kong (MARDEP)
Panama	Marine Accident Investigation Department (DIAM)
China	Fujian Maritime Safety Administration
United Kingdom	The Nautical Institute (MARS)
Latvia	Transport Accident and Incident Investigation Bureau (TAIIB)
USA	United States Coast Guard (Homeport) (USCG)
European Commission	SAFEDOR
Sweden	Swedish Accident Investigation Board (SHK)
European Commission	CONTIOPT (2011–2013)
Indonesia	National Transportation Safety Committee (NTSC)

2.6. Research Question

It is an established argument that the principal component of maximum maritime accidents is attributed to human factors. Studies show that an accident causation chain of around 80% operational maritime accidents either initiated or have a contributory effect from human action [9] [56]. As the root cause of maritime accidents is human factors. In this study, we are going to extract the results regarding those human factors. In maritime operational activities having human involvement, which Human factors contributes the maximum at any level of event chain which eventually becomes an accident. It can be validated either by the collection of segregated data in one whole and/or by analysis which signifies such factors. Hence, maritime accidents are the main problem and population while exploration and extraction of contributory factors becomes the outcome. The human errors are the indicators while intra- factors comparison are the supporting elements for this study. It becomes impossible for a human to survive at sea after the occurrence of an unfortunate accident. To control and reduce the existing risk to human life at sea, continuous improvements in the existing standards have been implements continuously. This will reduce the risk under the acceptable criteria [57].

CHAPTER 3: HUMAN FACTORS

The human factor is at the core of the rest of the factors that cause the accident [58] [59] [60]. The following Figure 8 is mentioning some key areas which have comprehensive human involvement [53].

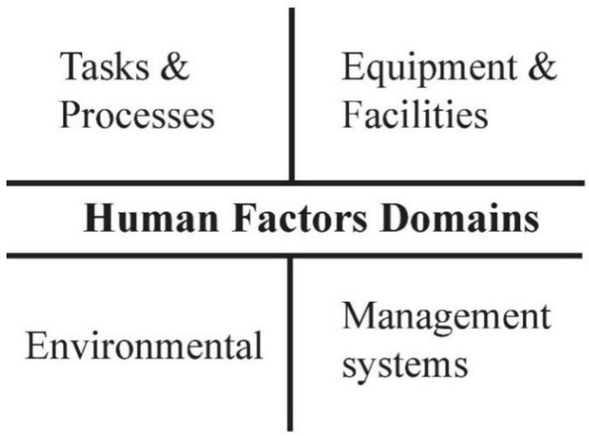

Figure 8: Human factor domains

El-laden maintained that Humans are logical actors and they are not bound to follow a preset process to do their behavioral activities and in maritime industry, the environment remains highly dynamic which requires the alterations in the set procedures to achieve a consistent output and system functionality which make the maritime operations vulnerable to an accident due to human factors more than any other industry. The human involvement in incidents in Nuclear is 65%, Aviation 60–87%, while in Chemical is up to 80–90% [61] [62] [63].

Human involvement in any maritime operation is vital, especially in navigational activities. The following Figure 9 shows the officer on watch (OOW) duties which comprise several human-technology interactions during any normal routine [64] [65] [66] [67].

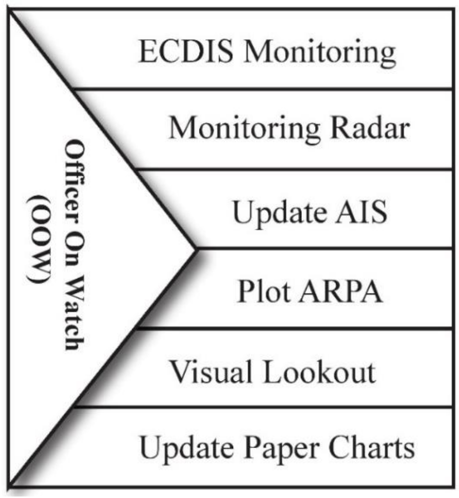

Figure 9: Various duties of OOW

High involvement of humans in maritime operations makes this industry highly vulnerable as humans are prone to erroneous activities on continuous bases. Humanly errors are either dynamic or invisible in nature [68]. The visibility of active error is immediate while latent errors may felt when they complemented with other factors. Corrective measure or error recovery process can be classified into identification, sign and finally redressing stages. The error can be traced back by identifying their consequential events [69]. Besides above mentioned models, several other methods were also proposed by renowned researchers that can be employed for identification of human factors which also suggests error rectification. O'Hare's Wheel of Misfortune, Moray's Socio-technical model, Wickens & Flach's Four-stage information processing model and Reason's Generic Error Modeling System (GEMS) among them [70].

A collision probability assessment approach has also been developed by Fujii and MacDuff [71]. The modified version of that approach proposed by Pedersen by suggesting following method which comprehensively assesses the potential collisions [72].

$$P = N_A . P_C$$

N_A is the number of candidates that may prone to the accident while P_C is the probability of causation.

3.1. Data collection and variables considered

In the recent past, many advancements have made for human error identification and various error classification methods have been developed [73]. Various methods including Reason's GEMS – Generic Error Modelling System, CREAM – Cognitive Reliability Error Analysis Method [74] [75], HEIST – Human Error Identification in Systems Tool [76], SHERPA – Systematic Human Error Reduction and Prediction Approach [77], and HFACS – Human Factors Analysis and Classification System [78] are available.

The number of human factors established in the literature and few of them also embedded in the existing accident causation models mentioned above to investigate their contribution but they having the investigating capabilities at very superficial levels which gives vague insight about the actual cause. In this study, the number of factors that causes human erroneous behavior is collected at a very basic level and listed as a sub-category of the broad factors [79] [80] [81] [82] [83] [84] [85] [86] [87] [88]. Few of them are reported in various studies root cause analysis of maritime accident [89], [90] [91] [92] [93] [94] [95] [96] [97] [98]. The comprehensive list of human factors is given as follow;

1. Human Characteristics
1.1 Competence
1.2 Slow Response pace
1.3 Deficient learning aptitude
1.4 Inattention
1.4.1 Nonchalance attitude toward work
1.4.2 Inadequate situational awareness
1.5 Uncommunicativeness
1.6 Perception ability
1.7 Complacency
1.8 Scared from risk
1.9 Inadequate working relationships
1.10 attentiveness
2. Improper and Insufficient Training/Skillset/etc.
2.1 Inadequate technical knowledge
2.2 Inadequate orientation of working environment
2.3 Inadequate practice
2.4 Lack of experience
2.5 Inadequate information of equipment/vessel's system
2.6 Inadequate update training
2.7 Inadequate initial training
2.8 Lack of team training (BRM/BTM)
2.9 Inefficient use of Information and Decision making
2.10 Inadequate knowledge of ship functionality
2.11 Insufficient information about regulations/standards
3. Safety related concerns
3.1 Absence of safety culture
3.2 Inadequate precautions taken
3.3 Perilous act
3.3.1 Unintended actions
3.3.1.1 Memory failures
3.3.1.2 Mistiming
3.3.1.3 Overlook

3.3.1.4 Miss-ordering
3.3.2 Intended actions
3.3.2.1 Improper attempt to avoid discomfort
3.3.2.2 Unnecessary time/effort saving attempts
3.3.2.3 Sabotage

4. Physical/physiological capacity
4.1 Alcohol/drug use
4.2 Sensory deficiencies
4.2.1 Other sensory disorder – touch/smell/taste/balance
4.2.2 Vision/hearing deficiency
4.3 Temporary/permanent disabilities
4.4 Sensitivity
4.4.1 Substance allergies
4.4.2 Acute sensitivities to minimal temperature, sound, etc.

5. Human Behaviour
5.1 Lack of self-discipline
5.2 Character
5.3 Culture

6. Psychological capacity
6.1 Emotional load
6.2 Panic
6.3 Mental/emotional illness
6.4 Frustration
6.5 Inappropriate aggression
6.6 Fears and phobias
6.7 Pre-occupation with problems
6.8 Time pressure
6.9 Misperception

7. Fatigue
7.1 Repetitive Routines, strict uneventful surveillance
7.2 Rest deficiency fatigue
7.3 Task or time duration overload fatigue
7.4 Extreme precision criteria
7.5 Fatigue due to high concentration/perception requirements
7.6 Fatigue due to sensory overload

8. Communication problems
8.1 Misunderstanding
8.2 Problem with communication equipment
8.3 SMCP not used
8.4 Inadequate communication
8.4.1 Poor communication between crew members
8.4.2 Poor communication between ships
8.4.3 Inadequate 3rd party communication by shipping company
8.4.4 Inadequate ship-shore communication
8.5 Language difficulties

9. Inadequate team culture
9.1 Inadequate leadership
9.1.1 Inadequate review of instruction
9.1.2 Unspecified or conflicting reporting channels
9.1.3 Inadequate workload allocation or program planning
9.1.4 Insufficient initial/starting instructions
9.1.5 Crew/Passenger discipline scarcity
9.1.6 Improper supervisory example
9.1.7 Lack of coaching
9.1.8 Inadequate supervisory and job management knowledge
9.1.9 Conflict or Non-conformity in responsibility assignment
9.1.10 Inefficient utilization of manpower
9.1.11 Improper or insufficient delegation
9.2 Lack of ownership
9.3 Absence of shared mental model
9.4 Equipment, people or system over-reliance
9.4.1 Over- reliance on supervisor
9.4.2 Over-reliance on system/equipment
9.5 Ineffective BRM

10. Inadequate manning
10.1 Inadequate manpower available
10.2 Inadequate manning level

11. Factors for lack of motivation
11.1 Hierarchical pressure

11.2 Improper performance is rewarded	measurement
11.3 Lack of incentives	11.6.1 Inefficient criteria for performance evaluation
11.4 Improper attempt to gain attention	11.6.2 Improper performance feedback
11.5 Proper performance is punished	11.7 Peer pressure among ship crew
11.6 Inadequate performance	

HFACS model incorporates the human factors to investigate the human erroneous acts but it also has a very narrow spectrum of act classes [99] [100]. Following is the list which sub-categorize the main factors to broaden the spectrum of such accident causation models [101] [102] [103] [104] [105] [106] [107] [108] [109] [110].

12. Unsafe acts
12.1 Errors
12.1.1. Skill-based errors
12.1.1.1. Visual Scanning Breakdown
12.1.1.2. Delay in Active Response
12.1.1.3. Attention priority failure
12.1.1.4. Inadvertent usage of control units
12.1.1.5. Substandard Techniques
12.1.1.6. Unintentional Operation(s)
12.1.1.7. Erroneous Checklist
12.1.1.8. Procedural mistakes
12.1.1.9. Under- & Over-control
12.1.2. Decision errors
12.1.2.1. False Risk Assessment
12.1.2.2. Inaccurate Task Prioritization
12.1.2.3. Necessary Action – Hasty Execution
12.1.2.4. Necessary Action – Delayed Execution
12.1.2.5. Deliberate ignorance of Caution and Warning
12.1.2.6. Improper startup
12.1.2.7. Improper shutdown
12.1.2.8. Improper Procedure
12.1.2.9. Misdiagnosed Emergency
12.1.2.10. Delayed Emergency Response
12.1.2.11. Exceeded Ability
12.1.2.12. Inappropriate action
12.1.2.13. Substandard Decision(s)
12.1.3. Perceptual errors
12.1.3.1. Misperception caused Errors
12.2 Violations
12.2.1. Routine Violation
12.2.1.1. Orders following failure
12.2.1.2. Rules/Regulations Violations
12.2.2. Exceptional Violations
12.2.2.1. under-qualification for Operation
12.2.2.2. Exceeding system limits intentionally
12.2.2.3. Violating implemented rules, policies and regulations

13. Preconditioned acts
13.1. Person related conditions
13.1.1. Cognitive factors
13.1.1.1. Excessive load of Information
13.1.1.2. Lack of attention
13.1.1.3. Narrow spectrum of attention
13.1.1.4. Cognition saturation
13.1.1.5. Confusion / Discombobulation
13.1.1.6. Negativity
13.1.1.7. Distraction
13.1.1.8. Checklist collision
13.1.1.9. Hasty tasks
13.1.1.10. Personal Stress
13.1.1.11. Situational Awareness related inability
13.1.1.12. Operational overload
13.1.2. Psychology & other behavioral factors
13.1.2.1. General Attitude
13.1.2.2. Psychological issues
13.1.2.3. Personality Disorder

13.1.2.4. General Psychosocial Problem
13.1.2.5. Emotional State
13.1.2.6. Personality Style
13.1.2.7. Overconfidence
13.1.2.8. Pressing
13.1.2.9. Complacency
13.1.2.10. Inadequate Motivation
13.1.2.11. Misplaced Motivation
13.1.2.12. Get-Home-Itis/Get-There-Itis
13.1.2.13. Response Set
13.1.2.14. Emotional Fatigue
13.1.3. Antagonistic physiological conditions
13.1.3.1. Impaired Physiological State
13.1.3.2. Recommended Drug Prescriptions
13.1.3.3. Operational sickness
13.1.3.4. Sudden Incapacitation
13.1.3.5. Former Physical deficit
13.1.3.6. Physical Fatigue
13.1.3.7. Fatigue - Physiological/Mental
13.1.3.8. Circadian Rhythm De-synchrony
13.1.3.9. Motion Sickness
13.1.3.10. Visual Adaptation
13.1.3.11. Physical duty over-scrupulous
13.1.4. Mental/Physical obstructions
13.1.4.1. Learning Ability/Rate
13.1.4.2. Memory Ability/Lapses
13.1.4.3. Anthropometric obstructions
13.1.4.4. Timing or strategy glitch
13.1.4.5. Technical/Procedural Knowledge
13.1.4.6. Insufficient Reaction Time
13.1.4.7. Personal work willingness
13.1.5. Intuitive factors
13.1.5.1. Operational states misinterpretation
13.1.5.2. Misinterpreted/Misread Instrument
13.1.5.3. Expectancy
13.1.5.4. Acoustics signals
13.1.5.5. Temporal deformity
13.2. Operators factors
13.2.1. Strategy and interpersonal communication elements
13.2.1.1. Team leading

13.2.1.2. Cross-monitoring activity
13.2.1.3. Task Delegation
13.2.1.4. Position Authority Gradient
13.2.1.5. Assertiveness
13.2.1.6. Critical information guidance
13.2.1.7. Generalize Nomenclature
13.2.1.8. Challenge and Reply
13.2.1.9. Operations Planning
13.2.1.10. Operations Briefing
13.2.1.11. Re-Planning of active tasks
13.2.1.12. Inadequate communication
13.2.2. Enforced stress
13.2.2.1. Physical strength
13.2.2.2. Alcoholic items consumption
13.2.2.3. Self-Medication/Sedate/Tonic
13.2.2.4. Diet or Nutrition
13.2.2.5. Improper Rest
13.2.2.6. Insufficient training
13.2.2.7. Undisclosed Disqualifying Medical states
13.2.2.8. undertreated medical complexities
13.3. Environmental factors/elements
13.3.1. Active/Physical environment
13.3.1.1. Interrupted Vision by fogged-up Panes/Etc.
13.3.1.2. Vibration
13.3.1.3. Vision limitations by Workspace environmental elements Dust/Smoke/etc.
13.3.1.4. Stress by Thermal condition – Cold/Heat
13.3.1.5. Fatigue by Thermal condition – Cold/Heat
13.3.1.6. Noise Interference
13.3.1.7. Lighting
13.3.1.8. Slippery
13.3.2. Technological
13.3.2.1. Sitting conditions – Furniture
13.3.2.2. Functionality of Feedback Systems
13.3.2.3. Controls and Switches
13.3.2.4. Automation
13.3.2.5. Human Incompatible workspace
13.3.2.6. Personnel Equipment interruptions
13.3.2.7. Communications – Equipment
13.3.2.8. Data Display System condition

14. Malicious supervision
14.1. Inappropriate and improper supervision
14.1.1. Inefficient Leadership/Oversight
14.1.2. Essential documentation and information provision failure
14.1.3. Supervision – Unsuitable/Irrelevant Role model
14.1.4. Domestic Training authenticity problems
14.1.5. Administration - Policy
14.1.6. Administrative Personality Conflict
14.1.7. Administrative Feedback failure
14.2. Inefficient operational plans
14.2.1. Beyond capacity task execution orders
14.2.2. Improper Crew formation
14.2.3. Incomplete task-related experience
14.2.4. Improper overall required experience
14.2.5. Competence
14.2.6. Formal Risk Evaluation
14.2.7. Authorization of Unnecessary hazardous environment
14.2.8. Providing inaccurate data
14.2.9. Insufficient preparations Time
14.2.10. Regulation defying Operation
14.2.11. Improper rest slot for crew
14.3. Visible malfunction correction failure
14.3.1. Staff Management
14.3.2. Process Management
14.3.3. Document error correction failure
14.4. Supervisory Breaches/Violations
14.4.1. Enforce Discipline
14.4.2. De facto Implemented Policies
14.4.3. Guided Violation

15. Organizational influences
15.1. Resources management
15.1.1. Operator Recreational activities
15.1.2. Attrition approaches
15.1.3. Management for Accession or Selection
15.1.4. Knowledgebase Support
15.1.5. Human Resources provision
15.1.5.1. Selection
15.1.5.2. Staffing/Manning
15.1.5.3. Training
15.1.6. Available Monetary Resources
15.1.6.1. Excessive cost-cutting
15.1.6.2. Funds scarcity
15.1.7. Facility and equipment availability
15.1.7.1. Poor design
15.1.7.2. Improper equipment procurement
15.1.7.3. Inadequate equipment
15.1.7.4. Defective procedure/system design
15.2. Organizational climate
15.2.1. Understanding/Awareness of Equipment
15.2.2. Task-oriented Equipment Deactivation
15.2.3. Approachability and availability of supervisor
15.2.4. Infrastructure
15.2.4.1. Chain-of-command
15.2.4.2. Delegation of authority
15.2.4.3. Formal communication
15.2.4.4. Adequate accountability and security for actions
15.2.5. Guidelines/Policies
15.2.5.1. Hiring and firing
15.2.5.2. Evaluation based Upgradation/Promotions
15.2.5.3. Sedate and alcohol consumption
15.2.6. Personal Cultural values
15.2.6.1. Norms and rules
15.2.6.2. Values and beliefs
15.2.6.3. Organizational justice
15.2.6.4. Cultural difference
15.2.6.5. Covetousness
15.2.6.6. Linguistic differences
15.3. De facto organizational procedures
15.3.1. Mandatory Organizational Training compulsion
15.3.1.1. Unavailability of compulsory

training	15.3.3. Operating Procedures
15.3.1.2. Inefficiency of suggested training	15.3.3.1. Poor operational processes
15.3.2. Organizational Routine Operations	15.3.3.2. Imposed standards
15.3.2.1. Excessive Workload	15.3.3.3. Strict objective following
15.3.2.2. Operation pace in Organization	15.3.3.4. Excessive Documentation
15.3.2.3. Time pressure	15.3.3.5. Unnecessary Instructions
15.3.2.4. Production quotas	15.3.3.6. Organizational Red-tape
15.3.2.5. Incentives	15.3.4. Oversight
15.3.2.6. Measurement/Appraisal	15.3.4.1. Doctrine following
15.3.2.7. Schedules	15.3.4.2. Excessive safety Programs
15.3.2.8. Inefficient operational planning	15.3.4.3. Risk Management

3.2. Development of candidate variables

In this study, human factors that have contribution in accident are the main variables. Statistical data of maritime accidents and their contributing factors specifically human-related factors for Meta-analysis and other statistical procedures have been collected and entered into the successive cells of the excel spreadsheet. Data against the above mentioned human contributing factors collected from various studies and reported in an additive manner. Factors either directly related to human job related are listed to the very precise level i.e. main classes then their subclasses are also mentioned. The data available in the literature is against the main class not up to their respective subclasses [71]. Any candidate variable to be included in the analysis was initially selected on the following grounds.

- The variable must have a theoretical as well as logical sense that it belongs to the human, i.e. there must exists sound reason to believe that the variable is a human trait and commonly involve in the operational tasks.
- Together with the other variables, it must have the capability to efficiently influence a range of possible tasks.
- The information about the variable must be available in most of the accident evaluation studies from which effects were derived (because to be included in Meta-analysis, different studies should have the same variables under observation for the same environmental situation).

3.3. Special concerns

3.3.1. Publication bias

The publication bias can explained as "a tendency not to publish a study if its findings are not statistically significant or are regarded as unwanted or difficult to explain" [111]. A Meta-analysis takes the results of the different studies which already been conducted in the same or related environment addressing the same question under observation [112]. In this study, for Meta-analysis, the capture-recapture method for population estimation is used in a novel way to collect the effect and utilize it in the analysis. A Meta-analysis combines the result from different studies and outputs a unique result while taking the effective input from each study even small enough to disregard. Hence, there is no such issue of publication bias.

3.3.2. Measuring and accounting for heterogeneity

Meta-analysis is incorporated with either fixed effect or random effect model, both treated the heterogeneity in different manner. The fixed-effect model developed on the underlying assumption of no trace of variation. On the contrary, the random effect model explains the inherent variations in the data under observation [113]. To test the heterogeneity component in the collected samples, the Higgin's I^2 test, and heterogeneity variance τ^2 has also been performed.

3.3.3. Dependency among individual effects

The data for Meta-analysis taken from the published articles and reports which either collect the data from direct investigations of the accidents or they precisely mentioned the source from which they gathered the data. Hence, all the data considered as taken from independent sources. However, few accident figures may have overlapped but they hold no significance to violate the estimator's assumptions as it already incorporates the tools to handle the data commonality.

CHAPTER 4: METHODOLOGY

4.1. Accident Statistics

Before the collection of numerical data for the factors which become the actual cause of the maritime accident, data of the true population is presented in the following table, out of which, ships prone to accidents and the analysis of these accidents will provide the required data of human factors [114]. Operational fleet numbers of Cellular Containerships and Large Crude Oil Tankers were collected from CONTIOPT (2011–2013) and SAFEDOR (2005–2009) projects while rest of the data of annual operational fleet has collected from Lloyd's Register of Shipping database [115] [116] [117]. Table 4 shows the total number of different types of ships from the year 2000 to 2012 roaming at waters [118].

Table 4: Total number of ships at risk from 2000 to 2012

Year	Ship Types									
	Bulk Carrier	**Car Carrier**	**Reefer Ship**	**Fishing Ship**	**General Cargo**	**LNG Ship**	**LPG Ship**	**Ro Ro Cargo**	**Large Tanker**	**Container Ship**
2000	3122	303	785	5337	7375	67	574	330	1554	2036
2001	3292	342	806	5629	7615	81	606	355	1538	2207
2002	3586	360	819	5977	7802	82	637	367	1567	2411
2003	3796	376	823	6233	8004	92	661	383	1636	2601
2004	3955	395	826	6408	8225	107	692	398	1663	2778
2005	4206	419	830	6554	8527	128	712	413	1756	3009
2006	4513	454	832	6684	8876	148	725	421	1855	3337
2007	4817	496	835	6770	9231	174	765	438	1977	3730
2008	5117	547	842	6824	9658	205	826	451	2114	4169
2009	5778	615	849	6907	10127	257	908	461	2258	4447
2010	6888	677	855	6972	10568	298	970	480	2373	4628
2011	8836	743	861	7054	10988	324	1031	499	0	4809
2012	9919	801	854	7113	11329	240	1086	512	0	4932
Total	67822	6528	10817	84462	118325	2303	10193	5508	20291	45099

The following graph in Figure 10 shows the number of maritime accidents in the last decade of twentieth century in Canadian waters. The given data was collected by the Transportation Safety Board of Canada [119] [102] [120].

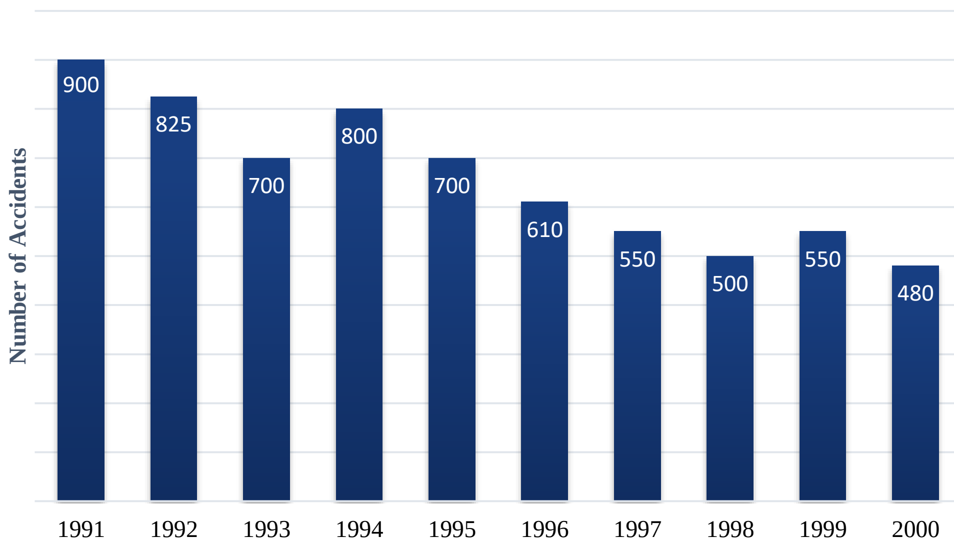

Figure 10: Ship accidents during 1991 - 2000 (TSB Canada, 2001)

The data of accident numbers belong to four broad human related categories is given in following Table 5 which happened due to the respective human erroneous act [114] [121].

Table 5: Accident data of four broad error categories

Error code	Error type	Collision	Grounding	n
1.1	Decision Error	95	102	197
1.2	Skill-based Error	89	61	150
1.3	Perception Error	53	114	167
1.4	Violations	56	106	162

The data presented in Table 6 is the number of accidents in the Shenzhen waters from 2003 to 2012. The main cause of these accidents is human factors which are also mentioned [122] [123] [124].

Table 6: Accidents in the Shenzhen waters from 2003 to 2012

Accident cause	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Negligence in watch keeping	6	5	4	3	2	2	1	4	4	2
Wrong assessment of situation	11	5	2	2	4	3	2	3	2	3
Improper emergency operation	21	4	3	4	4	4	1	2	3	2
Improper steering operation	8	5	1	1	3	2	1	1	0	0
Improper lookout	16	9	5	3	6	5	0	3	5	4

Uncoordinated avoiding operation	10	5	3	1	3	4	1	2	3	2
Improper avoiding operation	12	4	3	0	4	1	1	1	3	2
Unused safety speed	10	3	4	2	4	2	1	2	2	3

The same type of statistics given by other maritime agencies as well but due to the limited resources available with these agencies, very few of those accidents was thoroughly investigated. Hence, the actual cause of the accidents remained to unearth [125] [126]. As underneath cause never explored, data regarding human factors is available on a very limited scale as given in Table 7 [79] [101] [127] [128] [10] [82] [129] [130] [131].

Table 7: Data of four types of accidents due to human errors

Human Errors	Contact	Grounding	Sinking	Collision
Negligence	51	24	6	44
Judgement	21	62	11	320
Navigation error	51	31	45	15
Error in evaluation of speed	37	29	27	23
Improper use of machinery	49	31	19	41
Violation of procedures	27	42	78	13
Judgement & Negligence	24	41	23	300

The accidents data in Table 8 is taken from Fujian Maritime Safety Administration which caused by various human errors [132]. The collection of this data is further segregated into various environmental characteristics for more refinement of human errors [132] [133] [134] [135] [136] [137].

Table 8: Number of accidents according to characteristics from 2000 to 2014

Attributes	Observations	Negligence	Judgment	Judgment & Negligence
Season	Spring Season	34	156	122
	Other Seasons	60	383	246
Visibility	Poor Visibility	30	123	109
	Good Visibility	64	416	259
Wind	Normal Wind	71	424	306
	Strong Wind	23	115	62
Time	Day Time	38	274	179
	Night Time	56	265	189
Accident Type	Sinking	2	39	6
	Contact	11	71	24

	Grounding	24	62	31
	Collision	44	320	300
	F&E	1	23	0
	Others	12	24	7
Location	Near Port Area	59	343	192
	Far from Port	35	196	176
Navigation	Moored & Docked	16	123	41
	Underway	78	416	327
Ship Types	Container Ship	75	460	312
	Fishing Boats	11	50	115
	LNG/LPG/Oil Tanker	4	37	39
	Other Ships	21	87	61
Total		769	4407	3103

The data collected from the studies under evaluation is characterized against the human factors which are the main variables in this study. The intended variables are taken from the above-mentioned list. As data against such variables is available on a very limited scale, initially collected from each class but for the final evaluation, some of the variables were collapsed e.g. data is also collected against the main classes but for analysis, reinstate the data of sub-classes and their parent class didn't consider. Data presented in the tables are also representing the sub-classes.

Numbers of human factor which became the main cause of accidents extracted while analyzing the collision and grounding accidents and such statistics shows **Figure 11** and **Figure 12** respectively [12] [138] [102] [139] [140] [24] [141] [142] [143] [144] [145] [146].

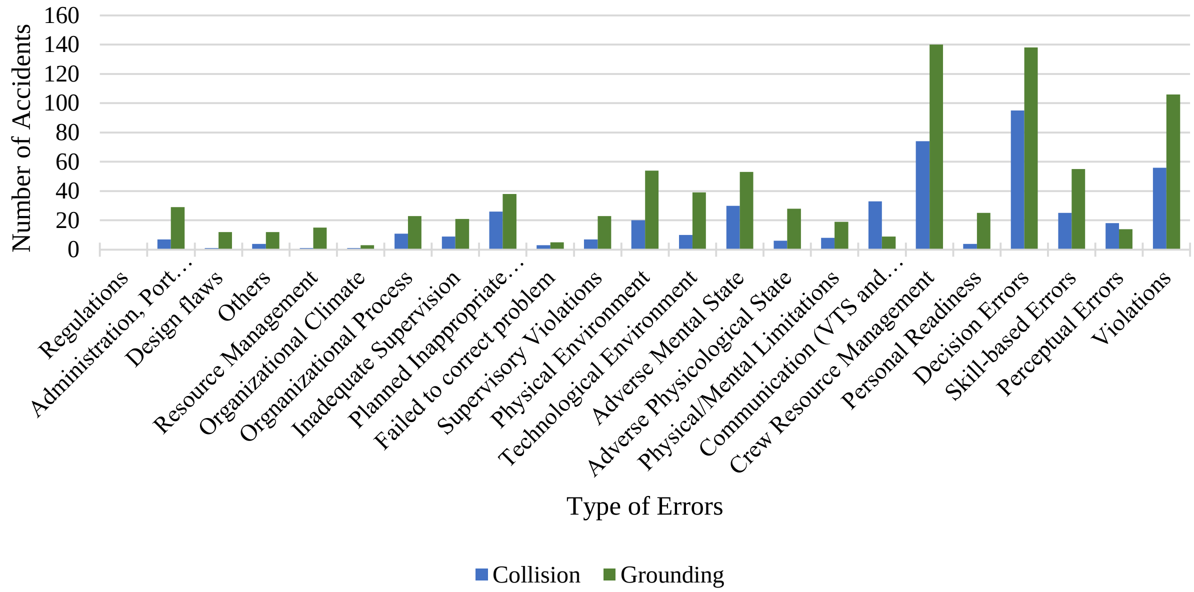

Figure 11: Types of human errors in Collision and Grounding accidents

The statistics of Greek maritime accidents classified per accident outcome mentioned above are shown below;

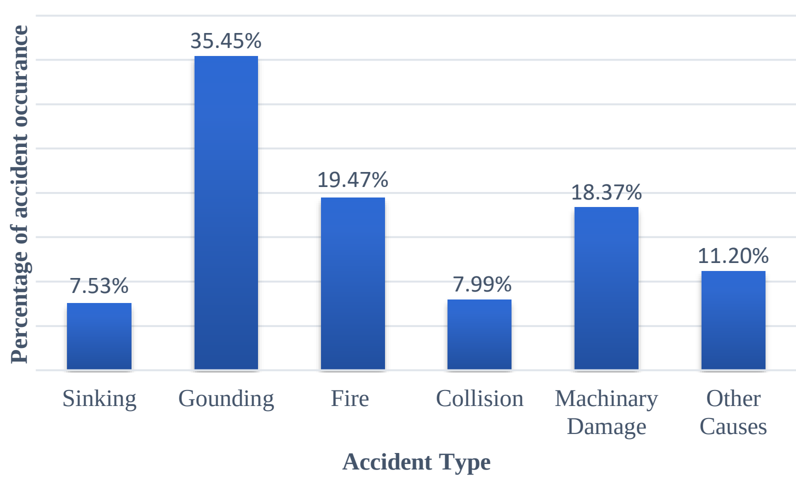

Figure 12: Greek maritime accidents classified per accident outcome

4.2. Statistical Method

Toffoli et al. [147] ascertained that the Lloyds world casualty statistics possesses the largest data of accidents of the following categories. We use these data of accidents for the statistical analysis;

- Collision
- Fire & Explosion
- Grounding
- Contact
- Wrecked/stranded

In terms of human factors, not all the extracted factors considered in the analysis as the data against these factors never been extracted during the analysis. The factors considered in the analysis falls in the following categories as according to the anthropotechnical systems, there exist three broad classes of human factors [83] [58].

- Individual factors
- Group factors
- Supervision and crew factors

The observation of the IMO which was based on the collected data also played its role in the selection of the factors as a variable in this study [148] [149]. The agency has observed human factor as the reason for 80% of all maritime accidents [150] mostly concentrated on two areas, ~30% of marine accidents due to the Negligence while ~20% of marine accidents due to not having adequate knowledge and practice.

Furthermore, the maritime accident investigation field has its embedded limitations [151]. The number of extracted human factors in this study which can be considered as the variable for the analysis are large in numbers but in comparison, the quantity of investigation reports is low and data against the variables is available in the same proportion [152] [153]. Also, investigating the influence and mental state of the shipmaster and other operators, exploring their personality characteristics, attitude towards the risk and error-prone situation, and finally, their decision making during the specific situation is very tough and difficult to achieve the task. These are also the reasons behind the specific data scarcity. To identify the significance of the extracted contributing human factors in the overall result, the statistical dependencies of the data sources of these factors were exploited and used them for estimation from the true representation of data [154].

At present, world maritime regulatory authorities developed the maritime regulations in the reaction of some disastrous event which has obvious embedded limitations for adoption at generalizing scale. To counter this ad-hocism, Formal Safety Assessment (FSA) system has been introduced. FSA requires the analysis of accident data to provide the potential input for the regulation proposal as it considers the many factors including hardware, overall ship conditions, human operator activities and organisational level management [155] [156] [157]. In the maritime industry, under-reporting is a serious problem for regulatory authorities who try to develop standards for maritime safety as well as for risk management companies and other such entities who have to rely on the casualty statistics [158], [159]. To counter this data scarcity problem, one solution is to estimate the data from the true sample of the population. Keeping in view the above mentioned serious issue of underreporting of the maritime accident, a novel approach rooted in a well-established capture-recapture method has been adopted [160] [161] [162] [163].

The capture-recapture method of estimation finds its root in the field of epidemiology and for animal population size estimation. This methodology has also found its application in the true number of accidents estimation from the two (even more than that) sources [164] [165] [166]. Similarly, in this study, such methodologies have been implemented to estimate the near actual number of human errors that contribute to maritime accidents but due to the underreporting, they never been surfaced [167]. For the correct use of these methods, four assumptions should be fulfilled [168]: (a) independent data source; (b) closed population; (c) data sources record-matching; and (d) capture homogeneity. As the data attributed to the human factors having involvement in the accidents is available on limited scale, miss-out the data may cause further havoc. Vector Space Model (VSM) provides the remedy of this problem as it helps to extract the matrix of numbers when applied to the text document [169]. The population estimation capture-recapture method from two sources employs several approaches to estimate the quantity which may represent the true population size. There exists several alternative approaches which are commonly used at present [9]. One of them is Lincoln–Petersen estimation which has many similarities with the Bayesian conditional probability approach [165] [170]. The Lincoln–Petersen estimation model stated as follow:

$$N = \frac{a_n b_n}{c_n}, \qquad (1)$$

where a_n is the data from the first source, b_n is the data from another source and c_n is the existed common data in both sources. However, if there exist zero-matchings then this model may fail. The appropriate alternative of this model is Chapman estimator given as

$$N = \frac{(a_n + 1)(b_n + 1)}{c_n + 1} - 1 \,. \qquad (2)$$

While the confidence interval for this model can be found as

$$95\% CI = N \pm 1.96\sqrt{\text{var}(N)} \qquad (3)$$

The Chapman estimator has widespread application in various fields but similar to the Lincoln-Petersen model, it also has the vulnerability of data source dependency [158]. There exists another estimator known as Chao's lower bound estimate [171] that employs the capture-recapture method. It is given as

$$x = \frac{(a_n + b_n)^2}{4c_n} \,. \qquad (4)$$

While population size can be found by

$$N = a_n + b_n + C_n + x \qquad (5)$$

The procedure for the confidence interval is the same as for Chapman's.

The results yielded by the Chapman or Lincoln–Petersen estimators are similar to those by conditional probability. They give positive dependence between all sources of data and estimated true numbers as well as the lower bound of accidents. These three converging approaches normally yield appropriate accuracy but Chao's lower limit estimation proves to be better estimator than Chapman's. Even though Chapman's variance relatively lower but Chao's estimator normally has a lower relative bias. Besides that, when there exists a doubt about the independence of sources, Chao's estimator has much better coverage of confidence interval than Chapman's and others [165].

4.3. Meta-analysis

The meta-analysis is a set of statistical methods employed to find the conclusive result by either combining or contrasting various studies investigating the same subject matter with different perspective [172]. This process is a continuation of the previous research and the statistical literature review for obtaining the effect magnitude. Meta-analysis processes the magnitudes of an effect extracted from various studies to produce their weighted mean [173]. The statistical significance of studies varies among them in accordance with their underlying finding having similar or combined research question and any study with higher magnitude hold maximum significance. Besides other important statistics, meta-analysis provides overall mean effect of combined studies [174]. Advance analyses have many improvements as to exclude outlier studies, traditional meta-analyses were unrealistically based on various heterogeneity tests. Either fixed-effect or random-effect model, meta-analysis estimates the heterogeneity and provide explanation of subject's characteristics on the taken effect and allows estimation of the effect extracted from studies [[175] [176]. The results are also available in graphical form [177].

CHAPTER 5: STATISTICAL ANALYSIS

5.1. Statistical Results

Statistically, meta-analysis combines the results of different studies which have been conducted on the same subject area. In this study, the capture-recapture method is employed in a novel way by considering human factors as variables which have been obtained from the thoroughly analyzed maritime accident studies. These accidents data sources are considered for the extraction of factors [165]. Performing the capture-recapture method yields statistics $\{(N_1,\sigma_1),.....,(N_4,\sigma_4)\}$ where N is the estimated population size and σ is the associated standard error respectively for each type of human factor. By using Chapman estimator, the estimated population size is given as

$$\hat{N} = \frac{(Source_1+1)(Source_2+1)}{(Common+1)} - 1 \quad . \tag{6}$$

While the associated estimated variance is given as

$$\hat{V}_{ar} = \frac{(Source_1+1)(Source_2+1)(Source_1-Common)(Source_2-Common)}{(Common+1)^2(Common+2)} \quad . \tag{7}$$

For validity, it is important to note that the employed Chapman estimator holds all four associated assumptions for effectiveness [178]. In this study, we employed the meta-analysis in its typical set-up: the measured effect estimates i.e. $\theta_1,....,\theta_4$ collected from different studies against the two types of accidents are given in Table 5. Figure 13 is the graphical representation of these four categories of human errors. $\sigma_1,....,\sigma_4$ are the associated variances.

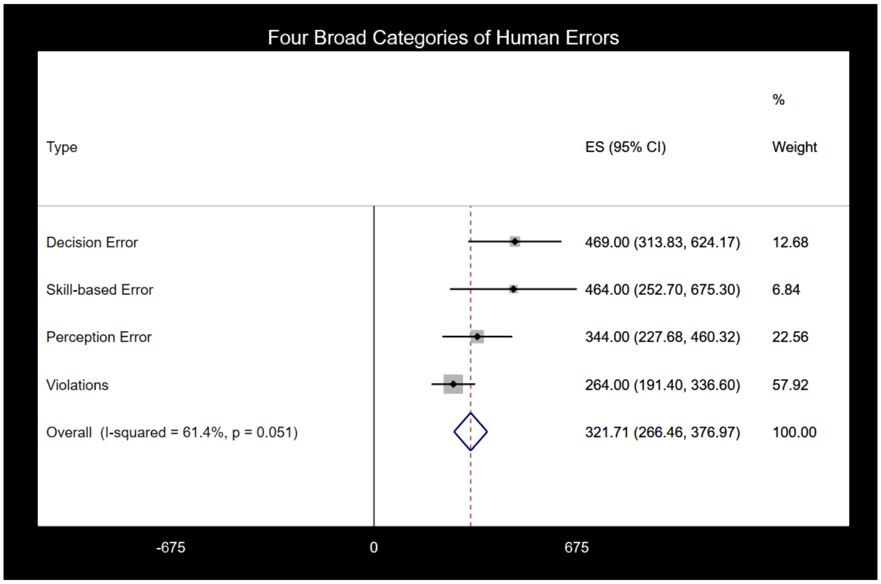

Figure 13: Forest plot of four broad categories of errors

In this typical setting, θ_i is considered as same as population size and $\hat{\sigma}_i$ is the same as variance which is calculated from the above-given equation that is associated with the population calculated with the Chapman estimator. An assumption is associated with this consideration is that the quantity is non-random, known and without any uncertainty [178].

Generally, random effect model is given as $\hat{\theta} = \theta + \delta_i + \varepsilon_i$, where $\delta_i \in N(0, \tau^2)$ is the normal random effect while $\varepsilon_i \in N(0, \sigma^2)$ is the normal random error and $\tau^2 > 0$. Also, let $w_i = \frac{1}{\sigma^2}$ and $W_i = \frac{1}{(\sigma^2 + \tau^2)}$ where σ^2 is the intra-studies variation while τ^2 is the inter-studies variations. Now, the heterogeneity statistics is given as

$$Q = \sum_{i=1}^{M} w_i (\hat{\theta}_i - \bar{\theta})^2 , \quad (8)$$

where $\hat{\theta}_i$ is the value estimated by random effect model while $\bar{\theta}$ is the mean estimated by fixed-effect model for meta-analysis and is given as

$$\bar{\theta} = \frac{\sum_{i=1}^{M} w_i \hat{\theta}_i}{\sum_{i=1}^{M} w_i}. \quad (9)$$

The heterogeneity statistics Q is employed to find $\hat{\tau}^2$ which is the base of the DerSimonian-Laird (DL) estimator. The expression for $\hat{\tau}^2$ is given as

$$\hat{\tau}^2 = \frac{Q - (M-1)}{(\sum_{i=1}^{M} w_i - \sum_{i=1}^{M} w_i^2) / [\sum_{i=1}^{M} w_i]}. \quad (10)$$

The DL estimator, $\hat{\theta}_{DL}$, is given by

$$\hat{\theta}_{DL} = \frac{\sum_{i=1}^{M} \hat{W}_i \hat{\theta}_i}{\sum_{i=1}^{M} \hat{W}_i}. \quad (11)$$

The variance associated with $\hat{\theta}_{DL}$ is $\sigma^2 = \frac{1}{\sum_{i=1}^{M} \hat{W}_i}$. Similarly, another magnitude of heterogeneity estimate i.e. Higgin's I^2 is given as

$$I^2 = \frac{Q - (M-1)}{Q}. \quad (12)$$

The value of I^2 is generally expressed as a percentage. I^2 can also be found as $I^2 = \frac{\hat{\tau}^2}{s^2 + \hat{\tau}^2}$, where s^2 is the variance average associated with the respective studies and is given as

$$s^2 = (M-1) \frac{\sum_{i=1}^{M} w_i}{[(\sum_{i=1}^{M} w_i)^2 - (\sum_{i=1}^{M} w_i^{\,2})]}. \quad (13)$$

I^2 is interpreted as the proportion of the total variance due to associated heterogeneity where $\sigma_i + \tau_i$ is the total variance [179]. The chi-square test for the above heterogeneity is 7.77 with p-value 0.051. The diamond shows overall mean estimate of studies i.e. 321.71 while the overall 95% confidence interval is 266.46 and 376.97. For each of the studies, the horizontal strands emanating from square show 95% confidence intervals. The smaller confidence interval containing the mean value exhibits more precision. The vertical dotted line shows the reference mean whereas the horizontal distance between the dotted line and center of squares (of each study) shows loss, which can be given as $\sum_{i=1}^{N}(y_i - \hat{y}_i)$, for each of the studies.

Generally, the estimated variance is considered as a known and a non-random quantity. Any consideration of the population for meta-analysis should restrict to the specific category as it combines the results of the same category from different studies. For the execution of analysis, we use a package of statistical software STATA15 named METAN [180] (Sterne). METAN command requires the estimated population size and the associated estimated standard error. METAN package has several flexible options that include the fixed and random-effects model. It also comprises sub-group analysis features and depicts the results as a forest plot [182] [177]. For the evidence of heterogeneity, I^2 value is also calculated and the fixed effects and random effects mean population sizes are coincide so do their confidence intervals. I^2 value explains the heterogeneity substantially [183]. The values of these test parameters are given below.

Higgins estimate $I^2 = 61.4\%$, $\bar{\theta}$ = 91.18 with 95% CI (72.46-109.90) and $\hat{\theta}_{DL}$ = 385 with 95% CI (346.77-423.72).

In this study, we used a specific capture-recapture approach [184] and employ a specific estimator. In literature, there exists a variety of estimators for the population size estimation. Log-linear models with different interaction terms estimate the population size from more than two sources. The Figure 14 shows the forest plot of human errors in the grounding and contact accidents given in Table 7.

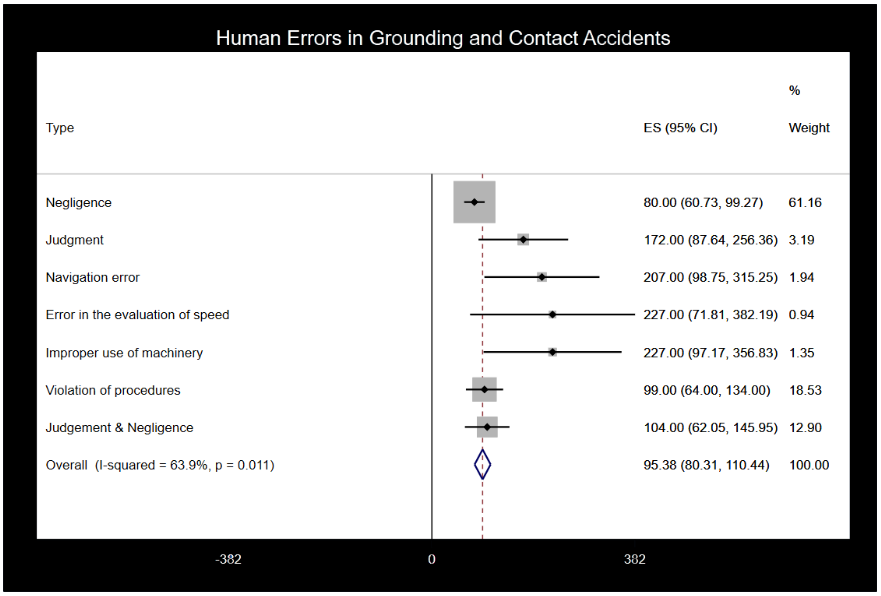

Figure 14: Forest plot of Human errors in Grounding and Contact accidents

The chi-square test for the above heterogeneity is 16.62 with p-value 0. The Higgins estimate $I^2 = 63.9\%$, $\bar{\theta}$ = 24.449 with 95% CI (14.75- 34.14) and $\hat{\theta}_{DL}$ = 172.667 with 95% CI (146.91-198.42).

Similarly, Figure 15 contains the forest plot of human errors in the sinking and collision accidents given in Table 7.

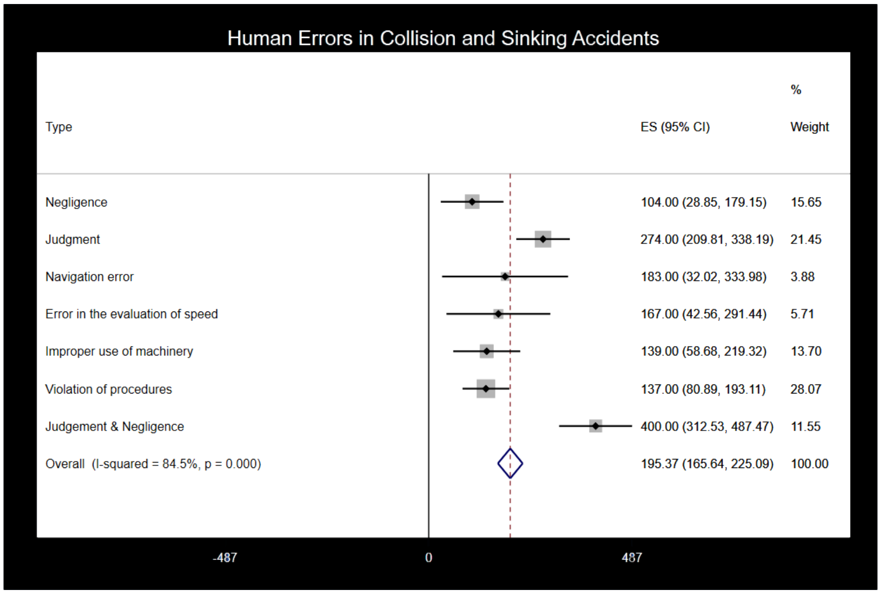

Figure 15: Forest plot of Human errors in Collision and Sinking accidents

The Higgins estimate $I^2 = 84.5\%$, $\bar{\theta}$ = 78.04 with 95% CI (60.72- 95.35) and $\hat{\theta}_{DL}$ = 216.66 with 95% CI (187.81- 245.51).

The data of various types of accidents collected from the databases of MIAB UK and Norway's AIBN are given in Table 9 and their forest plot is shown in Figure 16. Both of these maritime agencies operate in their respective territories so no commonality exists.

Table 9: Number of accidents available in two databases for certain time period

Accident Type	MIAB UK	AIBN	n
Collision	30	44	74
Contact	74	50	124
Damage	12	45	57
F&E	21	32	53
Grounding	15	101	116
Loss of Control	9	33	42
Flooding	1	0	1

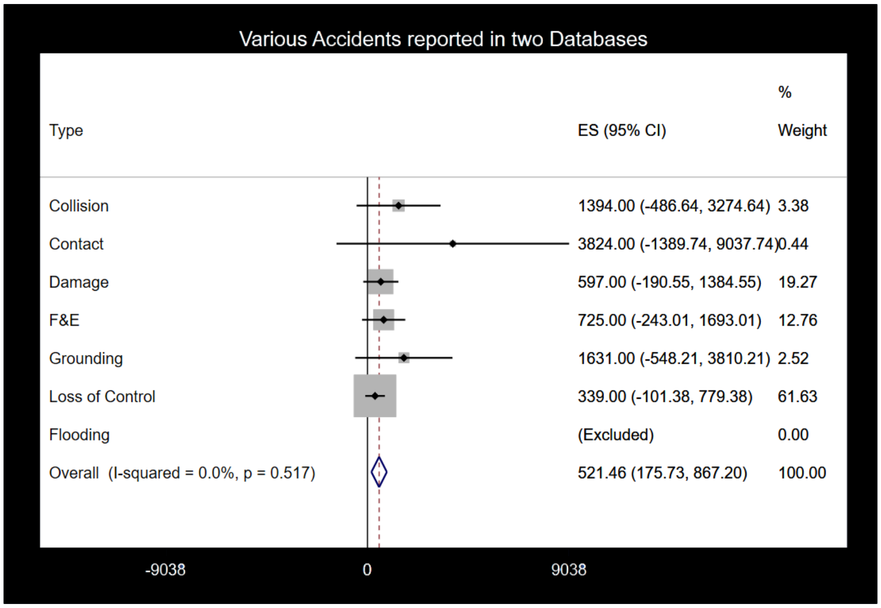

Figure 16: Forest plot of various accidents of two databases

The chi-square test for the above heterogeneity is 4.23 with p-value 0.517. The Higgins estimate $I^2 = 0.0\%$, $\bar{\theta}$ = 0.0042 with 95% CI (-0.12-0.13) and $\hat{\theta}_{DL}$ = 1186.16 with 95% CI (1118.66-1253.67).

5.2. Discussion

In this study, we aimed to explore and extensively report the collection of different human factors that contribute to the occurrence of maritime accidents. For the said purpose, literature has been thoroughly searched and such material has extracted which contain the analysis of maritime accidents that occurred due to human errors. A comprehensive list of human erroneous activities that are generally associated with the human operator at the workplace and become the cause of accidents was extracted. These factors categorize into main classes and then further into their sub-classes as well. Then, literature and reports have been screened to find data against these factors. After the collection of data, to present the combined mean effect of all the reported factors in the analysis, their meta-analysis was conducted. Keeping in view the issue of respective data scarcity, various population size estimators that are well-established in existing literature were explained and an estimator known as Chapman estimator implemented and trying to estimate the actual population from the sample of the true population. Extracted data from the literature considered as a sample of the true population as data is merely a fraction in comparison with actual quantity of underneath human factors in maritime accidents happened all over the world. Another explanation for the estimation of the population size is the already proven fact that 75-80% of the maritime accidents happened due to the human factor involvement or human errors exists in same numbers [185] [186]. This study focuses only on such an accident that has human involvement hence maximum studies employed the HFACS model for the analysis of accident causation as HFACS incorporates maximum human traits for accident analysis at a different level of accident causation chain. Even though, this study not specifically considered this model only but maximum data is available from this model [187] [46] [188].

KMST data shows that navigator's error responsible for the 79% accidents in South Korean waters, over the period of five years [189]. Another analysis of accidents in Baltic sea during the six year period from 2009 shows same trend [1]. An investigative study of human errors explores an interesting finding that other phenomenon occurrence reduces human errors [132]. A fishermen death investigation reveals negligence, judgement error, and unsafe act are the principal causes in vessel accidents [25]. Pourzanjani observed the lack of clear intentions, ineffective communication, negligence and inadequate judgement are main factors causing accident after analyze 59 accidents of same category [83]. An evaluation of causative elements in the cargo accidents, lack of knowledge, gross negligence and inadequate experience emerge as main factors [12]. A variant of basic model, HFACS-PV proves it worth in assessment of contact and collision accidents of passenger vessels [34]. The10 years data of accidents in Shenzhen waters shows human factors outnumbered other factors in term of influencing elements [122].

Besides the maritime industry, analysis of accidents from different sectors including process, Mining, Aviation, Rail, etc. has observed that skill-based errors which is the sub-class of not adequate knowledge and practice complimented with negligence, emerged as a single largest category [190] [191]. The nature of seafarers training is very much practical as they trained while on job [192]. Despite the highly skillful workforce available, skill-based error often tends to happen where skilled behavior is required. This can be characterized as a highly experienced and practiced behavior where the operator can only put a small conscious control on its behalf. This category of errors also includes technique errors, attention or memory failure and omissions [194]. To avoid such errors, Reason has suggested the placement of reminders at suitable locations. This will lead to a reduction of omissions [195]. Shappell stressed the error consequences absorbability of the system and deployment of warning systems which is the typical countermeasure to reduce such errors [196]. Michael et. el. suggested the mitigation techniques for the errors including skill-based, violations, perception and decision errors as they almost contribute equally to the combined results of the studies [197]. HFACS links the skill-based errors with adverse physiological states and violations with either adverse mental states, team resource management or with the physical environment. While organizational climate and resource management associated with inadequate supervision [198]. To counter skill-based errors, fatigue management and supervisor training for fatigue detection is proposed in literature. To guard against violations, in-depth analysis of violation data, evaluation of violation prone procedures and equipment has been proposed. Proper assessment and redesign of the existing supervisory systems will deter the problem of inadequate supervision. Communication clarity and persistent interaction between supervisors and subordinates are also required. For organizational climate and resource management, assessment and redevelopment of procedures and implemented systems and redesign of existing problem mitigation techniques are also proposed [199]. Human factors also the main contributor while measuring the safety performance of ships as they are the main contributor to accidents especially navigational accidents happens only due to the judgmental misunderstanding. Such factors can only be removed by the familiarization with the new technologies and also with crisis management [200]. Development of new models required rigorous struggle and enormous time for validation hence hybrid scheme by mixing the existing models to get maximum out of them [201] [202]. Poor decision making is the major human attribute which prove catastrophic in operative situation, so incorporation of effective decision support system (DSS) in humanly environment cause reduction of any such possibility [203]. The ER-based Cost-benefit assessment method allows field experts to use belief structures for subjectively aggregated judgement in linear as well as nonlinear manner [204]. To enhance the performance of fault tree and event tree analyses, a HBM-based framework for risk analysis has been proposed with flexible and universal applicability and such generalize frameworks leads toward the development of risk models with higher accuracy [205] [206].

Human interaction with any socio-technical system always problematic as highly complex systems required rigorous and Consistent training to operate. That's why it is evident that the main contention is human errors [207]. So, the fact is in place that majority of accidents occur due to the human factors but it is also evident that such erroneous behavior arises due to the complexity of installed technology, ergonomics, and organizational factors which are designed without considering the inherent limitations and abilities of human operator, thus, setting up a condition for failure [208]. Besides the extraction of human elements, the inherent limitation of systems casts serious problem as there exists a potential disconnect between the theoretical explanation & requirements and the results produced by the implementation of these techniques in practice [209]. Hence, the existence of the requirement of the more sophisticated techniques will be fulfilled by the combined execution of the different methods. Keeping in view the dynamic nature of the maritime environment, to maintain balance between efficiency and safety, operator's adaptation ability is the key factor [210]. Introduce autonomy in systems will also reduce a proportion of human element [211] [114].

5.2.1. Improvement of accident data collection

Even though, for this study, data were extracted from the articles which analyze the accidents and also from the accident reports developed by different maritime agencies, collecting data regarding human factors is still a challenge. A meta-analysis is not a common practice in the maritime field, data never been presented in any suitable form, hence, pre-processing is the main task. The problem of scarcity in availability of samples for the development of more advanced and sophisticated statistical models has been addressed. Another hurdle which also addresses by this study itself is the underreporting and incompleteness of the data [157].

5.2.2. Contributing factors for ship accident consequences

The proposed framework implement in this study can successfully suggest a reasonable number of contributing human factors to the accidents based on the well-defined capture-recapture method. Accident analysis based on RCA and HFACS can present the data in numerical form but data available in the accident reports is the explanation by the experts based on the available shreds of evidence to them [200]. With the improvement in data collection, it will become possible to develop more advanced statistical models which not only estimate the size of the true population but causality connections will also be establish between the causal factors and consequences of accident [157].

5.2.3. Threats to validity

Several factors are presented in this study for the validation of the study because there exist many aspects that can affect the validation. The prominent aspects are briefly discussed below.

5.2.3.1. External validity

In this study, those contributing human factors were analyzed data against them is available and to prevent the selection bias, robust criteria is also preselected. This aspect of confinement limits the validity of this study to only factors that were analyzed. As, this study includes various ship accidents and left all other maritime operations. In term of generalizability, the results can be extended to other marine installations because maritime covered all aspects of marine industry. In addition to that, many of the Nano-codes which are extracted from the maritime literature are also generally applicable [212] [99]. The reason of data not available against all Nano-codes is because they were never being analyzed during the investigation of the maritime accident investigation.

5.2.3.2. Internal validity

To concrete the internal validity, thoroughly examined framework by the field experts has been utilized as capture-recapture estimator has already authenticated and experts allowed its utilization in this field and also the estimator employed in this study has maximum usability, the assessed reports and analysis seems to be sufficient for the validation of this framework at this stage with the available data [213] [99]. Hence, the proposed framework for the meta-analysis is based on the existing literature.

5.2.3.3. Construct validity

This study has incorporated a statistical analysis and was constructed to explore the possibilities to check the mean contribution of the human factors in the overall analysis of all factors. All Nano-codes are extracted from different studies available in the literature. Few Nano-codes are related to the aviation and process industry as well and the adaption of a framework from one field to another is not a problem unless the underlying factors of observation remain the same [214]. All such factors which are related to the job were also removed, to ensure that only human-related factors remain in the study to analyze. This exercise is sufficient to make this framework efficiently exhaustive and generalize as Nano-codes data is sufficiently available for analysis [215].

CHAPTER 6: IoOT FRAMEWORK

6.1. Conception of system

Analysis shows that out of all factors and errors that committed by humans, negligence is the major constituent chunk of these factors. IMO also endorses the fact. Hence, we select this major portion for elimination and develop a system to mitigate these errors. Human behaviour is highly dynamic so each error domain requires its own elimination strategy. Figure 17 shows the selective portion of this domain as we deal with the gross negligent behaviour.

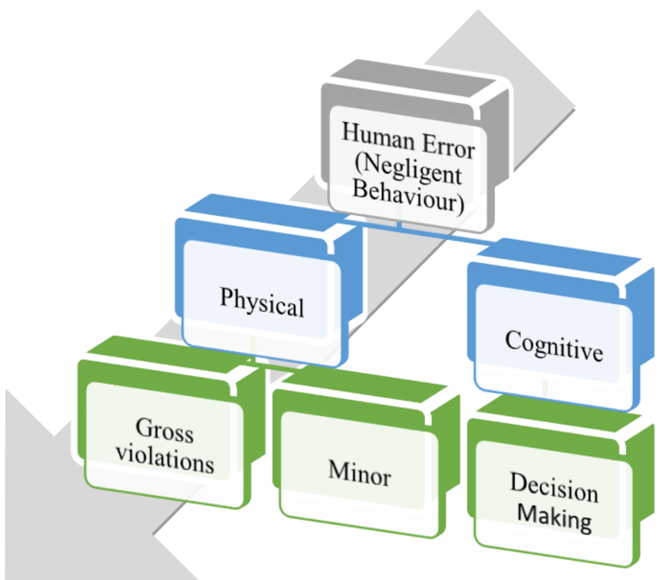

Figure 17: Major Human Error Domain

6.2. Operator monitoring

The proposed system will enable the management for automated and remote monitoring of the field operators and provide supervision capabilities to higher authorities while even not presenting at the live scene. The system will also trigger the alarm on the execution of any unwanted or out-of-course activity which classify as gross violation. MV Höegh Osaka and Wakashio Accidents happened due to such gross violation which can possibly be diverted if their operational staff monitored by such system.

6.3. IoOT Larch

For real-time monitoring and vigilance of an operator, a Human Centered Design IoOT Larch (Internet of Operator's Things) has been designed. Its main objective is to extract the accurate and recognizable data for human activities detection. The developed Larch has following sensors;

- Camera
- EMG sensors
- Gyroscope
- Accelerometer
- Magnetometer
- Heart-rate sensor/Pulse sensor

The included sensors are standardized for the purpose of human activity recognition. The developed system has the capability for the extraction of both the numeric and the visual data. Most of these sensors are packed in a package so it remains HCD as shown in Figure 18. It combines both type of data as well.

Figure 18: Myo armband

6.4. Dataset

The above explained IoOT Larch is deployed on various subjects' aka operators and data has been collected against 12 classes. A random snapshot of dataset comprises both the numerical and image data is shown in Figure 19.

EMG_Pod	Acc_X	Acc_Y	Acc_Z	Gyro_X	Gyro_Y	Gyro_Z	Ori_X
-3	-0.65039	-0.05811	0.754395	-4.6875	-0.3125	-5.0625	-0.08185
-3	-0.65723	-0.0542	0.75293	-2.875	1.375	-4.125	-0.08276
0	-0.43799	-0.06689	0.90332	-8.0625	4.3125	-1.6875	-0.08398
0	-0.29395	-0.10303	1.287598	-5.9375	1.125	0.0625	-0.08417
-1	-1.2124	-0.28906	0.407227	-2.75	0.375	-3	-0.08887
-3	-0.14697	0.173828	1.129883	-8.25	0.125	-3.125	-0.08649
-1	-1.28076	-0.30615	0.197266	2.9375	-0.875	-1.4375	-0.09076
0	-0.01221	0.165527	1.452148	-4.6875	0.125	-1.25	-0.08698
1	-0.09863	0.110352	1.55957	-1.875	0.5	-1.1875	-0.0871
1	-1.10449	-0.146	-0.01855	0	-1.25	0	-0.09009
-1	-0.37207	-0.00781	1.450684	-0.9375	0.6875	-1.1875	-0.08813
1	-0.58984	-0.14551	1.125	-6.8125	-0.6875	-0.125	-0.08942
2	-0.69141	0.017578	0.664063	1.5	-0.375	-2.625	-0.08875
-3	-0.67285	-0.06396	0.734375	0.375	1.5625	-1.125	-0.08899
-1	-0.66797	-0.04248	0.749023	0.0625	0.0625	-2.875	-0.08905
0	-0.67432	-0.05664	0.746582	-2.8125	-0.75	-2.5625	-0.08966
-2	-0.67334	-0.06641	0.737793	-3.4375	-1	-2.6875	-0.09052
-1	-0.66211	-0.05615	0.742188	-2.375	-1.5	-2.5625	-0.091

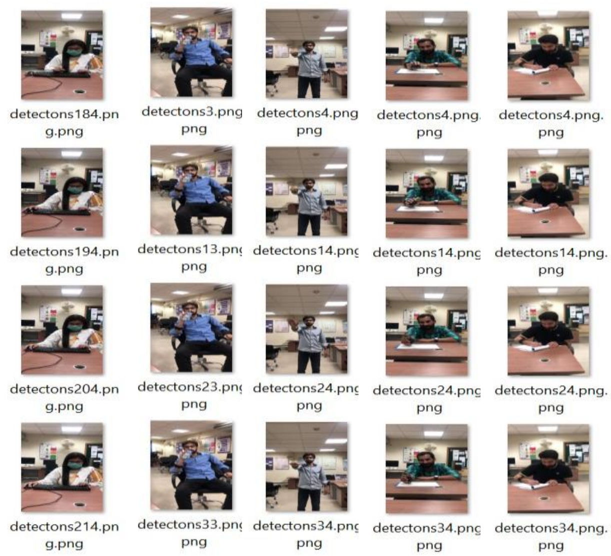

Figure 19: Numeric and Visual components of dataset

1490 examples of each class are included in the dataset and complete dataset has 125,160 entries.

6.5. System model

Conventional activity recognition systems use either numeric or visual data for recognition purposes. These systems work accurately because the under consideration subject tries to achieve perfect level of activity. But we are dealing with a mischievous operator who deliberately want to deceive the system and tends to malfunctioning. In order to cater the gross violations, requirement is correct activity at correct location. Due to the unique requirement of the system, we employ a novel multi-input AI model as shown in Figure 20 which takes both numerical input as well as visual input. Sensors provides numeric data while camera is responsible for images data. ResNet50 takes image data while ANN layer processes the numerical data which both merge at concatenate layer before providing the output.

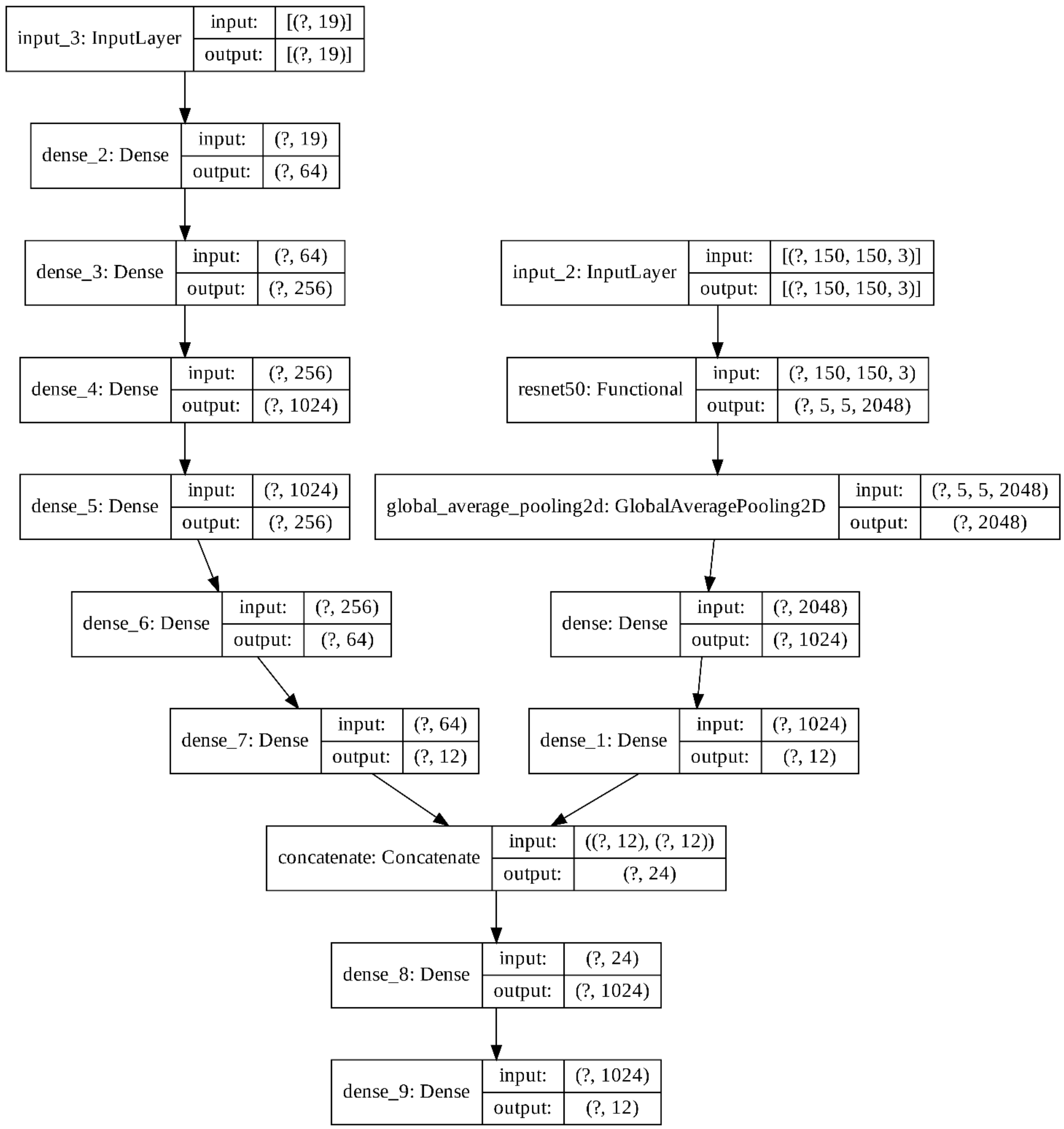

Figure 20: Multi-input Model

Figure 21 shows the accuracy and loss graphs of algorithm. Accuracy is approaches to 98% while F_1 score is also the same digit.

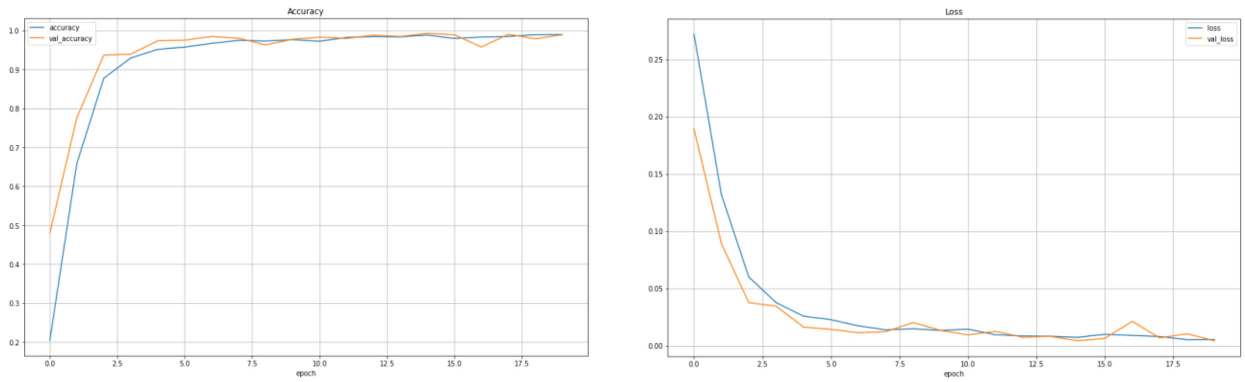

Figure 21: Accuracy and Loss graphs

The following Figure 22 shows the Confusion matrix which shows that all twelve classes are accurately classify and predicted accordingly.

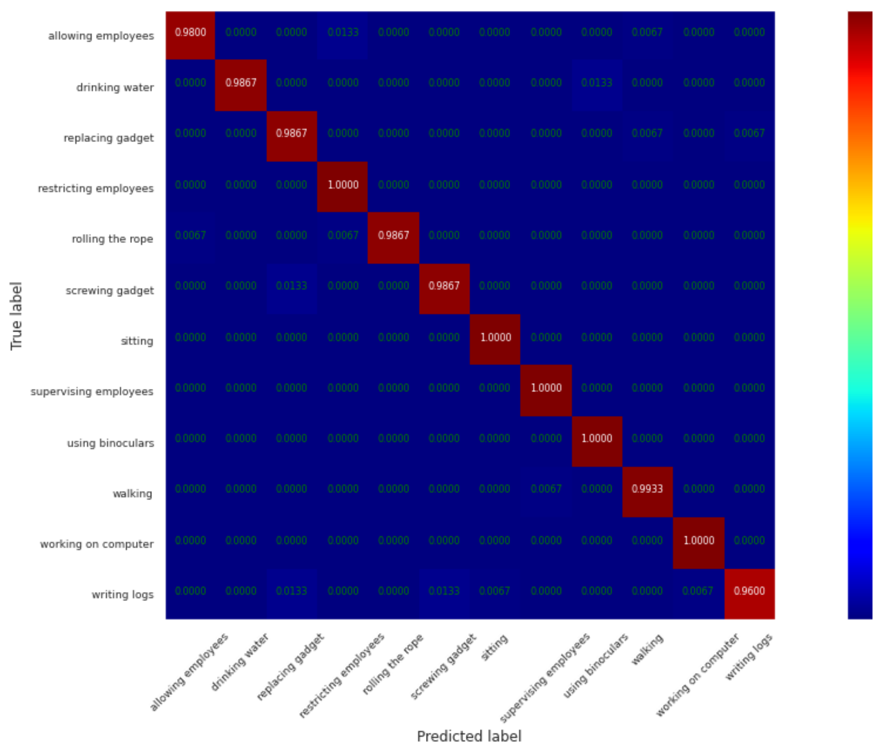

Figure 22: Confusion matrix

The numeric data its respective image data is printed together with actual and predicted labels. Following Figure 23 shows the completed results.

Figure 23: Predicted output

6.6. Features

Various aspects of an operator have to be covered in order to conduct his surveillance and vigilance for gross negligence violations while he perform his duties in an active environment. These aspects included in the system as an individual feature.

6.6.1. Activity Profiling

For any vigilance and surveillance system, recognizing and classifying the performed activities is the fundamental task. Hence, the first feature which the developed system has is the profiling of all the activities performed by the operator. System also color-code the activities so an observer can easily sortout and analyze operator’s actions. The system continuously stacks the activities in horizontal fashion in real time as shown in Figure 24.

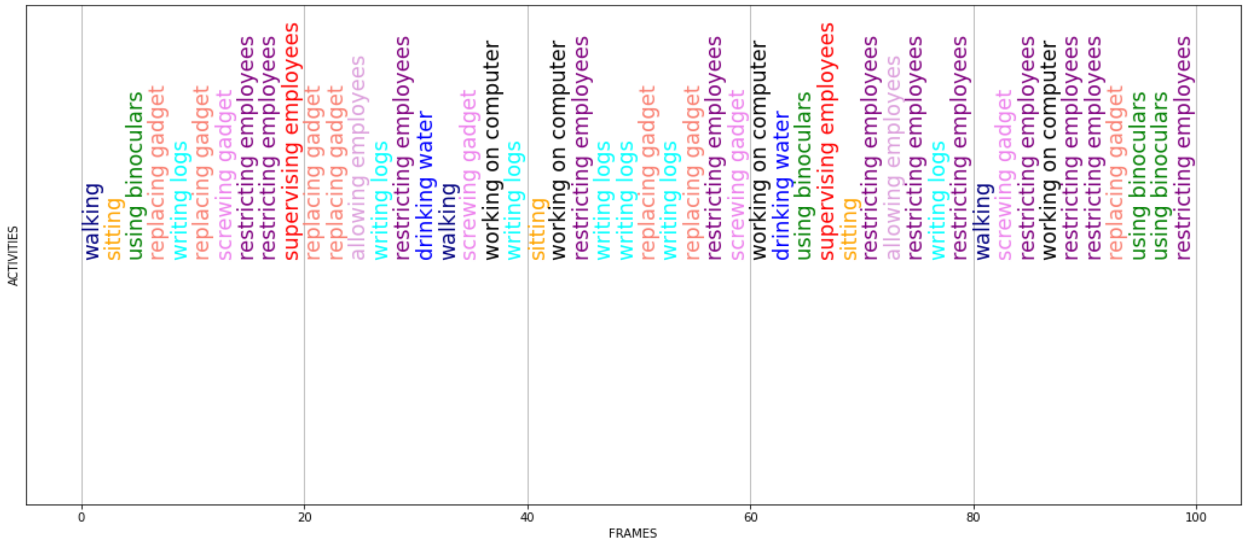

Figure 24: Profile of operator's activities

6.6.2. Activity Log

In real time and more importantly at the conclusion of the operator’s active session, the system will create the log of entire set of performed activities as shown in below Figure 25 which shows the estimated duration and number of times that specific activity has performed.

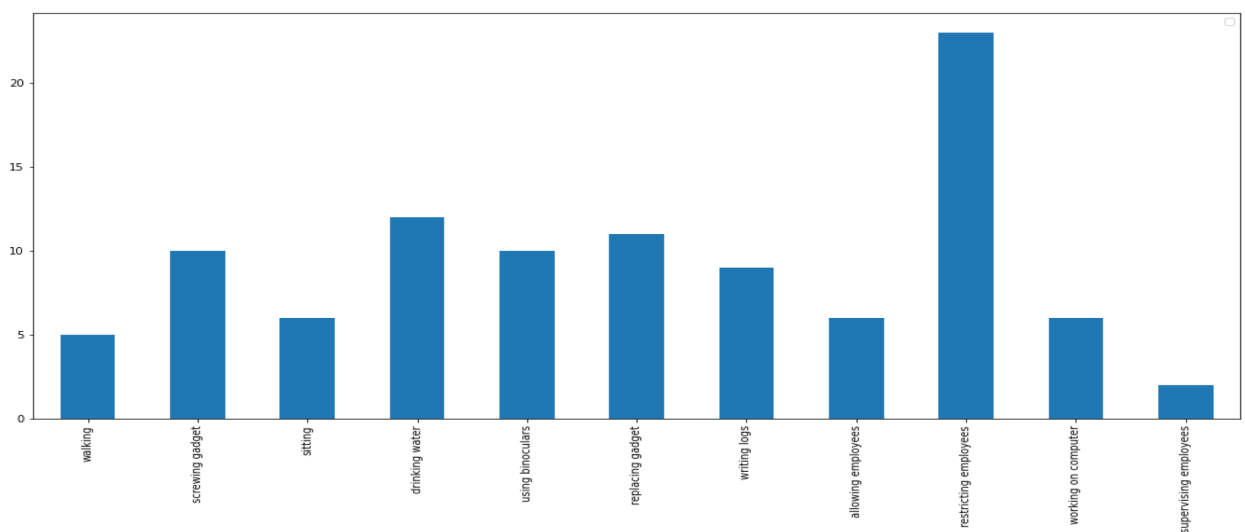

Figure 25: Log of operator's activities

6.6.3. Activity Validation

In any active environment, only few number of types of activities are required at a specific work-station while number of other activities may have termed as restricted. Performance of any of those activities considered as gross violation. Hence, any vigilance system should have been mandated for the validation of the performed activities. The currently performed activity detected by the system is either valid or invalid is another main feature of the system. After prediction, system will also identifies that either the current activity is desirable of not as shown in following Figure 26. A warning or an alarm may trigger by the system against the persistent invalid activity stream.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
WRITING IMAGE 4          PREDICTED : allowing employees
[ACTIVITY IS IN LIST OF VALID ACTIVITIES]
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
WRITING IMAGE 5          PREDICTED : sitting
[ACTIVITY IS IN LIST OF VALID ACTIVITIES]
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
WRITING IMAGE 6          PREDICTED : walking
[ACTIVITY IS IN LIST OF VALID ACTIVITIES]
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
WRITING IMAGE 7          PREDICTED : sitting
[ACTIVITY IS IN LIST OF VALID ACTIVITIES]
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
WRITING IMAGE 8          PREDICTED : walking
[ACTIVITY IS IN LIST OF VALID ACTIVITIES]
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
WRITING IMAGE 9          PREDICTED : drinking water
[ACTIVITY IS IN LIST OF VALID ACTIVITIES]
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

Figure 26: Validation token for activities

6.6.4. Activity Sequence

In any active environment where repetitive work being performed, a predefined set of activities is required. Hence, a well-defined sequence of activities needs to be followed. So, a matching scheme for activities can be implemented at such work station as shown in Figure 27. Such sequence matching can also be used for the detection of malicious activities committed in the past.

predicted	actual	match/not match
restricting employees	drinking water	activity not matched
using binoculars	using binoculars	activity matched
restricting employees	sitting	activity not matched
writing logs	walking	activity not matched
sitting	supervising employees	activity not matched
restricting employees	writing logs	activity not matched
sitting	working on computer	activity not matched
replacing gadget	allowing employees	activity not matched
working on computer	restricting employees	activity not matched
screwing gadget	screwing gadget	activity matched
sitting	replacing gadget	activity not matched
replacing gadget	rolling the rope	activity not matched
drinking water	drinking water	activity matched
restricting employees	using binoculars	activity not matched
sitting	sitting	activity matched
sitting	walking	activity not matched
replacing gadget	supervising employees	activity not matched
using binoculars	writing logs	activity not matched
drinking water	working on computer	activity not matched
writing logs	allowing employees	activity not matched
screwing gadget	restricting employees	activity not matched
using binoculars	screwing gadget	activity not matched
screwing gadget	replacing gadget	activity not matched
writing logs	rolling the rope	activity not matched

Figure 27: valid sequence confirmation

6.6.5. Activity Tracking

An operator may have assigned a static task or assignment may include some specific movements. In either case, to detect any potential gross violation, visual track record of his motion in a specified area is deemed necessary. The implemented system keep the record of all the movements carried out in the area under observation and shows the real time track as shown in Figure 28.

Figure 28: Activity track

The tracking profile of any individual operator will also shows his behavior and commitment towards the assigned duties. This traces will also help to understand the personal requirements of an operator.

6.6.6. Activity Estimation

Beside random movements and roaming around, presence of some specific object may lure the operator and causes distraction. Hence, keep tracking the objects that an operator approaches during his active session is also major requirement of this vigilance system. System will inform the observer well before the operator approaches any object present in his environment as following Figure 29.

Figure 29: Future activity prediction

This feature may also utilize to generate alarm for any unauthorized access to sensitive or hazardous material present at the scene but operator is not an authorize person for that.

6.7. Behavioral management

Operator's monitoring and surveillance can also provide the vital information about the natural behavior of operator at work. Attitude scale and dedication towards the assign tasks can be extracted. Figure 30 portrays the behavior of an operator at his work station and also his visits to various interest points in vicinity.

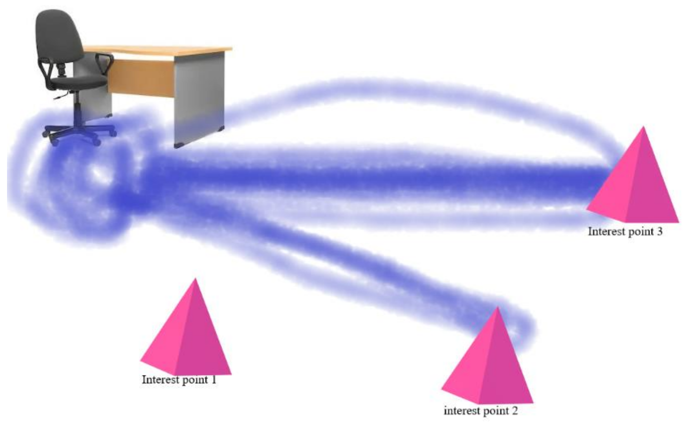

Figure 30: Operator behavior

6.8. Policy management

Prof. Annette Kluge of RUB quoted that "Breaches of rules are a frequent cause of accidents, as accident evaluations in different organisations show. Up to now there is neither a theoretical framework nor systematic investigations of the factors influencing rule violations."

All the requisite features included in the developed system regarding the vigilance and surveillance of an individual operator are gathered at one place and individual accounts are created for all operators. Operator's account provides all the information necessary for the vigilance, surveillance and cognition of the operator available to the observers, higher management and policy managers as shown in following Figure 31.

Figure 31: Operator's behavioral management

Surveillance of operator’s behavior for gross violation at this miniature level provides the unique information about operator and unearth various hidden aspects of operator’s behavior at work. Policies can be altered or reshaped in accordance with these aspects which will bring more efficiency and productivity to operator which ultimately enhance the throughput of the respective organization.

CHAPTER 7: FUTURE WORK & CONCLUSION

7.1. Conclusion

Accident causation models report the active as well as latent errors which cause the occurrence of fatal accidents. These models also show the human factor attribution to the accidents. These models can be applied to the diverse range of various scio-technical systems. Based on their reporting, the number of recommendations and accident avoidance strategies and guidelines has been devised.

This research work has examined more than 150 studies which directly reported and analyze the maritime accidents that occurred due to human factors. Included studies employed various accident causation models to analyze the accidents. HFACS, AcciMap, STAMP-CAST, and CREAM are few of them while the Human Factors Analysis and Classification System (HFACS) is the most prominent as the main selection criteria are the involvement of human factors. Their inclusion in this study is due to their capability of identifying, classifying and extraction of human factor extraction from analysis of maritime accidents. The implication of the employed statistical technique in this study leads to the revelation of facts like accident data scarcity, mala-fide factor classification, and under-reporting. It reveals the requirement of the more sophisticated accident and incident reporting system from all potential flashpoints across the sociotechnical system. Only then, the comprehensive evaluation of an accident will possible. The evacuation of the erroneous act well before it becomes irreversible is an error nonetheless. The scope of this study is circled the identification and collection of factors associated with humans and contribute to maritime accidents while accident statistics due to human errors, their mean results, list of accident causation models and maritime accident databases are its ingredients. The meta-analysis expressed the mean effect of factors while showing the combined effect of contributory factors and as aforementioned, it required further sustainment for exoneration of many trivial factors which will eventually manifest the niche for precise trainings, regulations and further assessments.

After the identification of principal factors contribute to major accidents, their mitigation technique has been proposed. An IoOT Larch has been developed for the continuous surveillance and monitoring of the operators in their active environment to cater the problem of malpractices and gross violations. Larch successfully deployed on various subjects and a comprehensive dataset has been created. A multi-input deep learning model trained on that data which then sophisticatedly classifies the performed activities against all of its included features and send-out respective notifications. The ultimate task of making the maritime industry safer approaches.

7.2. Future work

In the future, the development of frameworks for the evidence-based consequence assessments can be extended to study the cases available in various fragments which also possibly be combined in the big data form. Currently, scientists also introduced Genetic algorithms in the domain of human factor assessment [216]. Recently, a method developed based on the rough set theory known as Attribute reduction which can help to dig out the specific conditions and factors which become the cause of erroneous behavior in human [217] [218].

The above mentioned recent advancements for the extraction and assessment of human factors have a contribution to maritime accidents, will eliminate the problem of data scarcity due to the under-reporting of maritime accidents. The availability of classified data will help the implementation of specific data-intensive statistical analyses like meta-analysis, capture-recapture methods, and estimation techniques, etc. and enhance their viability and authenticity. The meta-analysis proves helpful to reach a specific conclusion but it requires results from various studies carried-out on same subject. In the maritime domain, accidents occurrence is a common phenomenon and a large number of research studies carried out on these accidents but there is exist no collective assessment to create synergy [219]. More comprehensive implementation of such statistical analysis will provide validated ground to chart out reliable standard operating procedures. Furthermore, employment of Artificial Intelligence tools like Machine Learning will also prove helpful to analyze the data and extract valuable information because underlying meta-analysis techniques can be deal with these modernize tools more comprehensively and efficiently [220] [221]. The on-going evolution of existing models for accident investigation enhance their reliability and generalizability on wide spread spectrum [222]. In case of larch, a mobile application may also include in the developed framework so remote monitoring can also be possible.

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Appendix A.

The PRISMA statement and checklist

Section/topic	#	Checklist item	Reported
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	✓
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	✓
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	✓
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	✓
METHODS			
Protocol	5	Indicate if a review protocol exists	✓
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	✓
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	✓
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	✓
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	✓
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	✓
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	✓
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	✓
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	✓
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	✓

Section/topic	#	Checklist item	Reported
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	✓

Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	✓
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	✓
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	✓
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	✓
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	✓
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	✓
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	✓
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression	✓
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	✓
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	✓
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	✓
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	✓