Influence of Human Factor in Maritime Domain and Measures to Mitigate Human Error to Enhance Maritime Safety

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***Abstract*— The study on Human Factors in enhancing the maritime safety and standards is an established field of study. The field of study has existed over many decades. The study has gained momentum in all sphere of Human activities with the enlightenment that, the machines invented by Human are unlikely to deviate from the behaviour designed to follow in algorithms or process based on which the system operates. Further, study conducted by various agencies indicates that, Human negligence is a major contributor towards accidents and incidents in majority of sectors, whether it is marine sector, mining industry, automobile sector, aviation industry, construction sector etc. The technological advancements in the field of Artificial Intelligence (AI) have developed autonomous vehicles wherein the Human Intelligence is being mimicked. There has been success as well as failures at the prototype and production level of such autonomous vehicles. At present, a combination of Human Intelligence and Artificial Intelligence proved to be the hybrid model in developing autonomous vehicles. The development of completely autonomous vehicles without Human intervention is near impossible. Hence, understanding the Human psychology and emotional intelligence can negate Human errors and contribute to a near perfect system even in these hybrid systems working in AI based algorithms. The Human factor study in the marine sector has been undertaken by various International, National and Non-Governmental Organisations but the accidents due to human negligence still persist in the marine industry. The study aims to identify contributory factors due to human negligence in marine industry**

***Index Terms*— Human Factor, Human Error, HFACS, Analytical Hierarchy Process.**

I. INTRODUCTION

The maritime safety standards adopted vary from country to country. The adoption of a single and holistic safety standard throughout the world maritime domain seems to be a challenging task. Main challenge in adopting the single standard is the variance in organisational objectives. Though the broad guidelines for achieving safety standard rests with the IMO, there are state run organisation which may incorporate additional guidelines to strengthen the IMO guidelines or may dilute the broad objective due to progressive mindset of the states by neglecting the safety guidelines. There are many non profit and state funded organisations aiming to achieve high safety standards by implementing policy guidelines, knowledge sharing through journals, articles and training on human safety regulations, however there still exists barriers to breakthrough to achieve 100 % safe maritime environment.

II SAFETY CULTURE

The importance of safety culture stemmed out from the afterthought from the Chernobyl accident[1] . The Fukushima nuclear accident in Japan caused as an aftermath of Japan earthquake on 11 Mar 2011 had brought out the importance of coexistence between the technology and human involvement. Every organisation develops basic assumptions to understand the interaction between human and machines. However, inorder to address the vulnerabilities and to succeed against the worst case scenarios, an integrated and constantly evolving approach is required taking into considerations the complex interactions between the environments, human, organisations and machines. The boundary conditions or assumptions which are introduced to consider human safety prior to the operation of any system needs to be revisited periodically to further strengthen the safety culture. According to the director general report on Fukushima nuclear

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[1] HP Berg, "Human Factors and Safety Culture in Maritime Safety", The international journal on marine navigation and safety of sea transportation, Vol 7, no Number 3, Sep 2013.

disaster, Human safety is a dynamic interaction between the following factors[2]:-

(a) Individual Factors. The individual factors are traits attributable to the operators or field personnel.
(b) Technical Factors. The technical factors such as usage of correct tools, proven technology and procedures along with use of certified equipments enhances human safety interactions.

(c) Organisational Factors. The administrative orders have a positive influence on human – safety interactions. Establishment of a conducive work environment motivates the operators to work effectively and efficiently.

III. MARITIME DOMAIN

A study conducted with respect to maritime accident lead to a conclusion that the marine transportation accidents are 25 higher than that of air transport system[3]. This figure still holds good as per the studies conducted. The influence of human factors in these maritime accidents are considerable. About 85% of bulk carrier accidents, 75% of groundings, 90-96% of collisions, 75 % of fire incidents on vessels are due to Human Error[4].

Figure 1. Human Error Vs Maritime Accident

[2] International Atomic Energy Report, The Director General. The Fukushima Daiichi Accident, CG 59/2014.
[3] HP Berg, "Human Factors and Safety Culture in Maritime Safety", The international journal on marine navigation and safety of sea transportation, Vol 7, no Number 3, Sep 2013.
[4] Rothblum A. 2000. "Human error and marine safety" Maritime Human Factors Conference, Linthicum, MD, March 13 - 14, 2000

Further, the between 2011- 2016, 14,828 liability claims where analysed and 75 % of which is attributed to human error. Safety management culture distils as it travels up the levels of management wherein the top management fails to assimilate the importance of safety culture due to lacks the field knowledge. Maritime safety culture is also subjected to such distillation of information as it is passed across the levels of management. There are various maritime safety cultures in maritime domain such as ABS model and drouin safety model.

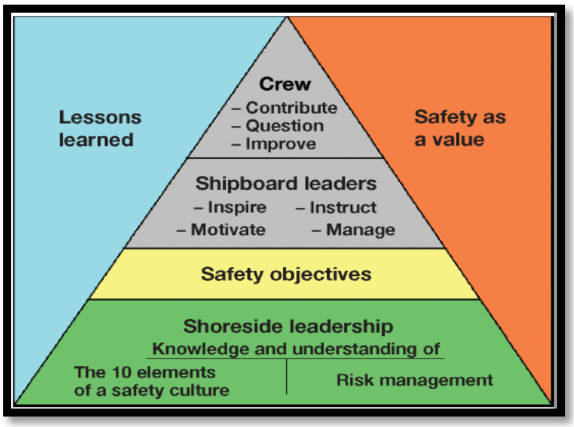

Figure 2. Dourin Safety Pyramid

IV ISM CODE

Growth in global transportation sector is on the steep climb due to the rising demands, post Covid-19 relaxations and globalisation. Growth in marine transportation sector has seen a sharp jump.

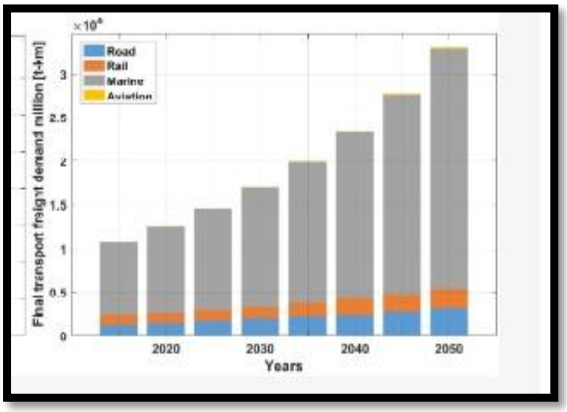

Figure 3. Global Transportation Demand 2015-2050[5]

[5] Shivash khalili, Etu Rantanen, Dmitrii Bogdanov and Christian Breyer, "Global Transportation Demand Development with Impacts on the Energy Demand and Greenhouse Gas Emissions in a ClimateConstrained World", School of Energy Systems, LUT University, Finland,

In order to maintain the conservative nature of maritime transportation in the field of maritime safety, International Maritime Organisation (IMO) has passed a resolution to uphold the maritime safety standards and constituted as International Safety Management (ISM) code. The code has been incorporated into the Safety of Life at Sea (SOLAS) chapter ix and made the code as a mandatory standards to be complied to maintain a fool proof safety management framework in the maritime transportation sector. The implementation of legislative frameworks posts an accident/ incidents in the maritime domain is a slow process due to the long approval process and ratifications. The importance of considering Human Factor as an important field of study towards achieving high safety standards in all the major industry sector has become major norm in the recent years. Human error has a very wide range of definitions and the definition binds with the process and procedure followed in the industry sector where in humans are involved. The human error can be classified in many ways, most commonly used classification criteria is as follows[6]:-

(a) Skill based
(b) Rule based
(c) Knowledge based

There are many failure theories available; however the more relevant failure theory is that of an immediate failure of accident when the operator deviates from the ideal operating conditions[7]. Another failure theory is that, a deviation from the ideal operating procedure or process can occur at any stage of operation however the effect of the same is not immediate, it remains dormant till the threshold is reached and failure occurs when the operator operates it even of the operating procedure is followed correctly. For example a design flaw during the manufacturing process can remain latent for a considerable period and may fail when the threshold is reached[8]. Another failure condition is a slip wherein the operator fails to execute a simple task such as during an engine changeover, failure to reduce the speed of running engine to the clutch engagement speed. Slip can occur in the simplest of the procedures. Lapse can occur when there is deviation from the operating procedure of failure to adhere to the standard operating procedure. An example of a lapse is omitting the engine starting mandatory checks. The difference between a slip and lapse is that, a slip occurs by the actions of an individual where as the lapse occurs in a team such as failure to communicate the critical defects to the next engine room watch keeper. A violation is another failure criterion and can be further classified into Procedural violations, misuse of authority and violation to follow regulations. The failures to adhere to the regulations of watch keeping certificates and Regulations for Preventing Collision at Sea are examples of violations in regulations. The procedural violations involve failures to adhere to the Standard Operating Procedures (SOP) laid down by the company to prevent any safety breach. Misuse of authority is a willful violation which is reflected in many accidents and incidents in the maritime domain

V. ANALYSING SHIPPING CAUSALITIES IN INDIA

The Director General Shipping under Ministry of Shipping based at Mumbai, is entrusted with the responsibility to ensure that the Indian Shipping Industry meets all the requisite regulations and standards with respect to the environmental safety, qualifications of seamen, living conditions. The DG shipping also maintains a repository of incidents and accidents happened in Indian waters and publish the reports frequently. Further, inorder to prevent recurrence of such incidents the DG shipping publishes circulars and directives through orders and instructions to be followed. . Extraction of accidents and incidents caused due to human error is a humongous task as there is no centralised repository available to seek the information about the accidents and incidents around the globe. However, DG shipping maintains and published reports on accidents and incidents that have occurred in the Indian waters.

https://www.mdpi.com/1996-1073/12/20/3870, accessed on 07 Mar 23.

[6] Rasmussen J, "Human Errors, a Taxonomy for describing Human Malfunction in Industrial Installations", Journal of occupational of occupational accidents, p311-333, Elsevier Scientific Publishing, 1982.

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VI. METHODOLOGY

The Analytical Hierarchy Process (AHP) is a proven method to deal with Multiple Criteria Decision Analysis (MCDMA). This method is selected as the maritime accident human causal factors are uncertain and difficult to isolate. Also, considering that all the causal factors are equally important the AHP tool is an effective decision making tool. The criteria helps to compare the human causal factors against each other to isolate the most important one.

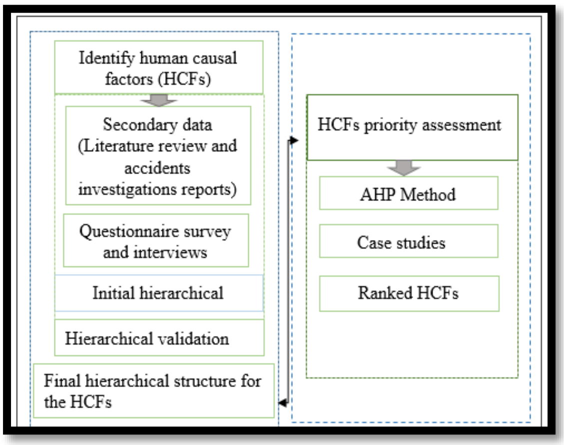

Figure 4. AHP Methodology

The extracted human risk factors contributing to accidents/ incidents in the Indian waters is the data set out of which the most critical human causal factor is identified using the AHP methodology. The human contributory factors extracted based on the analysis of accident and incidents published by DG shipping are further categorised in to Main Factors and Sub Factors for validation and classification process.

Ser	Main Factors	Sub Factors
(a)	Individual shortcomings	Stress Fatigue Mental and Physical Distraction Illogical and rash thinking Failure to wear PPE
(b)	Instruction and orders failure	Failure to adhere to the instructions Failure to follow SOP
(c)	Technical shortcomings	Lack of experience and training Lack of system and equipment knowledge Lack of planning Design deficiency
(d)	Non - Technical Shortcoming	Lack of team work Lack of effective communication Lack of exchange of information Lack of situational awareness Lack of supervision

Table. 1. The Main and Sub Factors for Validation

On completion of the database extraction and the sub classification of Human Causal Factors, a hierarchical taxonomy is initially constructed. The hierarchical taxonomy is constructed based on the inputs from experienced marine engineers and navigation experts available with the Indian Coast Guard, Merchant Navy and Indian Navy. These experts are all more than 12 years of sea experience. They also have indepth experience in handling marine emergencies at various point of serving onboard ships. A draft hierarchical structure was prepared and same was forwarded to 25 marine experts with varied experience. They were allowed to modify, add or amend the structure as per their knowledge and expertise. Accordingly, hierarchical taxonomy is prepared based on the inputs from mariners.

Ser	Factor	Hierarchical Taxonomy
(a)	Non - Technical Shortcoming	HF1
(b)	Technical Shortcomings	HF2
(c)	Instruction and orders failure	HF3
(d)	Individual Shortcomings	HF4

Table. 2. Human Factor and Hierarchical Taxonomy

The AHP process involves following steps:-
(a) Determine the objective.
(b) Formulate hierarchical structure.
(c) Carryout pair wise comparison.
(d) Calculate priority vectors and consistency evaluation.
(e) Calculate relative weight.

The main objective of the study is to identify the critical human causal factors that occur during the maritime operations. This enables to identify the most important human factors that affect the maritime operations. The hierarchical structure of the major factors are created based on the inputs from the experts from the maritime industry. The main group is further divided in to subfactors. The criteria for the major factors are HF1,HF2.HF3 and HF4. Next step is to carry out pairwise comparison between the crucial factors inorder to determine the weight. The AHP procedure uses simple pairwise comparison between the factors. A ratio scale is used to carry out comparison between various factors. The pairwise comparison scale and the numerical assessment important factors is as tabulated below:-

Ser	Numerical Values	Meaning
(a)	1	Equally important
(b)	1/3	A little unimportant
(c)	1/5	Unimportant
(d)	1/7	Very unimportant
(e)	1/9	Extremely Unimportant
(f)	1/2,1/4,1/6,1/8	Intermediate value of unimportance

Table. 3. Pair wise Comparison and Numerical Values for Important Factors

Post numerical value assessment, a decision matrix is prepared. The individual human factor is compared with other elements i.e. HF1 is compared with HF2 and If HF1 is judged equally importance to the HF 2, then HF1=HF2 = 1. Similarly, HF1 is little important than HF2 then HF1 compared to HF2 is 3 and HF2 is little unimportant to HF 1 and HF2 compared to HF1 is 1/3.

$$A \quad a_{ij} = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a/a_{12} & 1 & \cdots & a_{2n} \\ . & 1 & \cdots & . \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}$$

Post identification of the decision matrix, priority of each factor element is compared with each other and inorder to identify the importance of each human factor element Eigen vector element is utilised. The weight vector generated in the comparison matrix will decide the priority of each element. The Eigen vector determines the priorities of each pair wise element based on the Average of Normalised Column (ANC). The ANC method is applied in a three step process.

(a) Add each column values in the matrix.
(b) Divide each element by the total sum in that particular column.
(c) Normalisation of the matrix is done by adding the elements in each row then divide the sum with the number of elements in each row.
(d) The weights of each element is calculated by the following formula.

$$W_i = \frac{1}{n} \sum_{j=1}^{n} \left(\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}\right), \text{i, j, =1, 2, 3,..., n)}$$

A detailed questionnaire is prepared and emailed to engineers, deck officers and naval personnel to identify the important/unimportant human causal factors as mentioned in table 3 and 4, according to their experience onboard ships. The aim of the exercise is to utilise the expertise and experience acquired by the sea farers to identify the important and unimportant Human Causal Factors and create a decision matrix. If there are multiple numerical value received from the experts for the same questions, the geometric mean is calculated before calculating the Eigen vector priority.

Main Factors	HF1	HF2	HF3	HF4
HF1	?	?	?	?
HF2	?	?	?	?
HF3	?	?	?	?
HF4	?	?	?	?

Table. 4. Decision Matrix Framewok

VII. SURVEY SUMMARY

The survey results were received from 21 experienced maritime professionals. The majority of the professionals had an experience of more than 5 year in the maritime sector.

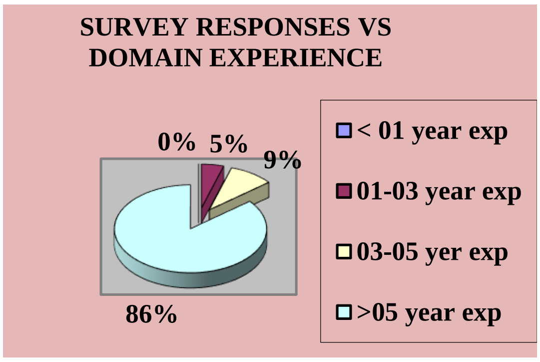

Chart 1. Survey summary

The response to the questionnaire of each maritime expert is used to generate a decision matrix and each matrix is named as T1, T2, T3........T21. the decision matrix of four human causal factor is generated. An example of the decision matrix of T1 response is shown in the table 7. These 21 matrix were normalised by adding elements in each column and then dividing each element in the column by the total sum of the column elements. The normalised matrix generated for T1 decision matrix is placed at table below:-

T1				
	HF1	HF2	HF3	HF4
HF1	1	1	3	7
HF2	1	1	7	5
HF3	0.333333	0.142857	1	5
HF4	0.142857	0.2	0.2	1

Table. 4. Decision Matrix

T1				
	HF1	HF2	HF3	HF4
HF1	0.403846	0.426829	0.267857	0.388889
HF2	0.403846	0.426829	0.625	0.277778
HF3	0.134615	0.060976	0.089286	0.277778
HF4	0.057692	0.085366	0.017857	0.055556
	1	1	1	1

Table. 5. Normalised Matrix

For the correctness of the normalised matrix, the sum of the elements in the column should be equal to 1. The normalised matrix for all the 21 responses were calculated and the correctness of the matrix were checked by adding the elements in each column. However, there were responses from 21 experts and prior calculating eigenvectors the geometric mean of all the elements from 21 normalised matrix were calculated. This matrix forms the basis for the calculation of eigenvector which determines the priority of the Human causal factors viz HF1, HF2, HF3 and HF4. The eigenvector or the weightage of the Human causal factors is calculated from the normalised matrix by adding the human elements pair wise comparison value in each row divided by the number of elements in each row.

WEIGHTAGE OF HUMAN FACTORS						
	HF1	HF2	HF3	HF4	Highest	Percentage
HF1	0.4118	0.46476	0.39052	0.296989	0.391017	39.10171089
HF2	0.24422	0.21915	0.341265	0.252695	0.264333	26.43329764
HF3	0.15582	0.11872	0.149965	0.310216	0.18368	18.36796611
HF4	0.18816	0.19737	0.11825	0.1401	0.16097	16.09702535
	1	1	1	1	1	100

Table. 6. Eigenvector Matrix

VIII. CONCLUSION AND INFERENCE

The eigenvector matrix correctness is checked with the summation of each column element which indicated 1. From the eigenvector matrix, the weightage of Human causal factor HF1 is dominant factor which contributes to the maritime incidents and accidents in Indian waters. The next dominant contributing factor is HF2 followed by HF3 and HF4.

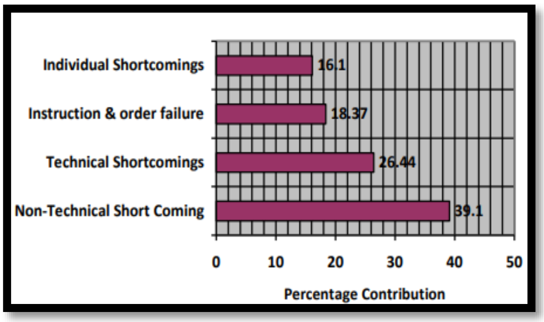

Chart 2. The Human Causal Factor Contribution in Maritime Accidents/ Incidents in Indian Waters

According to the above analysis the Non-Technical shortcomings viz lack of team work lack of effective communication, lack of exchange of information, lack of situational awareness and lack of supervision is the Human Causal factor which contributes 39.1 % of the maritime accidents and incidents in Indian Waters. This is followed by Technical Shortcomings viz lack of experience and training, lack of system and equipment knowledge, lack of planning and design deficiency which contributes 26.1 % of the maritime accidents. Together, the Non-Technical shortcomings and Technical Shortcomings contribute 65.2 % in the maritime accidents/incidents in the Indian Waters. The individual shortcomings and failures to follow the orders and instructions accounts for almost 15-16 % each contribute to maritime accidents and incidents. According to the analysis, the Human causal factor priority assessment where in the order of Human causal factor were positioned from highest to lowest by the academic experts is coinciding with the results of AHP method.

Priority	Priority Assessment by Academic experts	Priority Assessment based on field survey and AHP method
1	Non-Technical Shortcomings	Non-Technical Shortcomings
2	Technical Shortcomings	Technical Shortcomings
3	Individual Shortcomings	Individual Shortcomings
4	Instructions and Orders Failure	Instructions and Orders Failure

Table. 7. Comparison between the Priority Assessment Experts and Field Survey Analysis

The maritime accidents/ incidents can be drastically reduced by regulating the nontechnical and technical shortcomings as they contribute more than 60 % of accidents/ incidents followed by the Individual Shortcomings and Instructions and orders failure. According to the AHP investigation, the bulk of accidents and incidents in Indian water are caused by non-technical flaws such a lack of teamwork, ineffective communication, information sharing, supervision, and situational awareness. The second crucial cause is related to technical deficiencies, including insufficient knowledge of systems and equipment, lack of expertise and training, and insufficient planning and design. Individual flaws and failures in commands and instructions make up the remaining significant factors. According to the survey analysis, the top two causes account for more than 60% of accidents, as was mentioned in the previous chapter. The following steps are being taken to improve maritime safety by reducing incidents and accidents caused by human error.

(a) Proactive Approach in Implementation of New Regulation. The earlier chapters covered the regulatory environment that now exists in the maritime sector. Any regulatory framework must be implemented in a reactive rather than a proactive manner. Additionally, many of the laws governing maritime safety are the outcome of earlier accidents or occurrences. It is time to consider the installation of a strict and new framework that is widely accepted, given the arrival of new technology that lessens the stress on mariners and the demand of recruiting and training new sailors. The global maritime participants must be aware of the regulations that are implemented as a result of any maritime incidents that happen anywhere in the world. There must be another side to the framework that monitors the successful application of the law throughout the maritime sector; the application of the law is only one aspect of the framework. The management is required to keep a close eye on how the new rules are being applied

(b) Maritime Safety Management System. The safety of people and equipment at sea is significantly influenced by the safety management system. The regulations and 67 legislation are primarily focused on the management side of the marine business, whereas the safety management system is tied to ship operations. According to survey results and conversations with maritime industry experts, the current ISM code of conduct is complicated and turns into an administrative burden rather than streamlining processes and procedures by fostering a favorable work environment for seafarers. Additionally, the marine industry's complicated safety culture results in noncompliance with the safety management system. The safety management system can be tested to see if it is functioning properly through onboard audits. The use of technology, such as real-time monitoring of ship operations, can be useful given the size of the marine industry and the distance between ships and auditors. Accidents and incidents may occur as a result of the ship and land-based organizations' noncompliance with rules and safety management systems. This can be avoided by offering proper training and keeping track of how the safety standards are being put into practice.

(c) Accident/ Incident Database. Under the umbrella of the IMO, there are numerous state-level authorities. Every regulator keeps track of the accidents and incidents that happen in their jurisdiction. The authorities also analyze these accidents, and the results are stored in the regulators' data base. For practical solutions, this data base must be made available to all interested parties.

(d) Ship and Shore Organisation Interactions. To meet the marine industry's safety goals, shore-based and ship-based organizations must collaborate. Similar to the organization structure and authority maintained by ships, those maintained by shorebased organizations also have organizational structures and authorities, but there is a possibility of an authority gradient when these two organizations interact. Furthermore, hiring staff with little to no prior shipping experience may be detrimental to an organization's bottom line compared to hiring staff with prior shipping experience in shore-based organizations. This would lessen the gap in authority that currently exists between land-based and ship-based organizations in the shipping sector. Better communication, information sharing, and oversight are fostered in the maritime sector as a result.

(e) Analysing Near Miss Programs. The near miss program is a systemic analysis technique that allows the business to self-analyze the process based on feedback from the operators via the near miss scheme. The near-miss scheme can draw attention to concerns including insufficient supervision, insufficient training, lapses in procedure, ignorance, and oversights. The near miss scheme's inability to recognize a person's psychological condition is one of its limitations. The near-miss also highlights the poor living circumstances, defective tools, and equipment that interfere with supervisors' monitoring. The near miss is discovered to be the ideal instrument for locating such missed regions and taking appropriate steps to streamline the processes and procedures.

(f) Mandatory Experience in a Particular Rank. In the marine business, a significant human causal factor is a lack of supervision and leadership. Before being promoted to the next rank, ratings must have sufficient experience in the previous level in order to have experience-driven leadership and supervision skills.

(g) Introduction of Technology to Reduce Human Causal Factors. The best strategy to lessen risks from human variables is to use a system and technology approach. Understanding human capabilities and constraints is necessary for this. It also include researching how individuals interact with various pieces of machinery, technological systems, work environments, etc. Finally, safety experts need to assess and develop better systems, technologies, workplaces, and environments. A Control Of Work is a Safety Management System that makes that dangerous job operations, such entering restricted spaces or doing "hot work" like welding and brazing, don't happen before they have been approved and assessed. By streamlining step-by-step smart safety workflows to enhance compliance assurance, planning, and execution, Control of Work can control human factors. For instance, a worker must enter location and time stamp verification like signoffs in the system at important points when preparing a permit. Utilizing distinct worker identification, the roles and approval controls are tailored to varied authority levels for certain workflows. Additionally, real-time processes can be monitored from the live dashboard. This gives a thorough explanation of high-risk work and cumulative risk. By addressing low situational awareness, insufficient worker health and wellbeing data, and environmental exposure risk, a crew protection system assists maritime stakeholders in 69 managing risk and enhancing existing safety systems. By offering vital details on the working conditions, hazard exposure times, worker health, and other work-related hazards when they are identified by our Smart Watch, Crew Protect can help reduce risks. Additionally, it notifies Responsible Authority via Crew Assist notifications sent by the wearables when employees have trouble completing their responsibilities or feel sick. By sending out GeoFence warnings on their wearables to warn workers to avoid dangerous areas, it also rewards good conduct.

(h) Artificial Intelligence. The solution to increasing shipping efficiency and safety may lie in artificial intelligence (AI). Information unpredictability, complexity, and time constraints sometimes make navigational solutions difficult to implement. When making tactical choices to comprehend traffic patterns and potential vessel contacts, an agent sets goals and anticipates the following few moves, similar to a chess player.

A complex set of systems with numerous interconnected actors and processes makes up the shipping sector. The true impact of human factors on the safe operation of shipping can only be properly analyzed by comprehending ship operation and accurately modeling it. All the actors, processes, and interactions can be taken into account when using a socio-technical approach. This is made more difficult in the shipping business in particular because of how far away the ships are from the operational office and how the workforce is temporary. The industry's high rate of noncompliance may be attributed to the previously mentioned elements, such as a lack of control by the shore organization, insufficient training, and employee turnover among seafarers. The safety performance of shipping corporations will be improved and, more crucially, the danger to seafarers operating ships will be decreased by adopting a holistic approach to accident investigation and ship operations

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