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Collision between supply vessels and offshore installations case cargo handling and personal transferring operation

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المستخلص
هذا البحث يقدم منظومة تهدف إلى تحليل المخاطر المرتبطة بالأخطاء البشرية والعوامل المرتبطة بها، والتى ينجم عنها تصادم بين سفن الإمداد والتموين والمنشآت البحرية مع التركيز على ثلاث فئات من المخاطر الرئيسية هى عملية نقل البضائع والأفراد،وعدم الحفاظ على موقع السفينة،ومناورات السفينة.لإنجاز هذه المهمة تم تنظيم هذا البحث إلى ثلاث مراحل منفصلة وتطبيقها كدراسة حالة على عملية نقل البضائع والافراد.

تم استخدام نموذج حالة الانهيار والتأثيرات، والحرجية (FMECA) لتحديد المخاطر. كما تم استخدام النموذج التفسيري الهيكلي (ISM) متعدد المعايير لتصنيف سيناريوهات المخاطر بطريقة أكثر تفصيلاً مما يسهل عملية اتخاذ القرار (MCDM). بالإضافة إلى ذلك، تم إجراء تحليل لعواقب سيناريوهات الحوادث لسفن الإمداد والتموين باستخدام تحليل شجرة الأخطاء (FTA) لتقييم الأسباب الجذرية للحوادث الذي هو منهج شامل لتقييم وإدارة المخاطر فى إطار منهجية تقييم السلامة الرسمية (FSA) للمنظمة البحرية الدولية (IMO).

Abstract
This paper presents a systematic methodology aiming at investigating human-error induced collisions between attendant vessels and offshore installations, with focus on three key risk categories: Cargo handling and personnel transferring (CH), loss of station keeping (SK) and ship handling and maneuvers (SH). Because of space limitation, the methodology will be applied here to the first category (CH) only.

The Failure Mode, Effects and Criticality Analysis (FMECA) method was used to identify the hazards. Moreover, the Interpretive Structural Modeling (ISM) of Multi Criteria Decision Making (MCDM) was used for the same purpose and results of both methods were favorably compared. Moreover, the Fault Tree Analysis (FTA) was used to evaluate the root causes of accidents down to the Underling Factors (UFs) benefiting from the revised guidelines for the IMO Formal Safety Assessment (FSA).

Background

It is unanimously agreed upon that the majority of collision incidents between Offshore Supply Vessels OSVs and offshore installations are caused by human errors (Sánchez-Beaskoetxeaa, 2021).

The analysis of collision between attendant vessels and offshore installations, specifically focusing on human error, within the framework of risk management, presents inherent challenges due to numerous factors and causes that significantly influence this type of operation. This subject is a topic of considerable concern and exploration in numerous scholarly articles and research papers. Therefore, many researchers have attempted to come up with a methodology that would respond to the magnitude of the risks involved; however, reviewing the literature reveals that there has not been a one methodology that is considered the standard of the industry. Rather, some research endeavors have been attempted.

For instance, Tvedt (2014) considered collisions between attendant vessel and offshore installations and proposed a framework for risk modeling. The model provided no quantifications however, it a good foundation for future work. The generic collision scenarios involved have been analyzed using FTA to identify and break down the operational barrier functions available to reduce collisions. It tackled only three scenarios of attendant vessel- installations collisions while on voyage and did not consider attendant vessel operations within the 500m- zone.

Also, Azad (2014) employed the FMECA tool to assess risks related to attendant vessel, but again did not consider collision incidents between attendant vessel and offshore installations. In their research, Yasa and Akylidiz (2018) suggested a framework for applying FSA on attendant vessel aiming to improve safety. Their work has been based on expert judgments and historical data. They also recommended using FTA, ETA and Failure Mode and Effect Analysis (FMEA) as assessment tools. The study provided general and basic guiding for future research, but was not specific to the case of collision. Moreover, Zhu et al. (2022) were pioneers in employing ISM in their work in the offshore industry risk assessment; however, their work was current with storm risk and was not specific to attendant vessel.

This research attempts to fill this gap by proposing such a methodology and this is presented in the following three sections. The first section reviews the current risk management frameworks in the offshore maritime industry. The second section proposes the methodology for identifying, analyzing and evaluating the risks of human errors caused attendant vessel offshore installations collisions. Finally, the implementation of the methodology is detailed. considering one risk category only, i.e. cargo handling and personnel transferring.

Review of the current risk management frameworks in the offshore maritime industry

The risk management process for collisions involves a series of sequential steps that are placed within a framework. One of the most commonly used frameworks for risk management in the offshore industry is the Formal Safety Assessment (FSA) process used by the International Maritime Organization [IMO], (2019)

The FSA process steps are visually depicted in the flowchart of Figure (1) .Five distinct steps, commencing with system definition and concluding with cost-benefit assessment, constitute the process.

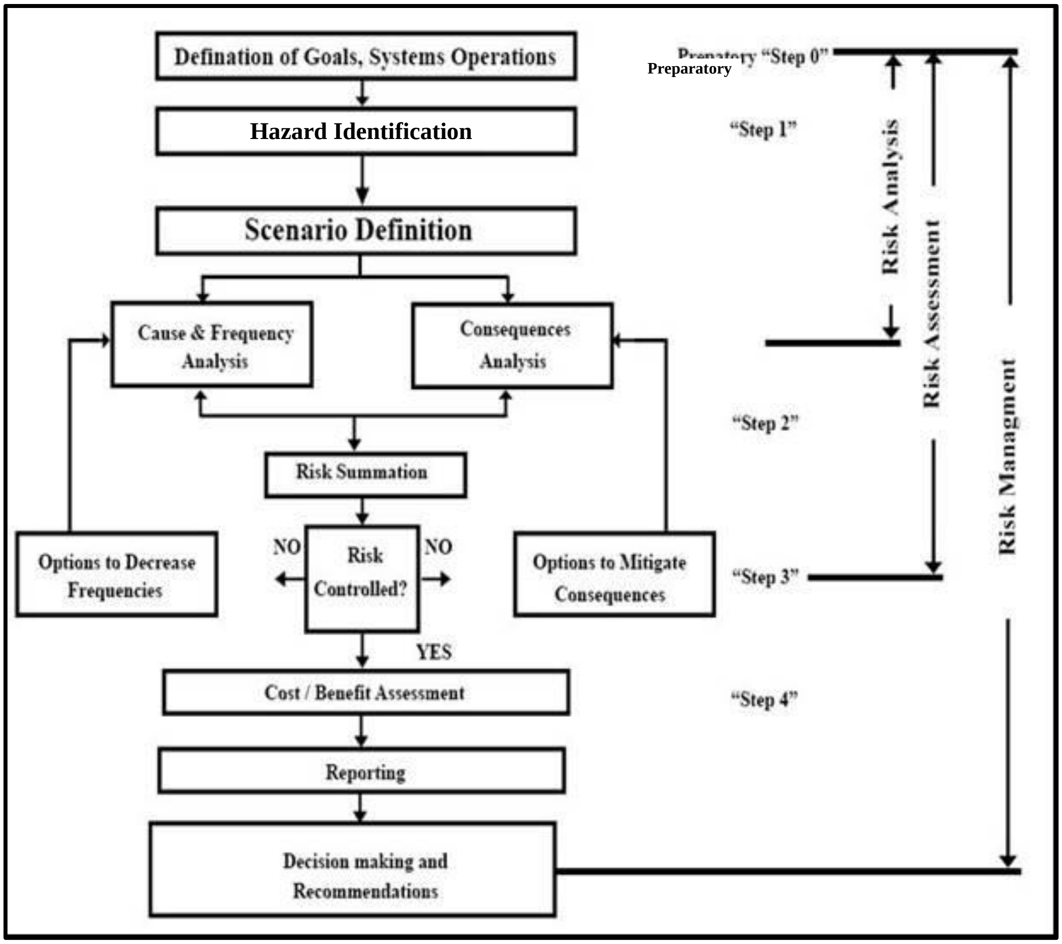


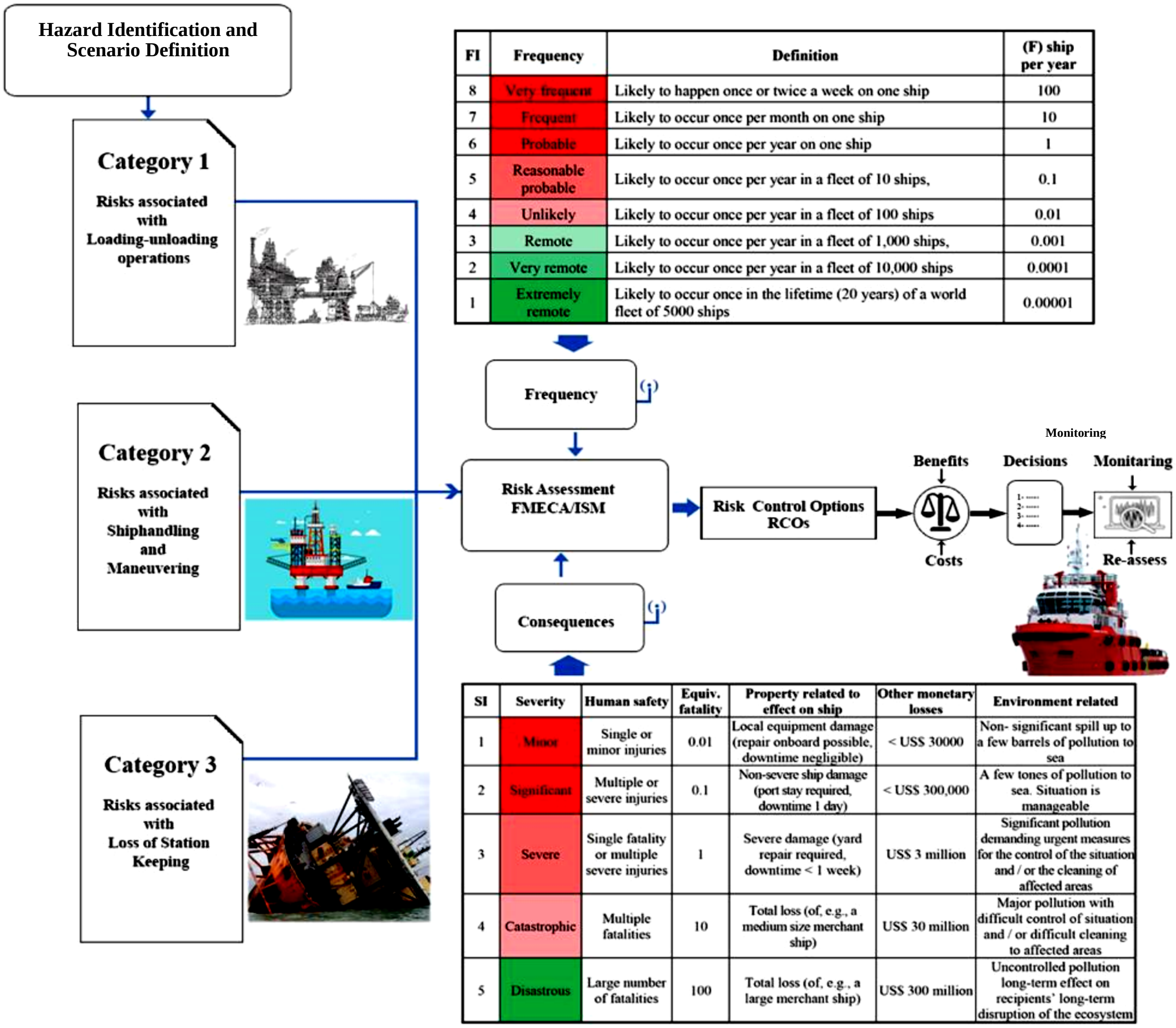
Figure (1): Flow chart of the formal safety assessment process (IMO, 2019)

There are other frameworks and methodologies, such as Hazard and Operability Studies (HAZOP), Failure Mode and Effects Analysis (FMEA), and Layers of Protection Analysis (LOPA), that are used in the offshore industry to assess and manage risks (Health and Safety Executive [HSE], 2015). Nonetheless, this research adopts the FSA methodology, which Where the FSA represents a baseline for the proposed methodology because of its comprehensiveness, support in early identification of potential failures and compliance with regulations.

Methodology for identifying, analyzing and evaluating the risks of human error caused OSV-offshore installation collisions

Figure (2) presents the organizational framework for risk management in attendant vessel operations within the 500m zone. Thus, the first steps included hazard identification and scenario definition. The following categories of risk scenarios were taken into consideration: (1) cargo handling and personnel transferring (CH), (2) ship handling and maneuvering (SH) and (3) loss of position keeping (SK).

The methodology proposed analyzes and evaluates these risks using a combination of quantitative and qualitative methods. It takes into account quantification of the frequency of occurrence of an event and its associated consequences (Brannen, 2017).



FI	Frequency	Definition	(F) ship per year
8	Very frequent	Likely to happen once or twice a week on one ship	100
7	Frequent	Likely to occur once per month on one ship	10
6	Probable	Likely to occur once per year on one ship	1
5	Reasonable probable	Likely to occur once per year in a fleet of 10 ships,	0.1
4	Unlikely	Likely to occur once per year in a fleet of 100 ships	0.01
3	Remote	Likely to occur once per year in a fleet of 1,000 ships,	0.001
2	Very remote	Likely to occur once per year in a fleet of 10,000 ships	0.0001
1	Extremely remote	Likely to occur once in the lifetime (20 years) of a world fleet of 5000 ships	0.00001

SI	Severity	Human safety	Equiv. fatality	Property related to effect on ship	Other monetary losses	Environment related
1	Minor	Single or minor injuries	0.01	Local equipment damage (repair onboard possible, downtime negligible)	< US$ 30000	Non- significant spill up to a few barrels of pollution to sea
2	Significant	Multiple or severe injuries	0.1	Non-severe ship damage (port stay required, downtime 1 day)	< US$ 300,000	A few tones of pollution to sea. Situation is manageable
3	Severe	Single fatality or multiple severe injuries	1	Severe damage (yard repair required, downtime < 1 week)	US$ 3 million	Significant pollution demanding urgent measures for the control of the situation and / or the cleaning of affected areas
4	Catastrophic	Multiple fatalities	10	Total loss (of, e.g., a medium size merchant ship)	US$ 30 million	Major pollution with difficult control of situation and / or difficult cleaning to affected areas
5	Disastrous	Large number of fatalities	100	Total loss (of, e.g., a large merchant ship)	US$ 300 million	Uncontrolled pollution long-term effect on recipients' long-term disruption of the ecosystem

Figure (2): The organizational framework of risk management; OSV-offshore installation collision

The aforementioned quantification of frequency of occurrence of an event and its consequences is transformed into frequency indices and severity indices, which serve as the basis for determining the risk indices. Subsequently, these indices are utilized to assess the risk to human life, to the environment, to the cargo and to the ship.

Then, risk analysis stage follows, which aims to develop an understanding of the vessel's risks and provide input data for the evaluation stage. Risk analysis involves assessing the two key components: probability/frequency and severity. Additionally, other relevant attributes are considered. This comprehensive risk analysis process incorporates both qualitative and quantitative impact assessment for each risk scenario category associated with attendant vessel-offshore installation collisions, considering human errors and their underlying factors. Once the risk analysis stage is completed, it is straight forward to evaluate the risk index using the equation:

$$\mathbf{R = F \times C} \quad (1)$$

where **R** is the risk, **F** the frequency, and **C** the consequence(s). Alternatively, the logarithmic form can also be used:

$$\mathbf{Log\ (R) = log\ (F) + log\ (C),} \quad (2)$$

or simply

$$\mathfrak{R} = \mathfrak{F} + \mathfrak{C}, \quad (3)$$

where $\mathfrak{R}$ is the risk index, $\mathfrak{F}$ the frequency index, and $\mathfrak{C}$ the consequence index (Skjong, 2002). Then, the hazard and scenarios are ranked accordingly, the process of proposing RCMs for mitigating the impact after most hazardous scenarios practiced. This process is complemented by a cost-benefit analysis, which aids in establishing a set of useful criteria for decision-making. Decisions are made with consideration for the broader context of risks, risk barriers and the risk tolerance of stakeholders, thereby complementing the overall risk management process.

Details of the Implementation of the FSA Methodology

Expert opinion demonstrates that risk management is an ongoing and iterative process that occurs throughout the entire duration of an activity. This process follows a cyclical nature and consists of five essential stages: establishing the organizational context and planning for risk, identifying hazards, conducting risk analysis (including quantitative, semi-quantitative, and qualitative approaches), establishing risk management strategies, and implementing monitoring and control measures (Goerlandt & Montewka, 2015). The proposed methodology in this study incorporated multiple approaches for risk planning, identification and ranking of hazard scenarios. First, experts identify the most significant operation scenarios, specifically focusing on collisions between attendant vessel and platforms caused by human errors and related factors. Historical events serve as primary data, combined with experts' judgment to assess risks.

To rank the contributing factors, the methodology recommends utilizing FMECA, an analytical method employed in the evaluation of mechanical and electrical systems to assess the potential consequences and probability of failure (Stavrou & Ventikos, 2015). Primarily, FMECA serves as a quantitative and qualitative tool for expert judgment during workshop-based sessions, which encompasses the following steps:

(i) Process identification, (ii) Listing operation function, (iii) Describing failure mode, (iv) Describing failure effect, (v) Describing failure causes, (vi) Describing failure probability, (vii) Describing failure severity, and (viii) Assigning risk priority number. to identify, evaluate, and prioritize pertinent hazards.

In this context, a group of experts is presented with specific questions pertaining to the object or system being analyzed, such as identifying potential failures, estimating their frequency, and

evaluating their severity. FMECA primarily focuses on conducting thorough analyses to assess system reliability and inform decision-making processes.
On the other hand, ISM is a widely recognized methodology used to establish relationships among specific components that address problems or raise concerns. Complex situations often involve interconnected aspects and considering each element in isolation may not accurately capture the overall situation. ISM helps provide a clearer understanding of the relationships between different components, both direct and indirect, which contributes to a more comprehensive depiction of the situation. By employing ISM, it is possible to gain insights into how individuals perceive these linkages in a general sense (Attri et al., 2013). Implementation of ISM involves the following steps (Vinodh, 2021): (i) Identifying structural self-interaction matrix, (ii) Developing initial reachability matrix, (iii) Establishing final reachability matrix, (iv) Levelling partition, (v) Developing a digraph, and (vi) modifying the ISM model.
In the current methodology, therefore, both FMECA and ISM tools are used for ranking the contributing factors and the results obtained are compared. This comparison is meant to aid in decision making regarding the ranking of operation types concerning human error and their underling factors.

The next stage of the methodology includes risk assessment. For such an objective, the framework recommends utilizing the widely adopted Fault Tree Analysis (FTA) tool to evaluate the root causes of accidents down to the UFs. Hence, FTA helps recommend Risk Control Measures (RCMs) that would subsequently reduce/mitigate risk of collision with emphasis on the most recurring causes of hazards associated with human error and UFs.
As per the International Association of Oil and Gas Producers (IOGP, 2010) provided by the Bureau of Safety and Environmental Enforcement [BSEE], (2023). Fault Tree Analysis (FTA) is a logical framework that defines the sequence of events required for an undesirable improper event to occur. In FTA, the undesirable event threat is usually placed at the top of the diagram. The analysis involves the use of gates to represent the relationship between events at different levels (IOGP, 2010).

There are two common types of gates in FTA: (a) OR gate (the event above this gate occurs if any one of the events connected below it occurs), and (b) AND gate (the event above this gate occurs only if all of the events connected below it occur simultaneously).
By implementing all the previous steps using the recommended methods and tools, the framework becomes complete. Hence, the proposed methodology is comprehensive in the sense that it embeds a mixture of both inductive and deductive approaches, and also uses qualitative and quantitative designs, which matches with the realism philosophy and the mixed approach that was selected to support decision making to improve safety (Smart, 2014).

Results and Discussion

The primary data required for FMECA analysis was collected via brain storming and in-person discussion sessions from a group of experts who were selected based on their experience in the offshore industry to identify the different operation hazard scenarios and later to conduct FMECA;

the group consisted of five attendant vessel captains. The years of experience for the individual experts ranged from 15 to 25 years. Since those experts came from different time zones and remote locations, zoom internet video sessions were carried out according to time suitability for the experts.

On the other hand, the secondary data was collected from IOGP reports. This data was in the form of historical attendant vessel -platforms collision accidents and incidents and was used to identify three different groups of hazard scenarios (G_1, G_2 and G_3). Group G_1 summarizes Loss of Station Keeping (SK) (8 scenarios), group G_2 Cargo Handling (CH) and personnel transferring (8 scenarios), and group G_3 Ship Handling (SH) and maneuvering (16 scenarios). The current paper is concerned with group G_2 only, consisting of eight scenarios, as shown in Table (1). These were further compressed to three scenarios only, namely CH-1, CH-2 and CH-3, as shown in Table (2), to reduce the effort provided by the experts and the time they spend to structure the FMECA and FTA analyses. Furthermore, the data used did not have accident reports including details about all the CH scenarios. In addition, the process of compression was essentially proposed by three experts. Moreover, Table (3) lists twenty eight underling factors of human errors, together with their individual definitions.

Table (4) illustrates the details of the FMECA session based on three accidents in the Gulf of Mexico (GOM). The table lists the risk index in each case, based on frequency and severity indices in terms of Health and Safety (H&S) and Environment (E),each corresponding to one CH scenario, in accordance with Loer et al., (2007). It also lists the failure causes (underling factors) associated with each accident based on Table 3. As may be seen from the RI values, the second scenarios CH-2 is the most risky scenario, followed by CH-3 and CH-1.

Table (1): Cargo handling (CH) and personnel transferring scenarios

N0.	Scenario
1	Bulk hoses of the wrong length
2	Crane limited to one side
3	Change in work scope (i.e., extended duration, hose work, etc.)
4	Unjustifiable prolonged periods near risers or other sensitive area
5	Idle time alongside installation “non-productive time”
6	Inadequate carne outreach
7	Unjustifiable prolonged periods of hose connections
8	Excessive stand-by time for the next lift or remaining connected to bulk hose

Table (2): Comprressed cargo handling (CH) and personnel transferring scenarios

Code	Scenario	Explanation
CH-1	**During cargo handling, the crane is Limited to the weather side (upwind) or the bulk hoses are of the wrong length or crane is limited outreach (poorly sited)**	The vessel is forced to work on the weather side (upwind) side in marginal weather due to the crane on the lee wind side being occupied with another operation or malfunctioning. In addition, the inadequate length of the bulk hose or the crane being poorly sited or the vessel has to handle too heavy lifts forces vessels to work too close to the installation to compensate for length and allow flexibility of hose or reach of crane increasing the risk of collision especially under the sudden changes of current, swell and wind.
CH-2	**The vessel spends excessive Non-Productive time alongside installation/ standby time for the next lift or remaining connected to bulk hose, or there is change in work scope during cargo handling with the rig (i.e., extended duration, hose work)**	The extra time spent by the vessel near the installation being on the DP System poses increased risk as any malfunction may occur at any moment. Moreover, the unplanned change in cargo handling plan by adding tasks that overload the vessel's captain/ chief officer in duty, and therefore could result in multiplied risk of error leaving vessel under collision risk due to weather and other failure factors.
CH-3	**There is poor communication between vessel and installation during cargo handling.**	Poor communication fails to prompt good planning for back cargo manifest problems such as dangerous cargo handling. This adds to the spent time to re-arrange cargo plan, and thus the collision risk.

Table (3): Definitions of UFs of human errors

No.	Underlying factor	Definition
1	**Bad visibility**	During an approach to the platform in dense fog or other weather conditions that reduce the visibility, the vessel cannot rely on visual lookout. Operating the radar and AIS equipment will then be amore important task and should have dedicated personnel. Bad visibility is a constant variable that cannot be improved or avoided.
2	**Blackout**	A complete loss of power resulting from damage or equipment failure in a power station, power lines or other parts of the power system (Babicz, 2015)
3	**DP incident**	A major system failure, environmental or human factor which has resulted in loss of DP capability. (International Marine Contractors Association [IMCA], (2013).

No.	Underlying factor	Definition
4	**DP undesired event**	A system failure, environmental or human factor which has caused a loss of redundancy and/or compromised DP capability (International Marine Contractors Association [IMCA], (2013).
5	**Drifting collision (Drift On)**	A collision of a vessel drifting towards the installation as it has lost its propulsion or steerage or has experienced a progressive failure of anchor lines or towline and its drifting only under the influence of environmental forces (Drift On) (Oltedal, 2012).
6	**Fatigue**	A reduction in physical and/or mental capability as the result of physical, mental or emotional exertion, which may impair nearly all physical abilities including: strength; speed; reaction time; co-ordination; decision making, or balance (IMO, 2000).
7	**Handling error in collision avoidance**	A process in which one ship (manned or unmanned) departs from its planned trajectory to avoid potential undesired physical contact at certain time at future (Huang et al., 2020).
8	**High workload**	Both high physical workload and high mental workload (such as tasks with excessive demands on attention) may lead to fatigue (IMO, 2019).
9	**Human control failure**	An inappropriate or undesirable human decision or behavior that leads to unwanted outcomes or has significant potential for such an outcome (Grech et al, 2008).
10	**Inadequate familiarization period**	The new crew not taking enough time to be familiarized with their duties and important information about the ship
11	**Inadequate knowledge of regulations/standards**	Lack of knowledge or understanding of required regulations due to inadequate regulations/ standards: experience and/ or training. Examples of possible regulations; company policies and standards, national and international regulations, maritime regulations of other port States, local jurisdiction regulations, shipboard regulations, cautionary notices, chart notations, or labeling (IMO, 2000).
12	**Inadequate knowledge of ship operations**	Lack of knowledge resulting from inadequate experience, ignorance of regulations, inadequate knowledge of procedures, inadequate training, and/or unawareness of role/task/responsibility. Examples of areas where an individual might lack knowledge: navigation, seamanship, propulsion systems, cargo handling, communications, and weather (IMO, 2000).

No.	Underlying factor	Definition
13	**Inadequate situational awareness**	Not knowing, due to inadequate experience, lack of communication, co-ordination and/or training, the current status of the ship, its systems, or its environment. Examples include lack of knowledge of location, heading or speed and lack of knowledge of status of ongoing maintenance onboard (IMO, 2000).
14	**Inadequate technical knowledge**	Not having, due to inadequate experience and/or training, the general knowledge which is required for the individual's job onboard. Examples include navigation, seamanship, propulsion systems, cargo handling, communications, and weather (IMO, 2000).

Table (3): Definitions of UFs of human errors (Cont'd)

No.	Underlying factor	Definition
15	**Inappropriate transfer of command**	Formal change of command on the bridge is a way to remove confusion as to who is in charge, and inappropriate transfer of command causes unclear roles and responsibilities which in turn can lead to important tasks (e.g. monitoring, steering) being left unattended. Related RIFs can be "adherence to procedures" and "organizational safety culture".(Oltedal, 2012)
16	**Lack of awareness**	Described as when the officer on the bridge for some reason is not aware of the offshore installation, the collision course or the position of the ship itself. This means that no actions to avoid a collision are undertaken on the ship (Geijerstam, and Svensson, 2008).
17	**Lack of communication or co-ordination**	Not making use of all available information sources to determine current status. This may be the result of a lack of initiative on the part of the individual or a lack of initiative and/or co -operation on the part of others. Examples of poor communication/co-ordination include: poor communication between bridge officers, poor communication with pilots, and poor deck-to-engine-room co-ordination (IMO, 2000).
18	**Lack of maintenance**	"Failure to maintain a ship and its equipment in a safe and efficient condition can have serious consequences, including loss of life, injury, pollution and damage to the marine environment, as well as financial losses for ship owners and operators (IMO, 2020).

19	**Lack of system understanding**	Lack of system understanding is listed as an underlying factor related to the detection of the autopilot status, but this can also be a factor for the watchkeeper when using the radar or AIS. Lack of system understanding can point to organizational deficiencies, in the same way as lack of familiarity with emergency steering. Related RIFs can be "competence", "familiarity" and “competence management".
20	**Layout and Design of the Bridge**	The bridge of a ship is intended to be the heart of the vessel and must provide a clear and unobstructed view of the surrounding area. the primary purpose must be fulfilled (Menon, 2020).
21	**Marginal Weather**	(Described by the significant wave height and wind force), up to which the ship can fulfill the criterion. For manoeuvrability in adverse conditions, a convenient and frequently used measure is the marginal (i.e., maximum) weather severity (Shigunov, 2018).
22	**Non-compliance with safety procedures**	Following the procedures is important for the safety, but this failure is very wide and basically not telling us anything of what went wrong. If a vessel is colliding with a platform, there will always be a breach of the procedures at some level. Addresses this as an underlying factor in all the major supply vessel collision accidents. Related RIFs can be "adherence to procedures" and "organizational safety culture". (Oltedal, 2012)
23	**Operator error**	An action which is not in accordance with planned procedures (Taylor, 2005).
24	**Poor visibility combined with undetected radar fault**	Any condition in which visibility is restricted by fog, mist, falling snow, heavy rainstorms, sandstorms or any other similar causes (Lloyd’s Register Rulefinder, 2005).
25	**Powered collision (drive on)**	Collision between a vessel moving under power and an installation (Drive On) (Oltedal, 2012).
26	**Technical failure**	A failure that is not affected directly by humans in the specific situation. This can for example be a production failure that arises during the usage of equipment but not related to the user (Geijerstam, and Svensson, 2008).
27	**Weather pattern**	Weather patterns risk refers to the likelihood of a vessel encountering adverse weather conditions that may pose a danger to the safety of the vessel, its crew, and the environment. These adverse weather conditions may include storms, hurricanes, heavy seas, high winds, and other weather-related phenomena that can impact the safe operation of a vessel. (IMO, 2017)
28	**Weather side**	the side (as of a ship) to windward **:** the side exposed to weather (https://www.merriam-webster.com)

Table (4): FMECA session and classification of hazards related to cargo handling and Personnel Transferring (CH) Category

Title: Attendant vessel HAZID | **Project :** RCMs to Reduce Risk of Collision Between Attendant Vessels and Offshore Installations

Date: 25.09.2023 | **Process :** **Cargo Handling (CH) And Personal Transferring Category**

Legend: 1- (SK). 2- (CH) 3- (SH)

Description of Function		Failure Effect			Failure Cause	Scenarios		Frequency index, (FI)		Consequence index, (SI)		Risk index, (RI)		Remarks
Accident (Scenarios)	Failure Mode Description	Immediate		Ultimate		Sc.	Category	H&S	E	H&S	E	H&S	E	
		To vessel	To Platform											
Crew boat 05/06/2013 GOM (CH-1)	Collision	Bent the back of the boat where it was under the platform.	This bent the piping, grating, and braced on the platform upwards several inches.	As a result, the back of the boat bent while being under the boat landing. The platform braced several inches upwards where piping, gratings suffered significant bent.	7- Handling error in collision avoidance 13- Inadequate situational awareness. 14- Inadequate technical knowledge. 19- Lack of system understanding 28- Weather side	2 3	G_2 G_3	3	2	4	2	7	4	1- Asset /Business Impact 2- Damage to both Vessel/Platform 3- No injuries or fatalities 4- No spill
M/V Warren G 06/06/2013 GOM (CH-2)	Collision	Damage to the vessel	The boat landing was damaged and appears to have moved to the north by as much as three feet. has a three-foot dent on Port Stern side	As a result, one individual was pushed against a handrail by the wave, the boat landing noticed to be moved three feet to the north and the attendant vessel has a three-foot dent on Port Stern side.	7- Handling error in collision avoidance 13- Inadequate situational awareness. 14- Inadequate technical knowledge. 19- Lack of system understanding 28- Weather side	2 3	G_2-G_3	5	3	3	3	8	6	1- Asset /Business Impact 2- Damage to both Vessel/Platform 3- Single injury 4- No spill
M/V Danielle Callais 05/12/2010 GOM (CH-3)	Collision and hit	A swell hit the Danielle pushing the vessel into the rig's port leg		Both rig and vessel suffered physical damage as a result.	7- Handling error in collision avoidance 13- Inadequate situational awareness. 14- Inadequate technical knowledge. 19- Lack of system understanding 28- Weather side	2 1	G_2 G_3	3	3	4	2	7	5	1- Asset /Business Impact 2- Damage to both Vessel/Platform 3- No injuries or fatalities 4- No spill

Although the three scenarios have been ranked using the FMECA, the process falls short of providing the influence of the scenarios on each other. Therefore, ISM model was used for two reasons: (I) to further confirm the results obtained from the FMECA and (ii to measure the mutual influences of the scenarios on each other. The ISM **re**sulted in the digraph shown in Figure (3), which illustrates the sub-dimensions of CH category. It is observed that CH-2 is considered as an influencing sub-dimension on the other sub-dimensions. On the other hand, the sub-dimensions, CH-1 and CH-3 are of equal ranks.

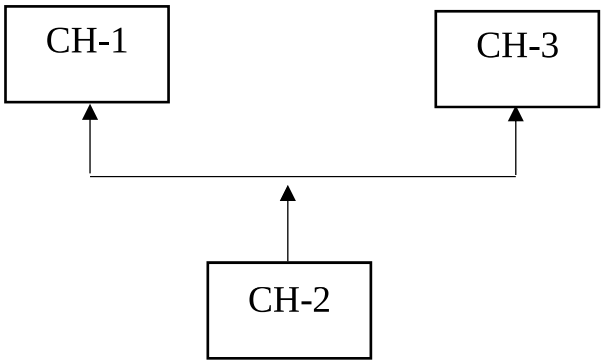


Figure (3): Digraph for cargo handling category sub-dimensions

Contrasting these results to those of FMECA, it becomes clear that both models have provided similar ranking, although RI values related to environment ranked CH-3 above CH-1. The experts, however, tended to be more in favor of the ISM results, because they show the mutual influences, as has been explained above. To summarize, both FMECA and ISM have shown the CH-2 is the most hazardous scenario, followed by CH-3 and CH-1. It remains to further investigate these accidents more deeply to single out the route cause (underlying factors) behind them; this was attempted implementing the FTA. It was felt, however, that using the scenarios of Table (1) would provide more accurate results compared to using the compressed scenarios of Table (2).

Figure (4) demonstrates the FTA for improper cargo handling and personnel transferring as the second threat (T2) that leads to the top event of collision between attendant vessel and offshore installation. The sequence of analysis proceeds from the bottom level of UFs to the next level up using the ‘AND’/‘OR’ gates. The figure shows that the top hazardous scenario is spending idle time alongside installation. The idle time is exemplified by time spent waiting for next lift, personnel transfer or to disconnect cargo hose. It may also be because of change in work scope, for instance by adding tasks. The previous probable reasons may be also combined with any malfunction in the DP system or weather factor that can cause the vessel to collide with the offshore installation closest to the vessel.

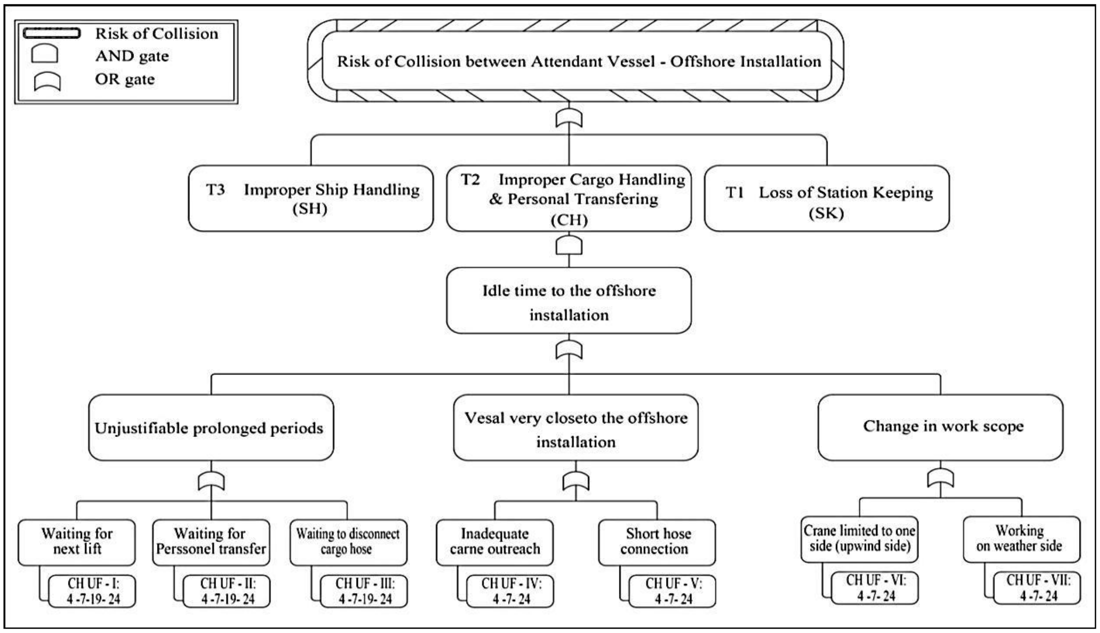


Figure (4): FTA analysis for CH scenarios

Generally, the current endeavor has shown that the causes of marine accidents primarily depend on more than one category of human factors. Additionally, it has confirmed that by addressing and influencing those human factor categories, the frequency of marine accidents can be reduced, leading to an overall improvement in shipping safety. Thus, after identifying the top UFs contributing to attendant vessel -installation collisions, future work would recommend a set of control measures to reduce the risk level.

Comparison of FMECA and FTA results show that 'Inadequate knowledge of ship operations' and 'Handling error in collision avoidance' came on top of the causing UFs in both analyses. It also identified many similarities in the top five causing UFs. This was important to validate the results, identify the critical UFs, and propose appropriate RCMs accordingly.

Furthermore, the researcher sought to validate the above results of other researchers; however, there is much rarity in available data that are related to quantifying UFs of HEs as contributing causes to maritime accidents. This rarity is even greater when it is specified to attendant vessel-installation collisions.

Conclusion

Collisions between attendant vessels and offshore installations during cargo handling and personnel transferring pose a substantial risk within the oil and gas industry. Human factors significantly contribute to these incidents. While several methodologies and tools have been created to evaluate and mitigate these risks, there are still shortcomings and constraints in the existing frameworks. To mitigate these risks effectively, it is crucial to address the human factors involved, establish comprehensive guidelines for risk assessment and management, and continuously explore new technologies through ongoing research. By taking these important steps and implementing the proposed framework, the aim to minimize the likelihood and severity of collisions between attendant vessel and offshore installations can be achieved. It is also worth mentioning that the proposed methodology and framework can be employed by other researchers in different applications to enhance safety in the maritime industry, or elsewhere.

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