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STUDENT REPORT

Reducing Slips, Trips, and Falls in the Maritime Industry and Offshore Installations - Best Practice

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Abstract

Slips, trips, and falls (STF) are the primary source of workplace injuries. Despite many measures set out by legislative requirements, best practices guidelines, and organizational policies to prevent STF in the maritime industry and offshore installations, the number of these accidents is still high. The project's objective was to identify the causes behind the STF and identify the measures that can be implemented to reduce further the STF in the maritime industry and offshore installations.

Triggers and potentially harmful events that could cause STF were identified in Preliminary Hazard Analysis and Root Cause Analysis. The obtained information generated input data for the Bowtie diagram and an Event Tree Analysis, where the consequence and likelihood assessment and barriers-safeguards analysis were performed. During the risk analysis process was revealed that one of the most critical factors affecting STF is the slipperiness of the handrails, guardrails, walkways, decks, stairs, and ladders' surfaces. The fatalities' overall risk of STF due to slip for every shift for the maritime industry and offshore installations workers was calculated. The Risk Management Option (RMO) aimed to reduce these surfaces' slipperiness was proposed, monitored, and evaluated. The RMO consists of KAG safety rails and anti-slip floor, stairs, and ladders surfaces solutions.

The probability of none slip or micro slip in potential slip event is increased with implementing an RMO by 9.9 % compared to without RMO scenario. The probability of slip, slide, or fall in a potential slip event is reduced from 10 % to 0.1 %. When comparing the fatalities overall risk of STF due to slip for every shift, it was calculated that this risk is reduced by 5.94×10^{-4} and is 1.1×10^{-6} with implementing the RMO. That means that the risk management objective to reduce the STF is achieved.

The technological solutions aimed to reduce the slipperiness of working-walking and railing surfaces can further reduce the STF due to slip in the maritime industry and offshore installations. However, for complex treatment of STF, the influence of individuals' human behavior and the organization's safety culture shall be thoughtfully investigated.

Preface

This master thesis project is written in the 4th semester of a 2-year master study program in Risk and Safety Management as a final 30 ECTS assignment. The purpose of the study curriculum is to apply the principles and complement the knowledge gained in the first three semesters of the master's program.

The project's objective is to present a qualitative, research-based approach to identifying the causes behind the STF, analyzing the current safety and health measures to prevent STF, and developing a strategy to reduce further STF in the maritime industry and offshore installations.

The project's outline is as follows:

- Chapter 1: Introduction
- Chapter 2: Establishing the Context
- Chapter 3: Methodology
- Chapter 4: Risk Assessment
- Chapter 5: Risk Treatment
- Chapter 6: Risk Monitoring
- Chapter 7: Discussion
- Chapter 8: Conclusion

All citations found in the report are stated in *cursive* and marked with citation marks.

Acronyms are written in brackets after the first use of the word or term. Hereafter only the acronym is used, e.g., Slips, Trips, and Falls – STF.

Figures are numbered, briefly explained, and refer to the source of origin.

References to the appendix are referred to in brackets, followed by the number of the appendix, e.g. (Appendix 1). All sources are referenced by the American Psychological Association citation style (APA), which usually includes a link to the source, date, name, author, etc.

Blank pages are left intentionally regarding printing layout.

Thanks to my supervisors José Guadalupe Rangel Ramirez and Hanna Barbara Rasmussen, for their support and guidance throughout my master thesis project's work and writing.

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Tanja Rasmussen

8th of January

ACRONYMS

Acronym	Definition
ACSNI	Advisory Committee on the Safety of Nuclear Installations
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
BST	Basic Safety Training
BOSIET	Basic Offshore Safety Induction and Emergency Training
COF	Coefficient of Friction
DMA	Danish Maritime Authority
ETA	Event Tree Analysis
FOET	Further Offshore Emergency Training
GDPR	General Data Protection Regulation
GRF	Ground reaction Force
GWO	Global Wind Organization
IMO	International Maritime Organization
ISPS Code	International Code for the Safety of Ships and Port Facilities
LTI	Lost Time Incidents
MTC	Medical Treatment Cases
OPITO	Offshore Petroleum Industry Training Organization
OSHA	Occupational Safety and Health Administration
PHA	Preliminary Hazard Analysis
PPE	Personal Protective Equipment
PSST	Personal Safety and Social Responsibility
PST	Personal Survival Techniques
RCA	Root Cause Analysis
RCOF	Required Coefficient of Friction

RMO	Risk Management Option
RWC	Restricted Work Cases
SCT	Social Capital Theory
SOLAS	Safety of Life at Sea
STCW	International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers
STF	Slips, Trips, and Falls
STFA	Slipping, Tripping, and Falling Accidents
STFL	Slip, Trip, and Fall on the Same Level
TSC	Total Safety Culture
UK	United Kingdom

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1 Introduction

Slips, trips, and falls (STF) are the primary source of workplace injuries (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Health and Safety Executive, 2020). The harsh environment for the maritime industry and offshore installations includes extreme weather conditions, such as strong wind, rain, ice, and working conditions that decrease the safety situation, such as vessel motion, loads carrying, and slippery surfaces due to spilled chemicals, oil, water, that significantly increased occupational risks of slip, trip, and falls (Song, G., Khan, F., Wang, H., Leighton, S., Yuan, Z., Liu, H., 2016).

Usually, the maritime and offshore workers perform various industrial tasks above or at ground level during maintenance, production, drilling, etc. Therefore, their activities involve using ladders, gangways, and steps that allow them to quickly move from one deck of the ship or offshore facility to another or out onto the higher or lower ground. However, stairs, steps, ladders, decks, and walkways are dangerous and cause many injuries or even death on board ships and offshore installations. STF onboard Danish-flagged ships accounted for approximately 27% of all maritime accidents during the 2013-2016 (Appendix 1: Electronic Interviews). The United Kingdom (UK) Offshore Statistics & Regulatory Activity Report 2019 showed that slips, trips, or falls on the same level were the most prevailing injury type in 2019 occurring in offshore installations, which is illustrated in figure 1 (Health and Safety Executive, 2020):

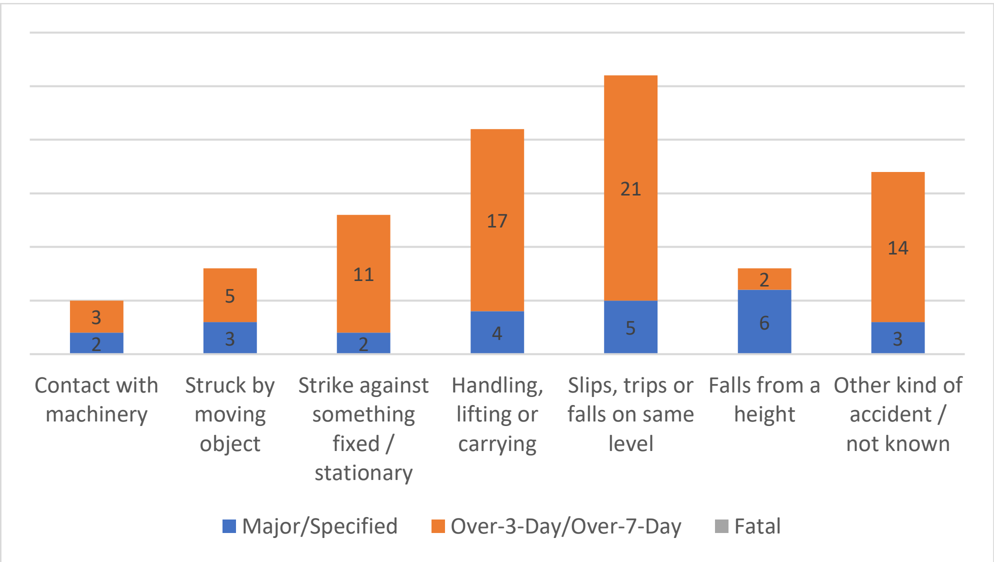

Figure 1: Reported injuries (offshore) by kind of accident in 2019. Source: (Health and Safety Executive, 2020)

As seen in figure 1, slips, trips, or falls on the same level accounted for 26,5% of all reported injuries. Besides, falls from height accounted for 8% of all reported injuries. Thus, in total, slip, trip, or falls on the same level and falls from a height are responsible for 34,5% of all reported injuries in the UK that occurred in offshore installations. From them, 67,6% were over-3-day/over-7-day injuries, and 32,4% were major/specified injuries (Health and Safety Executive, 2020).

The causes of slip, trip, and fall accidents began to be investigated in the early 1980s and continue to this day. Therefore, nowadays, the causes behind the STF are well-known. Hence, numerous measures to reduce STF are implemented in the maritime industry and offshore installations and, in general, at any workplace. However, the number of these accidents is still high, and their gradual decline is not observed in recent years, as shown in figure 2.

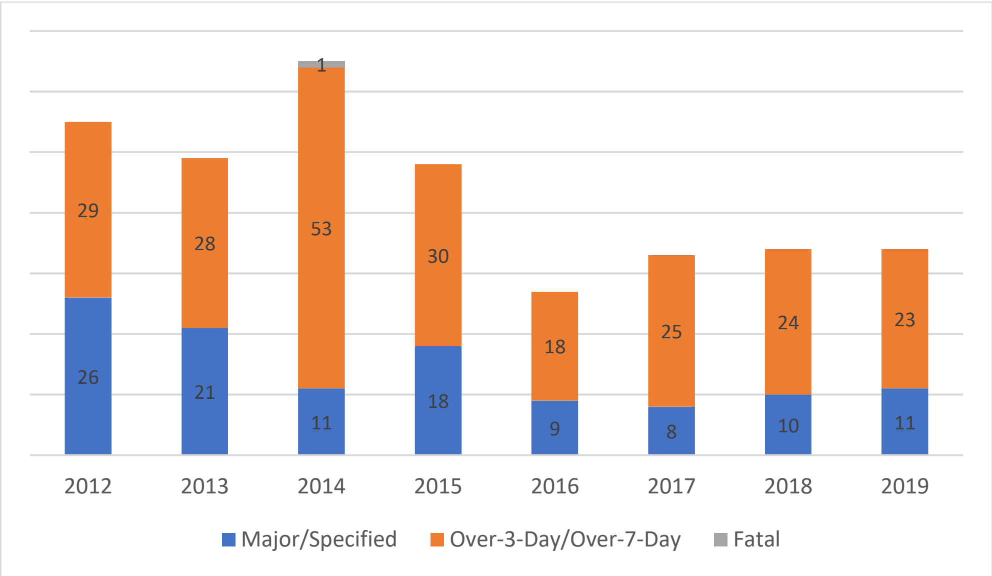

Figure 2: Reported injuries and injures severity caused by a slip, trip, or falls accident on the same level and falls from a height for the period from 2012 to 2019. Source: (Health and Safety Executive, 2020)

1.1 Project scope

The project's objective is to present a qualitative, research-based approach to identify the causes behind the STF, analyze the current safety and health measures to prevent STF, and develop a strategy to reduce further STF in the maritime industry and offshore installations. This project embraces and distinguishes the slips, trips, and falls occurring on the same level from falls from a height, including falls on the stairs as low fall accidents (below two meters). However, there is a lack of information, particularly on STF offshore and maritime. Therefore, the STF information used for this project is based on data from the general STF literature. Thereon, factors associated with a specific working environment that affect the STF were analyzed and applied.

The project focuses on commercial Danish-flagged ships and offshore wind turbines, offshore oil and gas facilities in the Danish part of the North sea during the operational phase of their life circle. However, the offshore statistics of the STF that have been used in this project were taken for the UK due to their online availability.

Both maritime industry and offshore installations operate under the same harsh environmental conditions as extreme weather conditions, vessel motion, slippery surface, etc. Therefore, the causes of slips, trips, and falls in these two industries are generally very similar. Thus, the analysis of slips, trips, and falls in this project focuses on the maritime industry and offshore installations.

A case study was carried out to investigate the organizational causes of STF and suggest a possible strategy to reduce these accidents further. As it can be seen from chapter *4 Risk Assessment*, there are many causes of STF. However, the strategy to reduce further risk of STF is focused only on STF due to slips. The reason for that is that most of the other possible causes are already well-regulated by different preventive measures such as legislative requirements and the organization's policies and rules. However, there are no concrete, existing legislative requirements regarding the coefficient of friction of floor, stair, and ladder surfaces and rails grip ability. While, the slipperiness of the rails, stairs, walkways, and deck surfaces was revealed as the leading cause of the STF. Hence, the practical test within the case studies was conducted to see how technological solutions influence the STF caused by a slip, particularly the slippery surfaces.

1.2 Delimitations

This subchapter describes the boundaries that have been established for this project.

Human error and distraction were identified as significant contributors to the STF. However, they are very complex and therefore require detailed researches and analysis. Consequently, due to limited time for writing this project, human error and distraction are explained briefly but not analyzed and investigated in detail within this project.

When it comes to falls from height, the project describes work at height that includes ladders and does not include scaffolds, platforms, etc. The project does not analyze or separate the details of falls from height in the marine industry and offshore installations. The analysis of falls from height in the wind, oil, and gas, or maritime industry is the subject for an individual project, as it embraces many factors associated with each industry's specific activities. Thus, this project describes and analyzes in a somewhat generalized way the reasons behind the STF and their preventive and mitigation measures during falls from a height for both the marine industry and for offshore installations.

When evaluating a proposed Risk Management Option (RMO), only a reduced risk and reduced number of accidents were considered. The costs and benefits are not included in this project's scope due to its limited time.

1.3 Problem statement

This project analyzed the current safety and health measures and their effectiveness in preventing STF and develop a strategy to reduce further the STF in the maritime industry and offshore installations. Through the literature reviews on STF phenomena, the main factors influencing its occurrence were identified and analyzed. Besides, the qualitative interviews within a case study allowed to investigate the critical organizational factors that influence the STF. Thus, the following problem statement question is arising:

What measures can be implemented to reduce further the slip, trip, and fall accidents in the marine industry and offshore installations?

Five sub-questions were listed to answer the problem statement:

- What are the most critical factors that influence the STF accidents in the maritime industry and offshore installations?
- What are the legislative requirements for the prevention of STF accidents in the maritime and offshore industries?
- What are the possibilities and challenges to reduce further the slip, trip, and fall accidents in the maritime and offshore industry?
- What is the acceptable level of risk for STF accidents in the maritime and offshore industries?
- Are the technological solutions the best way for reducing STF accidents in the maritime and offshore industry?

2 Establishing the Context

This chapter describes the most relevant terms used in the project, background information on STF phenomena in general, and identifies the most relevant stakeholders for reducing STF in the maritime industry and offshore installations. This chapter also provides an overview of the legislation involved in reducing STF in the maritime industry and offshore installations and briefly describes the organization's safety culture's influence on these accidents. The chapter aimed to determine all relevant factors in reducing STF in the maritime industry and offshore installations used as background information for conducting a case study.

2.1 Definitions and terms

The following subchapter describes the most relevant and essential terms for this project. Since the project is built upon an ISO 31000 framework, the terms have been defined following this framework and supplemented by books of Marvin Rausand's "Risk Assessment" and Charles Yoe's "Principles of Risk Analysis."

Risk

Risk is defined according to ISO 31000 as (International Organization for Standardization, 2018): " *effect of uncertainty on objectives*." The effect is a deviation from expected. The effect is understood as both positive and negative by bearing in mind that positive effect is often described as possibilities, while negative as a threat. Objectives can have distinct aspects and categories and apply at different levels. Risk is generally expressed in terms of risk sources, potential events, consequences, and likelihood (International Organization for Standardization, 2018).

According to Charles Yoe, the risk is defined as (Yoe, 2019): " *a measure of the probability and consequence of uncertain future events*." The risk is the chance of an unwanted outcome. A "chance" is usually created due to the lack of information about events that have not yet happened. Risk is often defined as an equation (Yoe, 2019):

$$\text{Risk} = \text{Probability} \times \text{Consequences}$$

Hazard

A hazard is something that may cause harm, such as human injury, loss of life, disability, property damage, financial losses, environmental damage, etc., to valued assets (Yoe, 2019).

Uncertainty

The National Research Council (2009) defined uncertainty in the following way (Yoe, 2019):

"Lack or incompleteness of information. Quantitative uncertainty analysis attempts to analyze and describe the degree to which a calculated value may differ from the true value; it sometimes uses probability distributions. Uncertainty depends on the quality, quantity, and relevance of data and on the reliability and relevance of models and assumptions."

Triggering Event

A triggering event is an event or condition necessary for a hazard to lead to an accident (Rausand, 2011).

Threat

The term threat belongs to the source and means of an attack of a particular type. A threat can be considered as any potential cause of an accident (Rausand, 2011).

Risk management

Risk management is the coordinated action of managing and controlling an organization's risks (International Organization for Standardization, 2018).

Stakeholder

A stakeholder is a person or organization who can affect or be affected by a decision or action (International Organization for Standardization, 2018).

Risk source

A risk source is an element that, alone or in combination, can give rise to a risk (International Organization for Standardization, 2018).

Event

An event is the occurrence or sequence of a specific set of circumstances. An event can be something that is expected that does not happen as well as something that is not expected that does happen. An event can occur one or more times and may have several causes and consequences. Besides, an event may be a risk source (International Organization for Standardization, 2018).

Consequence

A consequence is the result of an event that affects objectives. Consequences can be certain or uncertain and can have a direct or indirect positive or negative impact on objectives. The consequences may be pronounced qualitatively and quantitatively (International Organization for Standardization, 2018).

Severity

Severity may be determined as the seriousness of an event's consequences in terms of financial cost or categories, such as catastrophic, severe loss, significant damage, damage, or minor damage (Rausand, 2011).

Likelihood

The likelihood is the chance that something occurs. The term "probability" is often used as an equivalent of the term "likelihood." The probability may be defined, measured, or determined objectively or subjectively, qualitatively or quantitatively. Moreover, the probability may be described using generic terms or mathematically, such as probability or frequency over a given period (International Organization for Standardization, 2018).

Control

Control is a measure that maintains and changes risk (International Organization for Standardization, 2018).

Residual risk

The residual risk is defined as the risk that remains after implementing engineering, administrative and work control (Rausand, 2011).

Vulnerability

The vulnerability may be defined as the weakness of an asset or group of assets that can be utilized by one or more threat agents (Rausand, 2011).

Safety

"A state where the risk has been reduced to a level that is as low as reasonably practicable (ALARP) and where the remaining risk is generally accepted" (Rausand, 2011).

Accident

Marvin Rausand defines the accident as (Rausand, 2011): "*A sudden, unwanted, and unplanned event or event sequence that leads to harm to people, the environment, or other assets."*

Incident

Marvin Rausand defines the incident as (Rausand, 2011)*: " An unplanned and unforeseen event that may or may not result in harm to one or more assets."* Thus, as claimed by this definition, an accident is a specific case of an incident: that is to say, an incident that results in damage to assets (Rausand, 2011).

2.2 Slips, trips, and falls phenomena

According to the literature, the expression "slipping, tripping, and falling accidents (STFA)" was first presented in the early 1980s at a devoted international conference held in the UK. Later, the term "slip, trip, and fall (STF)" became widespread, including falls on the same level, falls from a height, and falls as a result of any other action (for example, moving a standing surface). However, most incident reports distinguish between slips, trips, and falls on the same level (STFL) and fall from a height. Besides, the last include falls on the stairs as low fall accidents (below two meters) (Scott, 2005) (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016). First of all, they are distinguished due to more severe consequences of falls from a height compared to falls on the same level. Secondly, the causes of falls from a height and STFL are different due to involving the change of height when walking the stair or climbing the ladders, and therefore, they have different biomechanics compared to STFL and require more elaborate measures to prevent fall accidents. Therefore, further analysis of slip, trip, and falls will highlight the difference between STFL and falls from a height.

Slip is a loss of balance as a result of too little friction or insufficient traction between the feet and floor surface. Based on the length of the slip, it can be distinguished three categories of slips such as "micro slip" (shorter than 3 cm), "slip" (as long as 8-10 cm), and "slide" (length exceeds 10 cm). While micro slips usually go unnoticed, a slip will lead to instinctive attempts to regain control over the posture, but the slide is likely to cause loss of balance leading to the fall. A trip occurs when the foot movement phase is unexpectedly interrupted due to insufficient ground clearance. In other words, a trip happens as a result of a foot striking or colliding with an object, a follow-on in a loss of balance, and commonly a fall. An unevenness of the walking surface of only 5 mm can be enough to trip over. Besides, unpredicted forced movement of the floor, which can occur while standing in a moving vehicle, can cause loss of balance, which will be enough to fall on the same level (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016).

Studies have shown that falls triggered by slips are the most common STFL. Therefore, further analysis will focus more on slips that can lead to falls, and slightly less on trips (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010)

Causes of slips, trips, and falls are very complex and required a comprehensive approach to analyze and treat them. Slips, trips, and falls causes comprise environmental and human factors.

Factors such as walking surface properties (e.g., surface roughness, compliance, surface unevenness, etc.), footwear, contaminants, elevation, grade, obstacles, uncovered cables, lighting, and climatic factors (e.g., rain, ice, snow, etc.) refer to environmental factors. While gait, anticipation, sensory health (such as vision, proprioception, somatosensory and vestibular), and neuromuscular health (e. g. low back pain, fatigue) are all human factors (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010) (Hanson, J. P., Redfern, M. S., and Mazumdar, M., 2010).

Although it shall be noted that the nature of the trips is more straightforward in comparison with slips. As mentioned above, the trip's occurrence depends on any obstacles (such as uncovered cables, clutter in a way, etc.) and unevenness of walking surface, which can unexpectedly interrupt foot movement and cause loss of balance resulting in a fall. In comparison, a slip's nature is more complex and requires more detailed analysis, which is described below.

One of the essential principles for establishing a floor-shoe interface's slip tendency is the relationship between friction required for the particular footstep being performed and the friction present at the floor-shoe interface (available friction). In theory, as long as the available friction is greater than required, a slip will not occur. Hence, biomechanical gait analysis is potentially a valuable tool in reducing slip-related fall accidents as it can identify potentially hazardous conditions for slipping. Besides, biomechanical gait analysis can be an essential contribution to setting available friction thresholds to determine if a shoe and walkway surface or a combination of both will be slip-resistant (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010) (Hanson, J. P., Redfern, M. S., and Mazumdar, M., 2010). Therefore, to understand the causes behind slips, trips, and falls and develop an effective approach to reduce these accidents, biomechanics of locomotion are explained in detail below.

Biomechanics of locomotion

Locomotion biomechanics is the most critical factor in preventing slip and fall-related injuries. Descriptions of the biomechanics of locomotion include ground reaction forces, lower limb joint moments, and kinematics. The most critical biomechanical parameters in slip and falls are the force interactions. To prevent fall accidents and slip tendencies, ground reaction force (GRF) and the required coefficient of friction (RCOF) are widely used as a standard measure for level gait analysis and stair climbing analysis. GRF is the force exerted from the ground on any contacting structures during all actions. When friction between the foot or sole of the shoe and the floor surface provides insufficient resistance to withstand the forward or backward forces that occur during the particular step process, that is, the interaction between the person's (foot or shoe sole) and the floor, slip occurs. GRF consists of vertical GRF (or normal force), horizontal GRF (or parallel force), and mediolateral GRF. Usually, the normal force is characterized by two peaks. The first peak occurs at the end of the loading phase, when all body weight is transferred to the supporting foot and the second peak occurs later in the posture, just before the start of the toe-off phase. This peak is critical concerning slip resulting in a fall. Horizontal GRF has a first large peak in the forward direction associated with load dynamics and the second maximum in rearward direction occurs when the heel rotates off the floor, pushing the toes to start the toe-off phase. The points where slips are the most likely to occur are the highest near heel contact and push-off phase of horizontal force. The hazardous phase for occurring of slip is heel contact. It follows that the forces generated by heel contact are critical in determining whether the frictional capacity of the shoe-floor interface will be sufficient to resist slips (Qian, X., Guangming, C., Kattel, B., Lee, S., and Yang, Y., 2018) (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010).

The ratio between horizontal GRF and vertical GRF exerted between the shoe and floor is called the coefficient of friction (COF). RCOF is defined as the peak value of COF while walking. When the RCOF to support walking exceeds the COF at the shoe-floor interface, a slip may occur. It has been suggested that a high RCOF is a major contributor to STF accidents. The RCOF must be lower than the COF at the shoe-floor interface to prevent slips, trips, and falls. Consequently, RCOF can be a valuable tool in slip, trip, and falls prevention. To predict the slip potentials for different types of walking activity, it was proposed to use the peak of RCOF (Qian, X., Guangming, C., Kattel, B., Lee, S., and Yang, Y., 2018) (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010).

Several studies have shown that the RCOF for turning can be as high as 0.36 and walking straight up to about 0.2. Descending a 20-degree ramp increases the peak RCOF from 0.18 to 0.45 (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010).

Walking on stairs

According to studies, physical demands and the risk of STF are higher when walking stairs than walking on level ground. Falls and slips on stairs may lead to a high risk of death or severe injuries with life-long disabilities (Qian, X., Guangming, C., Kattel, B., Lee, S., and Yang, Y., 2018).

Stair design is a relevant factor in the prevention of slips, trips, and falls. It is critical to comply with the requirements and rules for designing stairs established for the marine industry and offshore installations. Legislation for stair design is presented in subchapter *2.3 Legislation and industry standards of safety and health at work*. At the same time, a brief schematic diagram of stair terminology is presented in figure 3 below.

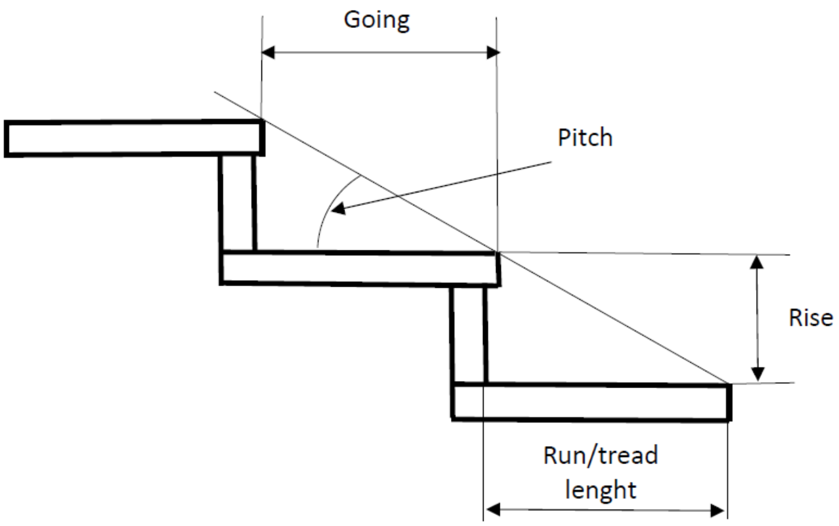

Figure 3: Schematic diagram of stair terminology. Source: (Scott, 2005) (Komisar, V., McIlroy, W.E., and Duncan, C.A., 2019)

As it can be seen from figure 3, stair terminology consists of tread/run, going, rise, and pitch. The tread or run of a step is defined as a distance from the nosing edge to the vertical riser. However, if the steps do not have nosing, then it is the same as going of step. The nosing is determined as the partition of the tread that overlaps the tread below. The going of a step is the horizontal distance between two sequential nosings. The rise is defined as the vertical distance between two sequential treads or between a tread and a landing. Lastly, the pitch is the angle between the line connecting sequential noses and the horizontal (Scott, 2005).

Walking on stairs requires a different gait style and is a more challenging task than level or ramp walking. When walking stairs, the body is transported vertically and in a forward direction, leading to joint movement and muscle demands, which are significantly different from walking at the same level. Walking stairs also requires substantial muscle balance and coordination. Each step in stair walking starts at the toes and ball of the foot, not the heel, as when walking on the same level. During the swing phase, there is the greatest chance of falling when walking on stairs. At this point, the rear foot goes over two nosings and is at the highest risk of tripping. When ascent stairs at the moment when the rear foot is pushing off the lower tread, there may be a risk of slip if the slip resistance of the tread at this moment is too low. Due to stair locomotion's vertical nature, a stair slip may result in a catastrophic event and, hence, severe injury. Stair slip, trip, and falls prevention is a demanding task, and therefore it is crucial to understand its biomechanics and solve the problem comprehensively thoroughly (Scott, 2005) (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010).

As earlier described, the RCOF is used to assess the slip capability of the floor-shoes interface. Studies have shown that when ascent stairs, the RCOF, while acceptance of weight corresponds to the values, indicated for level walking of 0.21. However, the RCOF seems to be slightly above 0.39 during toe-off. Such evidence suggests that during the late stance, when the body is being elevated, it is more likely to slip backward. As for the descent of the stairs, then, despite the relatively large difference in ground reaction forces when ascent and descent stairs, RCOF is very similar. However, it shall be noted that compared to level walking, walking on stairs requires a higher coefficient of friction of floor-shoe interface in order to prevent slip occurrence (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010).

As studies revealed, the stairs' falls are more frequent on the stair with a shorter tread/run length. Also, the trunk's inclination during the stairs' descent is less with a shorter rise of individual steps than a higher rise' height. Besides, considerable improvements in a person's ability to recover after the loss of balance and hence avoiding falling have been observed with the presence of handrails. Thus, in order to prevent falls on stairs, key design considerations of stairs include decreasing the height of a rise of individual steps, while the length of the tread/run of individual steps should be increased. Moreover, providing appropriately designed handrails are critical for balance recovery (Komisar, V., McIlroy, W.E., and Duncan, C.A., 2019).

Kinematics and joint moments during locomotion

Other biomechanic factors that influence the potential of slip, trip, and fall are kinematics and joint moments (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010).

Kinematics include walking speed, step length, joint angles, etc. It is evident that walking speed and step length affect slip and trip potentials. The study has shown that step length is one method that can reduce the likelihood of slipping when walking. It is supposed that the heel's kinematics when it comes to contact with the floor affects the likelihood of slipping and falling. Furthermore, an increase in walking speed decreases dynamic stability when walking. Consequently, a faster pace of work or walking speed during rushed production activities can negatively affect the slip, trip, and falls initiation and balance recovery processes. Avoiding rushed work is particularly essential when ascending and descending stairs due to increased GRF and RCOF, which potentially increase the risk of injuries and fatalities (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010) (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Qian, X., Guangming, C., Kattel, B., Lee, S., and Yang, Y., 2018).

Joint moments are the moments at the ankle, knee, and hip required to maintain or recover balance in response to slipping and tripping. Joint moments relate to the level of strength required for walking and the recovery action from the slip or trip if needed. After a slip or trip occurs, individuals have a series of biomechanical responses available to defend themselves against nearly falling to the ground. Their reactions may be automatic, involving reflexive reactions or volitional, involving conscious efforts, or both. Recoverability is most likely determined by many factors in the interactive relationship. These factors are likely to include those that affect the relationship between COF and ground support, such as the distance and velocity of the slipping or tripping foot and stride length of the recovering limb. Also, it has been observed that joint stiffness control is used to maintain balance in response to slip perturbations while walking on slippery surfaces. Furthermore, studies have shown that age, obesity, and fitness level of a person affect the balance recovery after slipping and tripping as well (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010) (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016).

Other factors that significantly improve a person's ability to recover from the loss of balance and therefore avoid falls on both level surfaces and stairs are handrails and guardrails. Studies have shown that higher handrails ranging from 96 to 107 cm along with cross-sectional geometry that allows a person to grip the rail and apply high forces to it in all directions, for example, cross-sections with a diameter of 38-44 mm or other structures that allow fingers to wrap around the rail in a "power grip completely," contribute to better balance recoverability.

Moreover, proactive use of handrails showed significantly higher perturbation than reactive use (Komisar, V., McIlroy, W.E., and Duncan, C.A., 2019).

It can be concluded that the most critical factors in slip and trip potentials are the unevenness of the walking surface and RCOF of the floor-shoe interface, which the most closely associated with a measured coefficient of friction. Comparing RCOF and COF may provide sufficient knowledge about slip and fall potentials. However, other biomechanical factors such as kinematic of the foot at heel contact and human postural control strategies play an essential role in preventing slips and falls. Therefore, complex and effective strategies shall be adopted and implemented to reduce occupational slip, trip, and fall accidents.

Besides, it shall be noted that walking on stairs is a more challenging task and therefore requires more strict measures to reduce the STF on stairs. First of all, walking on the stairs required a higher coefficient of friction between the shoe and walking surface than level walking. An increase in slip resistance at the floor and shoes' junction can be achieved by using appropriate non-slip shoes, increasing the floor roughness or slip resistance, etc. From the other side, it is essential to enhance balance recovery by installing appropriate handrails and guardrails and avoiding load carrying while walking on stairs to free the hands for handrail grasping. However, occupational load-carrying tasks are considered one of the main factors contributing to injury from slipping and tripping, even when walking on the level due to changing gait kinematics and, consequently, affecting balance recovery. Thus, avoiding load carrying while walking stairs is crucial in prevention slip and trip potentials (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010) (Hanson, J. P., Redfern, M. S., and Mazumdar, M., 2010).

Moreover, friction is directly related to perceived slipperiness. When a person perceives a surface as slippery, foot forces and kinematics will adjust, even if the person is instructed not to do so (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010).

2.3 Legislation and industry standards of safety and health at work

The legislation is an essential and integral part of any project and covers its various life cycle stages. This chapter refers to occupational health and safety legislation related to the prevention of slip, trip, and fall accidents that set out the requirements for the design and maintenance of the walking-working surface and entails safety training requirements for seafarers and offshore workers. The main goal is to analyze the law's requirements, evaluate their implementation in the project, identify possible scenarios of prevention of slip, trip, and fall accidents, and find possible gaps.

The main pieces of legislation for offshore facilities and maritime industry in Denmark are the Working Environment Act, Safety Offshore Act, and Maritime Safety Act. The main relevant to this project, regulations under the stated acts are *Executive Order on construction, connected infrastructure, and pipelines' construction, layout and equipment in connection with offshore oil and gas activities, etc.* and *Executive Order on the management of safety and health, etc. in connection with offshore oil and gas activities, etc*. under Safety Offshore Act and *Executive Order on Notices from the Danish Maritime Authority A, technical regulations on working environment in ships* and *Executive Order on shipbuilding and equipment, etc., Implementation of the International Convention for the Safety of Life at Sea (SOLAS) 1974* under Maritime Safety Act. Besides, DNV GL Offshore standards and *AT Guide 65.1.8-1 on risk management in offshore oil and gas activities* related to the Offshore Safety Act rules were used for establishing legislative requirements and standards related to reducing slip, trip, and fall accidents in the maritime industry and offshore installations.

According to *Executive Order on Notices from the Danish Maritime Authority A, technical regulations on the working environment in ships*:

"The work must at all stages be planned and organized in such a way that it can be carried out in a completely safe and healthy manner. Care must be taken not to prescribe or presuppose the use of constructions, plan designs, detailed solutions, and working methods that may be dangerous to or otherwise impair the safety and health of the work performed. Furthermore, it must be ensured that the overall impacts on the working environment in the short or long term do not impair the safety or health of workers."

(Ministry of Trade and Industry, 2009) Rule 2 Planning and organization of work.

Executive Order on the management of safety and health, etc. in connection with offshore oil and gas activities, etc. states:

"… the operator and the owner must respectively ensure that all safety and health risks and risks of major environmental incidents associated with the plant, the connected infrastructure or a pipeline's design, construction, layout and equipment and all activities associated with the facility, the connected infrastructure or a pipeline during its operation, including passenger transport to and from the facility, as well as activities associated with

combinations of several facilities, are identified, assessed and reduced in accordance with the ALARP principle."

(Ministry of Employment, 2019) Chapter 3, § 3.

However, these requirements for technical and workplace design of maritime vessels and offshore facilities, maintenance and inspections, personal protective equipment, and workers' safety training are general. They mostly describe that it is required for the maritime industry to ensure that work is executed safely and healthily, while for offshore installations, it is required to ensure that all health and safety risks are identified and reduced following the ALARP principle. Therefore, more specific requirements regarding safety training for seafarers and offshore workers and requirements regarding flooring design and means of access design, its cleaning and maintenance are taken from good practice guidelines, which are based on International Maritime Organization (IMO), Danish Maritime Authority (DMA), and Global Wind Organization, etc.

2.3.1 Technical standards and guidelines on working floor surfaces, lighting, cleaning, and maintenance

Work areas and access to cargo spaces and other places on ships

All spaces should be equipped with permanent means of access to ensure that general inspections and detailed examinations and measurements of the thickness of the ship's structure can be performed throughout the life of the ship by the Administration, the shipping company, the ship's crew, or others persons, in the case, may be necessary. Moreover, it should be ensured that the access to cargo spaces, trunks, ballast tanks, cargo tanks, and other spaces in the cargo area directly from the open deck is safe and allowed to be fully inspected. The means of access must comply with the requirements of par. 5 and in the "*Technical Provisions on Means of Access for Inspection*" adopted by the Maritime Safety Committee by resolution MSC. 133 (76) (Ministry of Trade and Industry, 2019). The detailed dimension requirements of the means of access are described and illustrated in Appendix 9: Requirements for means of access in the maritime industry and offshore installations.

Decks, deckhouses, floor slabs for the ordinary walkways, all inclined ladder/stair fitted, all stairs in accommodation areas, service rooms, and control rooms shall be steel or other similar material (Ministry of Trade and Industry, 2019).

All escape routes, including stairs and exits, should be marked with light or luminescent stripes, which should be located at a height above the deck, which should not go beyond 0.3 m at any point in the escape route. Moreover, escape routes shall not be blocked by furniture, clutter, or any other obstacles. Floor covering shall be secured (Ministry of Trade and Industry, 2019).

Areas with special risks in an offshore facility

Places where there is a potential risk of falling or falling objects, or where there is other particular safety or health hazard, shall, as far as possible, be fenced with handrails, guardrails, barriers, roofing, or other appropriate measures to prevent unallowed access to these areas (Ministry of Employment, 2019).

Work area surfaces in an offshore facility

The working room's floor must be made free of dents, openings, and level differences that may pose a safety risk. The floor coating shall be adapted to the work being executed in the work area and have adequate stability and slip resistance corresponding to the nature of the performed work (Ministry of Employment, 2017).

Work area surfaces should not release vapors or dust into the work area or generate static electricity to expose employees to harmful or highly irritating effects. The floor covering must be suitable and non-sparking in the work areas where there is a risk of explosion. The floor surfaces, walls, and ceilings in work areas should be designed so that during cleaning, it can be ensured that the health risks associated with these surfaces are reduced as much as practically possible. In the case of prolonged outdoor work, measures shall be taken to protect workers from bad weather and, if necessary, from falling objects (Ministry of Employment, 2017)

The offshore facility should be provided with sufficient lighting throughout the facility to ensure employees' safety and health. If there is not enough daylight, outdoor areas should be well lit with artificial lighting. Lighting should be designed so that operational checkpoints, escape routes, muster points, evacuation points, and danger areas remain lightened if the artificial lightning failure (Ministry of Employment, 2017).

The surfaces of decks, walkways, platforms, stairs, ladder rungs, etc., in offshore installations, shall be non-slip and designed for drainage and easy cleaning of contaminants such as mud and oil, where needed (DNV GL, 2015).

Cleaning and maintenance

The workplace must be in good working order, clean, and tidy so that the conditions are always safe in terms of health and safety. Floor coverings should be kept in a safe condition and free from objects, cables, spills, materials, etc., that could pose a hazard during workers' motion. The workplace must have adequate conditions for cleaning and maintenance. It shall be ensured that the work can be carried out safely for those who execute the work and other company employees (Arbejdstilsynet, 2001).

General requirements, advice, and best practice

Marking of the means of access

One of the basic principles that should be taken into account when designing a human-machine interface in a system is to ensure easy identification of commands. They should be of a suitable color and within the line of sight of the user. These principles should be applied in the design of means of access. Since, in order to avoid an accident, the first one needs to identify the hazard visually (Bureau Veritas, 2008).

Lightning

The lighting of the place where the means of access are installed is the first principle to be considered. Lighting on open decks can be severely degraded by weather conditions, especially at night. At the same time, indoor areas can be poorly enlightened due to insufficient artificial lighting. Moreover, some spaces, which are very rarely used, are in complete darkness and are enlightened with flashlights. The second principle is that the means of access and the hazards linked with their use must be marked so that they can be accordingly fast identified and easily prevented (Bureau Veritas, 2008).

Thus, there are some recommendations and best practices regarding these two principles. Stair treads, ladder treads, and steps in areas that are rarely enlightened should be marked with highly visible color or reflective strips on the edges. The top and bottom steps should be highlighted with a different color from other steps and decks. Treads of vertical ladders should be marked with highly visible color, dayglow paint, or reflective stripes. Escape ways should be marked with clear visibility escape guides that can be seen through thick smoke. Obstacles, edges of obstacles, outline of openings should be marked with strips of color dependent on the area's lighting (e. g., black and yellow, etc.) (Bureau Veritas, 2008).

Slip resistance

Since the maritime and offshore industries are exposed to factors such as weather conditions, ship movement, or oil and water leaks, walking surfaces can be covered with slippery substances. Besides, in places such as ballast tanks and peaks, walkways are often slippery and muddy, and visibility is inferior. Therefore, special attention should be paid to various surfaces that can cause slips, trips, and falls. Various decisions can then be made. It is necessary to consider the slip resistance of walking surfaces and tread coatings characterized by a coefficient of friction. One of the best solutions is to get a good coefficient of friction, i.e., a value > 0.75 (widely considered to imply very good slip resistance) for both dry and unpolished and wet surfaces. Such surface slip resistance can be achieved by installing high grip mats, paints, or tapes (such as carborundum finish or textured) (Bureau Veritas, 2008). While the Occupational Safety and Health Administration (OSHA) recommends a COF of 0.5 as a guideline for achieving proper slip resistance. However, it is not an absolute standard value. A higher coefficient of friction may be required for specific work tasks, such as carrying objects, pushing or pulling objects, or walking up or down a ramp (Occupational Safety and Health Administration (OSHA), Labor, 2016).

Maintainance

The means of access must be durable, which means that the materials used and the paint applied must ensure that the means of access are sufficient for the environment in which they are installed. Particular attention should be paid to corrosion. Means of access must be kept in good condition (Bureau Veritas, 2008).

2.3.2 Personal protective equipment

All work should be planned and organized in such a way that it can be carried out in a completely safe and healthy manner or risks to health and safety are reduced as much as reasonably practicable, following general principles of prevention, in order to avoid the use of personal protective equipment as much as possible. Personal protective equipment (PPE) means all equipment, including clothing, that is intended for use by employees to defend against one or more risks that may threaten a person's safety and health during work and any accessories that serve this purpose. It is crucial to ensure that personal protective equipment is presented, replaced and maintained in time, appropriately cleaned, and used during all working time following the *Executive Order on the use of personal protective equipment in connection with offshore oil and gas activities, etc*. and *Executive Order on Notices from the Danish Maritime Authority A, technical regulations on the working environment in the ship* (Ministry of Trade and Industry, 2009) (Ministry of Employment, 2015).

Personal protective equipment to prevent slip, trip, and fall accidents on the same level, such as safety shoes and safety gloves, are mandatory in the maritime industry and offshore installations. Personal protective equipment must be CE-labelled to be legal. In case if the PPE not CE-labelled, then it shall have an equivalent standard (Søfartstyrelsen).

Tree category of risk for personal protective equipment can be distinguished: category I – simple PPE, category II - intermediate PPE, and lastly, category III - complex PPE. Category I intends to protect the user against minimal risk, while category III intends to provide users against any risks with very severe consequences. It is imperative to use proper PPE, depending on the type of risk the user may face while performing the job. If an employee is potentially exposed to multiple, simultaneous risks while performing work, then personal protective equipment should be designed to meet the essential health and safety requirements specific to each of these risks (EUR-Lex, 2016).

Safety shoes

In order to prevent falls due to slipping, the outsoles of safety shoes must be designed and manufactured or equipped with additional means to ensure proper grip, taking into account the nature or condition of the surface (EUR-Lex, 2016).

Work at height

Work at height should be considered starting from the hierarchy of protective measures. A lower level of the hierarchy should only be used if the approach presented at a higher level is not reasonably practicable. Collective protection measures should prevail at every level of the hierarchy because if it is installed and maintained correctly, it protects people without requiring them to take any additional action to ensure safety. On the contrary, personal protection depends on the correct and consistent use of the equipment by the user (Offshore Wind, 2014) (Ministry of Trade and Industry, 2009).

Working at heights should be avoided wherever it is reasonably practicable, using an existing safe work area or a permanently installed access platform. If it is not feasible to avoid working at heights, following work equipment and measures should be used to prevent falls or to minimize the consequences of a fall (Offshore Wind, 2014):

- Collective protection (installation of fixed guardrails, safety nets installed at a high level on the structure, safety nets rigged at a low level)
- Personal protective equipment (full body harness, energy-absorbing lanyards with energy absorber, fall arrest slider, safety helmet, safety shoes, safety gloves)
- Procedural measures, such as ensuring an appropriate incident response and having a safety vessel standing by when working over water.

Where safety relies on the use of work equipment, users must have the necessary competence to use it properly, and employers must provide an appropriate level of training, supervision, instructions, and other procedural/behavioral controls (Offshore Wind, 2014).

Special provisions for the use of ladders

Ladders must be secured so that they are stable during use. Portable ladders should be prevented from slipping during use by attaching them to side members attached at the top or bottom, either by an anti-slip device or an alternative and identically effective method. Access ladders must be well above the access level so that the top of the ladder can provide support when moving to and from the ladder if no other safe reference point is available. Ladders should be used so that the worker always has a secure point of support and a secure point of holding. The worker must have a secure grip, even when holding something in his hand while on the ladder (Ministry of Trade and Industry, 2009).

2.3.3 Training requirements for seafarers

The International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) sets standards on seafarers' training, on Maritime Industry and Watchkeeping around the world. All training and assessment programs granted in connection with the STCW certificate shall comply with STCW standards and shall be approved by the relevant national maritime administration (EduMaritime, 2020) (Ministry of Trade and Industry, 2013). For seafarers employed or occupied in any position on board a ship at all levels, such as deck and engine room rating qualifications, and for most navigation and all engineering competency certificates, STCW Basic Safety Training (BST) or STCW Basic Training (BT) is required. The BST consist of (EduMaritime, 2020):

- Personal Survival Techniques PST (Practical Training)
- Fire Prevention and Fire-Fighting (Practical Training)
- Elementary First Aid (Theory & Practical)
- Personal Safety and Social Responsibility PSST (Classroom Training)

Moreover, Personal Safety and Social Responsibility (PSST) has additional topic requirements such as Communications, Control of Fatigue, Teamwork, and marine environmental awareness (EduMaritime, 2020).

Seafarers are also required to hold a medical certificate and may need additional training depending on their duties on the vessel (e.g., working at height, manual handling, etc.) (Ministry of Trade and Industry, 2009).

Besides, all persons, except passengers employed or partially employed on board a seagoing vessel under the provisions of *the International Code for the Safety of Ships and Port Facilities* (ISPS Code), must, before being assigned onboard duties, undergo safety instructions approved by the company and it should be conducted by a ship security officer or an equivalent qualified person. These instructions are aimed to ensure that the person is able to do the following (Ministry of Trade and Industry, 2013):

- can report a security incident, including a threat, pirate attack, or armed robbery;
- recognize what procedures to follow when identifying a security threat;
- can take part in emergency procedures and emergency related to security.

2.3.4 Training requirements for offshore oil and gas personnel

All personnel working at sea must pass the following (Oil Gas Denmark, 2018):

- Medical certificate (following the latest version of the latest admitted Guidelines for Physicians in the Danish Sector or other similar standards adopted by Danish operators).
- Basic Offshore Safety Induction and Emergency Training (BOSIET) or an equivalent training recognized by Oil Gas Denmark (the acquired competencies are to be maintained every 4th year).
- Further Offshore Emergency Training (FOET) approved by the Offshore Petroleum Industry Training Organization (OPITO), STCW, etc. Training Standards (this certificate has a validity of 4 years, after which a refresher training has to be completed).
- Pre-flight briefing video.

Personnel arriving at an offshore installation should, on their first visit, receive a safety and emergency briefing specific to that location. Personnel who have not attended or worked on the offshore installation in the previous 12 months should receive additional induction safety training. Besides, it is mandatory for all personnel working offshore on the Danish continental shelf to have participated in and passed training in escape chute at not more than 4-years intervals. Also, personnel may need additional training depending on their work responsibility on the facility (e.g., working with asbestos-containing materials, working at height, manual handling, etc.) (Oil Gas Denmark, 2018).

2.3.5 Training requirements for offshore wind industry technicians

Considering the remote location of work and the hazards to which offshore technicians are exposed, they shall receive advanced training in safety and emergencies. The Global Wind

Energy Organization (GWO), a not-for-profit organization created by the world's leading wind turbine manufacturers and owners, has developed standardized training that reflects industry risks for offshore wind power personnel (Offshore Wind, 2014).

The GWO basic safety training (BST) consists of (Offshore Wind, 2014):

- First aid
- Fire awareness
- Working at heights
- Sea survival
- Manual handling

Along with the BST, technicians shall obtain a valid offshore health certificate confirming their suitability for work in the offshore environment. GWO also offers a basic technical training standard containing modules in mechanics, electricity, hydraulics, and, if necessary, installation, as well as advanced training in rescue and first aid (Offshore Wind, 2014).

2.3.6 Human performance factor

There is no doubt that an appropriate vessel and offshore facility design and all control measures to prevent slip, trip, and fall accidents play an essential role in reducing these accidents. However, competence and the human behavior of individuals are key to ensuring that tasks are performed safely. Safety training is one of the most critical aspects of ensuring that the job is done correctly and safely. Still, successful completion of a training course does not certainly mean that an individual will be competent in all matters of the course content. Therefore, employers should have systems to develop and monitor competence, such as accompanying new staff during their first few sailings or transfers to offshore facilities (Offshore Wind, 2014). Competence can be defined as having the necessary skills, experience, knowledge, and attitudes, and the ability to apply them in a specific work environment to accomplish specific tasks following a predefined standard (Oil Gas Denmark, 2018). For maritime and offshore employees, personnel competence is assured through industry standards and requirements, such as compulsory training and control of personnel's health and fitness.

Behavioral safety encompasses all non-technical aspects of safety and defines how work will be performed, which may differ from how it would be expected under a safety management system. Knowledge, skills, and experience of individuals applied to safely perform and repeat a task, considering their limitations and constraints, are defined as the individual's human behavior. Human behavior can be influenced by the organization's safety culture, crew members, and external factors. For instance, factors as rushing tasks, work continuing in unsuitable conditions, trying to execute too many tasks at once, peer pressure, lack of communication or confidence between crew members, seasickness, distraction, fatigue, stress, etc. can negatively affect human performance (Offshore Wind, 2014).

It is essential to ensure that the ship and offshore facility are crewed to avoid working overtime. A formal Fatigue Management System should be maintained to control workload and rest hours to prevent fatigue. The master must ensure (unless work is required in the event of an emergency) that all crew members observe minimum hours of rest, receive adequate rest when they begin work, and adequate rest when not at work. Crew members who have participated in the emergency response during planned rest periods should be given an adequate rest period as soon as practicable (G9 Offshore wind, 2014).

2.3.7 Summary

The Danish legislation does not particularly indicate how the slips, trips, and falls reducing in the maritime industry and offshore installations should be managed. There are the following main pieces of legislation regarding surface flooring and means of access design, cleaning, maintenance, lightning, and workers training requirements such as the Working Environment Act, Safety Offshore Act, and Maritime Safety Act. However, DNV GL Offshore standards, *AT Guide 65.1.8-1 on risk management in offshore oil and gas activities* related to the rules of the Offshore Safety Act and Bureau Veritas' *Guidelines for the Design of the Means of Access for Inspection, Maintenance, and Operation of Commercial Ships* were used for establishing detailed legislative requirements and standards related to reducing slip, trip, and fall accidents in the maritime industry and offshore installations.

Safety Offshore Act and Maritime Safety Act set out general technical, design, workers training, working methods, equipment, and associated activities requirements for ships and offshore facilities. Moreover, Work Environment in Denmark describes general recommendations for the cleaning and maintaining flooring and means of access.

The main aspects related to slip, trip, and fall accidents are dimension requirements for means of access, floor surface, and means of access, and the material from which they are made. Moreover, the proper lighting, cleaning, and maintenance of floor surfaces and means of access play a significant role in reducing slip, trip, and fall accidents.

One of the main legislative aspects that should be highlighted is requirements for the coefficient of friction of the floor surface and means of access. *Executive Order on construction, connected* *infrastructure, pipelines' construction, layout, and equipment in connection with offshore oil and gas activities, etc.*, DNV GL Offshore standards state that work area surfaces in an offshore facility shall be slip resistance corresponding to the nature of the performed work. While in the maritime industry, there are no existing requirements for floor surfaces regarding slip resistance. However, according to the recommendations, advice, and best practice given by Bureau Veritas in order to reduce slip, trip, and fall accidents, special attention should be paid to the slip resistance of walking surfaces and tread coatings characterized by a coefficient of friction. The friction coefficient of > 0.75 is widely considered as very good slip resistance for both dry and unpolished wet surfaces (Bureau Veritas, 2008).

Other aspects that should be highlighted are the personnel competence and human behavior of individuals, which can be achieved by ensuring proper safety training and control of the health and fitness of personnel. Moreover, other factors that influence human behavior are the organization's safety culture, crew members, and external factors (such as seasickness, etc.).

2.4 Safety culture

Another aspect that should be considered when managing health and safety in organizations is the safety culture. The culture of the organization will influence the behavior and performance of individuals at work. The weak safety culture has contributed to many severe incidents and injuries (Haghighi, M., Taghdisi, Nadrian, H., Moghaddam, R. H., Mahmoodi, H., Alimohammadi, I., 2017). An organization with a well-developed safety culture is very likely to observe and identify a high number of potential hazards. In contrast, an organization with a weaker safety culture may see this as an indication of problems (HSE) (Offshore Wind, 2014). Therefore, to find the strategy to reduce the STF incidents in the maritime industry and offshore installations, it is essential to describe the organization's safety culture and how it affects human behavior and the number of incidents. The concept of "safety culture" is very briefly explained below as it is a very complex concept that can be the subject of an entire project.

The safety culture of the organization is defined by the Advisory Committee on the Safety of Nuclear Installations (ACSNI) Human Factors Study Group as (ACSNI Human Factors Study Group, 1993):

" the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety management."

Thus, safety culture can be understood as the fundamental beliefs and values of a group of people dealing with risk and safety. Much has been written about safety culture, yet there is no consensus on its definition, much less on how to improve it, despite the widespread recognition that a positive safety culture is a background for successfully safety and risk management (Glendon, A. I., Clarle, S. G., Mckenna, E. F., 2006).

Various theoretical models of safety culture were developed, such as organizational culture approach, total safety culture, informed safety culture model, a social capital theory, and others. The organizational culture approach is described as multi-layered, with three generally distinguished levels: deepest (core assumptions), intermediate (beliefs and values), and surface manifestations (norms and artifacts). The total safety culture (TSC) model is based on the behavioral approach to safety. This model involves interactions between three factors, such as environment (inclusive equipment, tools, machinery, housekeeping, physical location, etc.), human (inclusive knowledge, skills, motives, personality, attitudes, and beliefs, etc.), and behavior (inclusive safe and unsafe work practices, complying, coaching, communication, etc.).The social capital theory (SCT) approach focuses on the impact of shared behavioral norms, management commitment to safety, and trust as significant interpersonal aspects of safety. An informed culture theory is characterized by gathering safety-related information and proactive audits and contains four elements: reporting, just, flexible, and learning (Glendon, A. I., Clarle, S. G., Mckenna, E. F., 2006).

Thus, it can be seen that the mentioned theoretical models have different approaches to safety culture. However, the goal of these approaches is to develop a positive safety culture. The following factors are identified as supporting the development of positive safety culture: management (e.g., commitment, ability, leadership, communication), supervisors (e.g., support, participation style, and leading by example), individual and behavioral factors (e.g., participation, competence, and attitudes); reporting systems (e.g., reporting near misses, no-blame approach, feedback, and confidentiality), staff participation in risk assessment and development of best practices; rules and procedures (e.g., clear and practical); and good communications (Glendon, A. I., Clarle, S. G., Mckenna, E. F., 2006).

A risk management approach to safety is recommended in managing human risks in organizations. This approach underlines strategically integrating safety with other organizational objectives and using commitment-based personnel management practices to encourage employee engagement and participation. It represents a systematic approach to identifying and evaluating risks in an organization (Glendon, A. I., Clarle, S. G., Mckenna, E. F., 2006).

The researchers developed the following guidelines to create a positive safety culture (Glendon, A. I., Clarle, S. G., Mckenna, E. F., 2006) (HSE):

- Top management commitment to safety
- Employee involvement and communication - consulting with workers to ensure a shared understanding of the safety issues in the corporate workplace
- Safety training and competence - personnel must have the right information to do their job safely. Therefore, training and supervision are critical in achieving that outcome.
- Compliance with procedures and maintaining a safe workplace
- Managing the hazards in the workplace. To identify the hazards and fixes them before they become a problem. Prevention is the best strategy
- Organizational active learning through incidents investigation with finding a root cause of the incidents and the more importantly, the lessons learned from such investigations should be widely disseminated and the recommendations promptly implemented
- Keeping the records
- Monitoring, reviewing, and improving safety actions are already in place, keeping in mind that safety is not a static issue

To summarise, developing positive safety culture requires a high level of trust between and within different levels of the organization, as well as a clear leadership commitment to safety, confidence in the effectiveness of preventive measures, and effective two-way communication. Good leaders always seek innovative ways to improve the workplace's safety encouraging individuals to behave safely. It is unrealistic to expect an individual worker to change an organization's culture, but rather, the organization can influence an individual's behavior (Glendon, A. I., Clarle, S. G., Mckenna, E. F., 2006) (Offshore Wind, 2014).

2.5 Stakeholder analysis

The ISO31000 standard specifies as a requirement the identification of relevant stakeholders for the management system. Stakeholders are any groups, associations, and organizations with a high interest in reducing STF accidents, taking actions, or are partially involved or affected (ISO31000, 2018). Herein the author analyzes barely the main for this project stakeholders. All stakeholders mentioned below, directly or indirectly involved in STF accidents in the maritime industry and offshore installations, have been brainstormed, and their roles are briefly described.

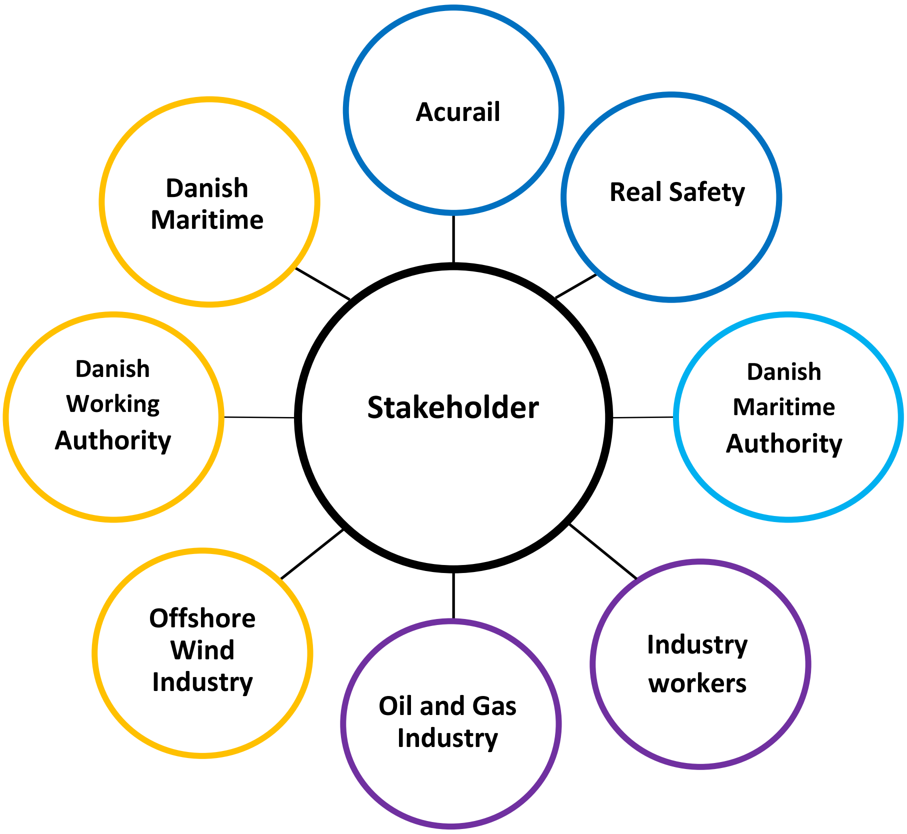

Figure 4: Stakeholder mapping. Source: Author

Industry workers: The industry workers are personnel on ships, oil and gas, or wind companies. They perform various industrial tasks and use walking-working surfaces while performing tasks, and therefore they may experience STF. Hence, their role and interest in reducing STF accidents are essential.

Acurail: The Acurail is a company located in Esbjerg (Denmark) that provide the KAG safety rails, formed from stainless steel, black steel, copper, aluminum, or brass tubing, with a broad range of safety measures that can be applied in any environment. The unique wavy profile maximizes handgrip on ladders, work platforms, stairs, walkways, grab and shower rails in all conditions. The company aims to reduce the risk of STF accidents and related injuries (Appendix 1: Electronic Interviews).

Real Safety: Real Safety is a company located in Esbjerg (Denmark) that manufactures, sells, and develops anti-slip solutions for any floor surface to enhance safety for oil, gas, wind, and maritime industries. The company provides anti-slip covers for walkways, stair treads, ladders rung, drill floor, platforms, decks, etc., with high durability and a high coefficient of friction for any environment or weather. The company aims to reduce the STF accidents in the environment they are installed (Appendix 1: Electronic Interviews).

Oil and Gas Industry: The oil and gas industry plays a vital role in STF accidents, as the industry companies are highly interested in reducing STF accidents among their employees. The oil and gas companies should comply with the health and safety requirements set by the Offshore Safety Act and the Danish Working Environment Authority.

Offshore Wind Industry: Offshore wind industry companies are highly interested in reducing STF accidents. The offshore wind companies shall comply with the Offshore Safety Act's legislative requirements and the Danish Working Environment Authority.

Danish Maritime Authority: The Danish Maritime Authority is a part of the Ministry of Industry, Business and Financial Affairs. The authority aims to ensure safety at sea and sea growth. The Danish Maritime Authority consists of several departments that strive daily to ensure a healthy and safe environment on clean seas and high competitiveness and jobs (Danish Maritime Authority).

Danish Maritime: The Danish Maritime is a Business Association for Danish manufacturers of maritime equipment and ships. Danish Maritime is the meeting point for Danish manufacturers of maritime equipment and vessels as an industry association. One of the association's essential tasks is contributing to the Danish maritime industry's continued success and global competitiveness by creating an enabling environment for the Danish maritime sector. Therefore, the association is very interested in measures to reduce STF accidents (Danish Maritime, 2020).

Danish Working Authority: The Danish Working Authority is the Danish authority in the space of a laboring environment. The authority's mission is to help create a safe, healthy, and upcoming work environment and prevent dismissal, sick leave, and exclusion from the labor market. Therefore, the authority has a direct and high interest in STF accidents (Arbejdstilsynet).

2.6 Case study

To investigate the most critical factors that influence the STF accidents, determine the acceptable level of STF risk, and find the possibilities and challenges to reduce further STF accidents in the maritime industry and offshore installations, a case study was carried out.

Afterward, the technological solutions were proposed and tested within a case study as a potential measure to reduce further the STF accidents.

The practical test was carried out within a case study on a particular Danish ship. The KAG safety handrails and Real Safety anti-slip solutions for stair treads were installed in a staircase on one side of a ship to evaluate their effectiveness as a complex solution for reducing STF in the maritime industry and offshore installations. They were compared to the staircase from the other side of a ship with existing smooth conventional handrails and stair treads without anti-slip products. The images of both staircases are shown in figures 5 and 6 below in the following subchapter. Both staircases have the same location, which is outside the ship under the effect of weather conditions. In addition, both staircases have approximately the same utilizing during the working shift. However, some problems have occurred, and the test failed. Some workers got scratches on their legs due to the surface roughness of the anti-slip solutions for stair treads, and hence they were removed.

Consequently, further evaluation of the effectiveness of the anti-slip solutions in terms of the level of slipperiness was not possible. Therefore the further evaluation at this ship was conducted just for KAG safety rails. Moreover, the KAG safety rails' evaluation was also supplemented by other Danish ship feedback, where the rails were installed a few years ago.

Evaluation of Real Safety anti-slip solutions proceed by getting feedback from the other companies, who have been installed these solutions 6-10 years ago. The Danish offshore wind company and two Danish ships were contacted, and positive feedback on anti-slip products was received. It should be noted that on the wind turbines of this company and ships, anti-slip covers were installed 6-10 years ago, and they did not have the problem of scratching the worker's skin.

In order to find the reason behind the scratches of a leg, the stair dimensions such as the height of the rise and the depth of the stair tread were measured. These dimensions were found to be within legislative requirements. A more detailed investigation was not possible due to the project's limited time. The author assumes that the reason behind these incidents is the human's walking habits.

The interviews with experts in maritime and offshore installations can be found in appendices 4, 5, 6, 7, and 8. The information obtained from the case studies was used throughout the report.

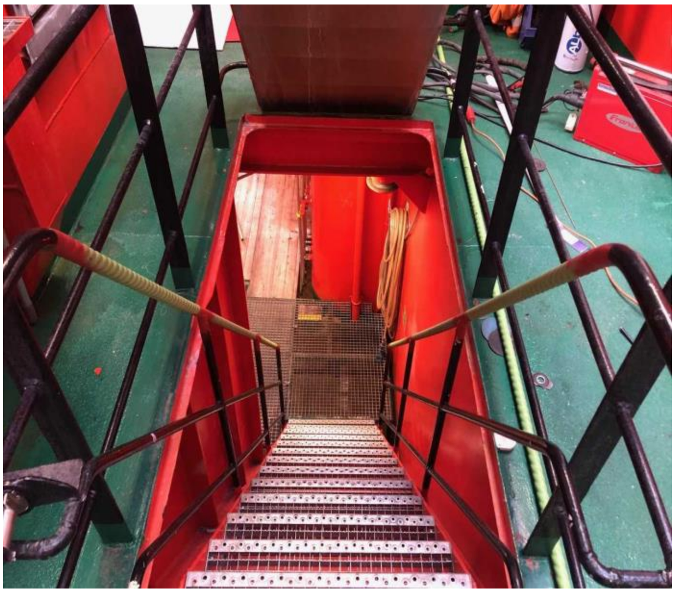

Figure 5: Staircase with existing handrails and stair treads without anti-slip covers. Source: Author

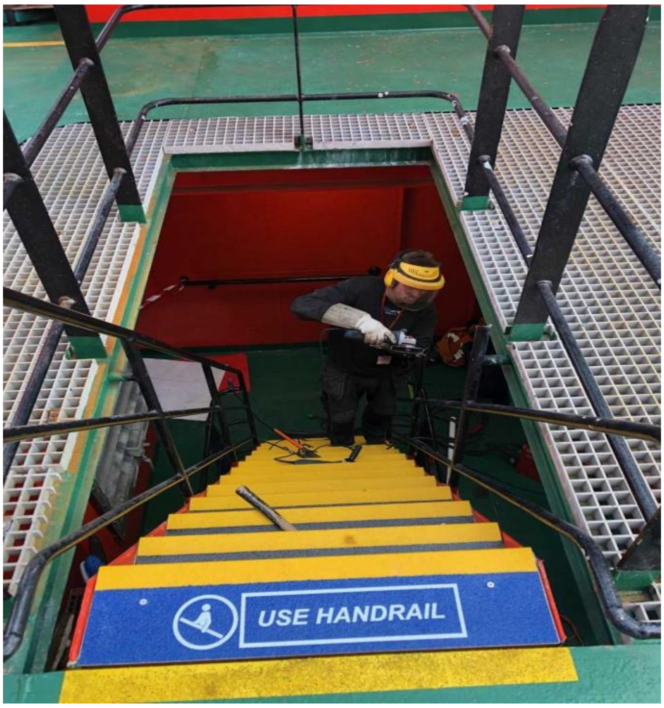

Figure 6: Staircase with KAG safety handrails and stair treads with anti-slip covers. Source: Author

3 Methodology

This chapter describes the theory and methodology applied to answer the problem statement. The research design, risk management, risk communication theories, and ALARP principles are described in further subchapters. The methods and risk tools were used in risk assessment are very briefly described in chapter *4 Risk Assessment,* prior to applying the method or tool.

3.1 Method of research

Using an abductive approach, the author conducted the research and investigation with fair use of related data to identify and understand the research topic's context and STF's phenomena itself (Kvale & Brinkmann, 2015).

To ensure the highest level of validity, a triangulation of multiple sources was applied throughout the report (Kvale & Brinkmann, 2015). This triangulation between different data collection methods within the case study included the literature review on STF phenomena, qualitative data collected through electronic and semi-structured interviews, and quantitative data collected through a questionnaire.

The foundation of the literature study was mainly based on the Google Scholar and Aalborg online library. The author searched on keywords such as "occupational slips, trips, and falls," "maritime industry and offshore installations," "causes," "behavior," "triggers," "hazards," "walking-working surfaces," "coefficient of friction," "slips, trips, and falls on the same level," "falls from a height," "reducing slips, trips, and falls," "falls on staircases" and many other relevant keywords benefited from identifying peer-reviewed scientific literature.

3.1.1 Case study

The reason for choosing the case study lies in the problem formulation and the research topic, as the case study help to gain a rich understanding of the context. Hence, the case study is appropriate for answering a "what" question of the problem statement developed in subchapter *1.3 Problem statement* and is consistent with the project's exploratory nature (Kvale & Brinkmann, 2015).

A selection of several Danish ships of the same company and Danish offshore wind company was made in order to gain a rich understanding of a context of STF in the maritime industry and offshore installations, to reveal the most critical factors that influence the STF, and finally to find measures that can be implemented to reduce further the STF accidents and evaluate their effectiveness. Besides, the practical test was conducted at one of the chosen ships to evaluate the effectiveness of technological solutions of Acurail and Real Safety that are available on the market nowadays. These solutions aimed to reduce the slipperiness of handrails, guardrails, and walking-working surfaces. The technological solutions' effectiveness was measured by comparing currently existing or previously existed ship rails and floor, stair, and ladder surfaces.

3.1.2 Data collections methods

The data collection took place through communication with engaged stakeholders. Several data collection methods were used, such as electronic interviews (herein emails) and qualitative interviews with the questionnaires, conducted in compliance with the General Data Protection Regulation (GDPR), keeping interviewees' and organizations' names anonymized.

3.1.2.1 Electronic interview

An email is a type of electronic interview undertaken offline (asynchronous). An email interview comprises a series of emails, and each comprises a small number of questions (Kvale & Brinkmann, 2015).

Several emails with stakeholders were held to gather the statistics on STF accidents onboard Danish vessels, causes behind the STF in the maritime industry and offshore installations, and establish legislative requirements relevant to this project.

First, contact was made to obtain consent to participate. The author initially emailed a small number of questions and presented a topic that the participant should answer. The author then specifically asked further questions, raised points of clarification, and discussed the ideas of onward interest. Due to the nature of email communications, these interviews took several weeks, and there were delays between asking a question and answering it. Thus, it was beneficial as it allowed both the interviewer and the interviewee to reflect on the questions and answers before giving a well thought out answer (Kvale & Brinkmann, 2015).

The conducted email communications are presented in brief in appendix 1.

3.1.2.2 Qualitative interview and questionnaire

After choosing the case, the next step was to develop a two-type questionnaire to ensure that the data collection method was transparent (Neergaard, 2007). The first questionnaire, called the pre-test questionnaire, was developed to find the most relevant factors contributing to the STF. This questionnaire was possible to prepare when the literature review on occupational STF accidents was done. The pre-test questionnaire with the interviewee answers may be found in appendix 2.

The second questionnaire, called the post-test questionnaire, was designed to evaluate the effectiveness of installed KAG safety rails and Real Safety anti-slip covers for stair treads installed on a Danish ship as a practical test, as was mentioned in the subchapter *2.6 Case study* above. Since it was supposed that implemented technological solutions would be testing by the crew members of the Danish ship during the short period, it was therefore expected that none accidents would occur. Hence, evaluating the effectiveness of these solutions by the reduced number of accidents was deemed inappropriate. Therefore, the author has decided to develop a scale in percentage to assess the effectiveness of the implemented solutions in terms of reducing the slipperiness of the surfaces. The prepared questionnaire may be found in appendix 3.

After opening a dialogue with the Acurail, Real Safety, and Head of HSE of the company of the tested Danish ship, interviews with the crew of a ship were planned. The communication before the interviews took place via email and start-up meeting. The interviews were conducted as group interviews with the first officers and crew members of a ship.

The dialogs were held in the form of a questionnaire combined with qualitative interviews. Some parts of the dialogs took place as a questionnaire with simple, short-answered, and scaled questions written on a paper to get quantitative data. In contrast, the other parts of the dialogs were conducted in the form of qualitative research interviews. That is characterized by the possibility of using an interview guide as a starting point for the interview, with defined themes and prepared questions. Still, both wording and order were adjusted during the interview. The questions were also developed further and explained during the interview, and the interviewed persons' questions were answered as well (Kvale & Brinkmann, 2015). The follow-up questions and additional questions were asked where needed (Kvale & Brinkmann, 2015).

The research interview was structured. The interviewer was well informed, asked clear, well-prepared, and accessible questions, was kind, and gave the respondents space to own thinking and talking speed. The interviewer was also sensitive and performed active listening to get as many nuances as possible. The interviewer was open to following the subjects that are important to the interviewed. The interviewer was leading and critical as well. The interviewer has asked follow-up ad clarifying questions (Kvale & Brinkmann, 2015).

Since it was not possible to fully conduct a planned practical test, as was described above in subchapter *2.6 Case study*, therefore, the author has been decided to evaluate the effectiveness of Real Safety anti-slip solutions by contacting a Danish offshore wind company and two other

Danish ships, where these solutions have been installed and tested for a 6-10 years. Consequently, few more interviews took place, where the differences between the interviewed persons meant that the interviews' style had to be adjusted. Moreover, some interviews were aimed to assess the effectiveness of the KAG safety rails, while others assess the effectiveness of the anti-slip surface solutions. Hence the questions were adjusted accordingly.

The information obtained from the interviews were used throughout the project. With the help of the information obtained, it was possible to carry out an Event Tree Analysis (ETA), evaluate the risk, propose, monitor, and evaluate an RMO. Moreover, during the interviews, it was revealed that human behavior resulting from an organization's safety culture and human level of risk perception plays an essential role in STF accidents.

After the interviews were conducted, only brief transcriptions were made highlighting the most critical aspects relevant for this project, which can be found in appendices 4, 5, 6, 7, and 8.

3.2 Risk Management

Risk management is determined in ISO 31000 (ISO31000, 2018): " *coordinated activity to direct and control an organization with regard to risk."* The purpose of risk management is to create and protect value. It improves productivity, encourages innovation, and supports the achievement of objectives (ISO31000, 2018).

According to the ISO 31000, the risk management process involves the organized application of policies, practices, and procedures to consulting, communication, contextualization, risk assessment, risk treatment, risk monitoring, risk reviewing, and recording and reporting risk (ISO31000, 2018). This process is demonstrated in figure 22, appendix 11.

This project uses most of the steps in the risk management process. The scope and context can be found in subchapter *4 Risk Assessment*. Risk treatment and risk monitoring can be found in chapters 5 and 6, respectively, where their theories are briefly described before applying the method.

3.3 Risk Communication

Risk communication is a fundamental part of the risk analysis process that has recently been gradually more recognized by organizations as being not as less important than the risk assessment and risk management tasks. Risk communication is an open, two-way interchange of information and views about risks that lead to better understanding and more functioning risk management decisions (Yoe, 2019). Risk communication utilized in this project to establish the context, legislative requirements, formulate a problem, conduct the case study, and collect the information on risk evaluation, risk management option, and risk monitoring.

When it comes to reducing STF in the maritime industry and offshore installations, the stakeholder's roles are essential. Therefore all the most relevant stakeholders were identified at an early stage of a project and were engaged at the project's different stages. Communication and consultation with engaged external and internal stakeholders took place within and throughout all steps of the risk management process. Strategies for communicating and consulting were developed at the beginning of a project.

3.4 ALARP principles

Health and safety risks associated with offshore facilities activities shall be reduced to the level that is as low as is reasonably practicable, the so-called ALARP principle (ALARP is an acronym for "As Low As Reasonably Practicable") or ALARA (As Low As Reasonably Achievable) (Arbejdstilsynet, 2017) (Yoe, 2019).

The ALARP principle is internationally recognized. In accordance with the ALARP principle, health and safety conditions must be fully justified taking into account the social and technological achievements of society, which includes weighing the achieved risk reduction against the associated cost. From an operational perspective, the requirement to reduce the risks following the ALARP principle means absolute compliance with all specific requirements and instructions and limit values in legislation. Enterprises also need to evaluate whether it is possible to eliminate completely or to reduce risks further. The further reduction of risks is also applied when the legislation does not comprise specific instructions or limit values but only contains common and functional requirements. By reducing risk means reducing the magnitude or frequency of a hazard or the duration of exposure or event associated with a hazard (Arbejdstilsynet, 2017).

The range between the highest acceptable level of risk and generally acceptable level of risk is defined as an ALARP range, which can be seen in figure 7. Risk in this area shall be reduced following the ALARP principle. The highest acceptable level of risk is defined as the highest level of risk at which activities can be performed. The generally acceptable risk level is defined as a level of risk at which no further risk reduction is required. The highest acceptable level of risk and generally acceptable level of risk is measurable. In all circumstances, this risk must be below the limits established as the highest acceptable level of risk and the enterprise's own acceptance criteria (Arbejdstilsynet, 2017).

The risk that is in the ALARP area shall be reduced to the reasonably practicable level. In assessing what is reasonably practicable, it needs to be assessed whether there is a clear disproportion between the benefits in the form of preventing deaths, injuries, or occupational diseases that are achieved through efforts to reduce the risk in the current situation and the costs incurred when implementing risk reduction measures (time, money and effort). The result of this assessment and the final decision on the need for further risk reduction depends on the specific situation and shall be demonstrated (Arbejdstilsynet, 2017).

Generally, a risk level of 1×10^{-3} is deemed the highest acceptable level of risk of death to an individual in most industries, while the risk level exceeding this value is an unacceptable level of risk of death to an individual, and any activity cannot be performed until the risk will not be reduced to an acceptable level of risk. The individual risk level of 1×10^{-6} is deemed an acceptable level of risk (DNV GL AS Maritime Advisory, 2015). If a risk is found to be in the generally acceptable level of risk, it is unnecessary to further reduce the risk. If the risk is in the ALARP area, then the risk should be reduced where reasonably practicable, taking into account the costs and benefits of risk reduction (DNV GL AS Maritime Advisory, 2015) (Arbejdstilsynet, 2017).

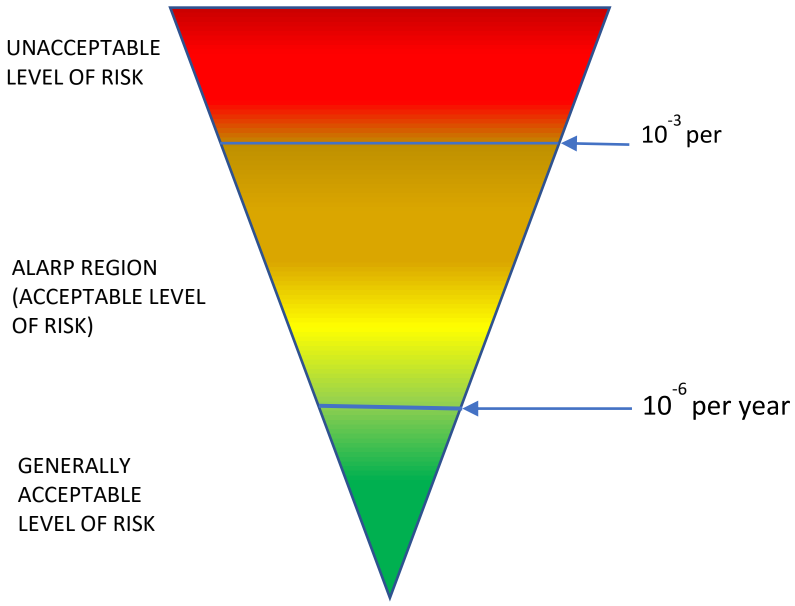

Figure 7: Individual risk form of risk criteria. Source: (DNV GL AS Maritime Advisory, 2015)

However, the individual risk form of risk criteria, which defines the acceptable level of risk of death to an individual, does not seem applicable for this project since individual risk includes all risks arising in a particular workplace and affecting the worker's health and safety. At the same time, this project focuses only on the risk of STF. Therefore, the author has decided to use the risk matrix form of risk criteria to show the acceptable regions on the matrix of accident frequency and consequence, which is illustrated in figure 8 below (DNV GL AS Maritime Advisory, 2015).

PROBABILITY	HIGH	ALARP	NO	NO
	MEDIUM	OK	ALARP	NO
	LOW	OK	OK	ALARP
		LOW	MEDIUM	HIGH
	CONSEQUENCE			

Figure 8: Risk matrix form of risk criteria. Source: (DNV GL AS Maritime Advisory, 2015)

As seen from the risk matrix form of risk criteria, the low consequence of the accident with a high probability of occurrence is in the ALARP area, the medium consequence of the accident with a high probability of occurrence is in the unacceptable area. The medium consequence of an accident with low probability is in an acceptable area.

The scale for the frequency of accidents and their associated consequences was developed by DNV GL and reflected in the risk matrix, shown in figure 21 in appendix 10. The risk matrix is built by the severity and frequency of the incident, where the red area is unacceptable, yellow is unwanted, bright yellow is tolerable, and the green area is negligible (DNV GL, 2015).

If the risk is in red or yellow areas, it means that this risk is unacceptable or unwanted and, therefore, shall be reduced to a tolerable level. If the risk is in a bright yellow area, it means that the risk is acceptable if measures to reduce risk further are considered following the ALARP principle. If the risk is in the green area, it means the risk is acceptable, and there is no need for further reducing measures.

4 Risk Assessment

Risk assessment is the systematic process of representing the character, likelihood, and greatness of the risk associated with a substance, situation, action, or event, including considering the associated uncertainties. Risk assessment can be qualitative, quantitative, or both (Yoe, 2019).

According to ISO 31000, risk assessment is part of the risk management process that consists of risk identification, risk analysis, and risk evaluation (International Organization for Standardization, 2018). Risk identification in this project comprises of hazard identification presented by Preliminary Hazard Analysis and Root Cause Analysis. Risk analysis consists of consequence and likelihood assessments, and barriers-safeguards analysis presented by Event Tree Analysis and Bowtie diagram. Risk evaluation consists of risk characterization presented by the risk matrix. Risk identification, risk analysis, and risk evaluation are explained in further sub-chapters.

4.1 Risk identification

Risk identification is performing as the first step of the risk assessment process. Risk identification aims to identify and describe the risks that may arise and prevent achieving one's objectives (International Organization for Standardization, 2018). The maritime and offshore industry presents many health and safety occupational and operative risks for workers due to harsh environmental conditions, including extreme weather conditions and specific working operations under the vessel motion.

The project is focused only on the occupational risk assessment of slip, trip, and fall events in specific operational areas of vessels and offshore installations. Therefore, a further subchapter is to identify the hazards that can lead to the risk of STF.

4.1.1 Preliminary hazard analysis

A Preliminary Hazard Analysis (PHA) is performing to identify triggers and potentially harmful conditions that could cause STF accidents in the maritime industry and offshore installations, as well as their potential consequences, causes, level of risk, and control measures associated with the prevention of the STF or mitigation of their consequences. The PHA concentrates on identifying weaknesses at an early stage in the system lifecycle, thereby saving time and money required for major upgrades if hazards are discovered later (Yoe, 2019). The PHA result is shown in table 1 below and described further.

Table 1: PHA for work on the same level, on stairs, and at height in the maritime industry and offshore installations. Source: Author based on (Offshore Wind, 2014) (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Bureau Veritas, 2008) (Komisar, V., McIlroy, W.E., and Duncan, C.A., 2019) (Appendix 2: Pre-test questionnaire) (Appendix 4: Interview with a Captain at Danish ship)

Triggers and potentially harmful conditions	**Causes**	**Consequences**	**Likelihood**	**Severity**	**Risk**	**Control measures**
Slippery surface	The insufficient slip resistance of the floor surfaces. Wet or oily surface.	Slip, fall.	HIGH (3)	LIKELY (2)	HIGH (6)	Regular maintenance and cleaning of the floor, stairs, and ladders surfaces. The proper and anti-slip floor, stairs, or ladder surfaces design.
Floor and shoe contaminations	Weather conditions (e.g., ice, rain, etc.). Spilled oil, grease, chemicals, water, etc.	Slip, fall.	MODERATE (2)	LIKELY (1)	MEDIUM (2)	Regular maintenance and cleaning of the floor, stairs, or ladders surfaces.
Carrying load in the hands	Industrial tasks require workers to carry loads or equipment in their hands.	Slip, trip, fall.	MODERATE (2)	LIKELY (2)	MEDIUM (4)	Restrictions in carrying heavy loads. Avoiding carrying loads in both hands.
Poor weather conditions (e.g., strong winds, ice, rain, etc.)	A remote location of the vessels and offshore installations on the sea.	Slip, trip, fall.	MODERATE (2)	UNLIKELY (1)	LOW (2)	Avoiding the execution of tasks under extreme weather conditions.
Poor lighting	Degraded lighting due to weather conditions. Insufficient artificial lightning.	Slip, trip, fall.	MODERATE (2)	UNLIKELY (1)	LOW (2)	Regular checks and maintenance of the lightning.

Rushed work	Industrial tasks require workers to perform their work faster. Performing too many tasks simultaneously. Peer pressure. Wanting to get back to shore. The safety culture of the organization.	Slip, trip, fall.	MODERATE (2)	LIKELY (2)	MEDIUM (4)	Organization's policies and rules in prevention rushing work.
Distraction	Fatigue, stress, low level of risk perception.	Slip, trip, fall.	MODERATE (2)	LIKELY (2)	MEDIUM (4)	A formal Fatigue Management System should be maintained. Risk awareness campaign.
Unpredictable and forcible vessel movement	Weather assessment failure.	Slip, trip, fall.	MODERATE (2)	UNLIKELY (1)	LOW (2)	Weather assessment before and during sailing.
Obstacles, clutter in a way	Improper housekeeping.	Trip, fall.	MODERATE (2)	UNLIKELY (1)	LOW (2)	Housekeeping policies and inspections.
Design failure or structural failure, or unevenness of floor, stair, or ladder surfaces	Unregular and improper maintenance and inspections of floor, stair, and ladder surfaces.	Slip, trip, fall.	HIGH (3)	UNLIKELY (1)	MEDIUM (3)	Regular checks, inspections, and maintenance of the floor surface, stairs, and ladders
Human error	Insufficient workers' competency regarding the performed tasks. Workers' low fitness level. Low level of risk perception.	Slip, trip, fall.	MODERATE (2)	LIKELY (2)	MEDIUM (4)	Safety training. Risk awareness campaign. Fitness level control.

4.1.1.1 Triggers and potentially harmful conditions

Several potentially harmful conditions and triggers that can lead to slips, trips, and falls are identified based on several studies, good practice guidelines, and interviews with experienced industry employees. Some of them are the insufficient slip resistance of the floor surface, obstacles (such as wires and cables run across the floor), and clutter in a way, bad weather condition(e.g., strong wind, rain, ice, etc.), low lighting, floor contaminations (e.g., oil, chemicals, water, etc.), design failure or structural failure of the floor, stair, ladders. Also, carrying the load in the hands, an unevenness of walking surface, work at height (climbing the ladder), unpredictable and forcible vessel movement, poorly maintained ladders, poorly covered and marked vertical and horizontal openings, unclear visibility of vertical and horizontal openings (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Scott, 2005) (Redfern, M.S., Cham, R., Gielo-Perczak, K., Grönqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Yi-Chung Pai IV, C., Powers, C., 2010) (Bureau Veritas, 2008) (Scott, 2005) (Offshore Wind, 2014). Besides, during the Interview with the experienced employee of the industry was revealed that distraction and human errors as consequences of human behavior are a major source of STF accidents at one of the Danish shipping company (Appendix 2: Pre-test questionnaire). Most of the potentially harmful conditions and triggers influence and reinforce each other. If two or three potentially harmful conditions and triggers are present simultaneously, the probability of slip, trip, and fall is higher. Such as walking on deck with a carrying load in hands during rainy weather or floor/shoe contamination (such as oil, chemicals, birds fouling, etc.). The worker can slip on the floor since the surface is slippery because of the rain or the impact of floor or footwear contaminations and experience difficulties in restoring a balance after a slip due to load in hand.

Moreover, if the worker is in a hurry to complete the task, then the probability of slip and fall is even higher. A similar situation is related to the trip hazard. If there are obstacles in the walkway accompanied by low lighting, it is likely to trip and fall. Besides, hazards such as carrying the load in the hands, rushing work, and strong wind increase trip and fall probability.

4.1.1.2 Causes

When it comes to the causes of the listed triggers and potentially harmful conditions, some of them are straightforward and obvious. The slippery surface is caused by the insufficient slip resistance of the floor surfaces or wet and oily contaminations of the surface, or a combination of these factors together. Obstacles, clutter in a way, are caused by improper housekeeping. Poor weather conditions cause floor and shoe contaminations (e.g., ice, rain, etc.) and spilled oil, grease, chemicals, water, etc. Low lighting is caused by degraded lighting due to weather conditions and insufficient artificial lighting. Poor weather conditions (e.g., strong winds, ice, rain, etc.) are caused by the vessels' remote location and offshore installations on the sea. Unpredictable and forcible vessel movement is caused by weather assessment failure. Structural failure or unevenness of floor, stair, or ladder surfaces is caused by unregular and improper maintenance and inspections of the floor, stair, and ladder surfaces. The floor, stairs, or ladders' design failure is caused by non-compliance with legislative requirements for such design. Distraction can be caused by fatigue, stress, and a low level of risk perception. Human error can be caused by insufficient workers' competency concerning the performed tasks, workers' low fitness level, and a low-risk perception level. However, human error is a complex aspect that requires a detailed and structured analysis, that it is not investigated in this project due to the project's limited time (Bureau Veritas, 2008) (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016). While such triggers as carrying the load in hands are due to industrial tasks that require workers to carry load or equipment in their hands and rushed work is associated with industrial tasks that require workers to perform at a greater work pace or to perform too many tasks simultaneously, or peer pressure, or wanting to get back to shore (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Offshore Wind, 2014). These triggers require more detailed analysis to understand their root causes and how they may trigger STF. Thus, Root Cause Analysis (RCA) is conducted to analyze the root causes of rushing work and carrying the load in hands and is presented in subchapter *4.1.2 Root Cause Analysis.*

4.1.1.3 Control measures

Following control measures to prevent STF and mitigate the consequences of STF are identified:

- Regular maintenance and cleaning of the floor, stairs, and ladders surfaces
- The proper and anti-slip floor, stairs, or ladder surfaces design
- Restrictions in carrying heavy loads
- Avoiding carrying loads in both hands
- Avoiding the execution of tasks under extreme weather conditions
- Regular checks and maintenance of the lightning
- Organization's policies and rules in prevention rushed work
- A formal Fatigue Management System should be maintained
- Weather assessment before and during sailing
- Housekeeping policies and inspections

- Regular checks, inspections, and maintenance of the floor surface, stairs, and ladders
- Safety training
- Risk awareness campaigns
- Fitness level control

4.1.1.4 Risk matrix (heat map)

The heat mapping process is performed qualitatively by analyzing the identified triggers and potentially harmful conditions, their severity, and the likelihood of occurring based on the risk matrix, see figure 9. The risks are mapped, and an overall risk rating for each trigger and the potentially harmful condition is applied.

The severity of the trigger and the potentially harmful condition can be understood as following (DNV GL, 2015):

- Critical - 1-2 killed
- Serious - several incidents requiring hospital treatment, one disabled
- Significant – several incidents requiring hospital treatment
- Negligible - 1 injury requiring hospital treatment
- None - bruises and minor damages that do not require hospital treatment

SEVERITY	LOW	1	1	2	3
	MODERATE	2	2	4	6
	HIGH	3	3	6	9
	RANKING		1	2	3
			UNLIKELY	LIKELY	VERY LIKELY
	PROBABILITY				

Figure 9: Risk matrix. Source: Author

Each trigger and potentially harmful condition earns a final risk ranking using a risk matrix. The risk matrix uses a multiplication method between the severity rating indexes and the likelihood ranking. If the multiplication equals 1 or 2, then the probability is considered to have a low value. If the multiplication equals 3 or 4, then the risk is considered to have a medium value. Finally, if the outcome is between 6 and 9, then the risk is considered to have a high value.

As shown in table 1, most of the triggers and potentially harmful conditions were assigned moderate severity due to their not direct effect on STF. Still, usually, a combination of these triggers and potentially harmful create the risk of STF. While slippery surface and structural failure or unevenness of the floor, stair, or ladder surfaces were assigned the high severity due to direct effect on STF accident occurrence, that not require other STF contributors. Moreover, the risk of STF caused by structural failure or unevenness of the floor, stair, or ladder surfaces, poor weather conditions, and unpredictable and forcible vessel movement, low lighting and obstacles, or clutter in a way are unlikely due to legislative requirements. While the risk of STF due to carrying the load in hands, rushed work, distraction, human error, floor and shoe contaminations, and slippery surfaces are likely due to weather conditions at sea, industry features, and the organization's safety culture. It should be noted that such potentially harmful condition as a slippery surface is very likely in the maritime industry and offshore installation due to their remote location at sea under the extreme weather conditions and surface contaminations. However, current legislation sets requirements for regular maintenance and cleaning of the work surfaces; therefore, the risk of STF due to the slippery surface is considered likely.

As demonstrated in table 1, most of the triggers and potentially harmful conditions from the analysis are considered to have a medium risk level. In contrast, the slippery surface is considered to have a high-risk level. Therefore, it can be concluded that most of the STF triggers and potentially harmful conditions should be prevented, mitigated, and treated in a comprehensive professional way to avoid negative effects on the health and safety of the individuals.

4.1.1.5 Consequences

Most of the triggers and potentially harmful conditions that may lead to slips, trips, and falls are common when working on the same level, on stairs, and at height. Nevertheless, the consequences are rather severe when working on stairs or even fatal when working at height. Therefore, to highlight some differences in preventive and mitigative barriers for reducing slip, trip, and falls in the maritime industry and offshore installations for work on the same level and elevated level, the author, has decided to create two separate Bowtie diagrams. The first Bowtie diagram is made for work on the same level, and the second is made for work at height or on stairs. Both Bowtie diagrams are presented and illustrated in the subchapter *4.2.5 Bowtie diagram*.

4.1.2 Root cause analysis

Root Cause Analysis is used to determine what, how, and why something happened to prevent a recurrence. Often, only the symptoms are fixed when a problem occurs, so it is expected that the problem needs to be fixed repeatedly. While looking more profound, it can be figured out why the problem is occurring and therefore fix the underlying systems and processes causing the problem (Yoe, 2019). Two RCA are being conducted as a part of the risk identification process to find the root causes of such triggers as rushed work and carrying the load in hands. The first RCA is conducted for carrying the load in hands, which is illustrated in figure 10 below.

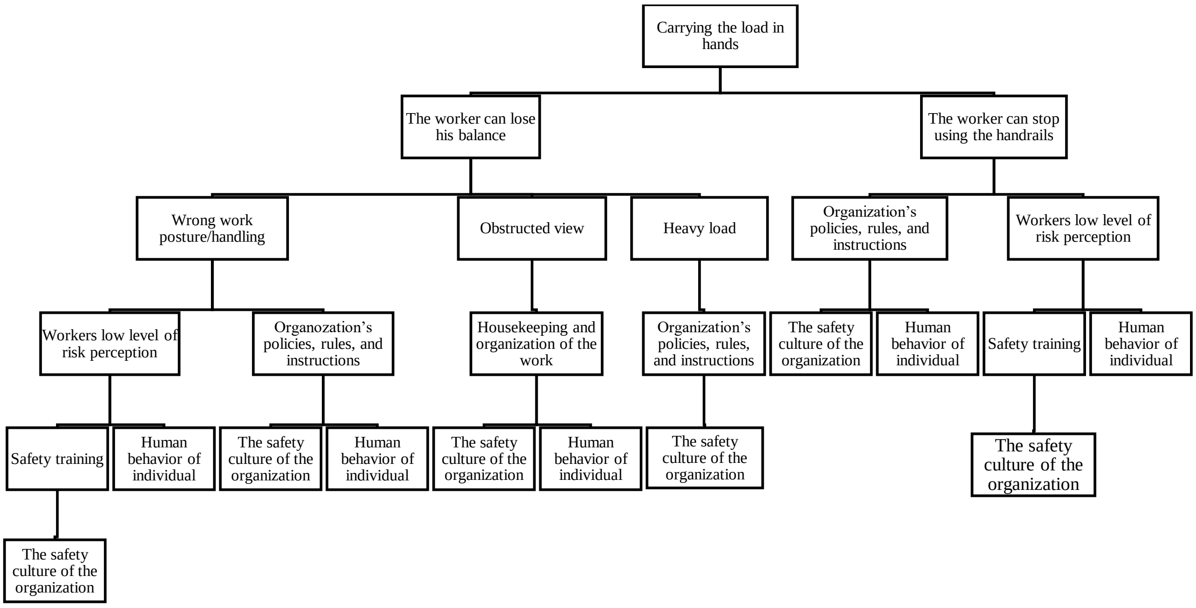

Figure 10: Root Cause Analysis for load carrying in hands. Source: Author based on (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Offshore Wind, 2014) (Office of Industrial Relations Workplace Health and Safety Queensland, 2016) (Castel, 2018)

As one can see from RCA for carrying the load in the hands, the first "why" is: Why carrying a load in the hands may trigger STF? There are two answers to this question. The first answer is that the worker can lose his balance, and the second answer is that the worker can contextually stop using the handrails.

The following describes the sequence of answers related to the loss of balance while carrying the load in hands. The workers can choose a wrong posture/technic while load handling due to a low level of risk perception or because the organization's policies, rules, and instructions regarding the work posture when load handling is not adequately established or workers fail to comply with them. Workers can have a low level of risk perception due to a lack of adequate safety training, which aims to develop a high level of risk perception regarding the consequences of improper posture/handling and, therefore, affects individuals' human behavior. The workers can not have appropriate safety training because the safety culture of the organization where they work is weak (Offshore Wind, 2014). A detailed description of the organization's safety culture and its effect on individuals' human behavior are described in subchapter *2.4 Safety culture.* The worker may have a wrong posture because of the organization's policies, rules, and regulations that do not set sufficient requirements for improper posture/handling, or the organization sets these requirements. Still, the worker does not comply with them. That can be primarily due to the organization's safety culture or the human behavior of individuals. However, these two factors are strongly linked. If an organization's safety culture is weak, human behavior can be unsafe (Offshore Wind, 2014).

A worker may lose his balance because the worker's view may be obstructed due to the load in his hands or that the worker may be carrying a heavy load in his hand. In the case of improper housekeeping and organization of work, such as cables and wires across the way, or the presence of the other workers on his way, the worker may not see them and therefore may experience STF. The improper housekeeping and organization of work can be caused by the organization's weak safety culture and individuals' human behavior. When carrying a heavy load in hands, the loss of balance is due to not well established the organization's policies, rules, and instructions regarding the acceptable weight and size of the load that the worker may carry in his hands. It can also be a result of the weak safety culture of the organization (Office of Industrial Relations Workplace Health and Safety Queensland, 2016) (Offshore Wind, 2014).

The following describes the sequence of answers related to stopping the use of handrails by a worker while carrying a load in his hands. The worker may stop using handrails while carrying a load in his hand due to a low level of risk perceptions of the consequences of not using handrails. That can be due to a weak safety culture in the organization, which may cause unsafe human behavior by individuals. Besides, the worker can stop using the handrails due to not established the organization's policies, rules, and instructions regarding the compulsory use of handrails, or if the organization established it, the worker might not comply with them. It can also be due to the organization's weak safety culture and the unsafe human behavior of the individual (Offshore Wind, 2014).

It can be summarized that the root causes of STF while carrying the load in hands are the organization's weak safety culture and the human behavior of an individual, which is strongly affected by the organization's safety culture.

The next RCA for rushing work is conducted, which is illustrated in figure 11 below.

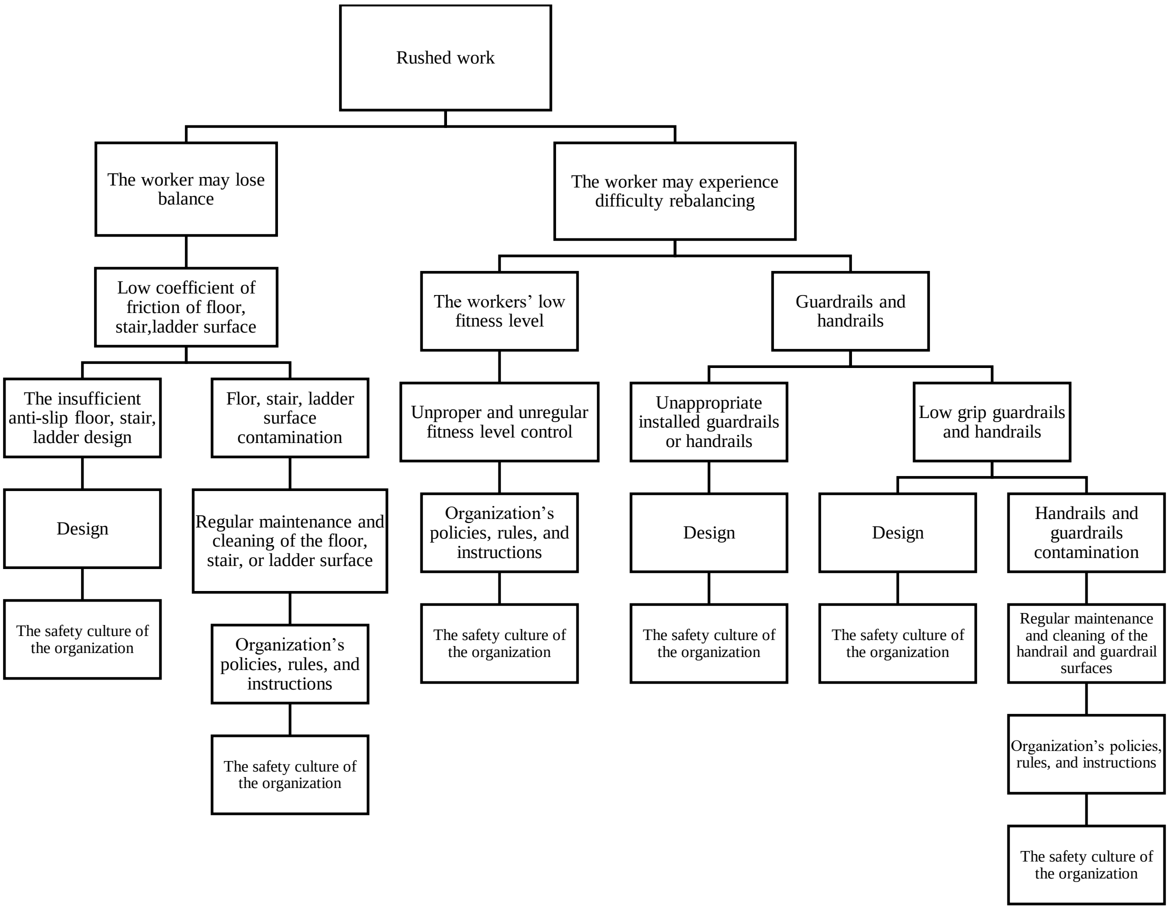

Figure 11: Root Cause Analysis for rushed work. Source: Author based on (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Offshore Wind, 2014)

As it can be seen from RCA for rushed work, the first "why" is: Why rushed work may trigger STF? There are two answers to this question. The first answer is that the worker may lose balance, and the second is that the worker may have difficulty rebalancing.

The next will be described the sequence of answers associated with the loss of balance during rushed work. The worker may lose balance due to increased friction demand and the risk of slip initiation when walking speed increases. Moreover, the increased walking speed reduces dynamic walking stability (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016). Therefore, if the floor, stair, or ladder surface has a low coefficient of friction that may be caused by the insufficient anti-slip floor, stair, ladder design, and the presents of contamination on the floor, stair, or ladder surface, then it can initiate STF. In turn, the insufficient anti-slip floor, stair, and ladder design are caused by design features influenced by the organization's safety culture. Along with this, the floor, stair, or ladder surface contamination depends on regular maintenance and cleaning, as prescribed by the organization's policies, rules, and instructions, driven by the organization's safety culture.

During the rushed work, the worker may experience difficulty rebalancing due to low fitness level and inappropriate installed handrails or guardrails, or their low grip. The worker's low fitness level may be caused by improper and unregular fitness level control prescribed by the organization's policies, rules, and instructions, driven by the organization's safety culture. The inappropriate installed handrails or guardrails and their low grip may be caused by design features influenced by the organization's safety culture. Also, handrails and guardrails contamination depend on regular maintenance and cleaning, as prescribed by the organization's policies, rules, and instructions, driven by the organization's safety culture.

It can be summarized that the root causes of the rushed work are design features of the handrails, guardrails, surfaces of the floor, stairs, and ladder, as well as the organization's policies, rules, and instructions. While the safety culture of the organization influences both design features and the organization's policies, rules, and instructions

4.2 Risk analysis

Risk analysis is a structured approach to decision making in the face of uncertainty. A risk analysis's primary purpose is to describe a risk by presenting an informative risk picture established through a cause analysis and a consequence analysis (Aven, 2015). Quantitative analysis for subsequent assessments of the likelihood of events in each possible failure sequence is represented by Event Tree Analysis. In contrast, qualitative analysis of causes and consequences of STF accidents and their preventive and mitigation barriers is presented by the Bowtie diagram, described further.

4.2.1 People at risk

The following step is to identify the maritime industry and offshore installations personnel at risk of STF. First of all, the workers in the maritime industry, i.e., captains, seafarers (such as the officers, stewards, engineers, electricians, etc.), and workers in the offshore industry who work on offshore oil and gas and wind installations (e.g., technicians, electricians, etc.) everyone is at risk of STF (Maritime-Connector) (Danish Maritime Authority). Second, persons like visitors or inspectors are also at risk of STF. It should be noted that industry personnel, inspectors, and visitors may vary in their physical shape and fitness, age, level and availability of safety training, and risk perception level.

4.2.2 Location of STF

Slip, trip, and falls can occur at any type of walking and climbing surface such as walkways, drill floor, pipe rack area, rotary tables, ramps, gangways, decks, stairs, ladders, etc. The STF is more likely to occur at the surface affected by weather conditions and contaminations such as oil, water, chemical, grease, etc. (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016).

4.2.3 Existing STF mitigation and prevention measures

Since the maritime industry and offshore installations involve many workers, particularly the wind turbines industry, which continues to grow, appropriate barriers to reduce slip, trip, and fall accidents should be in place. Moreover, the recently spreading of Vision Zero strategy to the maritime and offshore industries requires comprehensive and high effective measures to run the maritime and offshore world without occupational accidents and diseases.

Some measures are mandatory to prevent slip, trip, and fall incidents, while some are recommended. First of all, vessels, offshore oil and gas platforms, and offshore wind turbines shall comply with the technical requirements regarding their design, maintenance, cleaning, and lighting, as mentioned in subchapter *2.3 Legislation and industry standards of safety and health at work*. Other mandatory safety measures include the use of personal protective equipment such as safety shoes and safety gloves. Besides, during work at the height, it is also mandatory to use a full-body harness, energy-absorbing lanyards with an energy absorber, a fall arrest slider, and a safety helmet. Moreover, safety training and health certificate are required.

Recommended measures include marking means of access in a suitable color and within the user's line of sight. Since the maritime and offshore industries are exposed to weather conditions and contaminations, walking surfaces can become slippery. Therefore, there is a recommendation to have a good coefficient of friction of walking surfaces, tread, and ladders coatings, i.e., a value > 0.75 for both dry and unpolished and wet surfaces (Bureau Veritas, 2008). Besides, handrails and guardrails must be sized for a general fit and shall be installed at an appropriate height and have cross-sections of the proper diameter, allowing fingers to fully grip the handrail and guardrail (Komisar, V., McIlroy, W.E., and Duncan, C.A., 2019).

4.2.4 Event Tree Analysis

After identifying the triggers and potentially harmful conditions that may lead to STF in PHA, identifying the location of the STF, and analyzing existing STF's mitigation and prevention measures, the Event Tree Analyses (ETA) have been performed. The event tree analysis is a graphical, logical model that identifies and quantifies the possible outcomes after the initial event. The event tree structure is organized by time sequence. The ETA quantifies the effectiveness of barriers to reduce risk and ultimately calculates the residual individual risk of STF for the workers in the maritime industry and offshore installations.

Most of the work tasks performed by maritime and offshore workers take place on the vessel decks or offshore facility decks and simultaneously involve several workers' presence. Moreover, vessel decks or offshore facility decks are strongly affected by weather conditions. Therefore, the author decided to select the vessel and offshore facilities deck as the first STF's location point. Besides, it was decided to use stairs or ladders as the second STF's location point due to the frequent use of stairs when moving from one deck of a vessel or offshore facility to another or when accessing elevations or climbing the wind turbine ladder. Moreover, a change of height when walking the stairs or climbing the ladders has severe consequences in case of fall compared to the same level fall. Thus, the STF is more likely at vessel or offshore facility decks due to several workers' presents simultaneously. Still, the consequences of STF are more severe when working at an elevated level. Besides, both potential STF location points are affected by weather conditions.

As was mentioned in subchapter *2.2 Slips, trips, and falls phenomena,* the causes of slipping and tripping are different. They, therefore, require different measures to reduce the risk of slipping, tripping, falling. Although, for both slipping and tripping risks, proper housekeeping, proper floor, stairs, ladders design, and proper lighting are the fundamental factors in reducing these risks. Nevertheless, proper housekeeping to reduce the tripping risk embraces keeping stairs and access equipment free of obstacles and clutters in a way and regular maintenance and inspections. Proper housekeeping to reduce the slipping risk embraces proper and regular cleaning of the floor, stairs, ladders, guard rails, and handrails surfaces. However, reducing the risk of tripping consists of proper design and housekeeping, while reducing the risk of slipping requires more preventive barriers.

Even with the proper floor, stairs, ladders design, and proper household management, the risk of slipping still exists due to the industries' harsh working conditions. The following situations may pose a risk of slipping. For example, a sudden onset of rain when workers were doing their work on a deck, or stairs or walkways, forced them to escape across the wet slippery floor into the ship hastily. Either slipping while cleaning a floor contaminated with oil or chemicals, or both situations when a worker initiated cleaning a floor that is slightly contaminated with oil or chemicals and the sudden rain forced the worker to stop cleaning. When the rain ended, oil or chemicals were spread over the deck flooring, walkways, and stairs throughout the vessel. Another hazardous situation is the slippery floor and stair surfaces after their cleaning. Certainly, warning signs, high workers' attention, and slipping awareness can decrease the risk of slipping.

Nevertheless, it is not possible to fully eliminate hazardous situations related to slipping. However, it is possible to reduce the probability of slips by ensuring proper floor, stairs, ladders surface design, and proper housekeeping, as was mentioned above. Also, it is critical to mitigating the consequences of slips by introducing effective slips mitigation measures. Although, in this project, event tree analysis is aimed to evaluate only the effectiveness of STF reducing measures related to reducing the probability of slipping and hence falling. Such STF prevention measures as anti-slip covers for floor, stairs, and ladders surfaces are recommended, while safety shoes, safety gloves, guardrails, and handrails are mandatory in the maritime industry and offshore installations. Thus, event tree analysis follows the sequence of STF prevention measures in the following order:

- Anti-slip floor surface, anti-slip stair treads, and ladders covers
- Safety shoes
- Guardrails and handrails

The STF consequences for working on the same level and working at an elevated level are not the same. Falls from stairs have more severe health consequences for the worker than level falls, or even fatal when falling from a height. Besides, when working at height, a full-body harness, energy-absorbing lanyards with energy absorbers, fall arrest slider, and safety helmet are used, but the analysis of these measures is not considered the project. The created event tree analysis is presented in figure 12.

Under the anti-slip floor surface, means currently existing deck flooring surface on the Danish ship, where the practical test within a case study was conducted. One of the decks is made of steel painted with the adding of sand, while others are made of wood. Under the stair and ladder's anti-slip surface also means inclined ladders' surfaces currently existing on the mentioned Danish ship, made of steel grating with holes with smooth edges.

Due to the unavailability of the equipment to measure the COF of the existing decks, stairs, and ladder surfaces, some literature on the friction of different materials under various conditions was reviewed. Though, the exact values of the COF of the described types of flooring were not found. Nevertheless, it was found that the aluminum sheet, aluminum checker plate, mild steel plate, and mild steel durbar plate have been classified as high slip potential metal floors, particularly when wet or oily (Health and Safety Executive, 2007) (Swensen, E.E., Purswell, J.L., & Schleger, R. E., 1992). According to the Interviews, adding sand when painting the walking surfaces affords the floor surfaces' anti-slip effect during dry, wet, and oily conditions. However, the effect of such a painting is short. After 2-3 months after the painting, the walkways, decks, gangways, and stairways become slippery when wet or oily (Appendix 8: Interview with a Master at Danish ship). The wooden deck is extremely slippery under wet and oily conditions. The COF of wood flooring in contact with rubber heel under clean and dry conditions is 0.84, 0.40 under the dry and dirty conditions, 0.33 under the wet and dirty or clean conditions, and 0.26 under the soapy condition (Sigler, 1943).

Under the safety shoes and rails also meant safety shoes, and smooth guardrails and handrails are currently existing on the tested Danish ship.

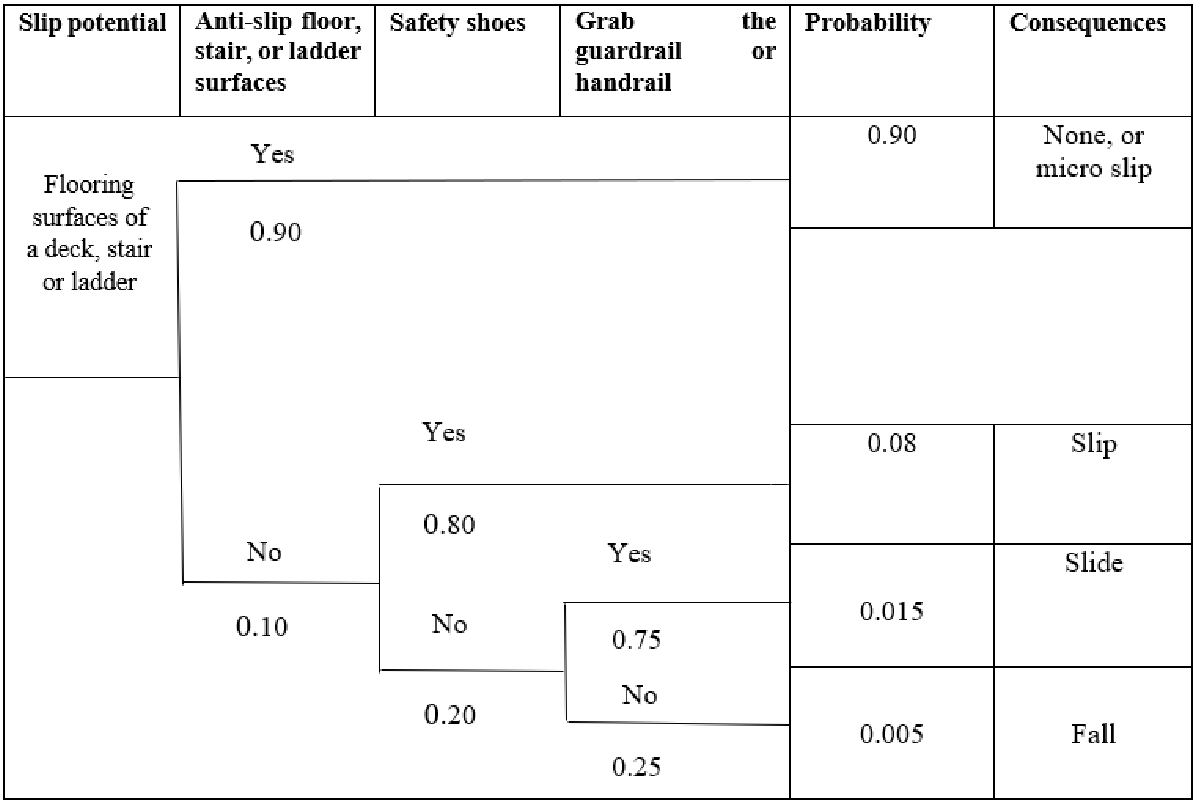

Figure 12: Event Tree Analysis of slip potential at vessel or offshore facility deck, stair, or ladder. Source: Author based on (Appendix 2: Pre-test questionnaire)

Event Tree Analysis of slip potential event at vessel or offshore facility deck, stair, or ladder has resulted in four scenarios.

In the first scenario, it is assumed that the slip will not occur in the potential slip event due to the success of the anti-slip floor, stair, or ladder surface, or either will go unnoticed. This scenario's probability is 0.9, with no consequences or just micro slip with no consequences for the worker's health.

In the second scenario, it is assumed that in the event that can cause a slip, the anti-slip floor, stair, or ladder surface fails. However, the safety shoes will help the worker resist the slippery floor, stair, or ladder surface and regain lost balance. This scenario's probability is 0.08 with such a consequence as a slip (as long as 8-10 cm) with minor consequences for the worker's health as muscular strain or back or leg pain (Courtney, T. K., Sorock, G. S., Manning, D. P., Collins, J. W., Holbein-Jenny, M. A., 2010).

The third scenario assumes that anti-slip floor, stair, or ladder surface and safety shoes fail in the slip potential event. However, the guardrail or handrail will help the worker to regain the lost balance. Nevertheless, the consequences are severe compared to the previous situation and can result in slides with major consequences for the worker's health as muscular strain, low back pain, and back, ankle, and neck injuries (Courtney, T. K., Sorock, G. S., Manning, D. P., Collins, J. W., Holbein-Jenny, M. A., 2010). The probability of this scenario is 0.015.

Lastly, in the fourth scenario, it is assumed that in the slip potential event, all STF prevention measures fail, which may cause a slide with loss of balance resulted in a fall. This scenario is the worst, with a very low probability of 0.005, resulting in major consequences as bone fracture, severe injuries with a life-long disability, or even death when working at height (Courtney, T. K., Sorock, G. S., Manning, D. P., Collins, J. W., Holbein-Jenny, M. A., 2010).

The probabilities of the events introduced in this event tree are brainstorming and based on the Interviews. The probability that anti-slip floor surface success (90%) means that during 90% of working time, the deck surface is not affected by atmospheric precipitations and not contaminated with oil, water, chemicals, or grease. During 10% of working time, it is assumed that the deck surface is influenced by atmospheric precipitations (such as rain, snow, ice, morning dew) and contamination (such as grease, oil, chemicals, water). This assumption is made due to the ships' remote location and offshore installations at sea, where they are constantly influenced by weather conditions and, therefore, precipitation. Thus, based on the Interviews, the author assumed that during 5% of working time, the weather precipitation decreases the COF of the deck, stairs, and ladders surfaces to the extend when the deck, stairs, and ladders become slippery. Along with this, contaminations on the floor during 5% of the working time also decrease the COF of the deck, stair, and ladders floor surfaces to the extend when it becomes slippery. Hence, the author assumed that the atmospheric precipitations and industrial contaminations decrease the COF of the deck, stair, and ladder surfaces to the extend when it becomes slippery during 10% of working time (Appendix 2: Pre-test questionnaire).

The probability that safety shoe success (80%) means that during 80% of working time, the shoes are free of any contamination, while during 20% of the working time, it may contain oil, chemicals, or grease, and therefore may be slippery (Appendix 2: Pre-test questionnaire).

The grip between the hand and the handrail is influenced by two factors: the surface of the hand and the surface of the handrail. Since maritime and offshore workers should always use protective gloves to have a good grip and to protect their hands from direct skin contact with chemicals, grease, etc., the grip of gloves is therefore considered. Due to industrial considerations, a worker's gloves can be affected by contamination. Therefore, the probability of guardrails success (75%) means that during 75% of the working time, the surface of the gloves is not covered with any contaminations such as water, oil, chemicals, grease or at least has minimal atmospheric precipitation, that does not affect the grip between the worker's hand and guardrail surface. While during 25% of working time, it is assumed that the gloves' surface is contaminated with oil, chemicals, water, etc. that decreases the gloves' grip, and therefore the workers may experience the slipperiness of the guardrails surface (Appendix 2: Pre-test questionnaire). Concerning the guardrails and handrails' surface contaminations, it is assumed that guardrails contaminations do not affect the grip between the worker's hand and guardrails surface due to the safety gloves.

As seen from the created event tree, the most severe consequences occur when all slip prevention measures are failed. Very low consequences occur if an anti-slip floor, stair, or ladder surface functioned successfully. The probability that all slip prevention measures fail is very low. Nevertheless, the consequences are extremely high. Thus, it can be concluded that STF prevention measures and regular maintenance and cleaning of such are critical to prevent the slip potential at the vessel or offshore facility deck, stair, or ladder surface and hence to protect the workers without causing any harm or, at least, causing minor harm.

4.2.5 Bowtie diagram

The Bowtie diagram helps conceptualize the interaction of hazards, causes, controls, and risk consequences. Bowtie focuses on control barriers between risk causes and risk events and recovery barriers between risk events and their consequences (Yoe, 2019).

The identified triggers and potentially harmful conditions and their associated consequences are visualized in two Bowtie diagrams to define all STF accidents' barriers and safeguards. The identified hazards and potentially harmful conditions are listed on the left side of Bowtie, while their associated consequences are listed on the right side of Bowtie. Preventive barriers (left side) and mitigating barriers (right side) were identified and classified accordingly. The first Bowtie diagrams (figure 13) illustrate slip, trip, and fall while work on the same level, and the second Bowtie diagram (figure 14) illustrates slip, trip, and fall while working at height or on stairs.

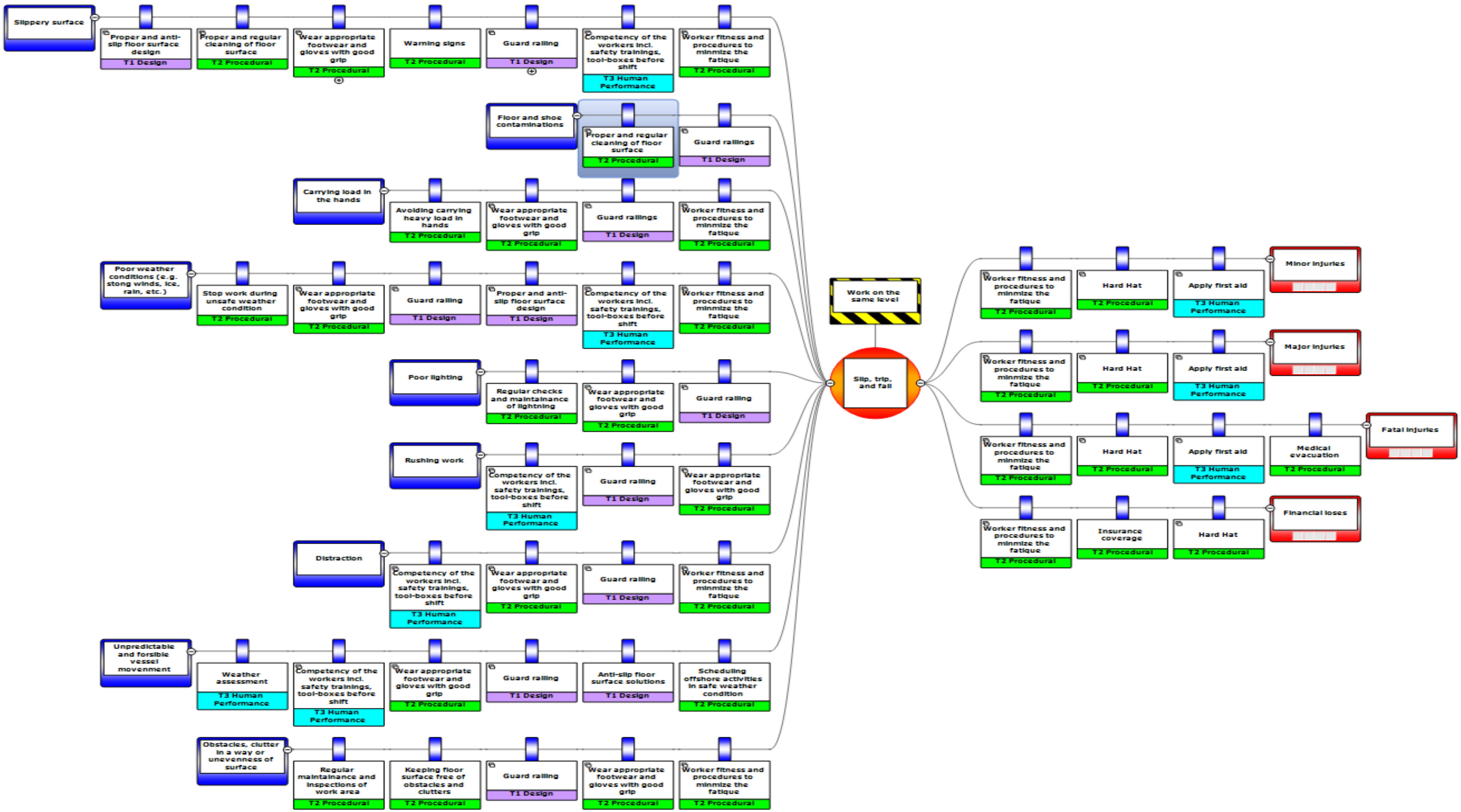

Figure 13: Bowtie diagram of STF for work on the same level. Source: (Komisar, V., McIlroy, W.E., and Duncan, C.A., 2019) (Hanson, J. P., Redfern, M. S., and Mazumdar, M., 2010) (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Appendix 2: Pre-test questionnaire)

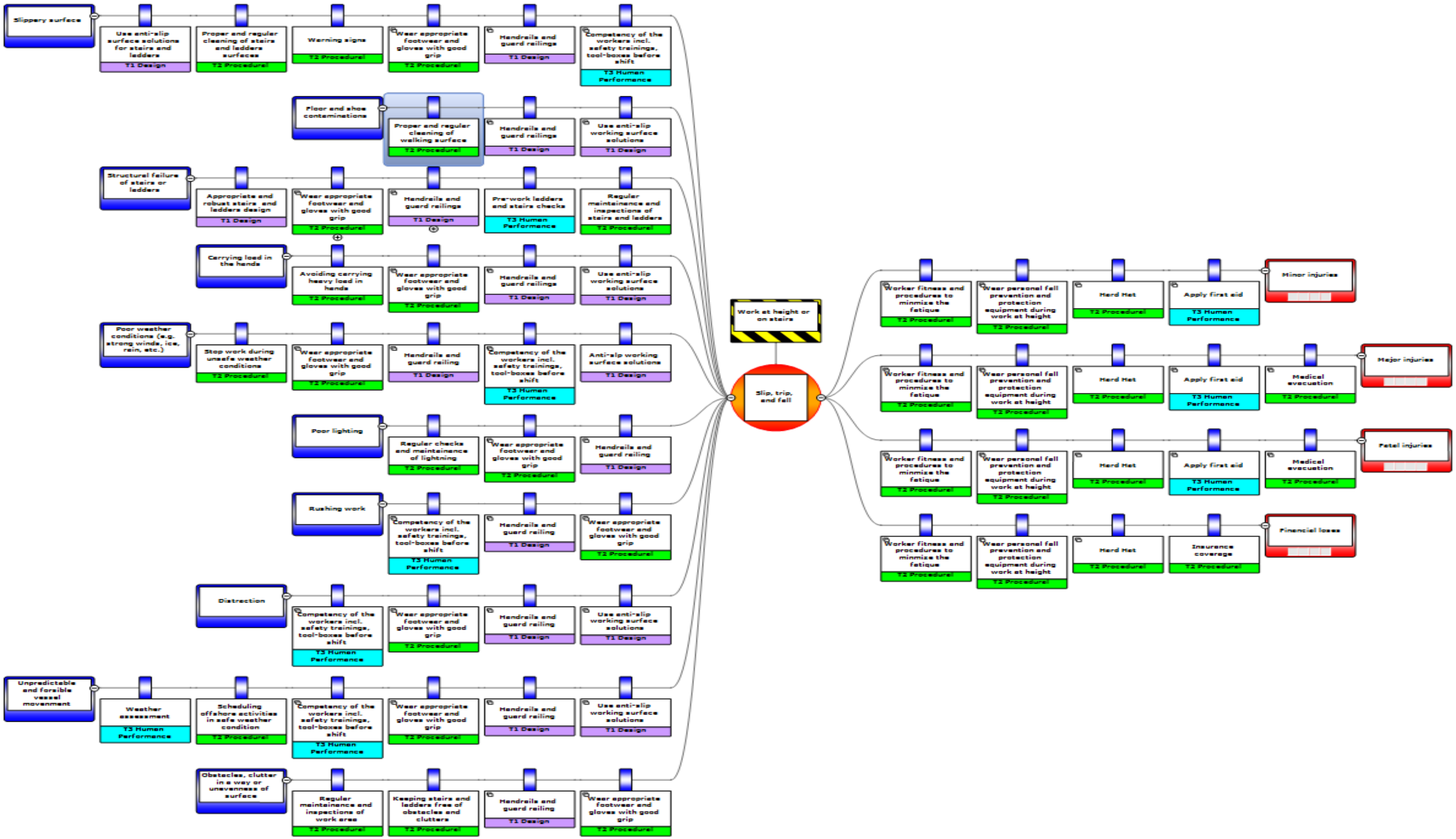

Figure 14: Bowtie diagram of STF for work at height or on stairs. Source: (Komisar, V., McIlroy, W.E., and Duncan, C.A., 2019) (Hanson, J. P., Redfern, M. S., and Mazumdar, M., 2010) (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Appendix 2: Pre-test questionnaire)

As mentioned in subchapter *4.1 Hazard identification*, there are several potentially harmful conditions and triggers in the maritime industry and offshore installations that can cause an STF, such as slippery surface, floor, and shoe contaminations, carrying the load in hands, poor weather conditions, low lighting, rushed work, distraction, unpredictable and forcible vessel movement, obstacles and clutter in a way, unevenness of floor surface, structural failure of floor surface, stairs or ladders. Some of the hazards could be prevented by ensuring appropriate and anti-slip floor, stairs and ladders surface design, proper and regular housekeeping and cleaning of the floor, stairs, ladders surfaces, appropriate handrails and guardrails, regular maintenance and inspections of working area and lightning, appropriate safety shoes and gloves with a good grip and avoid carrying a heavy load, especially in both hands. Furthermore, workers' competency, including safety training and safety toolboxes before each shift, weather assessment, scheduling offshore activities in calm weather conditions, and stop work during rougher weather conditions, are key in ensuring tasks performed safely (Komisar, V., McIlroy, W.E., and Duncan, C.A., 2019) (Hanson, J. P., Redfern, M. S., and Mazumdar, M., 2010) (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Offshore Wind, 2014).

Although most of these hazards seem to be relatively common and harmless, the consequences can be rather severe. For example, financial losses, injuries, life-long disabilities, or even fatal when working on stairs or height. In order to mitigate these consequences, several barriers can be implemented. Workers' fitness and procedures to minimize fatigue can help increase workers' ability to regain balance loss after a slip or trip accident. Moreover, wearing a hard hat and personal fall prevention and protection equipment while working at height can reduce the consequences of STF accidents. Besides, the timely provided medical evacuation and appropriate first aid can significantly influence STF accident consequences (G9 Offshore wind, 2014).

To conclude the STF's risk analysis, the author combined the PHA, RCA, ETA, and Bowtie results. It can be seen that STF-related triggers and potentially harmful conditions that were analyzed in this project can be prevented with more strict organization's policies, rules, and procedures for regular maintenance, checks, and cleaning of the floor, stairs, and ladders surfaces, use of handrails, carrying heavy loads, carrying the load in both hands, housekeeping, fatigue management, weather assessment, fitness level control and rushing work. Moreover, ensuring the proper anti-slip floor, stair, and ladder surface design and appropriate handrails and guardrails are critical factors in preventing STF accidents in harsh working environments such as maritime and offshore industries. Besides, the importance of safety training for developing a worker's high level of risk perception and the organization's safety culture plays an essential role in ensuring work is performed safely.

4.3 Risk evaluation

After the risk assessment process, it is time to evaluate the risk. Evaluation of risk means defining whether the risk is acceptable, defining the principles for establishing a tolerable level of risk, herein ALARP principle, and making a final decision. The risk evaluation is performed qualitatively by evaluating the accidents on a particular Danish ship's organization during 2019, their severity, and the likelihood. The risk of STF is mapped in the risk matrix following the ALARP principles.

During 2019 at Danish ships organization STF's incidents were as follows (Appendix 2: Pre-test questionnaire):

- Lost Time Incidents (LTI) - 2
- Restricted Work Cases (RWC) - 3
- Medical Treatment Cases (MTC) - 1
- Minor - 25

The accidents were grouped by their severity, and frequency rates were assigned as described below and divided by the number of offshore workers on that ship's company, i.e., 1000 employees (Safety, Quality and ESG Report 2019, 2019). The result is shown in the risk matrix, figure 15, where the value of 0.028 means 28 minor incidents per year per 1000 employees. The value of 0.01 means one incident per year per 1000 employees with negligible consequences. Lastly, the value of 0.02 means two incidents per year per 1000 employees with severe consequences. The risk matrix is built by the severity and frequency of the incident, where the red area is unacceptable, yellow is unwanted, bright yellow is tolerable, and the green area is negligible (DNV GL, 2015). A detailed description of the ALARP principles and areas of none, negligible, unwanted, tolerable, and unacceptable risk is presented in subchapter *3.5 ALARP Principle* in chapter *3 Methodology*.

The severity of an incident's consequences are described in subchapter *4.1.1.4 Risk matrix (heat map)*.

The frequency of the incidents can be understood as following (DNV GL, 2015):

- Very likely - more than one incident per year/month
- Likely - more than 0.1 incidents per 1-10 years

- Average - more than 0.01 incidents per 10-100 years
- Unlikely - more than 0.001 incidents per 100-1000 years
- Remote – more than 0.0001 incidents per 1000-10 000 years

		Consequence				
		None	**Negligible**	**Significant**	**Serious**	**Critical**
Frequency (number of incidents per year)	**1**					
	0.1-1	**0.028**				
	0.01–0.1		**0.01**		**0.02**	
	0.001-0.01					
	0.0001-0.001					

Figure 15: Risk matrix of the risk of the STF based on incident data on a particular Danish ship's company, 2019. Source: Author based on (DNV GL, 2015) (Appendix 2: Pre-test questionnaire)

As seen from the created risk matrix, 29 incidents are in the green area, which means that the risk is negligible and does not require further measures to reduce the risk of STF. Two incidents are in the yellow area, which means that this risk is unwanted and shall be reduced to a negligible level of risk according to the Danish ship's company incident target. During risk communication with the head of the HSE of that company, it was noted that their company has a target of 0 LTI (Appendix 2: Pre-test questionnaire). Therefore, risk treatment/control measures shall be considered further.

Moreover, the other stakeholder in an offshore wind energy company in Denmark during the interview noted that their acceptable level of incidents is 1-2 incidents with none consequences, while even one incident with the negligible consequence is in the ALARP area and shall be reduced as low as reasonably practicable (Appendix 6: Interview with an HSE advisor at Danish Offshore Wind Farm).

Besides, it is possible to measure fatalities overall risk of STF due to slip for every shift by weighing and combining the non-fatal injuries from the created ETA in subchapter *4.2.4 Event Tree Analysis*. The value of 0.001 is used for weighting of non-fatal injuries. The value of 0.1 is used for weighting major non-fatal injuries. Lastly, the value of 1 is used for weighting of fatal injuries. The introduced values are taken from the rail industry and are used as a reference point (Rail Safety & Standards Board, 2008).

$$\mathbf{R = P * C}$$

$$\mathbf{R} = 0.08 * 0.001 + 0.015 * 0.001 + 0.005 * 0.1 = 0.00008 + 0.000015 + 0.0005 = 0.000595 = \mathbf{5.95 \times 10^{-4}}$$

Thus, the calculated fatalities overall risk of STF due to slip is 5.95×10^{-4}. According to subchapter *3.5 ALARP principles*, the obtained value of 5.95×10^{-4} has an unwanted level of risk and therefore shall be reduced to a tolerable or negligible level.

It can be concluded that the decision from risk evaluation is to further reduce the STF risk in the Danish ship's company to a negligible level of risk, which means 0 LTI per year for that particular company. In an offshore wind company, the STF risk should be reduced to a negligible level of risk as well. The fatalities' overall risk of STF due to slip shall be reduced to tolerable or negligible risk levels.

4.4 Summary of risk assessment

To summarize, risk identification is the first step in the risk assessment stage, which identifies the triggers and potentially harmful conditions that may lead to STF. The next steps after risk identification are the risk analysis and risk evaluation, which are performed comprehensively for the risk of STF in the maritime industry and offshore installations as follows:

- Identifying the triggers and potentially harmful conditions, people at risk, possibility, and challenges for reducing STF by using the preliminary hazard analysis, root cause analysis, and bowtie methodology
- Clarifying the types and location of STF by elaborating the most hazardous and frequent location of their occurrence at the vessel and offshore installations and evaluate the existing STF preventive measures
- Defining the control barriers between risk causes and risk events and recovery barriers between risk events and their consequences using a Bowtie diagram

- Implementing the probabilistic approach by using the Event Tree Analysis for probability and consequence assessment and quantifies the effectiveness of barriers to reduce risk and calculate the residual individual risk of STF for the workers in the maritime industry and offshore installations
- Evaluating the risk of STF, taking into account its severity and frequency of occurrence using a risk matrix. After risk evaluation, the decision is to reduce further the risk of STFs in the maritime industry and offshore installations to a negligible risk level. Therefore, the next chapter is considered for this purpose.

5 Risk Treatment

The risk management process's final stages a risk treatment (International Organization for Standardization, 2018). Risk treatment is an iterative process of formulation, selection, and implementation of risk treatment options to modify the risk. There are such risk treatment options to modify the risk: avoiding, taking, removing the risk source, changing the likelihood or consequences, sharing, and retaining the risk (International Organization for Standardization, 2018). The risk modifying measures chooses to depend on the strategy used for managing risk. In this project, measures aimed to change the likelihood and consequences of STF are used as modifying risk measures. The desired outcome of risk treatment is reducing STF incidents in the maritime industry and offshore installation to a negligible risk level, as was mentioned in subchapter *4.3 Risk Evaluation.*

Following measures play an essential role in reducing STF accidents in the maritime industry and offshore installations (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016) (Appendix 4: Interview with a Captain at Danish ship) (Offshore Wind, 2014):

- Safety training
- Risk awareness campaign
- Safety shoes
- Safety gloves
- Fatigue prevention
- Pre-shift toolboxes
- Leadership commitment to safety
- Speaking up about safety
- Accidents reporting
- Handrails and guardrails
- Anti-slip walking-working surfaces

During the interviews with stakeholders in the industries and author's researches on legislative requirements regarding prevention and mitigation of the STF incidents in the maritime industry and offshore installations, were identified that such measures as safety training, safety shoes, safety gloves, fatigue prevention, toolboxes before the new shift, and reporting are existed and required. In contrast, such measures as leadership commitment to safety, risk awareness campaigns, and speaking up about safety are recommended. However, the level and quality of these measures vary from company to company. Moreover, some of them vary from ship to ship or from one offshore installation to another, even in the same company, depending on the master on-site (Appendix 4: Interview with a Captain at Danish ship). Besides, all the mentioned measures are strongly linked with the safety culture of the organization. Nevertheless, the author assumes that all the mentioned measures are in place. Still, their level of quality is not assessed in this project, and suggestions to improve their effectiveness are not given due to the limited time available for this project.

Moreover, it is assumed that such measures as regular maintenance and cleaning of the floor, stair, and ladders surfaces, regular checks, and maintenance of the lightning, restrictions in carrying heavy loads, avoiding carrying loads in both hands, avoiding the execution of tasks under extreme weather conditions, organization's policies and rules in prevention rushing work, weather assessment before and during sailing, housekeeping policies and inspections, regular checks, inspections, and maintenance of the floor surface, stairs, and ladders, and workers' fitness level control are in place as well.

As mentioned in subchapter *2.2 Slips, trips, and falls phenomena*, the surfaces' slipperiness is one of the main contributors to STF. Therefore, the appropriately installed handrails, the stair treads design with non-slip mesh and painting the walkways and decks with the added sand, or other measures to reduce the slipperiness of the working-walking surfaces are required on all ships and offshore installations. However, the effectiveness of the painting of the walkways and decks with the adding of sand gives the anti-slip effect, not for a long time. After 2-3 months, the effect is gradually decreasing. Moreover, there are new available technological solutions on the market today, such as the KAG safety rails with the extra grip and anti-slip tread covers, anti-slip walkways, and decks cover with a very high coefficient of friction of 0.95. Therefore, the author decided to focus on technological solutions available on the market today that aim to reduce the slipperiness of the floor, stair, ladder, guardrails, and handrails surfaces and potentially reduce STF accidents. Besides, some Danish ships and offshore installations have already been installed these technological solutions, and it is possible to evaluate their practical effectiveness in such a harsh work environment as the maritime and offshore industries.

5.1 Formulation of the RMO

Risk Management Option (RMO) is a strategy that describes specific ways to achieve risk management objectives. This strategy is subordinate to the objective (Yoe, 2019). The objective of this project is to reduce the slips, trips, and falls in the maritime industry and offshore installations. The strategy for achieving this objective is proposed as follows and consist of two components:

- Installing the anti-slip solutions for flooring surfaces of a deck, stair treads or ladders on ships, and offshore installations in places where the STF accidents could potentially occur (i.e., a means of access or in the places where the working activities are performed)
- Installing the KAG safety rails throughout the ship or offshore installation

Thus, the RMO for reducing STF in the maritime industry and offshore installations is formulated in the following way:

- installation of the KAG safety rails and anti-slip solutions at the floor, stairs, and ladders surfaces throughout the ship or offshore installation in places prone to STF.

The anti-slip solutions are products for any surface that provide high friction in any environment and weather. Different companies on the market deliver anti-slip products, but this project considers the anti-slip solutions from Real Safety. Real Safety is located in Esbjerg (Denmark). Real Safety anti-slip solutions can be non-slip on virtually all surfaces, and these products are non-slip whatever the environment and weather. Real Safety can offer non-slip solutions on wood, steel plates, steel gratings, concrete, and tiles surfaces. These solutions can be applied for stairs, steps, walkways, ship decks, platforms, platforms, terraces, etc. The COF of Real Safety anti-slip covers, tested in wet conditions, is 0.95 (Appendix 1: Electronic Interviews).

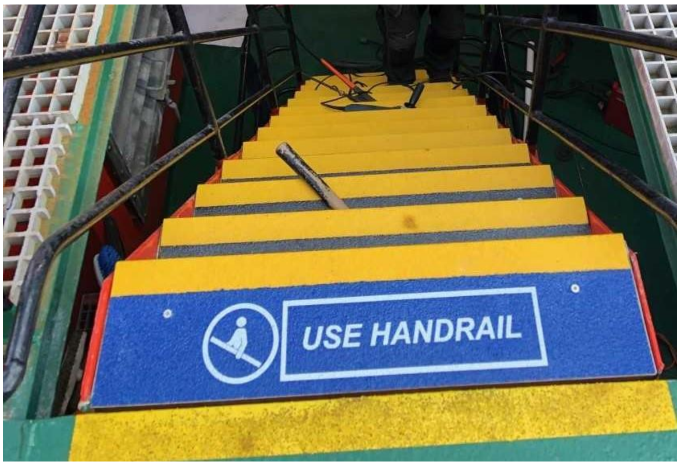

Figure 16: Real Safety anti-slip stair tread covers at Danish ship. Source: Author

The KAG safety rails are presented in Denmark by Acurail, which is located in Esbjerg. The KAG safety rails can be manufactured from stainless steel, black steel, copper, aluminum, and brass and are designed to afford increased grip levels to the user compared to plain tube handrails. The KAG rails give up to 300% better grip during oily conditions, up to 160% during dry conditions, and 80% under wet conditions than conventional products on the market. The KAG rails suitable for a wide range of premises and environments aimed to prevent accidents, injuries, and muscle strains while increasing comfort and ease (Pellegrin) (Appendix 1: Electronic Interviews).

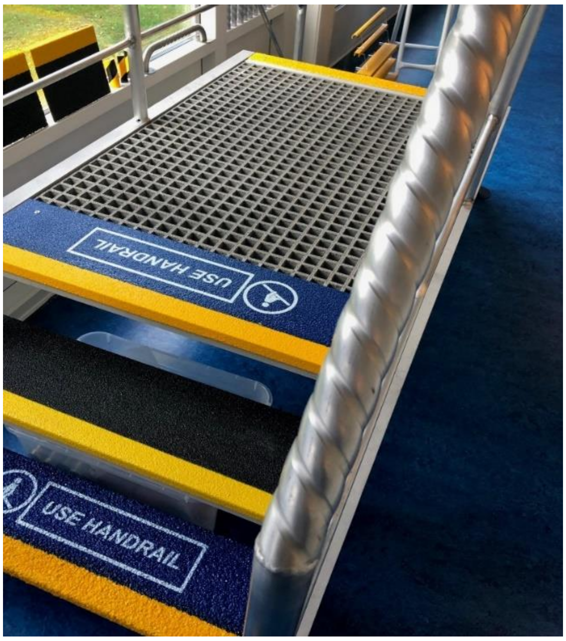

Figure 17: Formed KAG handrail sample. Source: (Appendix 1: Electronic Interviews).

Since some Danish shipping and offshore wind companies have already implemented anti-slip solutions and rails with KAG profile, it is, therefore, possible to get feedback from these companies on how well this RMO is achieving the STF accidents reducing objective. Thus, further chapter *6 Risk Monitoring,* aims to introduce the evidence on how the introduced RMO works. The RMO's improvement is measured on direct evidence of cause-and-effect relationships between the proposed RMO and the lowering of the risk.

6 Risk Monitoring

Risk monitoring aims to provide the organization with feedback on how well the implemented RMO achieves its objective. In order to see if the decision is working, the monitoring of the outcome is required. The monitoring of the outcome of the implemented RMO is an evidence-based process. However, to judge an RMO's success, it must first identify outcomes to monitor (Yoe, 2019). In this project, risk monitoring aims to determine if the desired risk-reducing achieves with RMO implementation. For this purpose, the evidence on how the implemented anti-slip solutions for flooring surfaces of a deck, stair treads, or ladders and rails with KAG profile works in terms of reducing the slipperiness of the surfaces and affecting the number of accidents were gathered, evaluated, and introduced in the further subchapter.

6.1 Evaluation of RMO

After the information gathering process, it is time to evaluate the RMO. This process compares the result obtained from the ETA without RMO for currently existing flooring surfaces of a deck, stair treads, or ladders and rails on most Danish ships and offshore installations, that have been evaluated in subchapter 4.2.4 *Event Tree Analysis*, with the ETA result with the implemented RMO, which evaluates below.

Evaluation of the RMO is performed by quantifying the possible outcomes after the potential slip event. That is done by conducting the ETA with the same steps as in subchapter *4.2.4 Event Tree Analysis,* but under the anti-slip floor, stair, or ladder surfaces, there are anti-slip solutions with a coefficient of friction of 0.95, and the KAG safety handrails and guardrails.

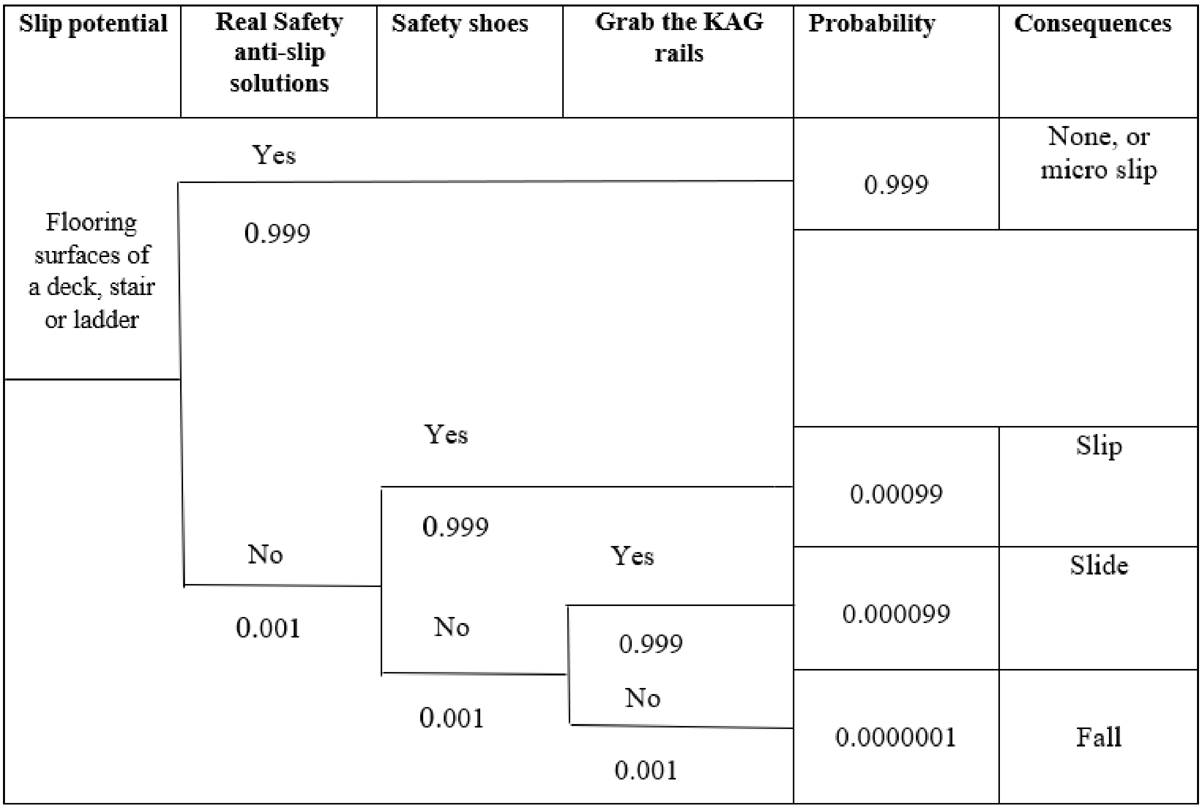

Figure 18: Event Tree Analysis of slip potential at vessel or offshore facility deck, stair, or ladder with implemented anti-slip solutions and KAG railing. Source: Author based on (Appendices 4, 5, 6, 7 & 8)

The probabilities of the events introduced in this event tree are brainstorming and based on the interviews with masters, chief officers of the several danish ships, and HSE coordinator of the Danish offshore wind turbine, where the anti-slip products have been installed and used for many years.

The probability that anti-slip floor surface success (99.9%) means that during 99.9% of working time, the deck surface, stair, or ladder surfaces has a sufficiently high coefficient of friction even if it is affected by atmospheric precipitations and contaminated with oil, water, chemicals, or grease. Based on the interviews, it was revealed that the presence of small contaminations or water drops, that are very likely at offshore wind turbine ladders and on walkways, stairs, and decks of ships, not affect or insignificantly affect the coefficient of friction of anti-slip solutions, but, moreover, they can absorb oil contaminations. While the interview with the oil and gas company was not conducted due to the limited time available for this project. Therefore, based on the author's research, the following assumptions had to be made. The presence of heavy contaminations of oil, chemicals, or grease, which are highly likely in oil and gas companies, may reduce the COF of the flooring surfaces of the deck, stair, or ladder. However, the coefficient of friction of anti-slip solutions of 0.95 is very high.

Therefore, even if it is reduced by 10 – 20 % due to contaminations, it still has very good slip resistance. The friction coefficient of > 0.75 is widely considered to be very good slip resistance for both dry and unpolished wet surfaces (Bureau Veritas, 2008). Thus, it can be concluded that the anti-slip solutions that are evaluated in this project are considered very good slip resistance solutions, and therefore the probability of their success is assigned to 0.999%. The probability that they fail assigned to 0.001% is because, in case of a very significant oil spill, they may be completely covered with oil and hence the anti-slip effect lost (Appendices 4, 5, 6, 7 & 8).

The probability that safety shoe success (99.9%) means that during 99.9% of working time, the safety shoes do not slip even if it is oil, chemicals, or grease contaminated, due to sufficiently high coefficient of friction of anti-slip solutions for the floor, stair, or ladder surfaces. Therefore the interface floor-shoes have good slip resistance even if the worker's shoes are contaminated. While the probability that safety shoes fail assigned to 0.001% because, in case of a very significant oil spill, the safety shoes and anti-slip solutions may be completely covered with oil, and hence the anti-slip effect is lost (Appendices 4, 5, 6, 7 & 8).

The grip between the hand and the handrail is influenced by two factors: the surface of the hand and the surface of the handrail. Since maritime and offshore workers should always use protective gloves to have a good grip and to protect their hands from direct skin contact with chemicals, grease, etc., the grip of gloves is therefore considered. Due to industrial considerations, a worker's gloves can be affected by contamination. Therefore, the probability of guardrails success (99.9%) means that during 99.9% of the working time, the surface of the gloves may be uncovered or even if it is covered with any contaminations such as water, oil, chemicals, grease, or at least has minimal atmospheric precipitation, that does not affect the grip between the worker's hand and guardrail surface. Since the handrails and guardrails with KAG profiles are proven by users at Danish ships and Queensland university to have a 300% extra grip under oily conditions, 80% extra grip under wet conditions, and 160% extra grip under dry conditions (Appendix 1: Electronic Interviews). While, the probability that the guardrails or handrails fail is assigned to 0.001% because in case of a very significant oil spill, the safety gloves, as well as guardrails and handrails surfaces, may be completely covered with oil, and hence the extra grip effect lost (Appendices 4, 5, 6, 7 & 8).

The effect on the probability of the implemented RMO compared to without RMO scenario in potential slip event is introduced in the table below.

Table 2: The effect on the probability of the implemented RMO compared to without RMO scenario in potential slip event. Source: Author based on (Appendices 4, 5, 6, 7 & 8)

	Probability			
Consequences		Without RMO	With RMO	Effect
	None, or micro slip	0.90	0.999	0.099
	Slip	0.08	0.00099	- 0.079
	Slide	0.015	0.000099	- 0.0149
	Fall	0.005	0.0000001	- 0.0049

Table 2 shows that with implemented RMO, the probability that the none or micro slip will occur in potential slip event is increased by 9.9 % compared to without RMO scenario. The likelihood that the slip, slide, and fall will occur in potential slip event with implementing the RMO is reduced by 9.9 % compared to without RMO scenario.

By weighing the non-fatal injuries, they are combined to measure fatalities overall risk of STF due to slip for every shift:

$$\mathbf{R = P * C}$$

$$\mathbf{R} = 0.0099 * 0.001 + 0.000099 * 0.001 + 0.0000001 * 0.1 = 0{=}0.0000011{=}\ \mathbf{1.1 \times 10^{-6}}$$

Table 3: Evaluating an RMO through the comparison scenarios with RMO and without RMO. Source: Author based on (Yoe, 2019) (Appendices 2, 4, 5, 6, 7 & 8)

Effect	With RMO	Without RMO	Change
Fatalities overall risk of STF due to slip for every shift	1.1×10^{-6}	5.95×10^{-4}	$- 5.94 \times 10^{-4}$

The fatalities overall risk of STF due to slip for every shift for existing RMO was calculated in subchapter *4.2.4 Event Tree Analysis* and is 5.95×10^{-4}. The fatalities overall risk of STF due to slip for every shift with introduced RMO as calculated above is 1.1×10^{-6}. When comparing the fatalities overall risk of STF due to slip for every shift with RMO and without RMO, it can be seen that the risk of fatality with implemented RMO is reduced by 5.94×10^{-4} compared to the risk of fatality without RMO, which is illustrated in figure 19 below.

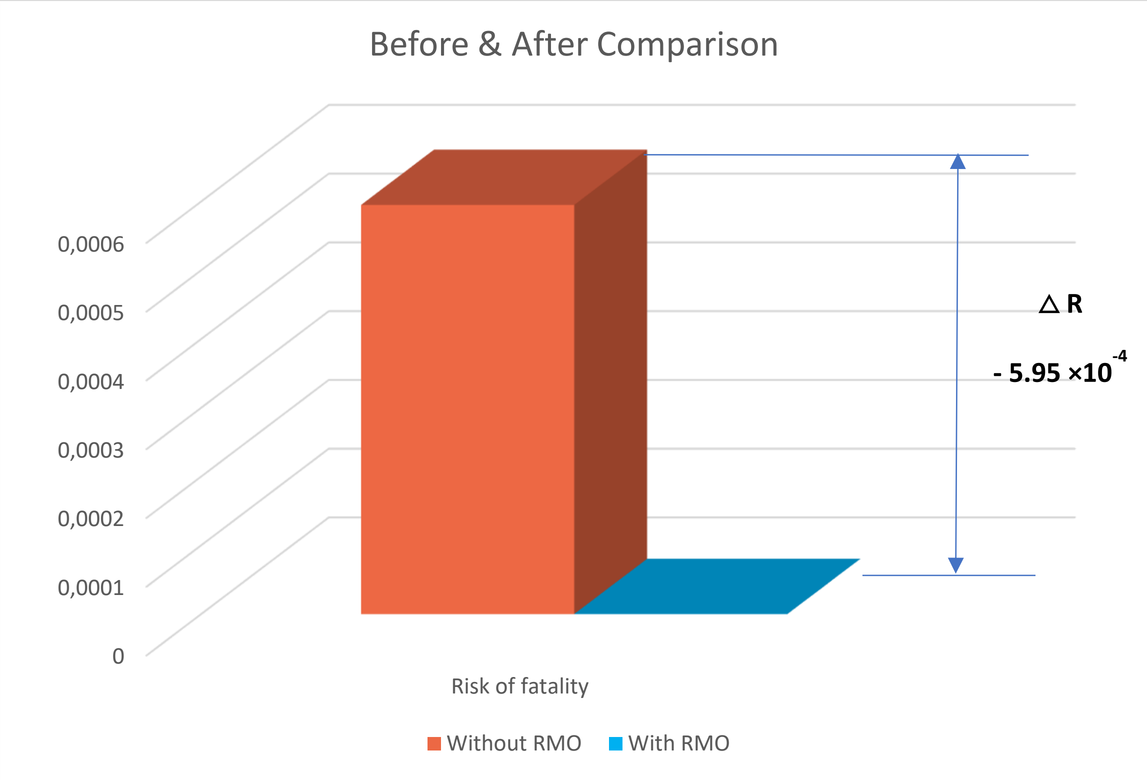

Figure 19: Before & After Comparison with RMO and without RMO. Source: Author

Thus, it can be concluded that when implementing anti-slip solutions for the floor, stair, or ladder surfaces and KAG safety rails, the fatalities overall risk of STF due to slip for every shift can be reduced by 5.94×10^{-4} and is 1.1×10^{-6}. That means that the mentioned risk is at a negligible level of risk, which is an acceptable level of risk.

The risk treatment objective is to reduce the STF in the maritime industry and offshore installations to a negligible risk level. Therefore, it can be concluded that the result achieved from the risk monitoring is successful since it is shown that the fatalities overall risk of STF due to slip for every shift with implementing the RMO is reduced from 5.94×10^{-4} to 1.1×10^{-6}. That means that the residual risk has a negligible level, which is a desired outcome of the implemented RMO.

Moreover, another metric for measuring an RMO's improvement is reducing the number of accidents. It shows how the reduced risk of fatality per shift due to slip is reflected in the number of incidents on the ships and offshore installations with implementing introduced technological solutions. As mentioned above, some Danish ships and offshore wind turbines have already installed anti-slip solutions and handrails with the KAG profile. The interviews with the ship chief officers and HSE offshore wind coordinator have been conducted to evaluate their effectiveness, and the following result has been received.

When comparing the number of STF accidents with and without the RMO at a Danish offshore wind company, the number of STF accidents prior to installations of anti-slip stair treads covers was 12 injuries with negligible consequences. In contrast, after installing the anti-slip treas covers, the number of accidents has reduced to 0 (Appendix 6: Interview with an HSE advisor at Danish Offshore Wind Farm).

The number of accidents at some Danish ship, where the chief officer and bosun were interviewed, was 3 STF with negligible consequences before installing the walkways, deck, and stair treads anti-slip covers. This number of STF accidents have been reduced to 0 after installing the walkways, deck, and stair treads anti-slip covers (Appendix 7: Interview with a Chief Officer and Bosun at the Danish ship).

6.2 Summary

The costs and benefits of an RMO are not calculated in this project due to the limited time and resources available. However, it shall be noted that the price, for instance, the KAG safety rails, does not differ significantly from existing conventional smooth rails (Appendix 1: Electronic Interviews). Therefore, if these rails are considered at the design stage of ships or offshore installations, it will not significantly impact capital costs.

It can be summarized that the probability of none slip or micro slip in potential slip event is increased with implementing an RMO by 9.9 % compared to without RMO scenario, while the probability of slip, slide, or fall in potential slip event is reduced from 10 % to 0.1 %. When comparing the fatalities overall risk of STF due to slip for every shift, it can be seen that this risk is reduced by 5.94×10^{-4} and is 1.1×10^{-6} with implementing the RMO. Besides, the feedback on the implemented RMO showed that the number of incidents decreased in Danish offshore wind company from 12 incidents to 0, on particular Danish ship from 3 incidents to 0. Thus, it can be concluded that the implemented RMO works and reduces the STF in the maritime industry and offshore installations. That means that the STF reducing objective has been achieved.

7 Discussion

This chapter aims to discuss and point out potential suggestions for future research that might significantly impact reducing slips, trips, and falls in the maritime industry and offshore installations.

During a literature review on STF phenomena, it was revealed that the most critical factors that influence trip potentials are the unevenness of the walking surface, and for the slip potential, the coefficient of friction of the floor-shoe interface. Thus, to reduce STF due to trips and slips, it is essential to ensure proper housekeeping, proper lighting, proper floor, stairs, and ladders design. Although reducing STF due to slip is a more complex process due to harsh working environment under extreme weather conditions and industrial contaminations that affect the coefficient of friction of floor-shoe interface, and require additional measures to be implemented. Therefore, as stated in chapter *5 Risk Treatment*, the strategy to reduce the risk of STF focuses on STF due to slip, particularly increasing the slip resistance of walking and railing surfaces in places prone to this risk. There are different ways to increase the coefficient of friction of the walking and railing surfaces. However, the project focuses on the specific way, such as installing the KAG safety rails and anti-slip solutions at the floor, stairs, and ladders surfaces throughout the ship or offshore installation in places prone to STF. The monitoring and evaluation of the introduced RMO were brainstorming through the ETA, where the probabilities were based on interviews conducted within a case study. On the ground of these limitations, the results only portray a rough estimation of the reducing STF in potential slip events in the maritime industry and offshore installations.

During the practical test as a part of the case study, an incident occurred. In the first week of testing the anti-slip stair treads covers and KAG handrails, two workers had scratches on their leg's skin due to the installed anti-slip covers' roughness. Therefore, they were removed, and further evaluation of anti-slip covers was not possible on this particular ship. Besides, it was not possible to evaluate the effect on human behavior of the bright color of the stair treads and embedded in it safety signs, which are designed to increase the worker's attention and hence influence their behavior (e.g., avoid missteps at staircases). Real Safety anti-slip products indicate that there is a risk of scratching the skin through direct contact. However, in interviews with the other companies that have installed the Real Safety anti-slip solutions and have been using them for 6-10 years, this problem does not exist because workers are aware of the roughness of the anti-slip covers. Moreover, their skin is always protected with safety clothes, gloves, and shoes. Therefore, it was assumed that workers' walking habits and level of their risk perception contributed to these incidents, as a stair design was within legal requirements.

In chapter *4 Risk Assessment,* several triggers and potentially harmful conditions were identified. For some of them, the causes were clear and obvious, while some required detailed analysis. For this purpose, RCA was conducted for carrying the load in hands and rushed work. It was revealed that the root causes of these triggers are the organization's safety culture and the human behavior of an individual. Besides, such potentially harmful conditions as human error and distraction resulting from individuals' human behavior were not analyzed. However, during the interviews within a case study and explored studies, the role of individuals' human behavior and the organization's safety culture was cited as essential, having an enormous impact on the number of accidents in the organization (Appendix 4: Interview with a Captain at Danish ship) (Offshore Wind, 2014) (Chang, W., Leclercq, S., Lockhart, T. & Haslam, R., 2016). Thus, the organization's safety culture and the human behavior of an individual require further analysis to determine their role and potentials for reducing STF.

Thus, the reducing STF in the maritime industry and offshore installations are a very complex process that requires a comprehensive approach, where the role of safety culture and human behavior of individual play an important role and shall be investigated further.

7.1 Future work

In the process of writing this project, many ideas originated for future work. Some causes of STF, such as coefficient of friction and unevenness of the floor surface, rushed work, obstacles on the way, carrying the load in the hands, weather conditions, etc., were systematically investigated in this project. Still, there is some area that has been slightly touched upon in this thesis.

One of the factors that have not been thoroughly investigated in this project is the organization's safety culture. Only a brief description of safety culture is given in subchapter *2.4 Safety Culture*. More research is needed to gain a clear understanding of the role of an organization's safety culture in reducing STF accidents and finding a comprehensive way to reduce further these accidents in the maritime industry and offshore installations. Two potentially harmful conditions, such as human error and distraction resulting from individuals' human behavior, were identified in PHA but were not analyzed in this project. The human behavior of an individual (their competence, attitude, risk perception and personality, skills, and habits) and the influence of the safety culture on his behavior shall be further explored within a given topic in order to comprehensively approach the reducing of slips, trips, and falls.

Another factor that was not included in evaluating the introduced RMO is a cost-benefit analysis, which should also be performed further. The cost-benefit analysis would ensure that the decision-makers know the potential cost related to the prize of the KAG safety rails and anti-slip solutions, their installations and maintenances, and potential benefits gained through the potential reduced number of accidents.

Moreover, evaluating the effect on human behavior of the stair treads' bright color and embedded into them safety signs was not possible. Thus, it requires further analysis to evaluate how the introduced anti-slip solutions increase workers' attentiveness and affect STF accidents. During the interviews were mentioned that the leading cause of STF accidents on stairs at a particular company is a distraction. Therefore, it is critical to evaluate anti-slip solutions' bright color and embedded into them safety signs influence when walking stairs to avoid missteps, since it can have a considerable influence in reducing STF (Appendix 2: Pre-test questionnaire) (Appendix 5: Interview with a Chief Officer at the Danish ship).

Including these factors would improve the quantitative models and offer a complete analysis of reducing STF in the maritime industry and offshore installations.

8 Conclusion

Slips, trips, and falls (STF) are the primary source of workplace injuries. Slip, trip, or falls on the same level and falls from a height are responsible for 34,5% of all reported injuries in the UK that occurred in offshore installations in 2019. STF onboard Danish-flagged ships accounted for approximately 27% of all maritime accidents during 2013-2016. Despite many measures set out by legislative requirements, best practices guidelines, and organizational policies to prevent STF, the number of STF accidents is still high. The project's objective was to identify the causes behind the STF and measures that can be implemented further to reduce STF in the maritime industry and offshore installations.

During the risk analysis process was revealed that one of the most critical factors affecting STF is the slipperiness of the handrails, guardrails, walkways, decks, stairs, and ladders' surfaces. Furthermore, the fatalities' overall risk of STF due to slip was calculated in the evaluation part of the risk assessment, which was found to have an unwanted risk level. Hence, the decision from risk evaluation was to reduce further the risk of the STF due to slip to a negligible level of risk. Therefore, the Risk Management Option (RMO) aimed to reduce these surfaces' slipperiness was proposed, monitored, and evaluated.

The project finalizes that reducing the slips, trips, and falls is a complex process that requires a comprehensive approach. Still, technological solutions aimed at reducing the surfaces' slipperiness can further reduce STF in the maritime industry and offshore installations. Two Event Tree Analyzes (ETAs) were carried out to evaluate introduced technological STF's reducing measures effectiveness compared to existing slip reducing measures on the Danish ship. The first ETA included such STF reducing measures as the existing floor, stairs, and ladders' surfaces and smooth conventional rails on the Danish ship. The second ETA included introduced RMO consisted of such STF reducing measures as KAG safety rails and anti-slip floor, stairs, and ladders surfaces solutions. The following results were achieved. The probability of none slip or micro slip in potential slip event is increased with implementing an RMO by 9.9 % compared to without RMO scenario. The probability of slip, slide, or fall in a potential slip event is reduced from 10 % to 0.1 %. When comparing the fatalities overall risk of STF due to slip for every shift, it was calculated that this risk is reduced by 5.94×10^{-4} and is 1.1×10^{-6} with implementing the RMO. That means that the risk of STF due to slip has reduced to a negligible level of risk, and the risk management objective is achieved. However, it shall be noted that during the assigning the probability in ETA, it is assumed that all other measures to prevent STF such as proper design and regular maintenance and cleaning of the floor, stair, ladders and rails surfaces, safety training, etc. are in place. In the absence of any relevant measures to prevent STF, the probability of micro slip, slip, slide, or fall and the fatalities overall risk of STF due to slip for every shift would increase in the case without an introduced RMO. Consequently, the probability of micro slip, slip, the slide of fall and fatalities risk of STF due to slip would reduce even more with implementing an RMO.

Moreover, it was possible to evaluate anti-slip solutions' effectiveness in terms of the reduced number of accidents since some Danish companies already implemented these solutions 6-10 years ago. At the Danish offshore wind company, the number of STF accidents has been reduced from 12 accidents with negligible consequences to 0 accidents. On one Danish-flagged ship, the number of STF accidents reduced from 3 to 0.

All in all, it can be concluded that technological solutions aimed to reduce the slipperiness of working-walking and railing surfaces can further reduce the STF due to slip in the maritime industry and offshore installations. However, for the complex treatment of STF, the influence of individuals' human behavior and the organization's safety culture shall be further investigated.

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Appendix 1: Electronic Interviews

This appendix collects the relevant for this project data received from the engaged stakeholders through numerous emails.

STF's statistics

From 2013 to 2016, 858 accidents have been reported; 231 of these reports have been due to slip, trip, and falls on bord the Danish-flagged vessels, which is 26,92% of all sea accidents in that period.

Table 4: Reported accidents onboard the Danish-flagged vessels from 2013 to 2016.

Year	**Type of accident**	**Number of accidents**	**Total of STF**	**All accidents pr. year**	**STF accidents in %**
2016	Slip	30	48	244	19,67%
	Trip	3			
	Fall	15			
2015	Slip	26	62	191	32,46%
	Trip	3			
	Fall	33			
2014	Slip	30	64	217	29,49%
	Trip	3			
	Fall	31			
2013	Slip	11	57	206	27,67%
	Trip	4			
	Fall	42			
		Total:	**231**	**858**	**26,92%**

Acurail KAG Safety Rails

The KAG rails suitable for a wide range of premises and environments aimed to prevent accidents, injuries, and muscle strains while increasing comfort and ease.

The KAG rails give up to 300% better grip during oily conditions, up to 160% during dry conditions, and 80% under wet conditions than conventional products on the market.

The KAG rails have a unique design and are shaped to fit into any hand size, delivering a new standard of grip and confidence.

The range includes products suitable for use in areas such as stairways, corridors, and hallways, and they are available in a diversity of finishes, including mirrored, brushed, and white.

KAG handrails have been tested by leading Science testing facilities in Queensland University and certified.

KAG rails have been tested and certified by the renowned test center ALS Global and recognized worldwide in the oil and gas sectors.

KAG rails provide testing documents (bend and Crush). Thus, it can be seen that so the KAG system is indeed the most tested and certified rail in the world and will meet and exceed any certified requirement anywhere in the world.

KAG tubs are introduced in stainless steel, black steel, copper, aluminum, and brass.

KAG safety rails are approximately DKK 50 more expensive per meters regardless of the type of steel, diameter, and thickness compared to smooth rails introduced on the market.

Real Safety anti-slip solutions

Real Safety anti-slip solutions can be non-slip on virtually all surfaces, and these products are non-slip whatever the environment and weather. Even when these solutions are exposed to water, oil, grease, ice, leaf fall, etc., the company ensures that the solutions remain non-slip.

Real Safety can offer non-slip solutions on wood, steel plates, steel gratings, concrete, and tiles surfaces. It can be anything: stairs, steps, walkways, ship decks, platforms, platforms, terraces, etc.

The most slip occurs on stairs and particularly at the edge of the tread - directly on the noising edge, as many footsteps naturally with the foot’s toe are set on this edge. Therefore, the exact point - on the edge angle must be anti-slip in particular. Often too many steel tread edges are not.

Another thing is to have contrasting colors like yellow/black or other; thus, the eye and brain catches the edge of the tread instead of just one large grey lookalike view.

The company also work with "nudging" as brain and eye psychology - text with pictograms and sign colors known from traffic like:

- Red/White = Not permitted
- Yellow/Black = Hazzard
- White/Blue = mandatory, etc.

The different types of flooring were tested on the coefficient of friction in the house. Result in wet conditions:

- Concrete: 0,27
- Diamond Plate (steel): 0,27
- Real Safety: 0,95

The price of the anti-sip solutions for one wind turbine mentioned in a project wind company is approximately DKK 7500. The price of anti-slip solutions for one ship mentioned in the project is approximately DKK 35000.

The surface of anti-slip solutions is rough, therefore the risk of scratches exists if direct contact with non-protected skin has occurred.

Appendix 2: Pre-test questionnaire

The author has developed the questionnaire before conducting a practical test at a Danish ship within a case study. The questions were asked to the first officer and crew at the ship. Besides, some specific questions regarding the number of accidents and the leading causes of the STF were asked to the head of HSE at this company. The questionnaire with answers is presented below.

1. What is your job position or charge? From 100% of your working time, which percentage you spend outdoor?

Master, deck workers.

2. How many hours are in your shift?

6 hours on and six hours off

3. Are your work affected by weather conditions outdoor?

Yes 1-100% **75%**

No 1-100% **25%**

4. How often do you stop your working tasks according to the weather or sea state in percentage from 1 to 100%?"

Calm

Mild **30%**

Storm **70%**

5. How often do you use the stairway? in the percentage of total working hours(1-100%)

40% of all working time

6. Have you experienced before slipperiness of the stair or handrails?

No, we have focused on this risk, and therefore surfaces are cleaned if slippery. But rails can get slippery when wet.

There is 10% that the stairs and handrails may be slippery during mild or stormy weather

7. Do you find slippery steps, handrails, or work surfaces to be a problem?

not a problem

a little problem

problem **Yes**

8. Are there situations where you stop using the handrail to carry goods or tools in your hands?

Yes 1-100%

No 1-100% **No, at least one hand always for a grip**

Sometimes 1-100%

9. Are the stairs visible enough during the day, at night, or in bad weather conditions?

Yes, 100% due to lighting

10. Do you think that a brightly colored step can enhance employee attention and thus safety?

Yes 1-100%

A little 1-100% **Yes, 20%**

No 1-100%

11. Are the handrails held without encountering obstructions, such as cable trays, light fittings, and box sections?

Without any obstacles 1-100% **Yes, 100%**

Sometimes obstacles are present 1-100%

With some obstacles 1-100 %

12. Are there any obstacles to the steps during daily work?

Always 1-100 %

Sometimes 1-100 %

Never 1-100% **No, 100%**

13. Are the handrails and steps in good condition without any physical damage and adequately secured?

Yes 1-100% **Yes, 100%**

No 1-100%

14. Are the handrails at a suitable height and have visual contrast to be obvious to users?

Yes 1-100% **Yes, 100%**

No 1-100%

15. When workers use handrails, are their hands (gloves) always dry, or may they be wet or oily?

Dry 1-100%

A little wet or oily 1-100% **30%**

Wet or oily1-100%

16. May the stairway surfaces contain any contamination, such as oil, chemicals, water, etc.? How often you experience contamination?

Always 1-100 %

Sometimes 1-100 % **5%**

Never 1-100%

17. How often are stairways and handrails cleaned?

Right away if contaminated 1-100 % **Yes, 100%**

Once a day 1-100 %

Once in a few days 1-100 %

18. Do you maintain statistics on accident/incident or the Lost Time accident/Incident (LTA/LTI) statistics?

Yes, we do. We have the following categories:

- **Lost Time Incidents**
- **Restricted Work Cases**
- **Medical Treatment Cases**
- **First Aid Cases**

19. If yes, are slips, trips, and falls included?

Yes. This category is a part of the registration system.

20. Are falls from the stairs, ladders, and gangway counts as slip, trip, and fall incidents or falls from a height?

Falls from height are part of this category. But in 2018 and 2019, we had no cases concerning fall from height.

21. Could you please provide numerical data for slip, trip, and falls on a deck, stairs, ladders, and gangways? How many of these incidents resulted in minor injuries, and how many were major?

2019: a total of slips, trips, and fall was – 31.

LTI:	**2**
RWC:	**3**
MTC:	**1**
Minor:	**25**

22. What are the leading causes of STF? What is the Individual Risk Per Annum at your company?

The leading causes of Slips/trips and falls are as mentioned below:

- **Wrong work posture/handling: 40%**
- **Lack of mental focus: 45%**
- **Working conditions (weather): 15%**

Regarding the IRPA, I do not have this information. However, as a company, we have a target that is: 0 LTI's.

Appendix 3: Post-test questionnaire

The post-test questionnaire was developed by the author of the project and was used during the interviews with some adjustments according to the evaluating [urpose and interviewee. The answers may be found in Appendices 4, 5, 6, 7 & 8.

1-100% means the percentage of total working time

1. How was the experience with a new stairway? Could you notice any difference?

Yes 1-100%

No 1-100%

2. During the test, were the conditions for both stairways the same, such as the frequency of maintenance and cleaning, the presence of contamination, obstacles, and lighting at night and in bad weather conditions? Or were they different?

Yes 1-100%

No 1-100%

3. How would you rate the safety of new stairways compared to a regular ones?

Same 1-100%

safer 1-100%

much safer 1-100%

4. Is there a noticeable difference in the number of accidents and near misses on the stairway with the implemented new handrails and anti-slip elements compared to the regular stairway? Has this reduced the number of incidents or near misses?

Yes 1-100%

No 1-100%

Near misses 1-100%

5. Is there a difference in visibility, due to the yellow color of anti-slip steps covers, between the implemented stairway and the regular one at night and in bad weather conditions? Is it better?

Yes 1-100%

No 1-100%

6. How would you rate the bright color of the steps and embedded in its safety messages and signs in terms of increasing safety(does it increase attentiveness)?

Yes 1-100%

No 1-100%

7. Has the bright color of the steps, the messages, and the safety signs embedded in them influenced your behavior?

Yes 1-100%

No 1-100%

8. How would you rate handgrip on the new handrails compared to the previous ones?

1. worse 1-100%

2. same 1-100%

3. better 1-100%

9. How would you rate the anti-slip step covers' effectiveness in terms of slipperiness during wet weather conditions?

1. worse 1-100%

2. same 1-100%

3. better 1-100%

10. How would you rate the effectiveness of the anti-slip step covers in terms of slipperiness under the presence of contaminations such as oil, chemicals, etc.?

1. worse 1-100%

2. same 1-100%

3. better 1-100%

11. How would you rate the anti-slip step covers' effectiveness in terms of slipperiness during the calm weather?

1. worse 1-100%

2. same 1-100%

3. better 1-100%

12. How would you rate the KAG handrails' effectiveness in terms of slipperiness under the presence of contaminations such as oil, chemicals, etc.?

1. worse 1-100%

2. same 1-100%

3. better 1-100%

13. How would you rate the KAG handrails' effectiveness in terms of slipperiness during wet weather conditions?

1. worse 1-100%

2. same 1-100%

3. better 1-100%

14. How would you rate the KAG handrails' effectiveness in terms of slipperiness during the calm weather?

1. worse 1-100%

2. same 1-100%

3. better 1-100%

15. How would you rate the importance of the anti-slip step covers and KAG handrails in terms of safety?

1. not important 1-100%
2. important 1-100%
3. very important 1-100%

Appendix 4: Interview with a Captain at the Danish ship

Interviewer: Tanja Rasmussen

Interviewee: Captain at Danish ship

Date: 20.10.2020

Captain

I am a captain for many years. I have been sailing on ships for 30 years.

Tanja

What is the responsibility of the captain on the ship?

Captain

I am basically responsible for the daily running of the vessel.

Captain

In normal conditions, we are all 25 people on board. So I am in charge, basically in charge of running the vessel. That means besides navigation, I also serve the safety aspects.

Tanja

Are you checking all safety issues regarding the vessels, for example, in the morning or during the day?

Captain

Not, particularly. I do, around every day on the vessel and in, for example, in the engine room. I have a chief engineer responsible for the department, but I am responsible for the whole tech department and the navigation.

Tanja

How you or the crew members experienced the slipperiness of the stairs or handrails?

Captain

The handrails can be slippery because basically, they are straight piping, normal handrails, I mean. So if the worker has greasy hands, dirty hands, because he has to conduct the maintenance on deck, where uses many greases to have all lashing gear. They also may be wet due to rain, snow, etc.

Tanja

What is the percentage from all working time, that the stairs and handrails may be contaminated?

Captain

Oh, it is hard to. It is almost impossible because, over the years, the safety culture has been increased. So, everyone knows that if we have grease spots on the deck, it is normally reported, then it cleans it up to avoid slips, trips and falls, and accidents. So, if earlier the slippery surface was around 50% of all working time, now it is a few percent.

Tanja

In case of stormy weather. Can it be cleaned all the time?

Captain

We cannot. We cannot clean all the time during stormy weather. During stormy weather, the outside handrails are wet and slippery.

For example, in the engine room, where there are many greases, I would say there the rails will be less slippery, just a few percent, compared to other working areas at the ship a few percent, due to clean it up.

It is many kilometers of handrails and guardrails all over the place in the engine room.

Tanja

Did you notice some difference with the new KAG handrails?

Captain

Yes, I feel it is better because your grip is a lot better on them. However, we test it on one stairway. We do not have the main power and recourses to change existing rails throughout all ships on KAG rails. Without a doubt, new handrails have a better grip on them. Nevertheless, for us to, you know, to convert that ship, it is impossible. So, the better solution is to forward our feedback to the new building department of the ship and include the KAG rails at the ship's design stage.

Tanja

How would you rate the effectiveness of the KAG handrails compared to previous ones under the contaminations?

Captain

Maybe it is 100 percent better grip.

Tanja

What is the percentage that the worker's gloves may be contaminated with oil, chemicals, etc.?

Captain

I would say between 80 and 90 percent. When the gloves are new, they are not contaminated, but as soon as they start to carry equipment and tools and perform maintenance, they become contaminated. They use them for several days before and then change.

Tanja

How often is the safety shoes changed?

Captain

It depends on it. However, in general, each assignment the workers out, they get a new pair of shoes. So it lasts one assignment for the workers on the deck. And then, in general, it is normally five months.

Tanja

What the crew members are doing outside of the ship, for example, on a deck. What tasks do they have?

Captain

If they are either cleaning, that is maybe with high pressure or corrosion control.

Tanja

What is your opinion about the safety culture of the organization? Do you think it affects the number of accidents?

Captain

Ten years ago, I said around ten years ago, and we could feel that the company started to increase safety awareness, and it has constantly been increasing in the last ten years. Moreover, we can see accidents coming down.

Tanja

Does the master on a vessel influence the safety issues?

Captain

Yeah, I would say so, because of the accident reports we get from other places in the country, some of them we can see repeated. And that is because, when we got the first report on this type of accident, the master on board a vessel where he takes it seriously and then the next safety meeting, he inform everybody about this accident and how to prevent it, then maybe rearrange the equipment to avoid it. The chance of having a similar accident is a lot less.

We can see sometimes there is the same accident that has happened three months later. The master and crew members have not appropriately talked about it, and they have not brought it to the same thing.

We have a program where we have all our risk assessments for all the not normal jobs but more specialized jobs.

Thus, we have a risk assessment, and then you have to print that out when you have to do that job. We have an agenda, and then we have some checklists for certain jobs such as isolation, working at height, etc. Then we have a checklist, and then we have some conservative groups. That is one picture with some photos of what not to do, and we have a red cross and some photos from various ships where something went wrong.

We have all these samples, how we should do this job and just small textbooks, for example, be aware of this, but it is all on one page. So all these four documents. The chief officers then go through the deck to check if the job is secure and check if everybody is fully aware of their job is connected with safety. If some equipment or circumstances are changed or failed, then the job execution will need to regroup. The chief officer should say that we can not do it the way we planned in the morning because of this obstruction. We need to adjust in this way. The chief obviously needs to be available for the group to do that often. But it is that way, a routine. break

Appendix 5: Interview with a Chief Officer at the Danish ship

Interviewer: Tanja Rasmussen

Interviewee: Chief Officer at Danish ship

Date: 29.10.2020

Tanja

How was the experience with an implemented staircase? You mentioned in an email that some incidents had occurred.

Chief Officer

We found that when people go up and down the stairs, three people scratch their legs. When they walk up and down the stairs, they come too close to the stairs and the vertical site of the plate, they scratched the skin of the leg. However, these are not severe incidents, but the skin was damaged a bit. Therefore, after we have had these incidents, we have removed anti-slip covers, as we cannot have accidents if we know something is not good for us. We think that that the present set up where we have a grating with holes is better solutions for us. We are also a bit worried about winter when we have snow sled, and it is freezing. Moreover, if we get water on anti-slip covers, despite the rough surface, if we have water on it and it freezes, we will have a very slippery surface with present steps where we have gratings with a-holes. We never mind whether it is freezing or not. We will have a safe stack.

Tanja

How was your experience with KAG handrails?

Chief Officer

We found that the handrails are good. We got a better grip compared to our normal pipes. So that was a good experience. I spoke to the deck crew, which are the people who walk up and down the most. And they think it is a great solution.

Tanja

How would you rate the effectiveness of handgrip on KAG handrails compared to existing ones in percentage?

Chief Officer

It is very difficult for me to answer. I can say that we have an increased grip. I think it is approximately around 40% increased grip.

Tanja

How would you rate the effectiveness of handgrip on KAG handrails compared to existing ones in percentage under the presence of contaminations such as water, oil, or chemicals?

Chief Officer

I think the percentage is the same when the handrails are wet. We do not have any experience with oil. Of course, we workers' gloves may be contaminated with some grease, but I think the increased grip percentage is still the same, around 40%.

Tanja

What is the place where the primary number of STF is happening?

Chief Officer

It is a deck, staircases, and walkways.

Tanja

Are the deck and walkways made of steel or wood? What is the percentage of all working time that the deck and walkways may be contaminated with water?

Chief Officer

It is mostly made of steel, and we also have the main deck, which is made of steel with some wooden planks. In wintertime, it always has water on it. It can be due to rain or snow, etc. We always take extra precautions when the weather is wet, and we know that the surface is slippery. Besides, we have different procedures to clean up the water on a deck.

Tanja

What are the main causes of STF at your company?

Chief Officer

The distraction is the main cause. Basically, if you walk up and down the staircase steps and your attention is attracted by something else, or you have to focus on something else, that is where we see the incident. We do not see the incident where the people have lost their grip. We see that they have happened because the focus has been somewhere else and not walking the stairs. We found the majority of our incident is because the attention and focus have been on something else. It could be a group of people you want to talk to, and then you forgot you have one or two steps more.

Chief Officer

Also, the right working position is very important. For instance, if the worker does not use the right lifting technique, he can injury his back. Or if the worker is walking with something in his hands, he may not see if something is lying in front of him and may trip and fall. Or if the worker does not comply with a rule of one hand for grip while walking stairs, he may experience STF.

Appendix 6: Interview with an HSE advisor at the Danish Offshore Wind Farm

Interviewer: Tanja Rasmussen

Interviewee: HSE advisor at an offshore wind farm

Date: 17.11.2020

Tanja

Can you please introduce yourself and your job responsibilities and job tasks?

HSE advisor

I am the HSE Advisor at the offshore wind farm, which means that I will conduct investigations regarding accidents and incidents, and I will ll be the one gathering all the observations and near misses working with. I am then responsible for reviewing and making sure our management system on-site regarding health and safety is up to date. It will then be me who will drive larger projects regarding safety as, for example, this improvement about slips, slip-resistant surfaces, and stuff like that.

Tanja

I would like to ask you about your experience with anti-slip covers. Did it affect the safety of your company? Did it decrease the number of slips, trips, and falls in your company?

HSE advisor

I can tell you much more that there was a reason why we installed it, which was that we had slips, trips, and falls quite often. And this was installed two years ago, nearly two years ago. And we have not had one single report about slips, trips, or falls in those areas at all. So, they have definitely increased safety.

Tanja

Could you provide me with numerical data about the number of accidents before installing the anti-slip products and after?

HSE advisor

However, I can tell you that looking back in the lifetime before anti-slips, it would be my best guess on the knowledge that we have had 12 or 13 actual sleep incidents.

Tanja

Was it a major or a minor injury?

HSE advisor

I would not call it major injuries. I mean, we have had people falling, but they do not fall off the turbine.

Tanja

Should they have gone to the doctor for an examination?

HSE advisor

No, not to the doctor. First, in cases where plasters and bandages and stuff like that, and maybe a couple of days, they could not go offshore and had to work onshore for a couple of days. Otherwise, it has been bruised. The last two years in regards to slips trips because we have not had any registrations. I can say that two or three registered incidents a year in a wind farm are quite a lot. I mean, where we do not tolerate anything at all.

Tanja

How would you rate the effectiveness of the anti-slip step covers in terms of slipperiness under the presence of contaminations such as oil, chemicals, etc., on a percentage scale from 1 to 100%? How much percent has been decreased the slipperiness of the ladders?

HSE advisor

I mean, we came from just steel, aluminum, and the anti-slip surfaces on the fiberglass sanded ones, and you cannot sleep on it at all. That is a fact. Even if there is some oil or some dirt on it, I would say from what we had to what we have now, and on those areas where we have fitted this surface, that is 100 percent decrease the slipperiness of the surfaces.

Tanja

Thus, you want to say that in cases of the presence of any contaminations such as oil, water, grease, or under bad weather conditions, it does not affect the surface of the ladders. Do they still have a very high level of roughness or friction?

HSE advisor

Definitely.

Tanja

Together with Real Safety and Acurail, we conducted a practical test on a Danish ship. During testing, anti-slip solutions scratched their skin of the leg. They just touched the anti-slips' surface and got some scratches, and therefore the anti-slip covers were removed. Do you have the same problem at your company?

HSE advisor

So now I can tell you this much, that if you have bare legs, for example, and you scrape that swath at the surface, that will make you were able to make you suffer like that. It is like sandpaper, and you are scraping against your skin. So, you need to protect yourself against that. However, in these environments, you have already had sharp edges and stuff like that, and the workers are aware of that and use special clothes, gloves, and shoes to protect themselves.

HSE advisor

We have had many cases when technicians, working in the turbine nacelle, slipped and then fell. Besides, the access way to the turbine was very slippery as well. This is an environment where you have many hydraulic systems, they might be just a little bit, just a few drops, and then you will have that hydraulic oil all over the environment out there. And aluminum stairs, if you just have a very, very thin layer of just oil or something, if you can imagine that an of any kind of oil or anything else, by the way. They become extremely slippery. We have had, I think, six or seven incidents where people have been falling when they are standing on that surface there and working and changing components out there (HSE advisor showed the images). After we have fitted anti-slip covers, the technicians can stand out there, and they can put their tools there (HSE advisor showed the images).

Tanja

What can you say about the bright color of anti-slip solutions?

HSE advisor

Before fitting the anti-slip solutions, everything was made from grey steel, more or less, and when the technicians worked out eight hours in the turbine. On top of the turbine, they have to transport about one and a half hours each way, so they have a 12-hour shift. Thus, working in this environment for 12 hours, where everything is grey, definitely impacts. Therefore, the fitted anti-slip covers, made of black and yellow, definitely increase the technician's attention when they walk the stairs or climb the ladders. Actually, we have no purpose of doing anything visual, but I could just call it a bonus.

Tanja

And what about outside is the ladders? Is it covered also with anti-slips?

HSE advisor

No, it is not. We do not have any outdoor ladders. We do have one going from there from where you are getting off the vessel of the ship that took you to the wind farm, and then you go on a ladder-climbing up that is made from steel. The ladder has been constructed so that you kind of have your foot on a sharp edge and like on the corner of a rung.

What I have experienced is the worst part is that the edges are very slippery. If you place your foot at the edge, it will slide off if there is just a drop of water. Even if the stairways is, it is made from something with holes in it and some sort of sharpness and tube, but then you have the last 25 millimeters or something that is leading out to the bend at the end of the step on the ground, which is just made of steel. So it is very slippery. What is happening? The workers are putting their heels on the rest of the stair tread, the stair edge. So, this is not touching the rung of the step, and then they slip. In contrast, the products are delivered from Real Safety have a sandy surface around that.

Tanja

Thank you very much for a very detailed conversation. Have a nice day

HSE advisor

Same to you.

Appendix 7: Interview with a Chief Officer and Bosun at the Danish ship

Interviewer: Tanja Rasmussen

Interviewee: Chief Officer and Bosun at Danish ship

Date: 19.11.2020

Tanja

Can you please describe your experience with Real Safety anti-slip covers?

Chief Officer and Bosun

The Real Safety anti-slip products were installed at deck, gangway and some walkways floor surfaced ten years ago. Also, one small anti-slip step has been installed at some particular place prone to STF. Compared to previous wood floor surfaces, the anti-slip solutions 100 % better in terms of safety. When it 12 people at deck changing boat in a rough sea, we can feel the difference. The previous wooden floor was very slippery. Thus, anti-slip covers significantly decrease the number of STF accidents.

Tanja

What about the cleaning of anti-slip solutions?

Chief Officer and Bosun

We just use soap in the water without any high-pressure.

Chief Officer and Bosun

Besides, the anti-slips' bright color makes some kind of designated walkways that you can see and walk safely, increasing attentiveness when you are walking.

Tanja

Are the flooring surface or shoe may contain any contaminations such as oil, grease, etc.

Chief Officer and Bosun

No, there is no contamination on this ship, apart from weather precipitation and water

Tanja

Did you have any STF incidents at this particular ship?

Chief Officer and Bosun

Before installing the anti-slips, we have three incidents at this ship, and it is now 0.

Tanja

Great. Thank you very much for the conversation and your time. Have a nice day.

Appendix 8: Interview with a Master at the Danish ship

Interviewer: Tanja Rasmussen

Interviewee: Master at Danish ship

Date: 19.11.2020

Tanja

Where did you have installed the anti-slip solutions on a ship? What was your experience with anti-slip products during bad weather conditions and oil contamination?

Master

We have it in the gangways, stairways and we have it on deck. We have them on every step. Moreover, we are very happy about that.

Tanja

Do the workers have any scratches on the skin, for example, because anti-slip' surfaces are rough?

Master

We do not have that. Every time the workers go on deck, they have to have their pants and safety shoes.

Tanja

The workers that got scratches also had the pants and safety shoes.

Master

We have no problem with anti-slip products. We never heard it. We are sailing for 15 years. We never had anything like that.

Tanja

How would you rate the effectiveness of the anti-slip step covers in terms of slipperiness under the presence of contaminations such as oil, chemicals, etc., on a percentage scale from 1 to 100%? How much percent has been decreased the slipperiness of the gangways, stairways, and deck?

Master

We do not have too much oil on this ship. However, if we do have any oil or grease, it should be cleaned right away. However, we can have spilled water. Indeed, it is impossible to clean everything 100%, so if we do not have anti-slip covers and the stairways are contaminated with oil, then I think it will be 100% that the worker will fall. So I think the safety of anti-slip products is 100% better than without them.

Tanja

What is the percentage that the surfaces can be contaminated with water, oil, chemicals, etc.?

Master

That is 20%, I think, but mostly contaminated with water. We do not have any oil on a deck.

I know some working ships that can have contamination around 50% of all working time.

I guess it would significantly decrease the number of incidents if this oil company would install these anti-slip covers.

We had only a good experience with anti-slips, and during very bad weather as well. And the workers are walked on stairways, decks, and walkways during bad weather, and there were no incidents. If we would no have these products, the workers would fall in such weather. So, we are really happy to have it.

Tanja

Do you have a deck made of wood or steel?

Master

The deck is made from steel, and we have anti-slip covers on it. If we would not have it, we should paint the deck and walkways by adding a lot of sand. That is not a lifelong and good solution compared to anti-slips.

Tanja

Suppose we compare the effectiveness of anti-slip covers with a painting by adding sand. What is the difference in effectiveness?

Master

If we painted it with sand and walking the same or next two days, I think the effectiveness is sufficient. However, when workers walk on a surface painted with the addition of sand, some of the sand remains on their shoes, and the effectiveness of such painting decreases with every worker walking on it. After 2-3 months, the painting with the sand effect is gradually decreasing. So, their painting with the adding of sand has a short lifetime. The anti-slip covers are the best solutions for our ship.

Tanja

If you do not paint the walkway and deck by adding sand, are the surfaces slippery?

Master

Yes, the deck, walkway, and stairway steps are made of steel, and they are very slippery. If they are not painted with adding sand on walking surfaces, the worker will fall. If some walking surfaces on a ship do not have anti-slip products, we should paint them with an adding of sand. It is required.

Master

We have walkways painted with the adding of sand just three months ago. So, they are relatively new. However, as you can see, the surface is not so rough. Thus, I can say that the anti-slip covers are 100% better than painting with sand.

Appendix 9: Requirements for means of access in the maritime industry and offshore installations

Requirements for the following means of access are described further: walkways and handrails, vertical ladders, inclined ladders, and stair ladders. There are more means of access used in the maritime industry and offshore installations, but due to the project's limited time, the author has been decided to describe the most used means of access.

General requirements for walkways

Clearances around obstacles and passage widths should be designed for the largest user. Obstacles must be visible. Handrails, treads, and guardrails must be sized for a general fit. Walkways, tunnels, and corridors must be large enough to allow an injured crew member to be evacuated on a stretcher (Bureau Veritas, 2008) (IACS, 2019).

General dimension requirements for walkways are as follows (Bureau Veritas, 2008) (IACS, 2019):

- Distance below overhead structure (A) - 1600 mm ≤ A ≤3m according to IMO-IACS requirements and 2020 mm ≤ A ≤ 3m according to Bureau Veritas guidelines requirements.
- Ramp inclination angle (B) - B ≤ 15° according to Bureau Veritas guidelines requirements.
- Guardrail height (C) - C = 1000 mm according to IMO-IACS requirements and C around 1200 according to Bureau Veritas guidelines requirements.

Besides, unobstructed width should be ≥ 700 mm, clearance height ≥ 1700 mm, clearance width ≥ 600 mm, sill height from bottom ≤ 150 mm, width (for going around vertical web frame) ≥ 600 mm, and handle length ≥ 600 mm (Bureau Veritas, 2008) (IACS, 2019).

It should be noted that handrails and railings are distinguished from each other. Guardrails are designed to help people maintain balance when walking (for example, due to ship movement or obstacles), and handrails are designed to prevent people from falling from a height (Bureau Veritas, 2008).

Requirements for handrails

Dimension requirements for handrails are as follows (Bureau Veritas, 2008) (IACS, 2019):

- Unobstructed width (A) - A ≥ 600 mm according to IMO-IACS requirements and A ≥ 700 mm according to Bureau Veritas guidelines requirements

- Top handrail height (B) - B = 1000 mm according to IMO-IACS and Bureau Veritas guidelines requirements
- Intermediate rail height (C) - C = 500 mm according to IMO-IACS requirements and C ≤ 540 mm according to Bureau Veritas guidelines requirements
- Distance between stanchions (D) - D ≤ 3m according to IMO-IACS requirements and D ≤ 1500 mm according to Bureau Veritas guidelines requirements
- Distance between stanchions across the gap, where the top and middle rails connected (E) - E ≤ 550 mm according to IMO-IACS and Bureau Veritas guidelines requirements
- Vertical clearance (F) - F ≥ 100mm according to Bureau Veritas guidelines requirements
- Lateral clearance (G) - G ≥ 60 mm according to Bureau Veritas guidelines requirements

Other dimension requirements for handrails are (Bureau Veritas, 2008) (IACS, 2019):

- Handrail diameter (A) - 30mm ≤ A ≤ 60mm, 45 mm recommended, according to Bureau Veritas guidelines requirements
- The gap between handrail sections (B) - B ≤ 50 mm according to IMO-IACS and Bureau Veritas guidelines requirements
- The outside radius of the bent part (C) - C ≤ 100 mm according to IMO-IACS and Bureau Veritas guidelines requirements
- Distance between stanchions across the gap, where the top and middle rails are not connected (D) - D ≤ 350mm according to IMO-IACS and Bureau Veritas guidelines requirements

Requirements for vertical ladders

The purpose of these requirements is to ensure that the person climbing the stairs can easily climb on and off the ladder (appropriate devices), has enough space around him not to strike into obstacles, have enough space to use the ladder as a surveying platform, cannot fall from a height that could seriously injure him, cannot slip from the ladder, and feels safe when using the ladder (Bureau Veritas, 2008).

General dimension requirements for vertical ladders (Bureau Veritas, 2008) (IACS, 2019)**:**

- Ladder height (A) - A ≤ 6 m according to IMO-IACS and Bureau Veritas guidelines requirements

- Distance from landing platform to overhead obstructions (B) - B ≥ 2020 mm according to IMO-IACS and Bureau Veritas guidelines requirements
- Distance between center of rungs and wall (C) - C ≥ 150 mm according to IMO-IACS and Bureau Veritas guidelines requirements
- Lateral clearance (D) - D ≥ 200 mm according to Bureau Veritas guidelines requirements
- Back clearance (E) - E ≥ 900 mm according to Bureau Veritas guidelines requirements

Ladders should not be placed in a line, but differently, limiting the height of possible falls from the ladders and hence reducing severity (Bureau Veritas, 2008) (IACS, 2019).

Dimension requirements for the arrangement of vertical ladders (Bureau Veritas, 2008) (IACS, 2019):

- Ladder width (A) - A ≥ 350 mm in general, A ≥ 300 mm for access to hold frames according to IMO-IACS requirements, and A ≥ 400 mm, 450 mm is recommended according to Bureau Veritas guidelines requirements
- The vertical distance between rungs (B) - 250 mm ≤ B ≤ 350mm according to IMO-IACS and Bureau Veritas guidelines requirements
- The lateral distance between two adjacent sections of the ladder (C) - at least the width of the ladder according to IMO-IACS requirements and C ≥ 500 mm according to Bureau Veritas guidelines requirements
- Gap length between wall and guardrail (D) - D ≥ 850 mm according to Bureau Veritas guidelines requirements
- Handles height above walking surface (E) - E = 1000 mm according to Bureau Veritas guidelines requirements
- The lateral distance between the ladder and linking platform (F) - 200 mm ≤ F ≤ 350 mm according to Bureau Veritas guidelines requirements
- Rung dimensions (square bars) (G) - G ≥ 22×22 mm according to IMO-IACS requirements and 22×22 mm ≤ G ≤ 35×35 mm according to Bureau Veritas guidelines requirements

Inclined ladders or stair ladders

The most significant number of accidents is recorded on inclined ladders since their inclination angle can reach 70 °. It is effortless to lose one's balance, particularly when going down the stairs. A hazardous situation is when an employee carries an object in his hands and therefore cannot grab both handrails or, even worse, at least one handrail to regain the lost balance. It shall be noted that providing appropriate handrails and guardrails are fundamental for stairs and ladders design (Bureau Veritas, 2008) (IACS, 2019).

General dimension requirements for inclined ladders are height (rise) - ≤ 6 m, distance from landing platform to overhead obstructions - ≥ 2020 mm, and guardrails height - 1100 mm ≤ C ≤ 1200 mm (Bureau Veritas, 2008) (IACS, 2019).

Detailed dimension requirements for inclined ladders are as follows (Bureau Veritas, 2008) (IACS, 2019):

- Inclination (A) - A < 70° according to IMO-IACS requirements and 50°≤ A < 70°, 50°≤ A ≤ 60°is recommended according to Bureau Veritas guidelines requirements
- The vertical distance between treads (B) - 200 mm ≤ B ≤ 300 mm according to IMO-IACS requirements and 200 mm ≤ B ≤ 300 mm, 200 mm for a pitch line of 50°, 250 mm for a pitch line of 60 °, and 300 mm for a pitch line of 70° according to Bureau Veritas guidelines requirements
- Top handrail height (C) - 840 mm ≤ C ≤ 1000 mm above the pitch line according to Bureau Veritas guidelines requirements
- Intermediate rail height (D) - half the top handrail's height is recommended according to Bureau Veritas guidelines requirements
- The horizontal distance between bars (E) - 90 mm ≤ E ≤ 140 mm according to Bureau Veritas guidelines requirements
- Bar dimensions (F) - F≥ 22×22mm according to IMO-IACS requirements and 22×22mm ≤ F ≤ 35×35 mm, 25×25 is recommended according to Bureau Veritas guidelines requirements
- Clear width (G) - G ≥ 450 mm for cargo holds, G ≥ 400 mm else according to IMO-IACS requirements, and G ≥ 560 mm according to Bureau Veritas guidelines requirements
- Distance between the inclined ladder face and barriers (H) - H ≥ 750 mm according to IMO-IACS requirements and H ≥ 1300 mm according to Bureau Veritas guidelines requirements
- Treads width (I) - 120 mm ≤ I ≤ 180 mm according to Bureau Veritas guidelines requirements

The step shall be on the equal level as the sill edge to reduce the risk of tripping over the sills when using stairs and stair ladders (Bureau Veritas, 2008).

Appendix 10: Risk Matrix

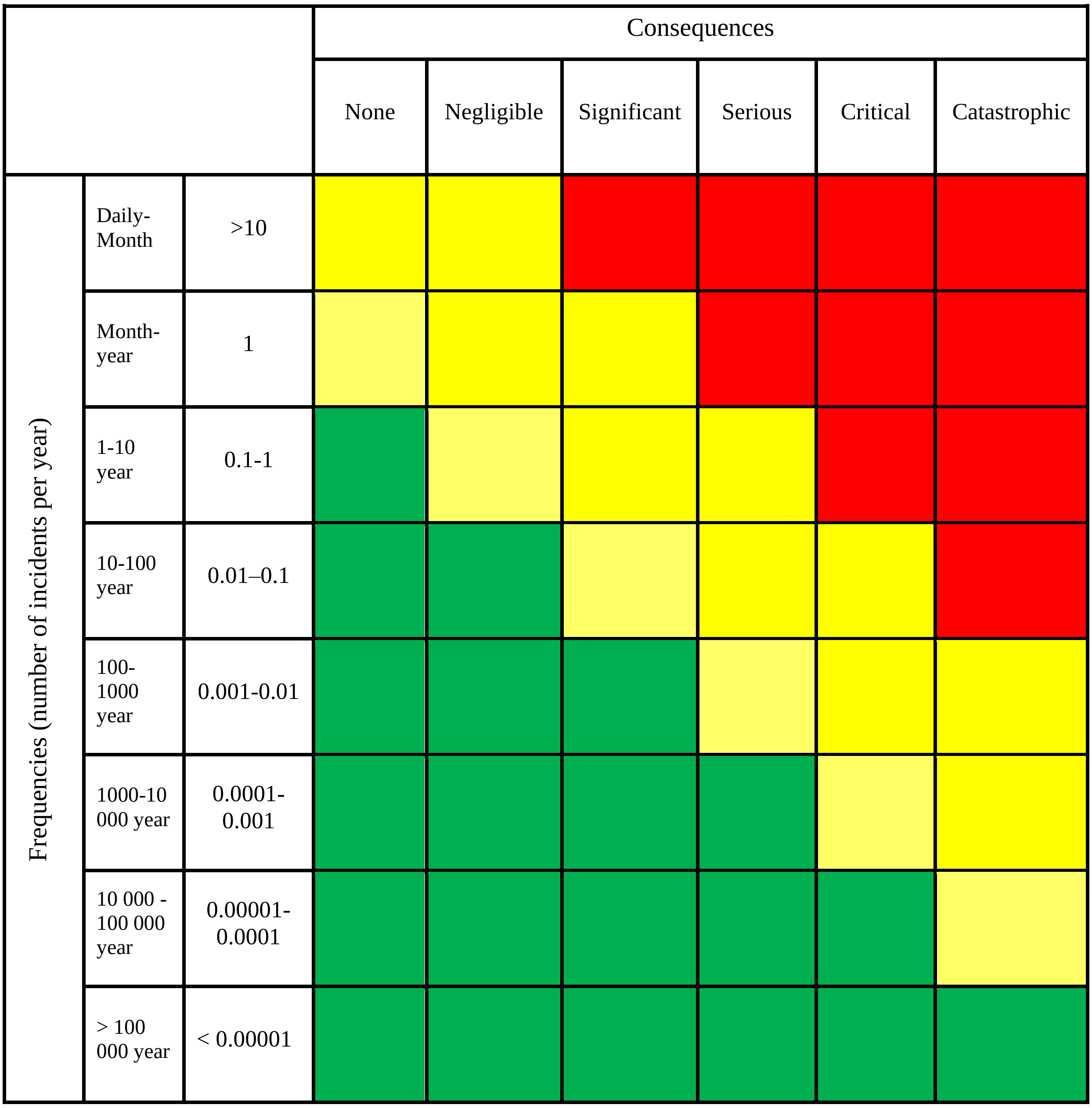

Figure 20: Risk matrix. Source: (DNV GL, 2015)

Appendix 11: Risk Management Process

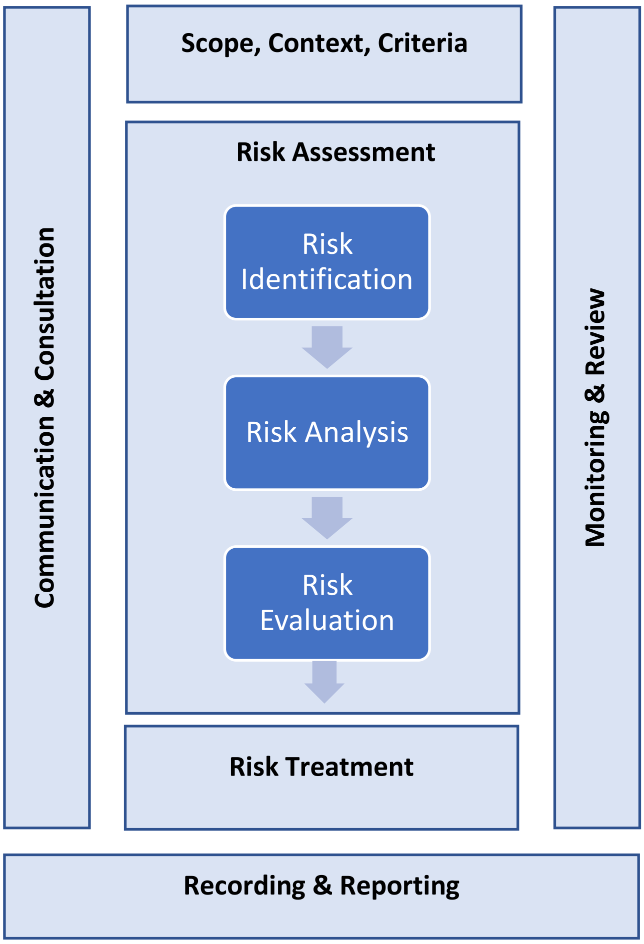

Figure 21: Risk management process. Source: (ISO31000, 2018)