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ACCESS SYSTEMS FOR OFFSHORE WIND TURBINES

A review of conventional and walk-to-work transfer methods

Master Thesis

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TITLE PAGE

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ABSTRACT

Access and egress to offshore wind installations account for an approximate 12% of all incidents reported in the industry in 2018. As the industry continues to grow, the number of incidents is likely to increase, heightening the demand for safe and efficient transfer methods. The aim of the project was to compare the conventional bump and jump method with the utilisation of active and passive motion compensated gangway systems in terms of accessibility, efficiency and risk to the transferee.

Accessibility is determined by comparing the safe transfer limits of access systems with historical metocean data of offshore wind farms. The efficiency is compared by means of case studies, considering crew transfers to several turbines in a row.

Hazardous events and consequences inherent to the different transfer methods were identified and visualised in BowTie diagrams. This information, together with other studies on transfer risks, formed the input for an Event Tree Analysis. This quantitative risk analysis allowed for calculation and comparison of the individual risk per transfer.

Considering motion compensated gangways are complex systems and vary greatly in design and operation this project presents a basic quantitative model that can be used to test the sensitivity of individual parameters and the effect of any proposed risk reduction measures for the different transfer methods.

PREFACE

This master thesis project was written in the second half of 2019 as final 30 ECTS assignment of the M.Sc. in Risk and Safety Management programme. The objective of the curriculum is to apply principles and add to the knowledge obtained in the first three semesters of the master's programme.

The aim of the project is to analyse and compare conventional and walk-to-work transfer methods used in the Offshore Wind Industry in terms of accessibility, efficiency and individual risk to the transferee.

Structure of the report is as follows:

- Chapter 1: Introduction
- Chapter 2: Background information on transfer to offshore wind turbines
- Chapter 3: Problem statement and delimitation
- Chapter 4: Methodology
- Chapter 5: Accessibility and efficiency of access systems
- Chapter 6: Risk assessment
- Chapter 7: Discussion
- Chapter 8: Conclusion

The acronyms, found in the front of the report, lists and gives a description of all acronyms used in the report. The acronyms have been spelled out at their first time of use, e.g. Crew Transfer Vessel (CTV)

Figures and tables are numbered continuously throughout the report, where e.g. Figure 1.2 refers to the second figure in the first chapter.

References enclosed in square brackets [x] can be found in the sources listed at the back of the report on page 57. Referencing follows the Institute of Electrical and Electronics Engineering (IEEE) style. The number inside the bracket corresponds to the reference number in the sources list.

Blank pages are left intentionally regarding printing layout.

I would like to thank Jannie Sønderkær Nielsen (Assoc. Prof. at Aalborg University) for the support and supervision of the work and writing of my master thesis project. I also express my gratitude to G+ Offshore Wind Health and Safety Organisation, the Energy Institute, TNO and Jelte Bos for granting me permission to make use of their figures shown throughout the report.

Nikki Twigt
10th of January 2020

ACRONYMS

Acronym	**Definition**
ALARP	As Low As Reasonably Practicable
BST	Basic Safety Training
CTV	Crew Transfer Vessel
DMS	Degrees, Minutes and Seconds
DP	Dynamic Positioning
EPIRB	Emergency Position Indicating Radio Beacon
ETA	Event Tree Analysis
FAS	Fall Arrester System
FMEA	Failure Mode Effects Analysis
GWO	Global Wind Organisation
HAZID	HAZard IDentification
IMCA	International Marine Contractors Association
IRPA	Individual Risk Per Annum
LCOE	Levelized Cost of Energy
LSA	Life Saving Appliances
LTI	Lost Time Injury
MISW	Marine Inspection for Small Workboats
MOB	Man Overboard
O&M	Operation and Maintenance
PFD	Personal Floating Device
PLB	Personal Locator Beam
PPE	Personal Protective Equipment

QRA	Quantitative Risk Assessment
SART	Search And Rescue Transponder
SES	Surface Effect Ship
SIMSOPS	Simultaneous Operations
SOLAS	Safety of Life at Sea
SOV	Service Operation Vessel
SOV	Service Operation Vessel
SPARTA	System Performance, Availability and Reliability Trend Analysis
SRL	Self-Retractable Lifeline
STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
SWAN	Simulating WAves Nearshore
SWATH	Small Waterplane Area Twin Hull
TP	Transition Piece
W2W	Walk-to-work
WRF	Weather and Research Forecast

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1 INTRODUCTION

The offshore wind industry has grown drastically since the start of the 21st century and continues to grow moving further out at sea and into deeper waters. Figure 1.1 shows the current and anticipated offshore wind power in Europe until 2025 based on under-construction, planned and consented offshore wind farms [1]. The colours, dark blue to white, indicate the installations' distance from shore.

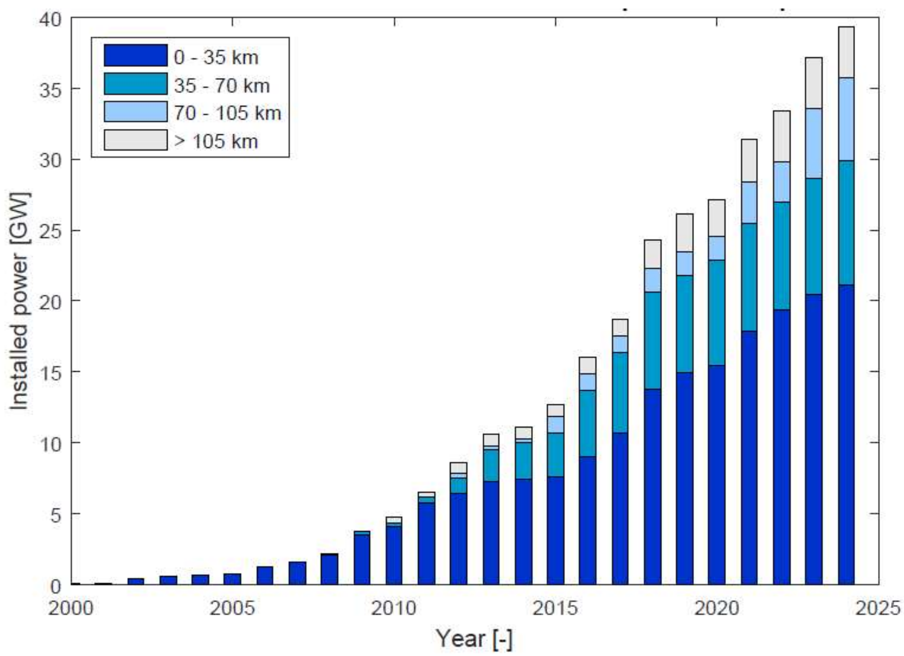

Figure 1.1: Cumulative annual installed offshore wind power in Europe from 2000 to 2025. Source: [1]

Occupational health and safety hazards during the operation and maintenance (O&M) of offshore wind farms are overall similar to onshore industrial facilities. There is an exception to this notion, gaining access to and egress from the place of work is more hazardous offshore. The reason for this is clear:

> "Offshore wind farms are exposed to the forces of waves, tides and extreme weather, which present greater challenges and risks in terms of access, work and dealing with emergency situations than equivalent onshore schemes." [2]

For offshore wind farms this involves the need for helicopter access to offshore facilities, personnel transfers between marine vessels and wind turbines, risk of collisions between vessels and wind turbines and falls into water by personnel.

In the 2018 incident report from the G+ Global Offshore Wind Health and Safety Organisation, a total of 854 incidents was reported. When reporting an incident, 37 work processes were available for selection by G+ members. Figure 1.2 shows the top 10 selected work processes and their respective percentages of identified high potential incidents.

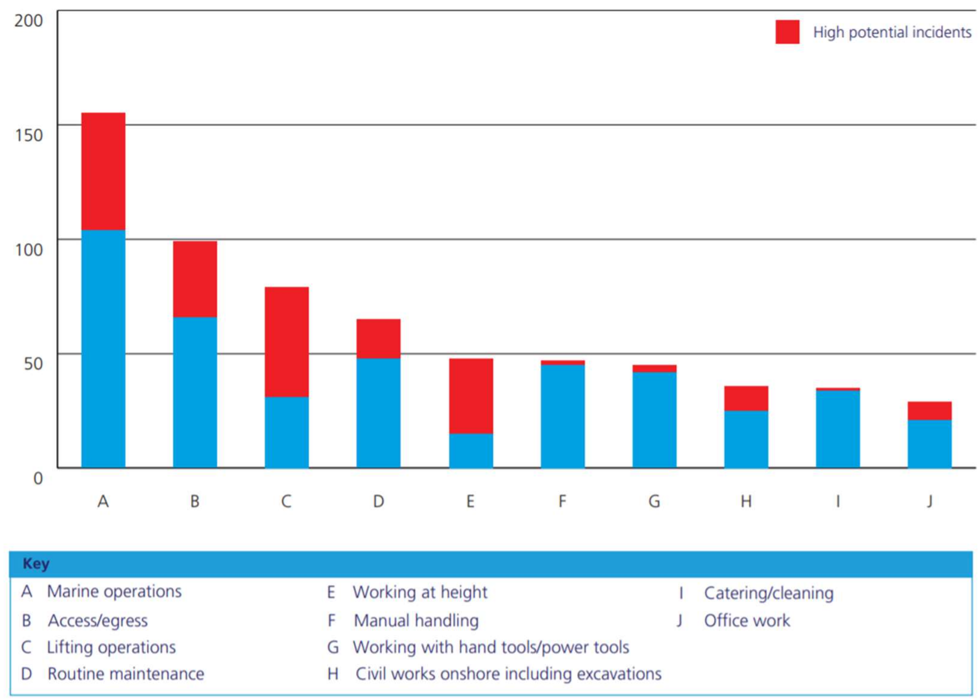

Figure 1.2: Top 10 work processes with the highest number of incidents reported with high potential incidents identified. Source: [3]

It was concluded that out of the 854 reported incidents, 99 were caused during the access or egress of personnel (B) of which 33% was denoted as a high potential incident with the potential to cause a fatality or life-changing injury [3]. It is of interest to note that marine operations (A) incidents compromising of; maritime operations, transfer by vessel, vessel operations and vessel mobilisation are also closely related to the transfer of personnel.

It is generally accepted within the industry that there is no safe means of personnel transfer. Regulators continue to encourage operators, developers, and manufacturers to de-risk the transfer process.

This reduction in risk must necessarily be achieved through development and implementation of innovative technologies. However, any equipment that is installed offshore can increase the risk to personnel who are required to operate and maintain. This is due to inherent hazards associated with the technology and the distance to shore, potentially leading to increased isolation and response times in the event of an emergency event.

The necessity to de-risk the transfer process is further hindered by the fact that the offshore wind industry is an emergent one. Technical, engineering and safety innovations occur more frequent than they would occur within a more mature industry. This imposes an increased burden on legislation and training of operators to ensure competent personnel.

As the need for renewable energy is increasing and the wind industry keeps expanding rapidly, further out at sea, safer transfer methods are vital in preventing incidents and ensuring a rapid emergency response when they do occur. Further from shore means longer transit times which increases the exposure of personnel to a noisy and vibrating environment, effectively imposing negative effects on human performance such as seasickness, boredom and loss of concentration.

Next to the need for safer access methods there is also a continuous search to increase the accessibility of offshore wind farms. There is no standard method yet to define accessibility of offshore wind farms which allows for comparison of access systems [4]. Accessibility is determined by weather conditions with the dominant statistical measure being significant wave height (H_s). Significant wave height is defined as the mean wave height (trough to crest) of the highest third of the waves.

Other factors are for example the safe transfer limits of an access system and characteristics of the vessel on which it is mounted [4]. Looking at significant wave height alone accessibility can be increased from 50% at 1,5 H_s to 80-90% once H_s of 3 metres are overcome.

However, as new access systems, such as motion compensated gangways, make their way on the market they also bring new risks with them. Although gangways may reduce risk in terms of falling and drowning hazards, they can introduce new hazards. Incident reports mention crush hazards between moving parts [5] [6] and uncontrolled detachment of a gangway or emergency retraction [7] known to have resulted in lost time injuries (LTIs).

2 OFFSHORE TRANSFER BACKGROUND

2.1 Offshore windfarm operation and maintenance

Offshore wind farm operation and maintenance (O&M) costs are a major part, 20 - 30%, of the Levelized Cost of Energy (LCOE) [8] . A large contributor to these costs is downtime due to accessibility restrictions resulting from severe weather conditions, preventing transfer of technicians or completion of maintenance tasks. With the continuous search to increase reliability of offshore wind turbines, effectively minimising the number of failures, the required number of transfers for maintenance is also reduced.

In the UK, the average number of personnel transfers per turbine fell by approximately 50% between 2014 and 2018, to around six trips per year, according to the System Performance, Availability and Reliability Trend Analysis (SPARTA) 2017/2018 portfolio review [9] as shown in Figure 2.1.

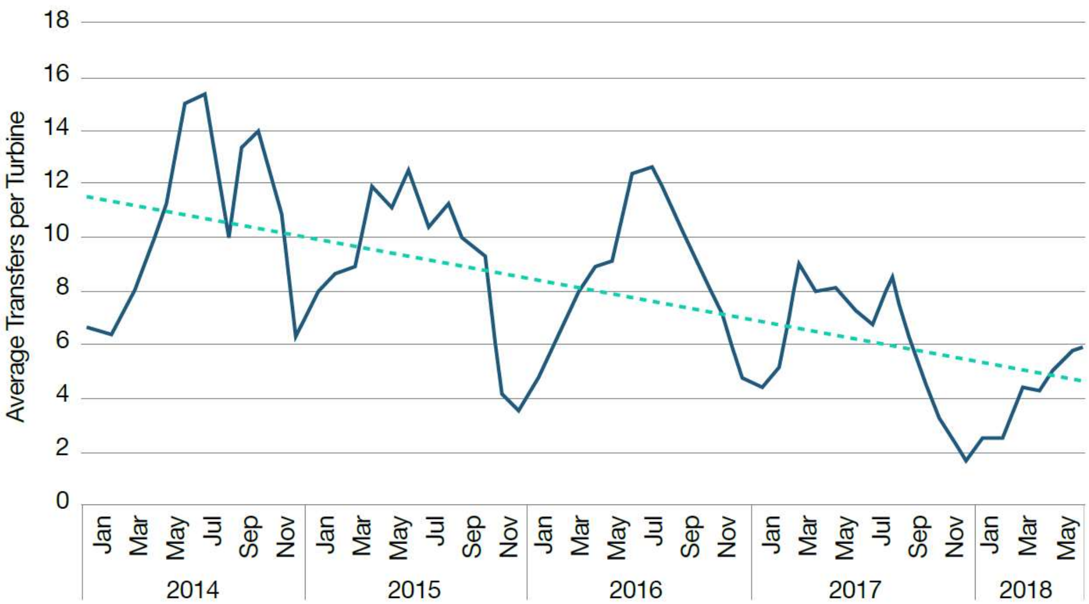

Figure 2.1: Average number of transfers per offshore wind turbine in the UK (2014-2018). Source: [9]

Sponsored by the Crown Estate and the Offshore Renewable Energy (ORE) Catapult, SPARTAs report data is summarised from 77% of installed UK operational offshore wind farms [10]. Though the amount of transfers per turbine is reduced, Europe has a total of 4,543 grid connected offshore wind turbines according to WindEurope 2018 statistics [11]. Six transfers per turbine account for a total of 27,258 transfers per year in Europe alone and will continue to increase with the continuing development of the industry.

2.2 Wind turbine access points

Overall there are three points from which an offshore wind turbine can be accessed. The first and most predominantly used point of access is the boat landing. The boat landing is located at sea level from where technicians climb two ladders and move through an opening to reach the platform located on top of the transition piece (TP). Another point of access is the TP platform, located approximately 15-20 metres above sea level. The final point of access is the hoisting platform located at the nacelle of the wind turbine by use of a helicopter where technicians are hoisted down onto the platform. A maintenance team typically consists of 2 to 4 technicians being dropped off on individual turbines.

2.2.1 ACCESS TO THE BOAT LANDING

Access by boat landing is often executed with a crew transfer vessel (CTV) or daughtercraft, where the vessels bow is thrusted against the boat landing and personnel is required to step from the vessel to the boat landing ladder. This is commonly known as the "bump and jump" method. The bump and jump method is by extent the most used method to access offshore wind farm installations [12]. Figure 2.2 gives an illustration of the transition piece and boat landing structure of an offshore wind turbine.

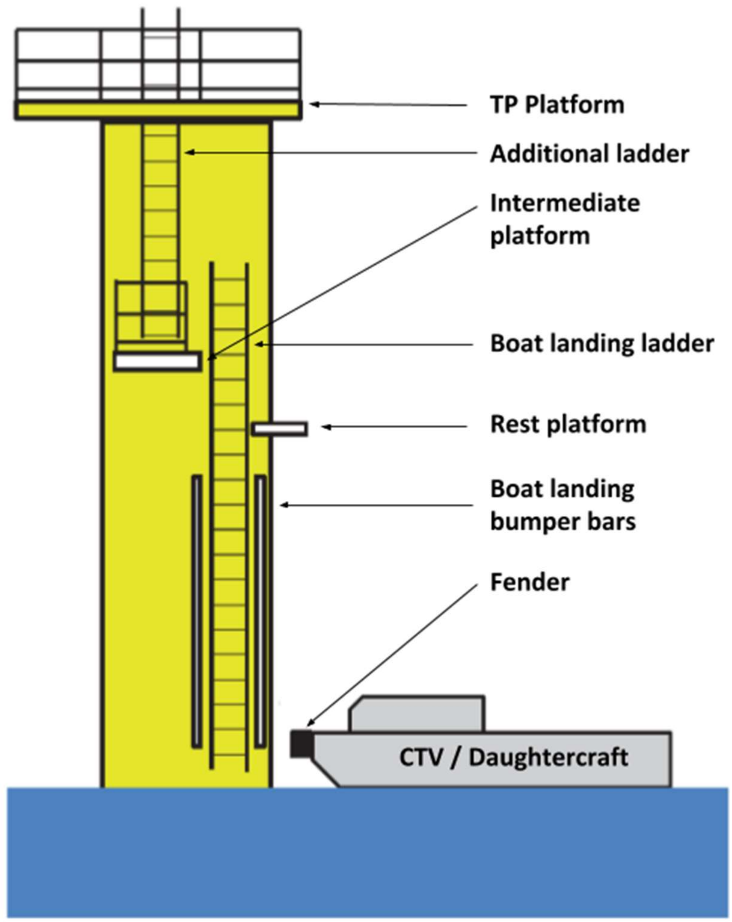

Figure 2.2: Transition piece and boat landing structure. Source: [13]

Personnel are required to step from the CTV or daughtercraft to the boat landing ladder across a maximum gap of 650 mm and a minimum safety gap of 500 mm, in accordance with industry practice [13]. This is to minimise the potential to crush personnel between the vessel's fender and the ladder rungs as depicted in Figure 2.3.

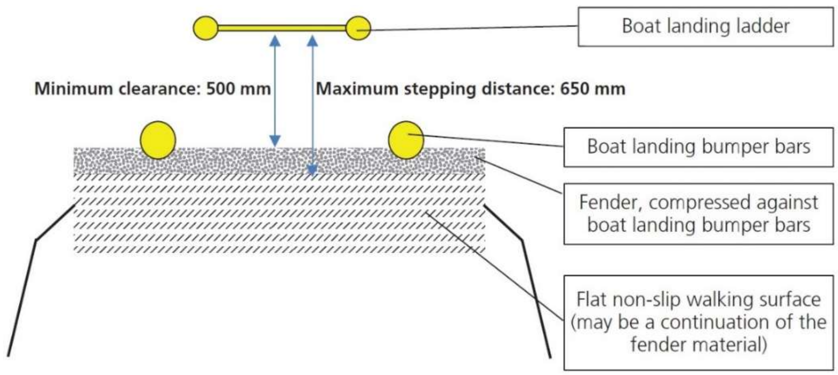

Figure 2.3: Minimum safety gap and maximum stepping distance bump and jump method. Source: [13]

2.2.2 BUMP AND JUMP METHOD TRANSFER PROCESS

In this section follows a detailed description and list of requirements from industry practise [13] for the transfer process utilising the bump and jump method. This entails personnel transfer from the deck of the CTV or daughtercraft, stepping from the vessel onto a stationary (near) vertical boat landing lander and climbing to the TP platform. The operation is reversed for transfer back from the TP platform to the CTV or daughtercraft.

The transfer process, using a Self-Retractable Lifeline (SRL), goes as follows for the access and egress from the TP platform of the turbine to the vessel [14]:

Access

1. Inspection of Personal Protective Equipment (PPE) prior to commencing a transfer process, e.g. by use of buddy checks.
2. Advance from the designated transfer waiting area to the vessels transfer position upon the command “ADVANCE” from the deckhand. While moving the technicians should maintain one hand on the handrail and then prepare his or her quick connector.
3. When the deckhand calls out the command “TRANSFER” and presents the SRL attachment point, the technician is to connect his or her quick connector to the SRL.
4. Immediately after connecting to the SRL, the technician steps over from the vessel to the boat landing ladder, with the loose retrieval line of the SRL placed over the shoulder.
5. Climb the boat landing ladder to the TP platform, or intermediate platform, close the platform gate or provide alternative fall protection and disconnect from the SRL. Give the command “CLEAR” to signal to the deckhand that the SRL is ready to use for the next transferee.

Egress

1. Inspect the SRL brake function and fall indicator before commencing egress from the turbine TP platform via the boat landing to the vessel.
2. Verify with the deckhand down on the vessel that transfer can commence by giving the command “READY FOR TRANSFER”.
3. Connect to the SRL and start your descent from the TP platform to vessel immediately.

4. Identify the deckhand's count down during climbing, this starts from the fifth ladder rung located above the vessel "FIVE, FOUR, THREE, TWO, ONE".
5. Upon the count of "ONE" move one hand to the to the quick connector's release function while keeping three points of contact with the ladder and orientate towards the vessel while stepping across.
6. Immediately disconnect the quick connector from the SRL once stable on the vessel with both feet.

At any moment during the transfer process the deckhand can command "ABORT" where the technician is to move to a save position and disconnect from the SRL immediately.

PPE requirements
The main hazards related to the bump and jump transfer process are falling and drowning. In order to successfully mitigate the hazard of falling a Fall Arrester System (FAS) is required, i.e. a SRL or twin fall arrest lanyards. To mitigate the hazard of drowning when a person does fall into the water a combination of the following PPE:

- Personal Floating Device (PFD);
- Personal Locator Beam (PLB);
- and immersion suit can be required.

A selection of PPE, such as an immersion suit, is dependent on several risk factors. Examples of risk factors are sea temperature, visibility and expected casualty recovery time. Depending on the risk factor the decision can be made to require technicians to wear an insulated immersion suit, a lightweight immersion suit or no immersion suit at all. An important factor is to ensure that all equipped PPE is compatible with each other, such that they do not counteract one another.

The above-mentioned PPE are an addition to the minimum PPE required when working at height, e.g. personal fall protection, a safety helmet, well-fitted gloves and footwear with good grip and clothes (worn underneath an immersion suit) that provide sufficient insulation.

2.2.3 CTV

There is a wide range of CTVs utilised for quick access to offshore wind farms from near-by ports. CTVs can typically carry 12 technicians and small parts and equipment. The types of CTVs include Mono-hull, Catamaran, Trimaran, Small Waterplane Area Twin Hull (SWATH) and Surface Effect Ship (SES). Typical characteristics and abilities of the CTV types are portrayed in Table 2.1.

	Mono-hull	Catamaran	Trimaran	SWATH	SES
Length (m)	12 – 25	15 – 27	19 – 27	20 – 34	26 – 28
Top transit speed (knots)	15 – 25	18 – 27	18 – 22	18 – 23	35 – 39
Passengers	12	12	12	12/24	12/24
Cargo (tons)	5 – 10	10 – 15	1 – 5	2 – 10	3 – 5
Max. H_s (m)	1 – 1.2	1.2 – 1.5	1.5 – 1.7	1.7 – 2.0	1.8 – 2.2

Table 2.1: Typical characteristics of CTV types. Source: [4].

Aluminium catamarans are the most commonly used CTVs due to their high speeds, good seakeeping behaviour and improved stability during personnel transfer [4], see Figure 2.4. They are more costly than the inferior mono-hull CTVs, whereas Trimarans, SWATHs and SES offer improved stability against a higher cost.

Figure 2.4: Aluminium catamaran CTV Cemaes Bay. Source: [15]

There is a continuous demand to further improve accessibility of wind farms and therefore a search for systems to enhance accessibility and overall safety. These systems can be mounted on the CTVs or on the boat landing to compensate motions and allow for more stable transfer via boat landing.

2.2.4 ACCESS TO THE TP PLATFORM

Direct access to the TP platform is often provided by use of a service operation vessel (SOV) equipped with a motion compensated gangway, see Figure 2.5. A gangway allows technicians to walk from the vessel directly onto the turbine, these so-called Walk-to-Work (W2W) systems, provide a more comfortable means of transfer as climbing the boat landing ladder is no longer required.

Figure 2.5: SOV BIBBY WAVEMASTER 1 equipped with a W2W system. Source: [16]

A SOV is substantially larger and more costly than a CTV but is used more frequently as wind farms move further from shore [4]. Currently most of the SOVs in the offshore wind industry are retrofitted vessels from the oil & gas industry. Since 2015, SOVs that are specifically designed for both installation and daily O&M of offshore wind farms have come to the market [4].

Compared to CTVs, SOVs offer an increased accessibility resulting in longer weather windows for installation, commissioning and maintenance activities and offers accommodation which allows technicians to work on a rotation. SOVs make use of Dynamic Positioning (DP) to maintain the vessel at a fixed position. By constantly measuring the vessel's surge, sway and heading and comparing it to the required position, the DP control system determines the position error. This information is used the calculate the required thruster's action to compensate for the position error.

The transit speed of an SOV is very slow (10 – 12 knots), especially when manoeuvring between turbines. For this reason some SOVs are equipped with daughter crafts, small fast cruising boats, however these can only be operated in relatively calm sea states with H_s less than 1.2 metres [4].

2.2.5 W2W TRANSFER PROCESS

W2W systems aim to eliminate the hazards of failing and drowning which have to be considered using the conventional bump and jump method and provide increased accessibility enabling access throughout the year. However, other hazards are introduced when utilising complex gangway systems which need to be assessed and minimised. An example of this is the potential for an emergency retraction of the gangway during a transfer process.

W2W systems are designed to be installed on the far port or starboard side of a vessel, from there the gangway can be manually steered by an operator by means of an interface or via remote control. This involves slewing, luffing and telescoping of the gangway into position as shown in Figure 2.6.

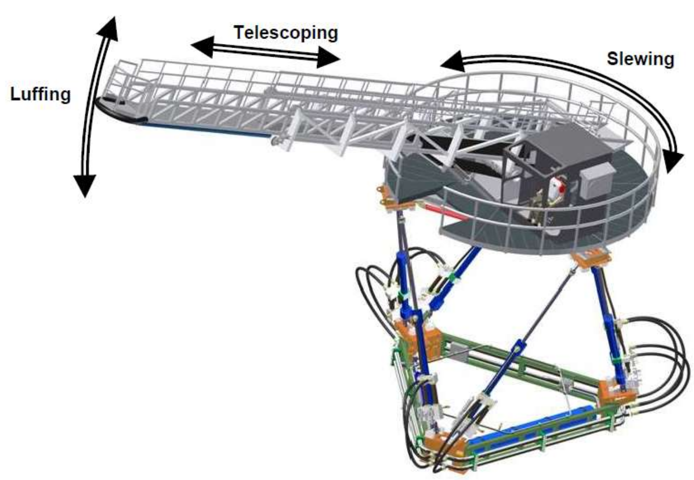

Figure 2.6: Degrees of freedom of a W2W system. Source: [17]

The figure depicts an Ampelmann system which compensates motions by use of six hydraulic cylinders known as a hexapod or Stewart platform frequently used for flight simulators. Other W2W systems have different means to compensate motions but the degrees of freedom are the same.

In order to ensure a fixation on an offshore wind structure, systems often exert a constant pressure or grip on the connection point. This requires minimal to no changes to be made to the structure accessed.

Overall there are two types of motion compensated gangway systems, passive and active. The design of a passive motion compensated gangway includes features that allow the gangway to reduce the relative motions between a vessel and structures or other vessel without using any external systems or equipment. An active motion compensated gangway entails a system powered by an external power supply that reduces or completely compensates the effect of vessel motions, from one degree of freedom to all six degrees of freedom on the gangway structure [18].

A vessel can move in six degrees of freedom which determine its displaced position and orientation. The motion in the horizontal plane is referred to as surge, the longitudinal motion usually imposed on the steady propulsive motion. Sway (sideways motion) and yaw (rotation about the vertical axis) describe the heading of the vessel [19]. The remaining three degrees of freedom are roll (rotation about the longitudinal axis), pitch (rotation about the transverse axis) and heave, determining the vertical motion of the vessel.

Sensors in active motion compensated systems continuously register displacements and rotations due to vessel movements and environmental forces and forward this information to the control system. The control system calculates the required opposite movement to cancel out the displacements signals the driver and actuators. This enables a stable platform and gangway to be used relative to fixed offshore structures.

As there are various types of W2W systems only a generic description of the transfer process utilising an active W2W system to access the TP platform is given.

1. Conduct PPE checks and ensure a barrier around the W2W system before pressurizing the W2W system.
2. Positioning of the gangway and ensuring a stable connection with the TP platform by applying pressure on the turbine structure. Before positioning the gangway some W2W systems require transferees to gather upon the W2W system transfer deck. Once on the transfer deck it is mandatory to keep at least one hand on the railing.
3. Signal to initiate transfer. The signal can be given in various ways, e.g. green light, sound signal or other means of communicating by the operator.
4. The transferee moves to transfer upon the signal, continuously holding at least one hand on the handrail of the gangway.
5. Carefully step over the sliding step (where the two parts of the gangway slide over each other to allow for compensation of motions) and continue moving to the TP platform or boat landing ladder.

The transfer back to the vessel is similar, where a transferee is to wait at a safe distance from the landing area for a signal from the operator before moving to egress.

Upon an emergency retraction an alarm will sound, after a short delay (approx. 3 seconds) the gangway will automatically retract. When the alarm sounds transferees are to stop walking, hold the rail firmly and to mind their hands and feet when the sliding step is coming towards them.

Passive W2W systems are used to enhance the access to the boat landing and are relatively smaller compared to active W2W systems. Only three commercially available and operating passive W2W systems were found [4]. In order to fixate on the boat landing the end of the gangway is equipped with a gripper. Once fixated vessel motions are compensated by means of a passive dampening effect, not requiring the use of any external systems and equipment, and thus less prone to technical failures.

The transfer process using a passive W2W system is similar to that of the bump and jump method, where the 'step over' from vessel to the boat landing ladder is replaced by a walk over via the gangway. Passive motion compensated gangways may or may not be equipped with an emergency retraction depending on the length of the gangway.

PPE requirements
Although the minimum standard of PPE will differ between W2W operations, depending on requirements from the ship- and facility operator's procedures, it may include [20]:

- fire retardant coveralls;
- a hard hat;
- safety glasses;
- safety boots;
- gloves;
- hearing protection as determined by ambient noise level;
- automatic lifejacket (including PLB);
- and personal fall protection.

2.2.6 ACCESS VIA HOISTING PLATFORM

Helicopters can provide access to wind turbines via the hoisting platform located on top of the nacelle for wind speeds up to 20 metres per second. Helicopters significantly decrease travelling time compared to CTVs, but they are expensive and have limited capacity to carry technicians and spare parts and tools. As transport via helicopter is expected to be primarily used for emergency transfers and auxiliary rather than for regular transportation it is not analysed further.

2.3 Legislation and industry standards for transfer of personnel

To ensure safe transportation of personnel to and from offshore structures numerous laws and industry standards are to be adhered by. At a European level, directives include:

- Directive 2014/90/EU: Ensuring uniform application of the SOLAS (Safety of Life at Sea) Convention on marine equipment.
- Directive 2009/16/EC (including amendments from directive 2017/2110): on common rules and standards for ship inspection and survey organisations and for the relevant activities of maritime administrations.
- Directive 2009/45/EC (including amendments from directive 2017/2108): on safety rules and standards for passenger ships.
- Directive 2012/35/EU: Training and competency standards for seafarers

2.3.1 TECHNICAL STANDARDS AND GUIDELINES FOR TRANSFER VESSELS AND ACCESS SYSTEMS

All small service vessel operating within a wind farm, e.g. CTVs, are required to have undergone a series of assessments and inspections. In accordance with good practise guideline; 'the safe management of small service vessels used in the offshore wind industry' [21], vessel selection should compromise of:

- a suitability assessment, determining whether a vessel is fit-for-purpose for the area of operation and activities to be undertaken;
- a Marine Inspection for Small Workboats (MISW) in accordance with (IMCA) M 189/S 004;
- and a site verification inspection to audit the points stated above and test the crew's familiarity with the vessel, including witnessing an emergency drill.

Regardless of equipment required by the Flag Administration or Classification Society, all service vessels should be fitted with the following lifesaving and safety equipment [21]:

- Approved life jackets for the number of persons on board +10% and sufficient immersion suits.
- At least two life buoys on each side of the vessel.
- A man overboard (MOB) recovery arrangement.
- Emergency pyrotechnical signal equipment.
- Search And Rescue Transponder (SART).
- Emergency Position Indicating Radio Beacon (EPIRB).
- An updated supply of medicine and medical equipment.
- An automated external defibrillator.
- A means of monitoring and tracking Personal Locator Beams (PLBs).
- At least one permanently mounted searchlight and one battery-powered portable searchlight.
- A spine board and stretcher for casualty evacuation.
- Displayed emergency posters/muster lists, clearly showing the responsibilities of crew, technicians and passengers.

DNVGL-ST-0358

Industry standard DNVGL-ST-0358 describes in detail the requirements for offshore gangways and includes both passive and active motion compensated gangways.

The standard includes minimum requirements with respect to:

- Documentation and certification
- Materials and fabrication
- Structural design and strength
- Functional requirements
- Safety and safety equipment
- Testing and marking

The provision of safety functions such as control and monitoring systems and their design with respect to redundancy and robustness against single failures is especially relevant to this project.

Control system design and components, e.g. Programmable Logic Controllers (PLCs), I/O cards, operator stations and network switches, are to be installed such that in the event of a failure personnel safety is the prime concern where the control moves to a fail-safe position. Errors in communication will trigger an acoustic alarm. The requirements apply to both hardwired control stations and wireless remote controls, where remote controls are to be provided with a key switch to disable when not in use and a dead man's switch.

With respect to active motion compensated gangways there is a safety philosophy based on a fail-operational concept. Fail-operational systems guarantee operation of a function even if a failure occurs with sufficient time, typically not less than 60 seconds, to safely abort the transfer operation.

Redundancy of active components of a gangway, e.g. gears, winches, cylinders etc., is generally not required with sufficient reliability, protection from mechanical damage and regular inspection and maintenance [18]. Control systems supporting both main and secondary safety functions and the power supply (electric or hydraulic) are required to be redundant in order to maintain a fail-operational gangway. A safety philosophy based on a fail-passive concept, where a single failure leads to a reduced or complete loss of function, may be used if the same or a higher level of safety is ensured as a fail-operational concept.

2.3.2 TRAINING REQUIREMENTS FOR TECHNICIANS

Given the remote location of work and hazards imposed on offshore technicians, they are required to undergo advanced safety and emergency training. The Global Wind Organisation (GWO), a non-profit organisation established by globally leading wind turbine manufactures and owners, has developed standardised training, reflecting industry risks for offshore wind personnel [22].

The GWO framework aligns generic safety and technical training standards, common to all wind energy companies ensuring a safe working environment and enabling personnel to work for all GWO member companies.

The GWO basic safety training (BST) consists of five courses with a duration of 4 – 16 hours each and a validity period of 2 years upon which a refresher course can be taken [14]. These courses are:

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

Next to the BST, technicians must obtain a valid offshore health certificate deeming them fit to work in an offshore environment. It is not mandatory to undertake GWO training if occupational safety legislation requirements set by countries are fulfilled in another way. However, as the offshore wind industry is dominated by major operators, actively participating in the standardisation process, the GWO standards have become the best and only practise.

GWO also offers advanced training with respect to emergency rescue and first aid and a basic technical training standard containing modules on mechanical, electrical, hydraulics and optionally installation.

Specifically related to the transfers process the sea survival course includes a module on safe transfer. The aim of the module is to provide technicians with knowledge on the hazards and risks of transfers and to ensure correct preventive measures are taken accordingly [14]. This is done by following the procedures and using available Life Saving Appliances (LSA) and PPE in a correct and safe manner.

Technicians are educated on the different types of transfer vessels commonly used in the offshore wind industry, the hazards related to the different methods of transfers and how to mitigate them. Herein the distinction is made between the following types of transfer situations; dynamic to static, static to dynamic and dynamic to dynamic. During the training technicians learn to use a SRL and twin fall arrest lanyards for example while climbing on or descending from the wind turbine via the boat landing ladder. A detailed training on the use of fall protection is also given during the working at heights course. Technicians are made aware that the final decision on whether it is safe to transfer always lies with them.

2.3.3 TRAINING REQUIREMENTS FOR SEAFARERS

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) sets the minimum qualification standards relating to training, certification and watchkeeping for masters, officers and watch personnel on ships. Educational and training institutions must comply with STCW in order to courses and issue certificates, this requires authorization from the respective national maritime administration [23].

The Basic Safety Training (BST) is a legal minimum requirement for seafarers employed or engaged in any capacity on board a ship. A STCW BST certificate has a validity of 5 years after which a refresher training has to be completed [24]. The STCW BST, has a total duration of 4 to 6 days and includes the following courses:

- Personal survival techniques
- Fire prevention and fire fighting
- Elementary first aid
- Personal safety and social responsibilities

Seafarers must also hold a medical certificate and can require additional training depending on their function on a vessel.

In regard to the transfer process the coxswain or SOV master, being in command of the vessel, makes the decision on whether the weather conditions are suitable for transit from shore to the offshore structure. Another assessment is made once in the location of the offshore structure whilst in open communication with the marine controller regarding any updates on weather conditions. Lastly the coxswain or SOV master are continuously observing the conditions throughout the transfer process, and ready to stop the operation once conditions become unsafe.

The Deckhand, or transfer assistant is responsible for preparing and guiding the transfer process. The deckhand will call transferees forward when ready and the conditions, vessel movement and swell, are suitable to initiate transfer to or from the wind turbine. The decision on when to step over from the vessel to the ladder and vice versa however remains with the transferee.

Before initiating transfer the Deckhand should [21]:

- conduct visual inspections of the ladder, transfer area, boat and structure fendering;
- conduct per-use checks of the SRL;
- and conduct pre-use checks of any transfer system in use.

Upon satisfactory completion of the above-mentioned checks the Deckhand is to [21]:

- check the correct use of PPE by the transferee;
- check the transferee for any items that may fall during climbing or working at heights;
- pull the SRL down and assist the transferee in attaching or detaching it.

Lastly, the Deckhand is also tasked with providing aid in the event of an incident or recovery in the event of a man overboard.

2.4 Human performance factors

All sorts of design and control measures can be in place in order to prevent incidents, but ultimately competence and human behaviour of individuals is key in ensuring tasks are executed safely. Competence can be defined as a combination of knowledge and skill, developed through education and training, and experience. For the offshore wind industry competency of personnel is ensured and maintained through industry standards and requirements, e.g. mandatory training and monitoring of health and fitness of personnel.

Human behaviour of individuals determines how their knowledge, skills and experience is applied in order to enable them to perform and repeat a task safely whilst taking their own limitations and constraints into consideration. This behaviour can be influenced directly by crew members, the safety culture of an organisation and other external factors.

Factors that can negatively impact human performance during the transfer process are:

- peer pressure;
- time constraints;
- weather conditions (e.g. seasickness);
- pressure to get the job done;
- wanting to get back to shore/boat;
- personal aggravating factors (e.g. stress, distraction, fatigue);
- and a lack of communication or trust between crew members.

Personnel undertaking offshore transfers should be under no pressure to transfer if they do not feel safe or feel unable to do so for any reason. This empowerment to say no is built up from a safety culture where open communication, feedback and a review of decisions made are seen as essential elements. Regardless of the method, transfer risks cannot be managed without full consideration of safety culture, crew interaction and the competency of individuals to recognise limitations of their performance.

Planning thoroughly to ensure sufficient time is available to conduct all foreseeable tasks is vital to minimise most of the factors negatively impacting human performance. The same counts for the factor weather conditions, where transfers should be scheduled in the summer months as much as possible to prevent effects as seasickness and reduce the overall risk related to the process. Roll is the most influential degree of freedom to induce seasickness as it produces the highest acceleration, similarly pitching and heaving feel uncomfortable to transferees [19].

Seasickness can highly affect an individual's ability to perform. Even when individuals are familiar with conditions at sea, the probability of making mistakes increases depending on the severity of seasickness, see Figure 2.7.

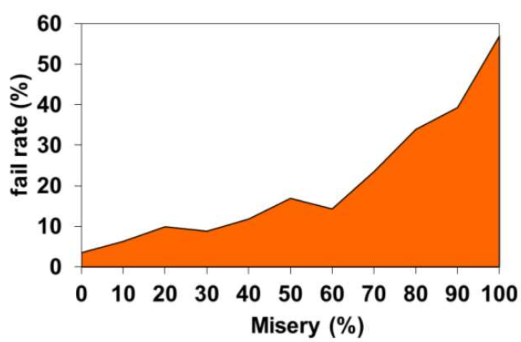

Figure 2.7: Percentage of tasks failing due to seasickness (0 = no problems at all, 100 = vomiting) in adapted naval crew. Source: [25] [26]

2.5 Literature review

2.5.1 INTRODUCTION

In addition to the industry standards, good practise guidelines, articles and incident data reports used in chapter 2, a number of studies provided invaluable information and probability data which allow for a concrete comparison between transfer methods. The studies have been summarised and reviewed within this section of the report.

2.5.2 OFFSHORE WIND ACCELERATOR - SLIDING ACCESS RISK ASSESSMENT

The Offshore Wind Accelerator (OWA) programme is a joint initiative by the Carbon Trust and nine offshore wind developers which account for 76% of Europe's installed offshore wind capacity [27]. Carbon Trust is a global organisation helping, supporting and advising businesses, governments and the public sector to accelerate the move to a sustainable, low carbon economy. The OWA programme aims to do so by reducing the cost of offshore wind to be competitive with conventional energy generation, overcoming market barriers, developing industry best practise and triggering the development of new industry standards [27].

The aim of the Sliding Access Project (2018) was to determine the risk factors and existing procedures to determine how the sliding access method could be de-risked and considered safe for day to day operations. Sliding access is an alternative technique to the bump and jump method, by which a vessel slides against a boat landing and the wave motion gives a more predictable moment of stepping over to and from offshore wind turbines.

The Project includes a quantitative risk analysis of the sliding access method through means of an Event Tree Analysis. The input values were assessed in a workshop taking inputs from experienced parties. Results of the quantitative analysis were found to be similar to those presented in another risk assessment by Ørsted, which concludes the risk of sliding access to be lower than the bump and jump method, but significantly higher than an approximate figure provided by incident data. This suggests the results of the risk analysis to be conservative [28]. The study is as of yet not made publicly available.

2.5.3 AMPELMANN DEMONSTRATOR

This is the final report is on the development and testing of the Ampelmann Demonstrator (2006 – 2007) by the Delft Technical University of Technology [29]. The Ampelmann, a to compensate wave induced ship motions in a transfer deck to allow for easy and safe access to offshore wind turbines, was invented in July 2002. The objective of the project "To make offshore access as easy as crossing the street".

The report includes the design philosophy, boundary conditions, geometry and operating of the transfer deck and the gangway. To ensure the safety of the design a Failure Mode Effect Analysis (FMEA) and risk analysis was carried out. This determined the need for the system to have sufficient backup and redundancy in critical components to be able to continue an operation in the event of a single failure.

2.5.4 DEVELOPMENT OF THE ACCESS SYSTEM FOR OFFSHORE WIND TURBINES

Written by David Julio Cerda Salzmann as PhD thesis proving the Ampelmann technology to be a safe method to transfer personnel to fixed offshore structures, providing access in sea states with a significant wave height of over 2.5 metres [17].

In addition to the Ampelmann Demonstrator the PhD thesis provided a more detailed overview of a W2W system's fail-operational safety philosophy and its consequences for design and operation. Examples of this are the requirement for a 60 seconds ride through failure, and a safety based operational procedure effectively minimising the risks induced by technical failures and human errors.

3 PROBLEM STATEMENT

How do motion compensated gangways fare in terms accessibility, efficiency and individual risk to the transferee relative to conventional methods of transfer to offshore wind turbines?

Three sub questions have been listed to help answer the problem statement, of which the first sub question has already been answered in part in Chapter 2.

1. What are the differences in transfer methods regarding the operation, training, safety and technical requirements, between conventional, passive and active motion compensated transfer systems?
2. How can the accessibility and efficiency of transfer methods be determined and compared?
3. What are the risks a transferee is exposed to during the access and egress of offshore wind turbines when utilising different transfer methods?

3.1 Delimitation

In this section the boundaries set for this project are described.

Within the project only personnel transfer to offshore wind turbines is analysed, access to other offshore installations, i.e. offshore substations, is not taken into consideration.

Case studies within the project are geographically limited to the North Sea to ease acquisition of metocean data.

The risk of a ship collision and other hazards related to offshore transit or work conducted offshore is not included in the scope of this project.

4 METHODOLOGY

4.1 Introduction

This chapter describes the methodology applied to answer the problem statement. The method is based around the following steps and depicted in Figure 4.1:

1. Determine the accessibility and efficiency of access systems by means of case studies.
2. Identify hazardous events and consequences related to the transfer process for each method.
3. Visualise identified hazards and consequences, including preventive and mitigating barriers utilising a BowTie analysis. Barriers are derived from industry standards and guidance on good practise.
4. Conduct a quantitative risk analysis (QRA) using an Event Tree Analysis (ETA) where the BowTie analysis serves as input.
5. Evaluate the risks per transfer and the Individual Risk Per Annum (IRPA) for each of the transfer methods.
6. Compare the different transfer methods, draw conclusions and make recommendations for future work.

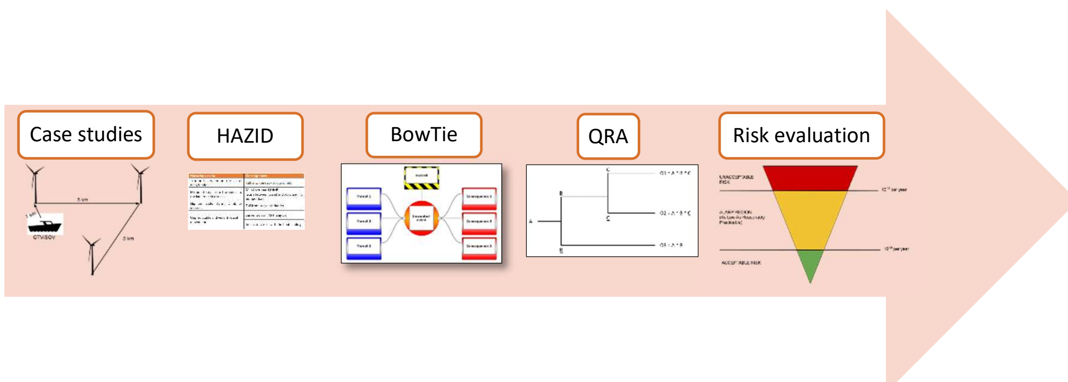

Figure 4.1: Method schematic

4.2 Case studies

A selection of wind farms and access systems is made in order to conduct a concrete assessment and comparison of their accessibility and efficiency. Hereby the safe transfer limits of access systems can be compared with historical met-ocean data of the wind farms in order to determine the accessibility they provide throughout the year for the respective wind farms. The efficiency of access systems can be tested by a base case wherein sets of technicians are dropped off or picked up at several turbines in a row. From here out conclusions can be drawn on the time differences per transfer method.

4.3 Hazard Identification

A HAZard IDentification (HAZID) is a brainstorm method used to identify all threats and hazardous events that can lead to harm during an activity or process. In order to do so incident reports, good practise guidelines, system specifications and operations and risk assessments have been consulted.

4.4 BowTie Analysis

4.4.1 BASIC METHODOLOGY

A BowTie analysis is a structured and chronological method to visualise threats and consequences of an unwanted event. Figure 4.2 shows a schematic of the basic BowTie structure.

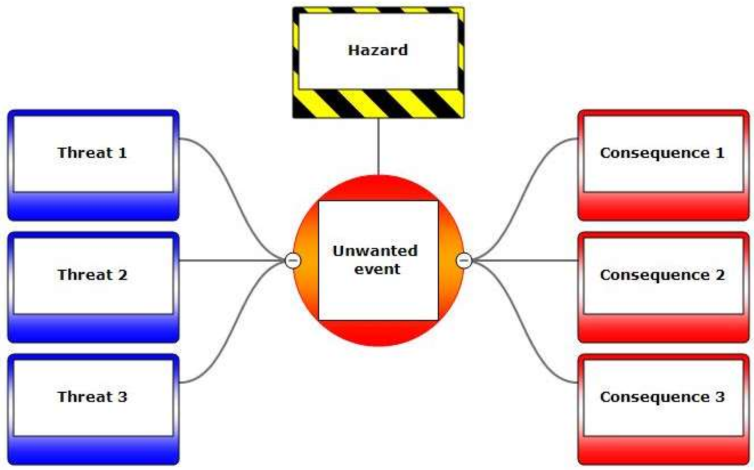

Figure 4.2: Basic BowTie structure

The unwanted event usually pertains a loss of control over a process or activity. The hazard is the process or activity that makes it possible for the unwanted event to occur. Take for example driving a car as the hazard, with the unwanted event 'losing control of the car'. Possible threats can be slippery roads, an intoxicated driver or worn tires. Consequences of the unwanted event can be injury or fatality of occupants of the car or damages to the car.

Once all threats and consequences have been identified, the BowTie technique identification and analysis of barriers to prevent a loss of control, and barriers to mitigate its consequences. Potential weaknesses in both preventive and mitigating barriers are highlighted by escalation factors. Figure 4.3 shows the BowTie structure including barriers and escalation factors.

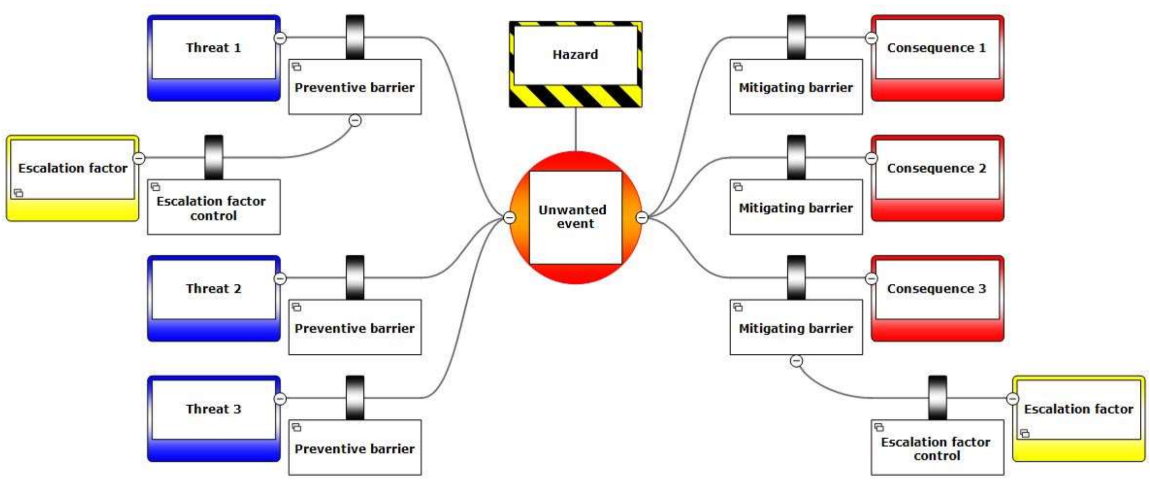

Figure 4.3: BowTie structure with barriers

Considering the same example as before preventive barriers can be speed limits on slippery roads, alcohol testing by law enforcement and regular inspection of cars, including the thread depth of tires. Mitigating barriers are for example the activation of air bags upon a collision and response of emergency services. Escalation factors are factors that can reduce or completely disable the function of a barrier. For emergency services this can for example be a lack of manpower or obstruction on the road. Escalation factors can in turn be controlled with barriers of their own, effectively preventing the effects of an escalation factor.

The BowTie diagram visually maps how hazards are managed so that the risk can be understood, and weaknesses can be identified. This allows for the making of informed decisions and improvement of risk management.

4.4.2 PRESENTATION OF INFORMATION

In section 4.4.1 the basic BowTie structure is explained, however, more information can be provided in a BowTie diagram as shown in Figure 4.4.

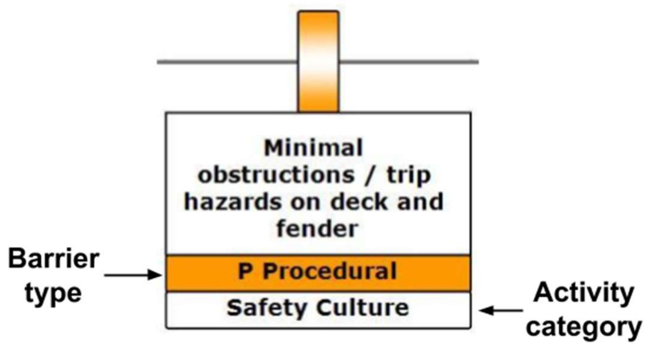

Figure 4.4: BowTie Barrier information

To provide a more detailed overview of the risks related to the transfer process a distinction is made in barrier types, as listed in Table 4.1.

Table 4.1: BowTie barrier types

Colour	Barrier Type	Description
	Engineering	Barriers that are design features, e.g. boat landing and CTV, and require human involvement only for maintenance, inspection or testing.
	Human Performance	Barriers directly related to the competence of personnel to execute their tasks.
	Procedural	Procedural barriers can for example be operating procedures, regular inspection and maintenance and selection of PPE.

Next to a distinction in type, barriers have been grouped in terms of the following categories:

- Vessel Design and Selection
- Boat landing Design
- Deckhand Supervision
- Inspection and Maintenance
- Instrumentation
- Redundancy
- PPE
- Competence
- Weather Management
- Safety Culture
- Training
- Fitness
- Emergency Response

4.5 Event Tree Analysis

An Event Tree Analysis (ETA) is used to study the threats of a BowTie diagram and how they result in consequences. An ETA provides a picture of possible scenarios leading from a process or activity, the threats form event sequences or steps along the way. Assigning probabilities to the steps and consequences is a way to qualitatively assess the risk of a process or activity [30, p. 78].

Each event tree step poses a question that is usually answered by either yes or no, forming two new paths. The more steps are introduced, the larger the event tree and the more outcomes there are. A simple example is shown in Figure 4.5. Herein A is the initiating event, a fire, B is the fire alarm going off, and C the emergency response from the fire brigade.

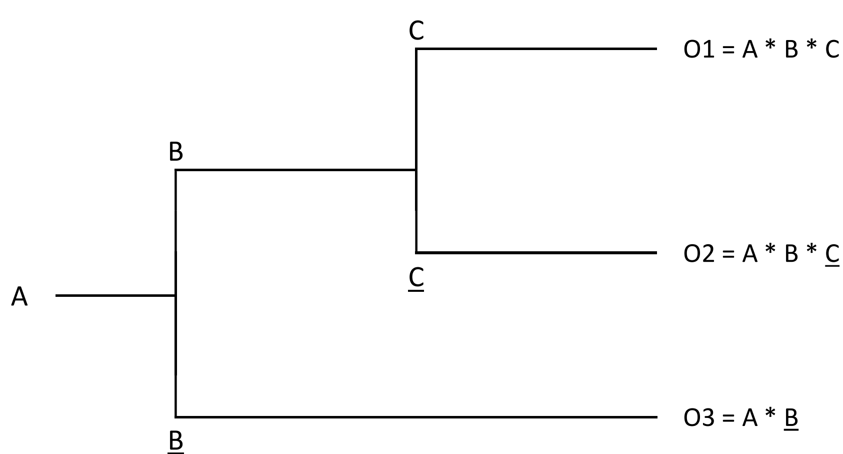

Figure 4.5: Event Tree Analysis example, B means 'not B' and C means ‘not C’.

The example shows us two event steps and three different outcomes. Outcome 1 (O1) occurs if the fire alarm goes off and the fire brigade responds in the event of a fire. In the case of outcome 2 (O2) the fire alarm goes off, but the fire brigade fails to respond. Lastly, in the case of outcome 3 the fire alarm does not go off and thus the fire brigade is not informed of the fire.

It is common practise to pose the event steps as such that the answer yes is up, and no is down for all questions and makes an event tree easier to read. If there is a larger number of event steps and outcomes, most of which are almost identical, it is prevalent to group the various event outcomes before processing them further in the risk analysis [30, p. 78].

The developed event trees for the access methods have been grouped on severity. The severity of outcomes has been qualitatively assigned with respect to the type of injury they might inflict on a transferee. The types of injury are:

- None, i.e. the outcome leads to a successful transfer or safe landing/recovery of a misstep;
- Minor, i.e. minor impact or fall injury;
- Major, i.e. major impact or fall injury;
- Fatal, i.e. unsuccessful recovery of MOB.

The developed ETAs calculate the risk per transfer and give an overview how likely a transferee is to sustain one of the above-mentioned injuries during a single transfer. By weighting non-fatal injuries, they can be combined and determine the overall risk of fatality for each of the transfer methods.

The values in Table 4.2 are commonly used within the rail industry and are used as reference point.

Table 4.2: Equivalent fatality severity for non-fatal injuries. Source: [31]

Injury type	Description	Weighting	Ratio
Minor	Physical injuries without serious implications, first-aid is sufficient.	0.001	1000
Major	This includes loss of consciousness, fractures, major dislocations, loss of sight and other injuries that require hospital attendance for more than 24 hours	0.1	10
Fatal	Death occurs within one year of the accident	1	1

4.6 Risk evaluation

Multiplying the overall risk of fatality per transfer with a postulated number of transfers per year allows for calculation of the Individual Risk Per Annum (IRPA).

In general an IRPA higher than 1×10^{-03} is deemed unacceptable for workers in most industries and above 1×10^{-06} is deemed acceptable as shown in Figure 4.6 [32]. For the public an IRPA higher than 1×10^{-04} is deemed unacceptable.

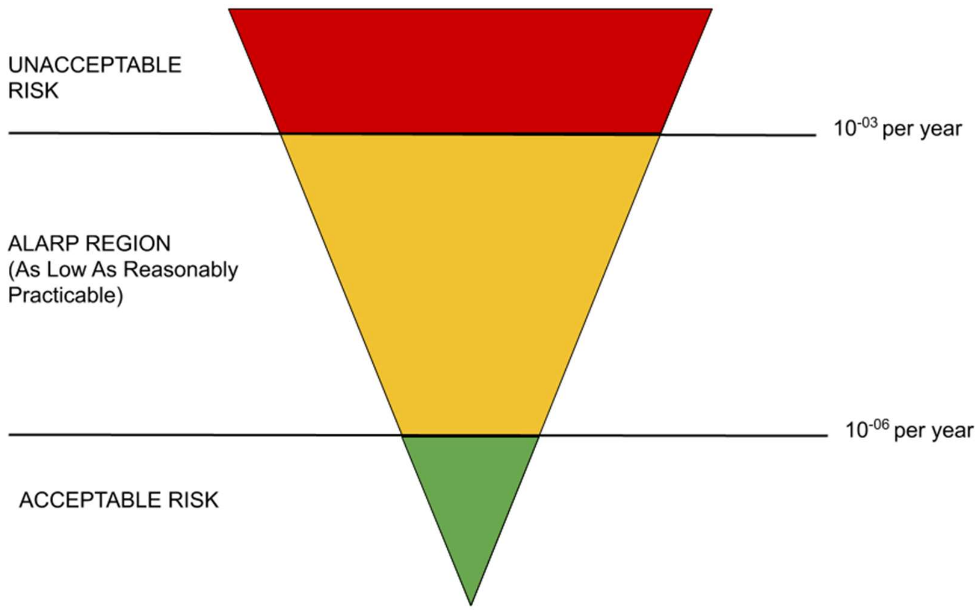

Figure 4.6: Individual Risk Per Annum Risk Criteria

5 ACCESSABILITY AND EFFICIENCY OF ACCESS SYSTEMS

5.1 Case studies

In order to make a concrete comparison between different types of access systems and how they fare in terms of accessibility and efficiency five existing offshore windfarms located in various places within the North Sea were selected. The location of the selected wind farms is can be seen on Figure 5.1.

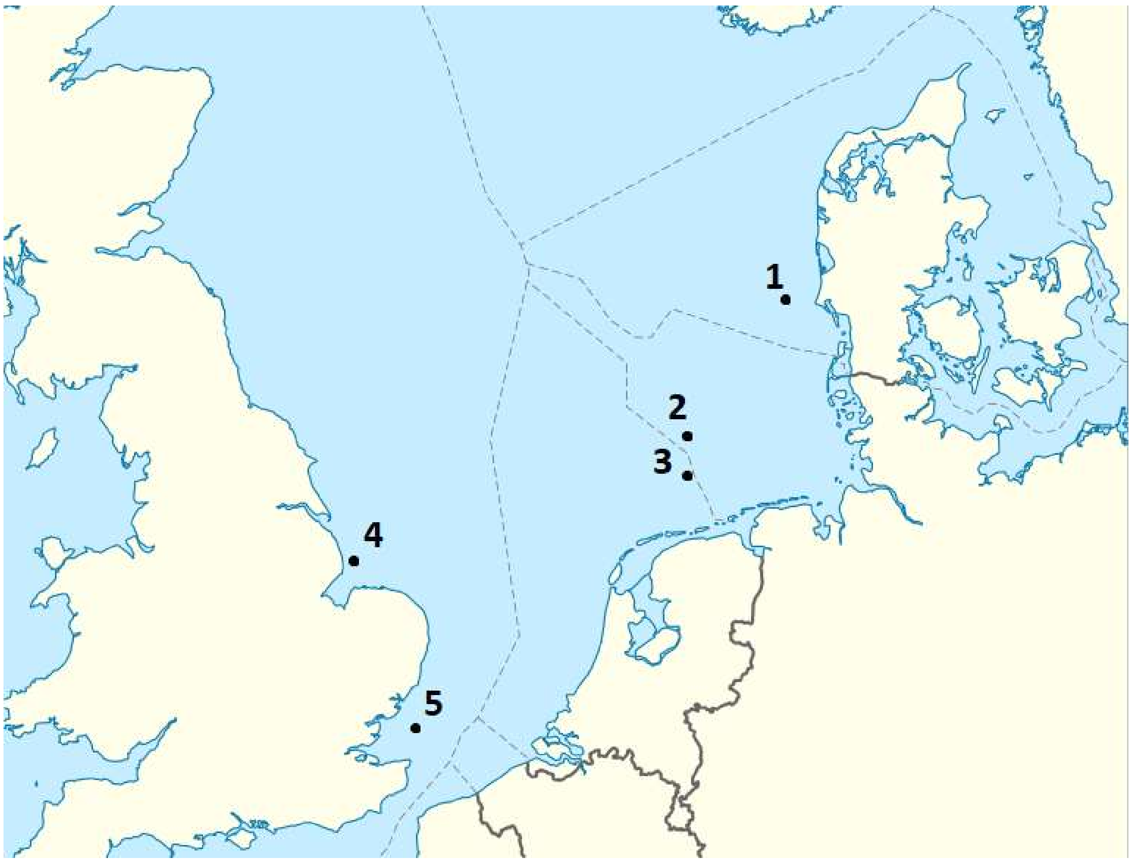

Figure 5.1: Selected offshore wind farms, (1) Horns Rev II, (2) BARD Offshore 1, (3) Gemini, (4) London Array, (5) Lincs

These five were selected based on their differences in location, size and distance to shore to offer a broad spectrum for analysis, their details are listed in Table 5.1.

Table 5.1: Selected offshore wind farms

No.	Wind Farm	Capacity (MW)	No. Turbines	Location (DMS)	Distance to shore (km)
1	Horns Rev II	209	91	55°36′00″N 7°35′24″E	32
2	Gemini	600	150	54°2′10″N 5°57′47″E	55
3	BARD Offshore 1	400	80	54°21′18″N 5°58′48″E	100
4	London Array	630	175	51°38′38″N 1°33′13″E	20
5	Lincs	270	75	53°11′0″N 0°29′0″E	8

Gemini and BARD Offshore 1 currently both utilise SOVs with daughtercrafts and CTVs to transfer personnel. Horns Rev II, London Array and Lincs generally only utilise CTVs.

5.2 Metocean data

Localised historical weather data for the selected wind farms was gathered from MetOceanView utilising their freely available hindcast data. The data is compiled using a SWAN (Simulating WAves Nearshore) model at 3 hour intervals and WRF (Weather and Research Forecast) model at 1 hour intervals dating back from 1979 to, and including, 2015 [33]. Figure 5.2 shows the historical mean wind speed for the selected offshore wind farms.

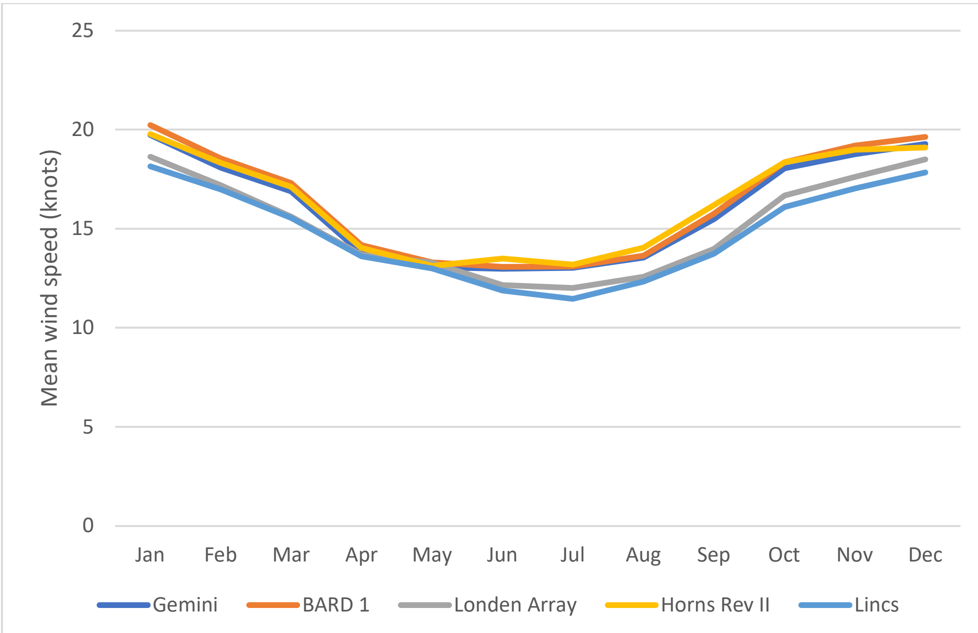

Figure 5.2: Mean wind speed (knots) selected offshore wind farms (1979 – 2015)

Figure 5.3 shows the historical mean wave height for the selected offshore wind farms.

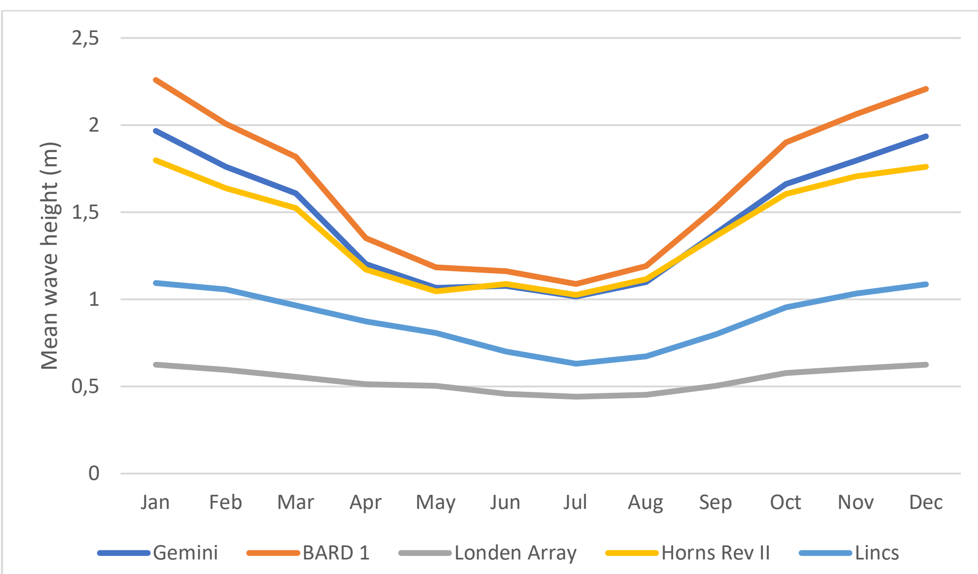

Figure 5.3: Mean wave height (m) selected offshore wind farms (1979 – 2015)

Waves are disturbances of the ocean's surface mainly created by the wind. The height of waves is determined by three factors, being:

- the wind speed;
- the wind duration, i.e. the amount of time the wind blows;
- and the fetch, which is the uninterrupted distance over open water for which the wind blows without a change in direction.

It is therefore natural that wave heights are increased during the winter months, from October to March, and are at their lowest during summer following the same trend as wind speeds.

Wind farms London Array and Lincs, though experiencing similar wind speeds as the other wind farms, have lower mean waves heights. This is because the fetch is limited by the surrounding coast of the mainland. The other three wind farms, Bard 1, Gemini and Horns Rev II are located farther from shore and have a large distance of open sea from which the wind is blowing.

5.3 Accessibility

Accessibility is determined by the operability limit of vessels, their access systems and type of operations conducted. The operability limit is determined by the ability to withstand weather conditions, such that they provide for safe transfer and operations.

Accessibility is predominantly determined by significant wave height, H_S. Other metocean parameters used to determine accessibility of offshore structures are wind speed and sometimes wave peak period, i.e. the wave period with the highest energy. When all relevant metocean parameters are below the operability limits it is safe to transfer. Forecasting so called 'weather windows' determines how quickly and for what consecutive length of time O&M activities can be conducted.

Due to limited access to localised weather data and the operability limits of access systems only H_S is considered for each of the case studies. Significant wave heights for each of the selected wind farms were determined from historical wave counts per month listed in intervals. This was done by using the average of the intervals of 0.5 metres, i.e. wave counts within the 0.0 – 0.5 interval were averaged out to be 0.25 metres.

It is to be mentioned that using monthly data only results in a rough estimation of accessibility as wind speeds fluctuate strongly, where winds are typically strongest in the late afternoon and light during the late evening and early morning.

The derived mean significant wave heights per month for each of the selected wind farms is portrayed in Figure 5.4.

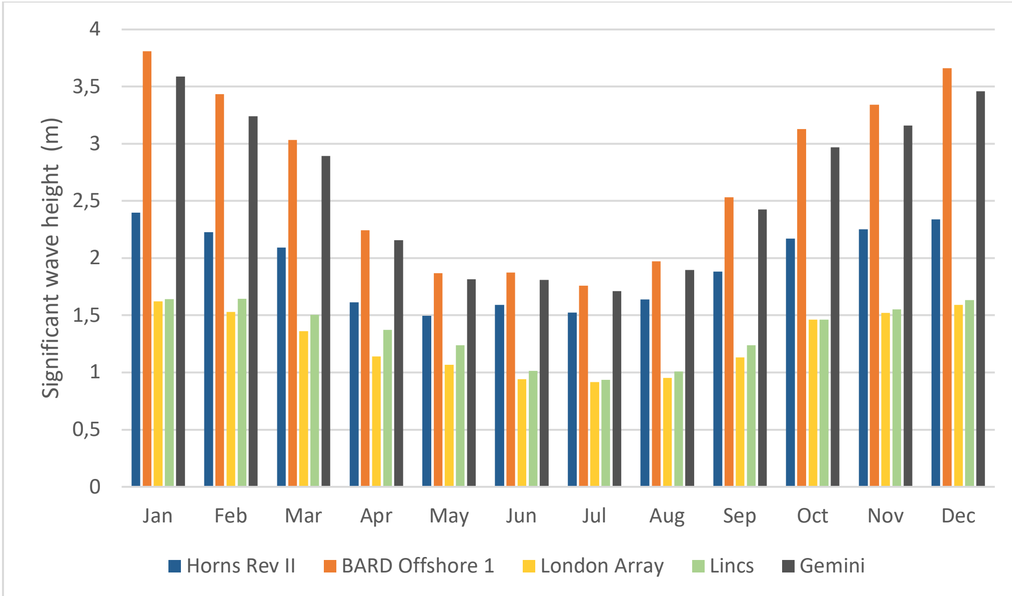

Figure 5.4: Mean significant wave height (m) selected offshore wind farms (1979 – 2015)

To represent both the conventional method, passive and active motion compensated systems with varying points of access to the turbine, a selection of four access systems was made. The accessibility of access systems is determined by how many months per year an access system can be utilised given their maximum allowable H_s. The safe transfer limit using the conventional bump and jump method is generally set at 1,5 m H_s [12], this value is therefore used as the maximum allowable H_s.

Out of the selected systems, with exception of the conventional bump and jump method, the Ampelmann systems have the highest number of personnel transfers recorded, with the A-type responsible for more than 3 million transfers and the L-type more than 200.000 [4]. The Uptime 23.4m, has carried out approximately 1 million transfers and has been used at the Gemini wind farm [4]. A complete overview of the limiting wave condition of the selected access systems is listed in Table 5.2.

Table 5.2: Safe transfer limit *Hs* of selected access systems. Source: [4] [34] [35].

Access system	Type	Point of access	Safe transfer limit H_s (m)
Bump and jump	Conventional method	Boat landing	1,5
Ampelmann L-type	Passive W2W system	Boat landing	2
Ampelmann A-type	Active W2W system	TP platform	3
Uptime 23.4m	Active W2W system	TP platform	3,5

5.3.1 BUMP AND JUMP METHOD

With a safe transfer limit of 1,5 H_s the following accessibility was determined for the selected wind farms when utilising the bump and jump method, see Table 5.3.

Table 5.3: Accessibility bump & jump method, (x) accessible, (-) not accessible

Bump and jump method												
Wind Farm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Horns Rev II	-	-	-	-	x	-	-	-	-	-	-	-
Gemini	-	-	-	-	-	-	-	-	-	-	-	-
BARD Offshore 1	-	-	-	-	-	-	-	-	-	-	-	-
London Array	-	-	x	x	x	x	x	x	x	x	-	-
Lincs	-	-	-	x	x	x	x	x	x	x	-	-

5.3.2 AMPELMANN L-TYPE

With a safe transfer limit of 2 H_s the following accessibility was determined for the selected wind farms when utilising the Ampelmann L-type, see Table 5.4.

Table 5.4: Accessibility Ampelmann L-type, (x) accessible, (-) not accessible

Ampelmann L-type												
Wind Farm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Horns Rev II	-	-	-	x	x	x	x	x	x	-	-	-
Gemini	-	-	-	-	x	x	x	x	-	-	-	-
BARD Offshore 1	-	-	-	-	x	x	x	x	-	-	-	-
London Array	x	x	x	x	x	x	x	x	x	x	x	x
Lincs	x	x	x	x	x	x	x	x	x	x	x	x

5.3.3 A-TYPE

With a safe transfer limit of 3 H_s the following accessibility was determined for the selected wind farms when utilising the Ampelmann A-type, see Table 5.5.

Table 5.5: Accessibility Ampelmann A-type, (x) accessible, (-) not accessible

Ampelmann A-type												
Wind Farm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Horns Rev II	x	x	x	x	x	x	x	x	x	x	x	x
Gemini	-	-	x	x	x	x	x	x	x	x	-	-
BARD Offshore 1	-	-	-	x	x	x	x	x	x	-	-	-
London Array	x	x	x	x	x	x	x	x	x	x	x	x
Lincs	x	x	x	x	x	x	x	x	x	x	x	x

5.3.4 UPTIME 23.4M

With a safe transfer limit of 3,5 H_s the following accessibility was determined for the selected wind farms when utilising the Uptime 23.4m, see Table 5.6.

Table 5.6: Accessibility Uptime 23.4m, (x) accessible, (-) not accessible

Uptime 23.4m												
Wind Farm	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Horns Rev II	x	x	x	x	x	x	x	x	x	x	x	x
Gemini	-	x	x	x	x	x	x	x	x	x	x	x
BARD Offshore 1	-	x	x	x	x	x	x	x	x	x	x	-
London Array	x	x	x	x	x	x	x	x	x	x	x	x
Lincs	x	x	x	x	x	x	x	x	x	x	x	x

5.3.5 COMPARISON

Figure 5.5 shows an overview of the accessibility of that the selected access systems offer per year, relative to the five offshore wind farms.

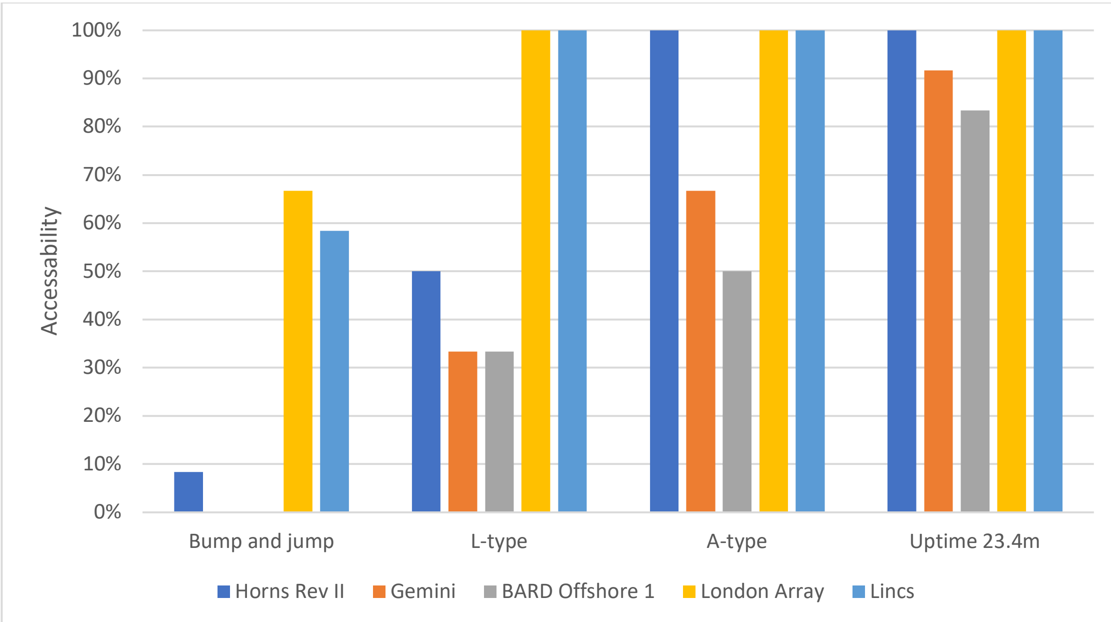

Figure 5.5: Comparison of the accessibility per year of access systems for the selected wind farms

5.4 Efficiency

The speed of an access system depends on the transit speed of the CTV or SOV on which it is placed compared to the distance it is required to overcome to reach its destination, the deployment time of the access system itself and the transfer time. As maintenance campaigns often entail sets of technicians being dropped off at several turbines, potentially to surrounding wind farms as well, the manoeuvrability of a vessel and its access system is also an important factor.

Transfer to an offshore structure can be split up into three phases; transit, approach and transfer. Transit entails the process of transporting personnel from or to the shore to the offshore structure. Approach is a controlled engagement or disengagement from the boat landing or TP platform, e.g. the deployment of a W2W system. Transfer is the process where personnel moves from the vessel to the offshore structure and vice versa.

5.4.1 TRANSIT

Transit time is determined by the time it takes for personnel to reach the offshore structure or shore. The transit time is solely determined by the vessel it is mounted on. To give an insight on differences in transit time a short comparison is given.

A catamaran CTV has a transit speed between 18 – 27 knots whereas an SOV generally has a transit speed of 10 – 12 knots. This means that it will take an SOV approximately twice as long to reach an offshore wind farm. Considering wind farm BARD Offshore 1, located 100 km from shore, an SOV would have a transit time longer than 5 hours. Because of this reason SOVs usually make trips to offshore wind farms once every two weeks and conduct transit during night-time, ensuring no working hours are lost. CTVs only conduct day trips.

5.4.2 MOBILISATION TIME

Mobilisation time to install access systems upon a transfer vessel can be a detrimental factor in case of uncertain weather windows and emergency repairs. The mobilisation time per access system [4] is shown in Table 5.7.

Table 5.7: Mobilisation time of access systems

Access system	Installed on	Mobilisation time
Bump and jump	N/A	N/A
Ampelmann L-type	SWATH CTV	8 hours
Ampelmann A-type	SOV	12 hours
Uptime 23.4m	SOV	40 hours

5.4.3 APPROACH AND DEPLOYMENT

The time of approach is defined as the time it takes a transfer vessel to move into position against the boat landing or TP platform. Once in position, the deployment time of access systems will determine the overall time required before conducting safe transfer of personnel from or to the vessel.

For the conventional bump and jump method and the L-type, manoeuvring the CTV against the boat landing is estimated to be neglectable in calm weather conditions. With more dire weather conditions, it can take several attempts to fixate the CTV against the boat landing when utilising the bump and jump method. The L-type does not require a fixation of the CTV to the boat landing and is required to be installed on a CTV with a length of more than 30 metres, such as a SWATH. SWATH CTVs are able to withstand higher H_s and will therefore also be more suited against rougher weather conditions.

The time an SOV is estimated to take to move into position next to the TP platform is set at 60 seconds to account for a slower and less nimble vessel. The deployment time was found to be identical at 60 seconds for each of the gangways [4]. An overview of the approach and deployment times of access systems is shown in Table 5.8.

Table 5.8: Approach and deployment time of access systems.

Access system	Approach (s)	Deployment (s)
Bump and jump	0 - 30	N/A
Ampelmann L-type	0	60
Ampelmann A-type	60	60
Uptime 23.4m	60	60

5.4.4 TRANSFER

The transfer time is determined by how long it takes personnel to move from the transfer vessel to a safe location upon the wind turbine, i.e. the TP platform, and vice versa. The estimated access and egress times for a single transfer for each of the access systems have been derived using best knowledge and video footage of transfers. An overview is listed in Table 5.9.

Table 5.9: Access and egress time of access systems

Access system	Access (s)	Egress (s)
Bump and jump	30	45
Ampelmann L-type	30	45
Ampelmann A-type	15	15
Uptime 23.4m	19.57	19.57

For the bump and jump method the access is estimated to take 30 seconds per technician, whereas the egress by climbing downwards is estimated to take longer with approximately 45 seconds. The actual time can vary significantly depending on the type of wind turbine foundation and is predominantly determined by the length of the ladder. Utilising the L-type compared to the bump and jump method is considered to have no effect on the access and egress time. Walking over, as compared to stepping over, from the CTV to the boat landing ladder is seen as a neglectable difference in this respect.

For the Ampelmann A-type and Uptime 23.4m the access and egress consist of technicians simply walking the length of the gangway to the TP platform. Considering an average walking speed of 1.4 metres per second the transfer time was derived according to the average length of the gangway. The average length of the A-type was determined to be 21 metres and 27.4 metres for the Uptime 23.4m. No distinction is made in walking speed regarding the sloping of a sloping gangway.

5.4.5 COMPARISON

In order to determine and compare the efficiency of the selected access systems an analysis made considering crew transfers to three offshore wind turbines in a row. Herein the transfer vessel, a catamaran CTV or SOV, starts at a distance of 1 kilometre from the first turbine. The other two turbines are both located at a distance of 5 kilometres from the previous visited turbine. The analysis ends upon completion of transfer at the third turbine and retraction of the access system. Figure 5.6 gives an illustration of the described process.

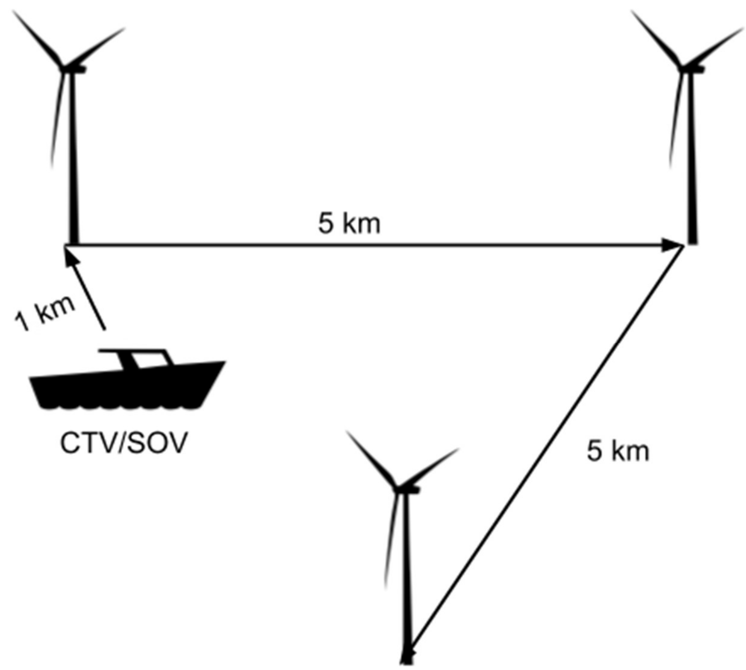

Figure 5.6: Crew transfers to three offshore wind turbines in a row

As a base case it is considered that at each turbine three technicians are dropped off or picked up. The analysis starts by a short transit towards the first turbine after which the approach and, when applicable, deployment takes place. The transfer then initiates, where three technicians move from the vessel to the TP platform or vice versa. After the retraction of an access system this process repeats itself for the other two turbines. Herein it is assumed that:

- transfer takes place in calm weather conditions;
- the retraction time is considered to be the same as the deployment time;
- a catamaran CTV has a transit speed of 22.5 knots;
- a SWATH CTV has a transit speed of 20.5 knots;
- and a SOV has a transit speed of 11 knots.

The crew drop off and pick up times for each of the access systems is determined using the following equations:

$$C_1 = \left(\frac{D_1}{T_s} + X + 2Y + nE\right) + V\left(\frac{D_2}{T_s} + X + 2Y + nE\right)$$

$$C_2 = \left(\frac{D_1}{T_s} + X + 2Y + nA\right) + V\left(\frac{D_2}{T_s} + X + 2Y + nA\right)$$

where,

C_1 = crew drop off time

C_2 = crew pick up time

D_1 = distance to the first turbine in metres

D_2 = distance to the following turbine in metres

V = number of turbines visited – 1

T_s = transit speed of the vessel in metres per second

X = approach time in seconds

Y = deployment/retraction time of the access system in seconds

n = number of technicians dropped off/picked up per turbine

A = access time in seconds

E = egress time in seconds

The results from the base case analysis are listed in Table 5.10.

Table 5.10: Base case results crew drop off and crew pick up

Access system	Crew drop off (s)	Crew pick up (s)
Bump and jump	1220	1355
Ampelmann L-type	1673	1808
Ampelmann A-type	2619	2619
Uptime 23.4m	2660	2660

The base case determines that a utilising an SOV with a gangway system compared to the conventional bump and jump method with a catamaran CTV takes approximately twice as long. The L-type is slightly slower than the bump and jump method, predominantly due to the deployment time of the system. As already noted in Table 5.9, the egress time of the bump and jump and the L-type is longer than the access time, this results in an overall longer crew pick up time relative to a drop off.

5.4.6 SENSITIVITY ANALYSIS

A sensitivity analysis was carried out considering the following changes in the base case:

1. The number of technicians dropped off/picked up is increased to four.
2. The crew transfer is changed to six wind turbines in a row with a drop off/pick up of two technicians at each turbine.
3. The transit distance between wind turbines is increased to 10 kilometres where the distance to the first turbine remains 1 kilometre.
4. Transfer takes place in rough weather conditions, effectively adding an approach time of 30 seconds for a catamaran CTV and increasing the access and egress times for the bump and jump method and the L-type to 45 and 60 seconds respectively.

The results of the sensitivity analysis are presented in the following tables, the difference denotes the time difference between de base case in percentage. Herein Table 5.11 displays the results for a crew drop off and pick up for the bump and jump method and L-type.

Table 5.11: Results sensitivity analysis for the bump and jump (B&J) method and L-type

	Crew drop off (s)				Crew pick up (s)			
No.	B&J	Difference	L-type	Difference	B&J	Difference	L-type	Difference
1	1280	+5%	1763	+5%	1490	+10%	1943	+7%
2	2636	+116%	3546	+112%	2786	+106%	3726	+106%
3	2084	+71%	2621	+57%	2219	+64%	2756	+52%
4	1445	+18%	1808	+8%	1580	+17%	1943	+7%

As can be seen the time differences in crew drop off and crew pick up for the bump and jump method and the L-type remain small regardless of the changes in the base case. Table 5.12 shows the sensitivity results for the gangway systems installed on an SOV.

Table 5.12: Results sensitivity analysis for the A-type and Uptime 23.4m

Crew drop off/pick up (s)				
No.	A-type	Difference	Uptime 23.4m	Difference
1	2664	+2%	2719	+2%
2	5855	+124%	5910	+122%
3	4386	+67%	4427	+66%
4	2619	0%	2660	0%

Sensitivity case 1 shows a clear time increase for the bump and jump method and the L-type, especially during a crew pick up. The A-type and Uptime 23.4m only have a slight increase in comparison as they are designed to quickly transfer a group of people.

Naturally doubling of the amount of wind turbines to visit or the distance between visits increases the crew drop off/pick up time drastically for all access systems. The crew drop off/pick up time of access systems installed on SOVs are affected slightly more with an increase in visits. Lastly, sensitivity case 4 shows that rough weather conditions will negatively affect the time of CTV drop off/pick-ups but not SOV drop off/pick-ups.

6 RISK ASSESSMENT

This chapter entails the risk assessment of three transfer methods; the conventional bump and jump method, an active motion compensated W2W transfer to the TP platform and a passive W2W transfer to the boat landing.

6.1 Risk identification

An identification of all initiating events that can lead to a hazardous situation is the first step within the risk assessment. As one cannot prevent or reduce the effects of something that has not been identified, it is vital that this process is a thorough one. In the offshore industry, all transfers at sea, irrespective of method, have to be treated as a stand-alone operation and require formal risk assessments to be carried out beforehand [36].

Considering the amount of risk assessment conducted, care has to be taken that this task does not become a routine. Simply copying a list of hazards and threats from previous, similar analyses, is not sufficient as special aspects and features of a system, the environment and circumstances such as simultaneous operations (SIMSOPS) might be overlooked [30, p. 39].

A HAZard IDentification (HAZID) was conducted in order to determine hazardous events and their potential consequences related to the access and egress of an offshore wind turbine using the bump and jump and W2W methods. The identified hazardous events and consequences for the different access methods are derived from incident reports [5] [6] [7] [37] [38] [39] [40] [41] [42] good practise guidelines [13] , system specifications and operations [17] and risk assessments [28] [29].

The results from the HAZID for the bump and jump method are listed in Table 6.1.

Table 6.1: HAZID bump and jump transfer

Hazardous event	Consequences
Trip or fall when on the vessel deck/fender	Fall onto the deck or guard rails
Mistimed step from the vessel to the ladder or vice versa	Man Overboard (MOB)
	Crush between vessel and boat landing bumper bars
Slip on ladder during climb or descent	Fall from or against ladder
Unpredictable and violent vessel movement	Suspension of FAS (hang-up)
	Significant impact of vessel with the boat landing or turbine structure
Structural failure of the boat landing bumper bars or ladder	Crush between vessel and boat landing bumper bars
	Fall from ladder

Table 6.2 lists the identified hazardous events and consequences utilising an active motion compensated W2W system to directly access the TP platform.

Table 6.2: HAZID active W2W system to TP platform

Hazardous event	Consequences
Personnel on deck in proximity of moving parts of the gangway while it is active	Personnel on deck is hit by the gangway or crushed between moving parts
Operator error	Collision between gangway and turbine structure
	Uncontrolled movement of gangway during transfer
Poor selection of location where the gangway connects with the TP platform	Increased risk for personnel to hit lower parts of the turbine structure (e.g. jacket legs, boat landings or foundation) upon a fall from height
Emergency retraction of gangway	Fall from height from outer open end of the gangway
	Trip/stumble on moving sections of the gangway
Loss of power or motion control	Uncontrolled movement of gangway during transfer
	Loss of fixation of gangway on the TP platform
Support structural failure of the gangway during transfer	Fall from height
	Fall from transfer deck of the W2W system
Violent vessel movement outside the motion envelope of the W2W system	Loss of fixation of gangway on the TP platform
	Uncontrolled movement of gangway during transfer

Identified hazardous events and consequences for a passive W2W transfer to the boat landing are a combination from the previous HAZIDs. An overview is listed in Table 6.3.

Table 6.3: HAZID passive W2W system to boat landing

Hazardous event	Consequences
Trip or fall when on the vessel deck	Fall onto the deck or guard rails
Personnel on deck in proximity of moving parts of the gangway while it is active	Personnel on deck is hit by the gangway or crushed between moving parts
Operator error	Collision between gangway and turbine structure
Emergency retraction of gangway	Fall into water from outer open end of the gangway
	Trip/stumble on moving sections of the gangway

Unpredictable and violent vessel movement (outside the motion envelope of the W2W system)	Loss of fixation of gangway on the TP platform
	Uncontrolled movement of gangway during transfer
	Suspension of FAS (hang-up)
Support structural failure of the gangway during transfer	Man Overboard (MOB)
Slip on ladder during climb or descent	Fall from or against ladder
Structural failure of the boat landing bumper bars or ladder	Crush between vessel and boat landing bumper bars
	Fall from ladder

6.2 Risk analysis

6.2.1 BOWTIE DIAGRAM

The objective of a risk analysis is to describe risk by presenting an informative risk picture [30, p. 4]. The identified threats and hazards have been visualised in a BowTie diagram for the three transfer methods as shown in Figure 6.1, Figure 6.2 and Figure 6.3. Herein "Loss of control" is denoted as the top event as every identified hazardous event or threat results in a form of loss of control.

The threats are listed on the left side of the BowTie and the consequences listed on the right side of the BowTie. As part of the risk analysis preventive (left side) and mitigating (right side) barriers have been identified and categorised accordingly. A detailed explanation of the barrier types and categories can be found in section 4.4.2.

The ⊕ sign underneath a barrier indicates that the barrier has an escalation factor. Enlarged BowTie cut-outs per threat and consequence line, including escalation factors and escalation factor controls can be found in Appendix A.

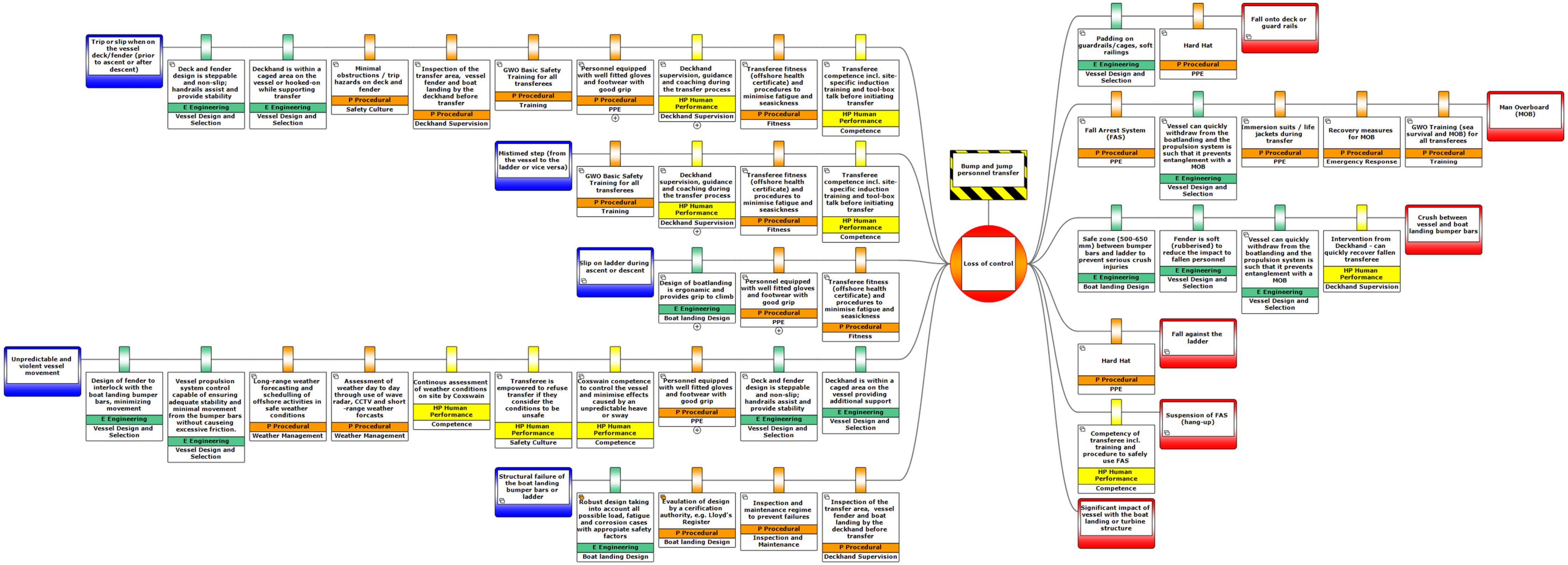

Figure 6.1: BowTie "Loss of control during bump and jump personnel transfer"

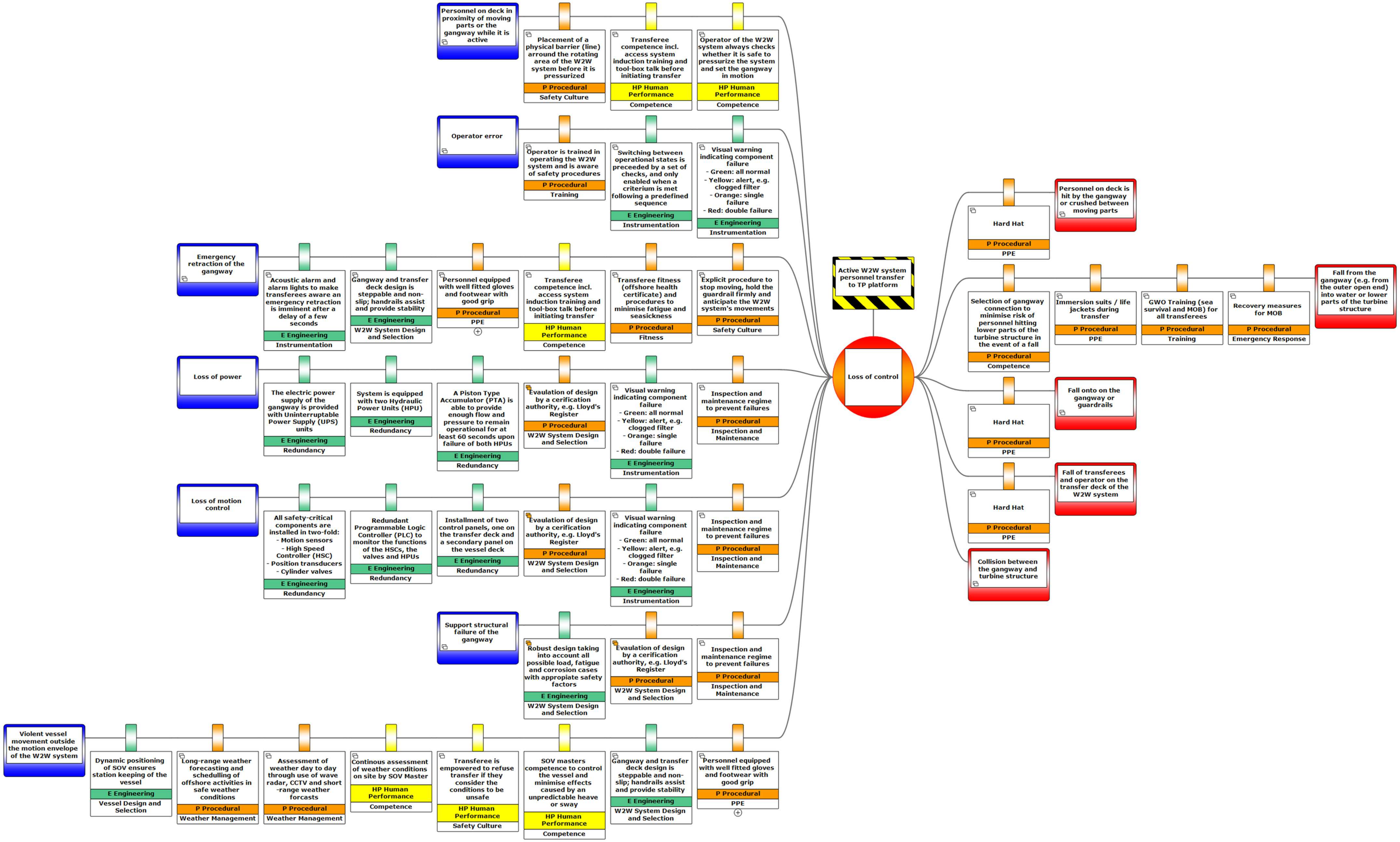

Figure 6.2: BowTie "Loss of control during active W2W system personnel transfer to TP platform"

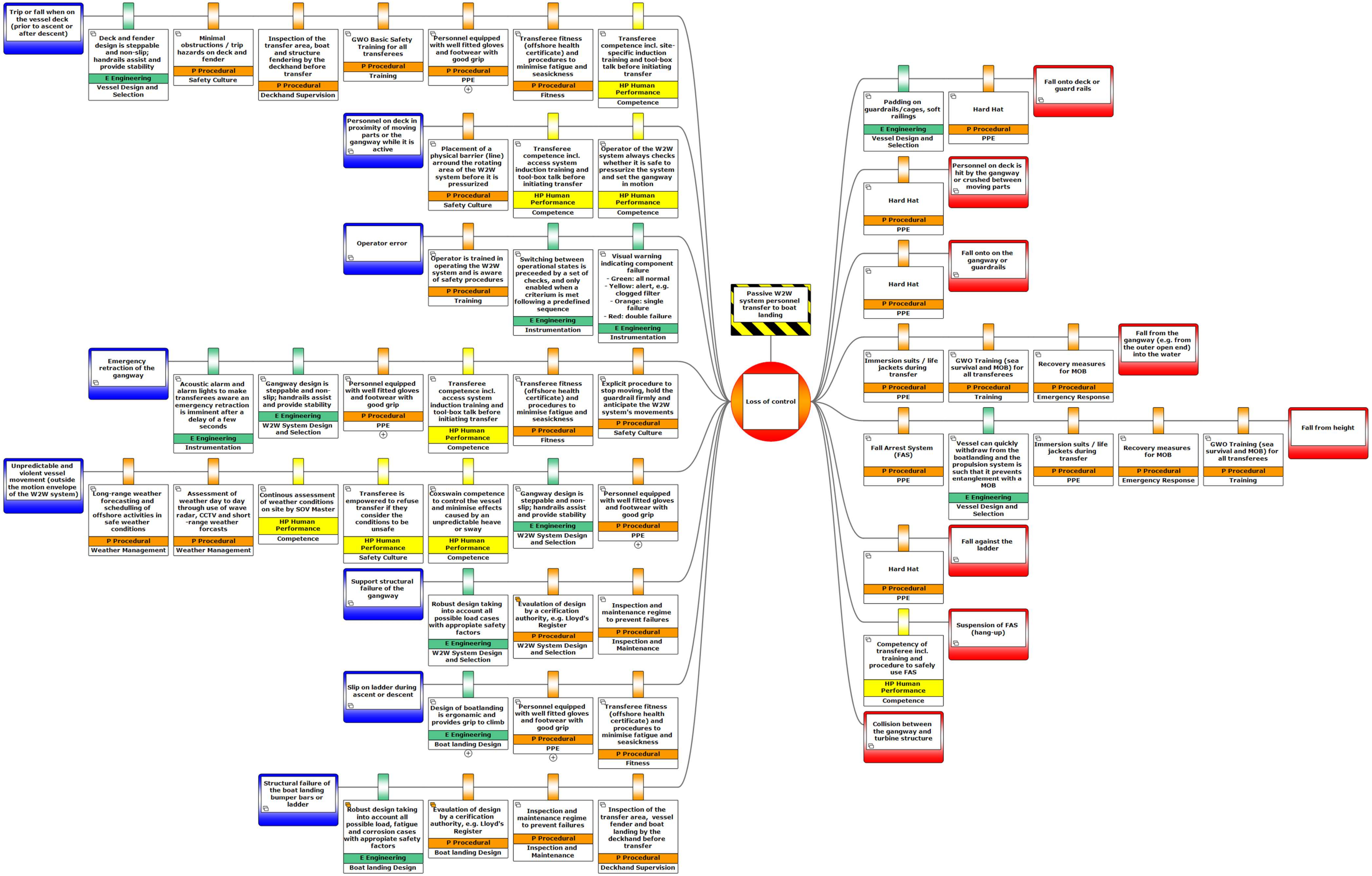

Figure 6.3: BowTie "Loss of control during passive W2W system personnel transfer to boat landing"

6.2.2 EVENT TREE ANALYSIS

After a qualitative visualisation of the risks of different methods of personnel transfer in BowTies, Event Tree Analyses (ETA) have been conducted incorporating the identified threats and consequences from the Bowties. The ETA gives a quantitative assessment of the effectiveness of barriers to reduce risk and ultimately calculates the residual individual risk for the transferee per transfer to an offshore wind turbine.

The ETA methodology is described in section 4.5.

Bump and jump method

Considering differences in ascending and descending during the transfer process, the decision was made to develop two separate ETAs. The complete ETAs, can be found in Appendix B (ascent) and Appendix C (descent).

The ETAs involve a series of event tree steps, these steps are presented with a detailed description and associated probability values in Table 6.4. The probability values have been derived from a risk assessment on sliding access as mentioned in the literature review, section 2.5.2. The results of the risk assessment on sliding access conclude on risk values higher than approximate figures derived from incident which suggests that the probability values used are conservative. Missing probability values regarding the likelihood of where a transferee falls and what they might impact with have been estimated using best knowledge.

Table 6.4: Event Tree Steps bump and jump method

Step	Description
Unpredictable and violent vessel movement	This considers one of the following occurs: • Random and unexpected movement due to weather conditions; • Vessel propulsion system failure; • Fender failure, including a failure to detect damage to the fender. The probability of occurrence is set at 0.0003 assuming an operation in safe weather conditions in accordance with the study on sliding access.
Trip or fall when on the vessel deck/fender prior to ascent or after descent	This concerns the potential for the transferee to trip or fall when on the vessel deck/fender. The assigned probability is set at 0.01 in the case of unpredictable and violent vessel movements. Without unexpected, violent vessel movements the probability is estimated at 0.00001.
Mistimed step from the vessel to the ladder or vice versa	This considers the potential for a transferee to mistime a step during the ascent or descent. Directly derived from the study on sliding access, the probability of a mistimed step during violent vessel movements is set at 0.3. Without violent vessel movements this is set at 0.0001.
Slip on ladder during ascent or decent	This step includes the potential of a transferee slipping on a ladder rung during their ascent or decent. The

Step	Description
	probability of this occurring is set at 0.0004 and identical to the value used for sliding access.
Lose contact with ladder	After a slip occurs, the probability that a transferee loses contact with the ladder, effectively falling, is set at 0.2.
FAS locks on	This considers the event that a FAS will fail upon demand, aligned with the study on sliding access this probability is conservatively set at 0.1. This value can easily be updated utilising failure rate data from manufacturers.
Fall or recover to	A 'recover to' can occur after a mistimed step after which a transferee manages to recover to either the vessel or ladder, a recovery is deemed easier during the ascent than the descent. Their respective probabilities are set at 0.7 and 0.55. A fall considers the likelihood of a transferee falling into the water, the tower or in between the vessel and the boat landing bumpers.
Impact with	This considers the likely landing of transferees in the event of a fall. This can be a: • safe landing; • impact with the deckhand; • impact with the side of the vessel; • impact with the water; • impact with the deck or guardrail.
Successful recovery	The last step considers the success of a recovery in the event of a transferee falling into the water, denoted as Man Overboard (MOB). This probability is set at 0.9999 in accordance with the study on sliding access.

The ETAs for the bump and jump method were conducted under the assumption that all barriers listed in the BowTie are fully implemented and that the transfer operation is conducted in safe weather conditions.

Considering the large number of event outcomes, a total of 46 during the ascent and 71 during the descent, the outcomes have been grouped on severity as described in section 4.5. Summarizing risk values per injury type led to the individual risk values per transfer utilising the bump and jump method as shown in Table 6.5.

Table 6.5: Individual risk values per transfer utilising the bump and jump method base case

Injury type	During ascent	During decent	Combined
Minor	5.86×10^{-05}	8.63×10^{-05}	1.45×10^{-04}
Major	6.85×10^{-06}	7.81×10^{-06}	1.47×10^{-05}
Fatal	4.07×10^{-09}	5.98×10^{-09}	1.00×10^{-08}

Table 6.5 shows an increased risk for all injury types during the descent compared to the ascent. This is solely due to the reduced likelihood of recovering from a misstep during the decent.

The largest contributing event tree outcomes were found to be the following for the different injury types:

- Minor injury; a fall into the water or impact with the vessel or bumper bars after a misstep.
- Major injury; a crush injury between the vessel and bumper bars after a misstep and impact with the deck or side of the CTV after a fall from height due to a slip on the ladder and a failing FAS.
- Fatality; an unsuccessful recovery of a MOB following a misstep.

The highest contributing outcomes remained the same regardless of the ascent or descent. The other scenarios for each injury type were found to be at least an order of magnitude less.

By weighting non-fatal injuries and summarising them the overall risk of fatality per transfer utilising the bump and jump method is determined to be $\mathbf{1.62 \times 10^{-06}}$.

It is to be noted that the major injury risk value, weighted at a fatality equivalent of 0.1, contributes the most to the overall risk of fatality per transfer.

Active W2W system to TP platform

No significant difference was found in the risk a transferee is exposed to when accessing or egressing an offshore wind turbine utilising a W2W system to the TP platform. It was therefore decided to simply double the values determined for the access process to represent the overall risk value per transfer.

The developed ETA can be found in Appendix D.

The ETA involves a series of event tree steps, these steps are presented with a detailed description and associated probability values in Table 6.6. The probability values have been derived from a qualitative risk analysis on an Ampelmann system [29] and system characteristics with respect to redundancy in safety critical elements [17]. More information on these studies can be found in the literature review, section 2.5.3 and 2.5.4

The same probability of a violent vessel movement, this time exceeding the motion envelope of the W2W system, has been used.

Table 6.6: Event Tree Steps active W2W system to TP platform

Step	Description
Violent vessel movement outside the motion envelope of the W2W system	This considers one of the following occurs: • Random and unexpected movement due to weather conditions; • Vessel propulsion system/ dynamic positioning failure; The probability of occurrence is set at 0.0003 assuming an operation in safe weather conditions.

Step	Description
Fall whilst on the transfer deck of the W2W system	This concerns the potential for the transferee to fall when waiting for transfer on the transfer deck of the W2W system. The assigned probability is set at 0.01 in the case of a violent vessel movement outside the motion envelope of the W2W system and is effectively unable to compensate adequately. Without violent vessel movements the probability is estimated at 0.00001 considering the event of a double failure resulting in instability.

Loss of fixation of the gangway on the TP platform	This considers the possibility of the gangway to lose its fixation on the TP platform and considers one of the following occurs:
	• W2W system exceeds its motion envelope
	• Gangway is too short, i.e. operated outside of its maximum allowable reach or failure to keep the SOV within operating range.
	• A double failure:
	    o loss of hydraulic failure
	    o loss of electrical power
	    o loss of valve control
	    o failure of position transducers
	    o failure of measurement system
	    o failure of control computer
	Relative to the presence of violent vessel movement the probability is conservatively set at 0.5 and 0.00001.

Emergency retraction	An emergency retraction will occur in the event of: • the W2W system operating outside its motion envelope; • a double failure; • one minute after a single failure. It is conservatively assumed that an emergency retraction has a probability of failure on demand of 0.001. The same value is used considering a spurious trip where an emergency retraction occurs when undesired. This value can easily be updated utilising failure rate data on components from manufacturers.
Trip or fall whilst on the gangway	This step includes the potential of a transferee tripping or falling whilst on the gangway, this can be due to: • Violent vessel movement outside the motion envelope of the W2W system • A loss of fixation of the gangway • A trip over the sliding step (e.g. during an emergency retraction) A combination of these factors resulted in various probabilities with the worst scenario, a violent vessel movement with a loss of fixation of the gangway and a failure to initiate an emergency retraction, assumed to be 0.5.

Step	Description
Fall to	This step considers the likelihood of a fall to either the gangway, the water or lower parts of the turbine structure.
Impact with	This considers the likely landing of transferees in the event of a fall. This can be a: • safe landing; • impact with the transfer deck or its guardrail; • impact with the water; • impact with the vessel deck; • impact with the gangway or its guardrail; • impact with the tower, i.e. lower parts of the turbine structure.
Successful recovery	The last step considers the success of a recovery in the event of a transferee falling into the water, denoted as Man Overboard (MOB). This probability is set at 0.9999 in accordance with the study on sliding access.

The ETA for a transfer to the TP platform using a W2W system was conducted under the assumption that all barriers listed in the BowTie are fully implemented and that the transfer operation is conducted in safe weather conditions.

The large number of event outcomes, a total of 53, has been grouped in terms of severity as described in section 4.5. Summarizing risk values per injury type led to the individual risk values per transfer utilising an active W2W system to the TP platform as shown in Table 6.7.

Table 6.7: : Individual risk values per transfer utilising an active W2W system to the TP platform base case

Injury type	Per transfer
Minor	3.14×10^{-05}
Major	2.08×10^{-06}
Fatal	1.97×10^{-08}

The largest contributing event tree outcomes were found to be the following for the different injury types:

- Minor injury; due to an impact injury resulting from a fall on the transfer deck or gangway of the W2W system.
- Major injury; a major impact injury resulting from a fall from the transfer deck of the W2W system to the vessel.
- Fatality; a fall from the gangway to lower parts of the turbine structure resulting from a violent vessel movement, loss of fixation on the TP platform and emergency retraction or an undesired emergency retraction during normal conditions.

The other outcomes for each injury type were found to be at least an order of magnitude less.

By weighting non-fatal injuries and summarising them the overall risk of fatality per transfer utilising an active W2W system to the TP platform is determined to be **2.59×10^{-07}**.

It is to be noted that the major injury risk value, weighted at a fatality equivalent of 0.1, contributes the most to the overall risk of fatality per transfer.

Passive W2W system to boat landing

The risks of a passive W2W transfer via the boat landing are a combination of those mentioned in the previous methods. Considering a transferee is no longer able to make a misstep when moving to or from the ladder, no significant difference was found in the risk a transferee is exposed to when accessing or egressing. A doubling of the values determined for the access process was therefore used to represent the overall risk value per transfer.

The developed ETA can be found in Appendix E.

The ETA involves a series of event tree steps, these steps are presented with a detailed description and associated probability values in Table 6.8. As the event tree steps are a combination of steps from the previous transfer methods, identical probabilities have been applied. Herein only the qualitative assumptions regarding the likely 'fall to' and 'impact with' deviate considering the presence of a gangway instead of a CTV at the foot of the boat landing ladder.

Table 6.8: Event Tree Steps passive W2W system to boat landing

Step	Description
Unpredictable and violent vessel movement	This considers one of the following occurs: • Random and unexpected movement due to weather conditions; • Vessel propulsion system failure; The probability of occurrence is set at 0.0003 assuming an operation in safe weather conditions in accordance with the study on sliding access.
Trip or fall when on the vessel deck/fender prior to ascent or after descent	This concerns the potential for the transferee to trip or fall when on the vessel deck/fender. The assigned probability is set at 0.01 in the case of unpredictable and violent vessel movements. Without unexpected, violent vessel movements the probability is estimated at 0.00001.
Loss of fixation of the gangway on the boat landing	This considers the possibility of the gangway to lose its fixation on the TP platform and considers one of the following occurs: • Gangway is too short, i.e. operated outside of its maximum allowable reach or failure to keep the CTV within operating range. • W2W system exceeds its passive motion envelope Relative to the presence of violent vessel movement the probability is conservatively set at 0.5 and 0.00001.

Step	Description
Emergency retraction	An emergency retraction will occur in the event of the W2W system operating outside its passive motion envelope or a loss of fixation of the gangway on the boat landing. It is conservatively assumed that an emergency retraction has a probability of failure on demand of 0.001. The same value is used considering a spurious trip where an emergency retraction occurs when undesired.
Trip or fall whilst on the gangway	This step includes the potential of a transferee tripping or falling whilst on the gangway, this can be due to: • the W2W system operating outside its passive motion compensation envelope; • a loss of fixation of the gangway; • A trip over the sliding step (e.g. during an emergency retraction); A combination of these factors resulted in various probabilities with the worst scenario, a violent vessel movement with a loss of fixation of the gangway and a failure to initiate an emergency retraction, assumed to be 0.5.
Fall to	This step considers the likelihood of a fall to either the gangway, the water or lower parts of the turbine structure.
Impact with	This considers the likely landing of transferees in the event of a fall. This can be a: • safe landing; • impact with the vessel deck or its guardrail; • impact with the water; • impact with the gangway or its guardrail; • impact with the tower, i.e. lower parts of the turbine structure.
Successful recovery	The last step considers the success of a recovery in the event of a transferee falling into the water, denoted as Man Overboard (MOB). This probability is set at 0.9999 in accordance with the study on sliding access.

The ETA for a transfer using a passive W2W system to access the boat landing was conducted under the assumption that all barriers listed in the BowTie are fully implemented and that the transfer operation is conducted in safe weather conditions.

The large number of event outcomes, a total of 88, has been grouped in terms of severity as described in section 4.5. Summarizing risk values per injury type led to the individual risk values per transfer utilising a passive W2W system to access the boat landing as shown in Table 6.9.

Table 6.9: Individual risk values per transfer utilising a passive W2W system to access the boat landing base case

Injury type	Per transfer
Minor	3.57×10^{-05}
Major	1.31×10^{-05}
Fatal	1.14×10^{-09}

The largest contributing event tree oucomes were found to be the following for the different injury types:

- Minor injury; due to a fall on the gangway or due to a fall into the water with successful MOB recovery after an emergency retraction.
- Major injury; resulting from a fall from height onto the gangway or its side after a slip on the ladder and a failure of the FAS.
- Fatality; a fall into water with an unsuccessful recovery after an undesired emergency retraction during normal conditions or after a fall from height to the side of the gangway due to a slip on the ladder and a failure of the FAS.

The other outcomes for each injury type were found to have risk values of at least an order of magnitude less.

By weighting non-fatal injuries and summarising them the overall risk of fatality per transfer utilising a passive W2W system to access the boat landing is determined to be $\mathbf{1.35 \times 10^{-06}}$.

It is to be noted that the major injury risk value, weighted at a fatality equivalent of 0.1, contributes the most to the overall risk of fatality per transfer.

6.3 Risk evaluation

The Individual Risk Per Annum (IRPA) of the transfer process, conservatively assuming a technician will conduct 250 transfers per year, was determined for each of the transfer methods and is shown in Table 6.10.

Table 6.10: IRPA transfer methods base case

Transfer method	IRPA base case	Risk reduction compared to the bump and jump method
Bump and jump	4.05×10^{-04}	-
Active W2W TP platform	6.48×10^{-05}	84.02%
Passive W2W to boat landing	3.37×10^{-04}	16.89%

All transfer methods fall into the ALARP region of the risk criteria as described in section 4.6. Compared to the conventional bump and jump method utilising an active W2W system to directly access the TP platform reduces the IRPA by 84,02%. Choosing a passive W2W system to access the boat landing reduces the IRPA by 16.89%.

The results are similar to those of the risk assessment on sliding access and can, combined with several conservative input values, be interpreted as conservative.

6.3.1 SENSITIVITY ANALYSIS

A sensitivity analysis was carried out considering an increased likelihood of unpredictable and violent vessel movements, e.g. due to transfer in unsafe weather conditions. The probability of an unpredictable and violent vessel movement was increased a tenfold and set at 0.003 for all transfer methods. The effects of this adjustment on the IRPA per transfer method can be seen in

Table 6.11: Sensitivity increased likelihood of unpredictable and violent vessel movements

Transfer method	Increased likelihood of unpredictable and violent vessel movement to 0.003	Risk difference with base case
Bump and jump	1.07×10^{-03}	+164.20%
Active W2W to TP platform	2.38×10^{-04}	+267.21%
Passive W2W to boat landing	3.60×10^{-04}	+6.86%

The most apparent is that the IRPA using a passive W2W system to access the boat landing is affected significantly less by an increased likelihood of unpredictable and violent vessel movements. This is because the risk of failing from height when climbing the boat landing ladder contributes the most to the IRPA and is not affected by vessel movements in the ETA.

In comparison, a significant part of the IRPA of the bump and jump method consists of the risk of making a misstep which is highly influenced by vessel movements.

Considering an active motion compensated system directly transferring to technicians the TP platform, almost all potential risks are related to an inability to compensate. This accounts for the significant increase in IRPA considering an increased likelihood of violent vessel movements outside the motion envelope of the W2W system.

Considering a more reliable FAS the probability of failure on demand is reduced by a tenfold to 0.01 in Table 6.12.

Table 6.12: Sensitivity increased reliability of FAS

Transfer method	Reduction of FAS probability of failure on demand to 0.01	Risk difference with base case
Bump and jump	1.81×10^{-04}	-55.31%
Passive W2W to boat landing	4.15×10^{-05}	-87.68%

Table 6.12 shows that the IRPA of both methods reduces significantly upon utilising a more reliable FAS which effectively reduces the risk of one of the highest contributing risk factors, a fall from height.

Considering an improved reliability of the emergency retraction the probability of failure on demand/spurious trip is reduced by a tenfold to 0.0001 in Table 6.13.

Table 6.13: Sensitivity increased reliability of emergency retraction

Transfer method	Reduction of probability of failure on demand/spurious trip emergency retraction to 0.0001	Risk difference with base case
Active W2W to TP platform	6.20×10^{-05}	-4.29%
Passive W2W to boat landing	3.35×10^{-04}	-0.67%

Table 6.13 shows a minimal risk reduction for both W2W systems by improving the reliability of an emergency retraction.

A further analysis was carried out to determine the effects of failings in competence and safety culture on the IRPA. To reflect this effect on human performance the probability of a transferee mistiming a step from the vessel to the ladder and vice versa was doubled for the bump and jump method.

For the W2W systems this is reflected by a doubled probability of losing fixation of the gangway with the boat landing/TP platform. This can be due to an operator error, i.e. gangway operated outside of its maximum allowable reach, or failure of the SOV master/coxswain to keep the vessel stationary also resulting in an exceedance of the maximum allowable reach of the gangway. Table 6.14 gives an overview of the IRPA determined for each of the transfer methods.

Table 6.14: Sensitivity failings in competence and safety culture

Transfer method	Increased likelihood (x2) of a mistimed step	Increased likelihood (x2) of a loss of fixation	Risk difference
Bump and jump	5.60×10^{-04}	-	+38.27%
Active W2W to TP platform	-	7.02×10^{-05}	+8.44%
Passive W2W to boat landing	-	3.39×10^{-04}	+0.54%

The final sensitivity analysis reflects poor fitness of a transferee, e.g. due to seasickness, wherein the likelihood of slipping on a ladder and tripping or falling is doubled. The results of this alteration are shown in Table 6.15.

Table 6.15: Sensitivity poor fitness of transferee

Transfer method	Poor fitness of transferee (likelihood of slipping, tripping and falling x2)	Risk difference
Bump and jump	6.55×10^{-04}	+61.62%
Active W2W to TP platform	1.29×10^{-04}	+99.79%
Passive W2W to boat landing	6.73×10^{-04}	+99.98%

7 DISCUSSION

This chapter presents and critically discusses the used literature, findings and limitations of the project and includes suggestions for further research on the topic.

As already highlighted shortly in section 5.3, the accessibility of access systems is determined using monthly weather data. Because of this limitation the results only portray a rough estimation of the accessibility of access systems for the respective offshore wind farms.

The comparison in terms of efficiency is based on a number of estimations in with respect to the approach, access and egress times of access systems. In actuality these times vary per transfer due to factors as weather conditions and human performance. In order to obtain a more accurate representation of the effectivity of access systems further research is required, e.g. by timing a predefined number of transfers. Nevertheless, the calculations give a general impression of time required to transfer personnel in various case studies and the sensitivities associated with these.

The ETA conducted for the different transfer methods is, due to a lack of access to failure rate data, based on several conservative estimations. An example of conservatism is the probability of failure on demand assigned to a FAS. Reducing this probability by an order of magnitude resulted in a significantly lower IPRA for the bump and jump method and the passive W2W system accessing the boat landing, as listed in Table 6.12. Actual failure rates of FAS and safety critical components of W2W systems are likely to be lower.

Motion compensated gangways are complex systems and vary greatly in design and operation. As a relatively novel transfer method, especially within the offshore wind industry, it is difficult to obtain information regarding their functioning, capabilities and risks. This is especially the case for smaller, passive W2W systems used to enhanced boat landing access. Even though risk assessments are required to be carried out for access systems and transfers at sea, these are almost never made publicly available.

As there is minimal knowledge sharing between operators and researchers, the inputs for risk assessments in the offshore wind industry are often limited to each operator's own knowledge. This leads to a gap in information, where each operator must experience rare events before these can be analysed and incorporated in a safety management framework.

Because of this reason the ETAs made to quantitively assess the risk of W2W systems is largely based on design and operation of the Ampelmann system. Significant alterations in event tree steps and probabilities might have to be applied in order for it to accurately represent other W2W systems. It does however form a basis for analysis wherein the presented risks, identified barriers and human performance factors remain largely the same.

The project thus presents the basis for a quantitative model that can be used to test the sensitivity of individual parameters and the effect of any proposed risk reduction measure for different transfer methods.

7.1 Future work

During the process of writing this project numerous ideas for future work came to mind. As already mentioned, it can be challenging to find relevant work on this topic and there are several areas that have not been touched upon in this thesis.

One of the factors that has been not been included in the comparison of transfer methods is an analysis on the costs. These can be cost related to the purchase, mobilisation and maintenance of access systems which would have to be obtained from the manufacturer. Next to these, access systems can require additional training of personnel or induce extra costs by the failure of an access system on demand, e.g. resulting in an increased downtime of turbines. This information can prove invaluable to operators in deciding which access system is most suited for their daily operations.

Two risks were identified in the HAZID and BowTie diagrams which were not incorporated in the ETA. These are the risks of a FAS 'hang-up' and a ship collision. A 'hang-up' incident can occur when a transferee is attached to the FAS and the vessel they are standing on makes a sudden downward motion. A sudden heave can take place due to a loss of friction between the fender and the boat landing, after which a buoyancy thrust-up is followed by a wave trough resulting in a significant drop that can cause a FAS to lock-on.

Ship collisions with the turbine structure can also occur during transfer operations. Herein studies have shown a positive correlation between the size of maintenance ships and risks of their collisions. Notably vessels equipped with an Ampelmann system contribute to 43% of the collision risk [43].

An inclusion of these risks would improve the quantitative models and offer a complete analysis of all identified hazards on the individual risk per transfer.

8 CONCLUSION

Access and egress to offshore wind installations account for an approximate 12% of all incidents reported in the industry in 2018. As the industry continues to grow, the number of incidents is likely to increase, heightening the demand for safe and efficient transfer methods. In this project a comparison was made between the conventional bump and jump method and utilisation of active and passive W2W systems to access the TP platform and boat landing. The different transfer methods were compared in terms of accessibility, efficiency and risk to the transferee.

The bump and jump method was found to have the lowest accessibility with a safe transfer limit of 1,5 metres H_s. The conventional method is generally only suited to be used in summer months unless the fetch length of an offshore wind farm is limited by a nearby coast. Equipping small cruising vessels with an enhancement, such as a passive motion compensated gangway, enabling safe transfers up to 2 metres H_s, significantly increases accessibility and facilitates access throughout the year for near shore wind farms. SOVs equipped with active motion compensated gangways can provide almost continuous access to all offshore wind farms with a safe transfer limit of 3 metres H_s and above.

In terms of effectivity the bump and jump method was determined to be approximately twice as fast as active W2W systems, considering crew transfers to three wind turbines in a row. This difference is predominantly due to the contrast in transit speed and manoeuvrability between the vessels used. Passive W2W systems accessing the boat landing were determined to be slightly slower than the conventional method, due to the additional time spent deploying and retracting the gangway.

A HAZID determined the different transfer methods to mainly have the same consequences, e.g. falling and drowning hazards. Identified threats such as violent vessel movements are applicable to all, whereas other threats are inherent to the operation and design of the method used.

An Event Tree Analysis (ETA) was conducted to quantitatively assess the risk a transferee is exposed to, for each of the transfer methods. For the bump and jump method the most significant consequence outcomes were found to be a crush injury between the vessel and bumper bars following a misstep, and a fall from height after a slip on the ladder. Utilising an active W2W transfer, this was determined to be a major impact injury resulting from a fall from the transfer deck of the W2W system to the vessel deck. The highest contributing outcome for a passive W2W transfer was found to be a fall from height onto the gangway or its side after a slip on the ladder.

Calculating the Individual Risk Per Annum (IRPA) of the transfer methods, conservatively assuming a transferee undergoes 250 transfers per year, determined the bump and jump method to have the highest risk at an IRPA of 4.05×10^{-04}. In comparison an active W2W system offers a risk reduction of 84.02% at an IRPA of 6.48×10^{-05}, whereas a passive W2W system can provide a risk reduction of 16.89% with an IRPA of 3.37×10^{-04}. The calculated IRPA values are deemed to be conservative but provide a good understanding of the sensitivities of individual parameters and the effect of proposed risk reduction measures for the different transfer methods.

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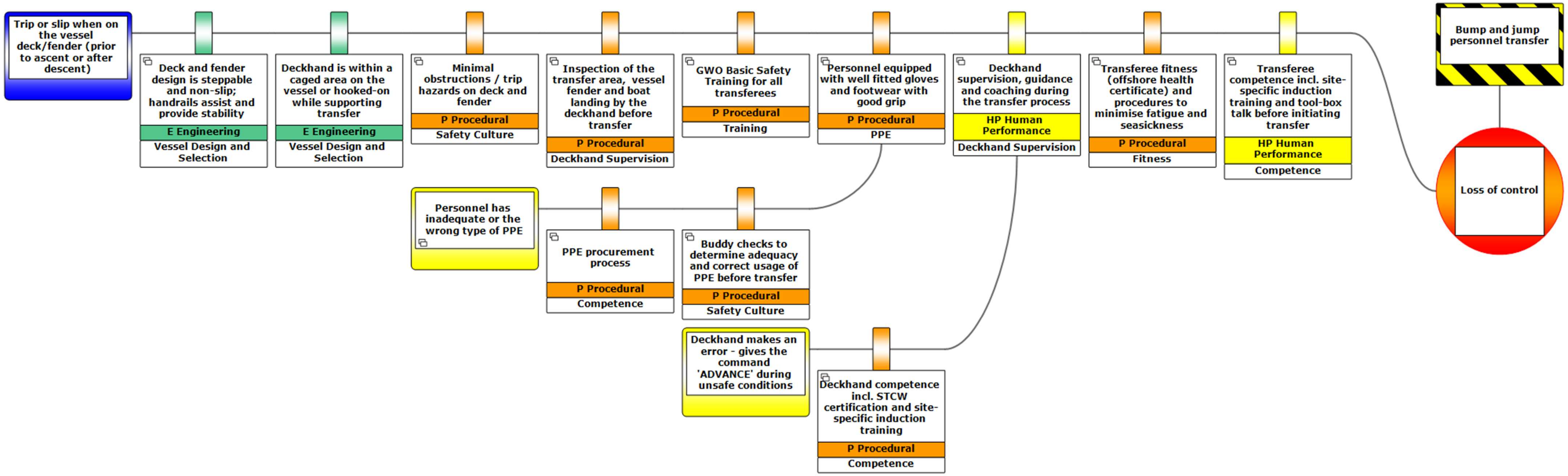
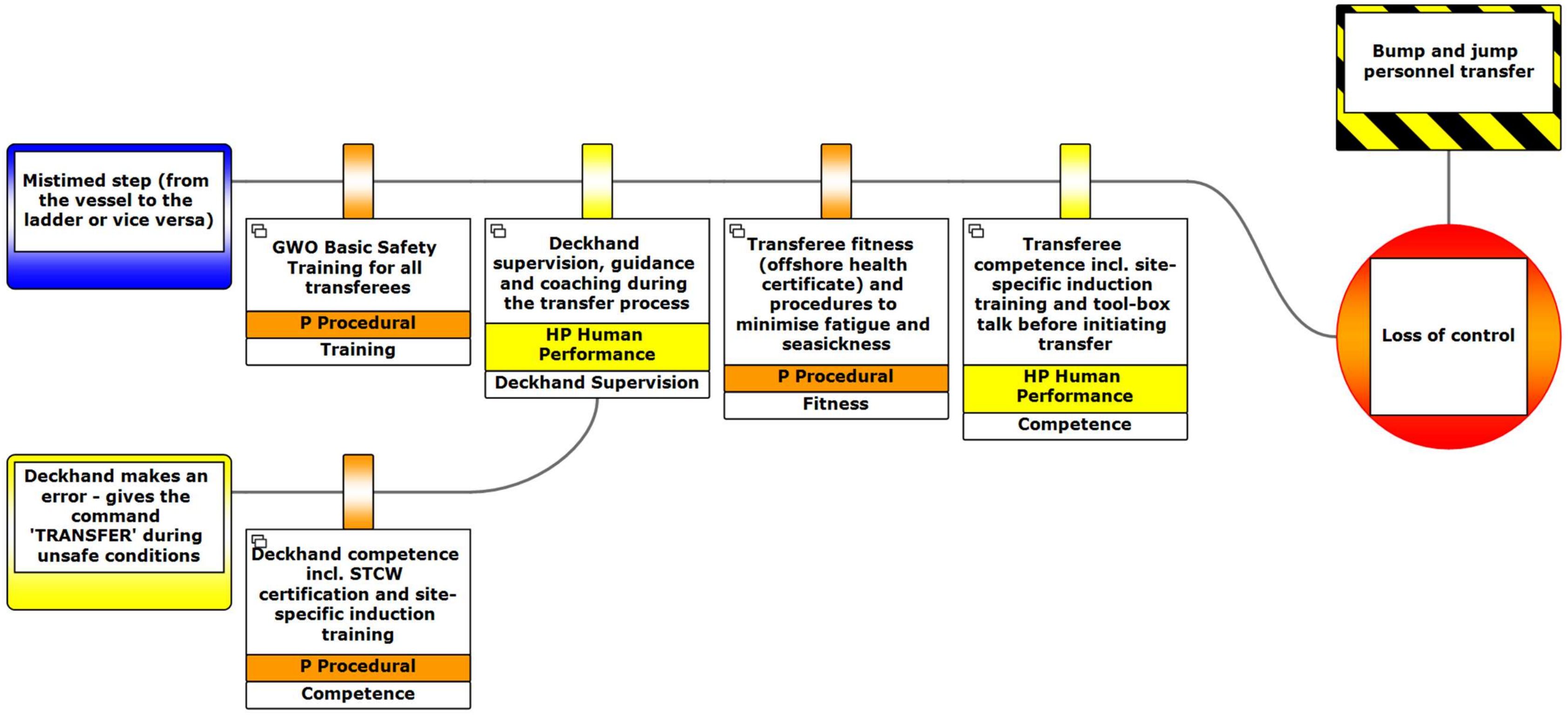
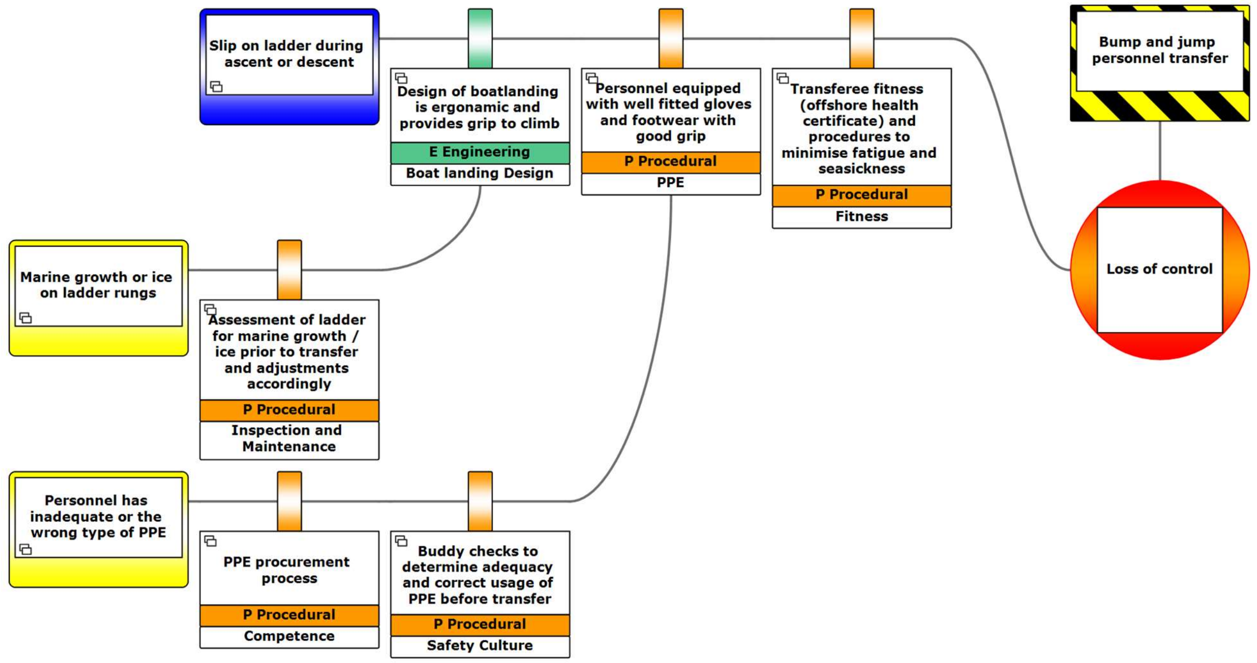
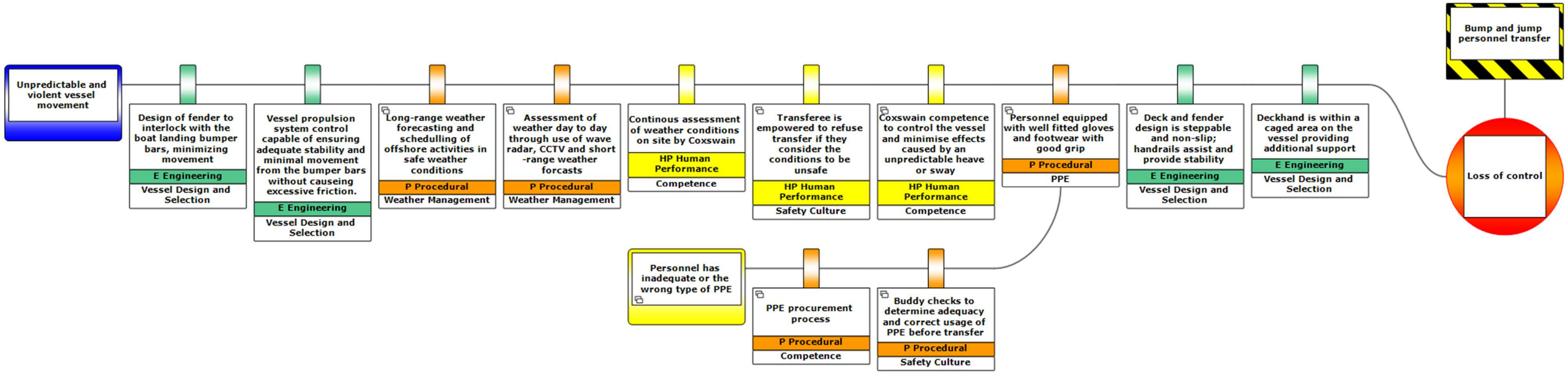
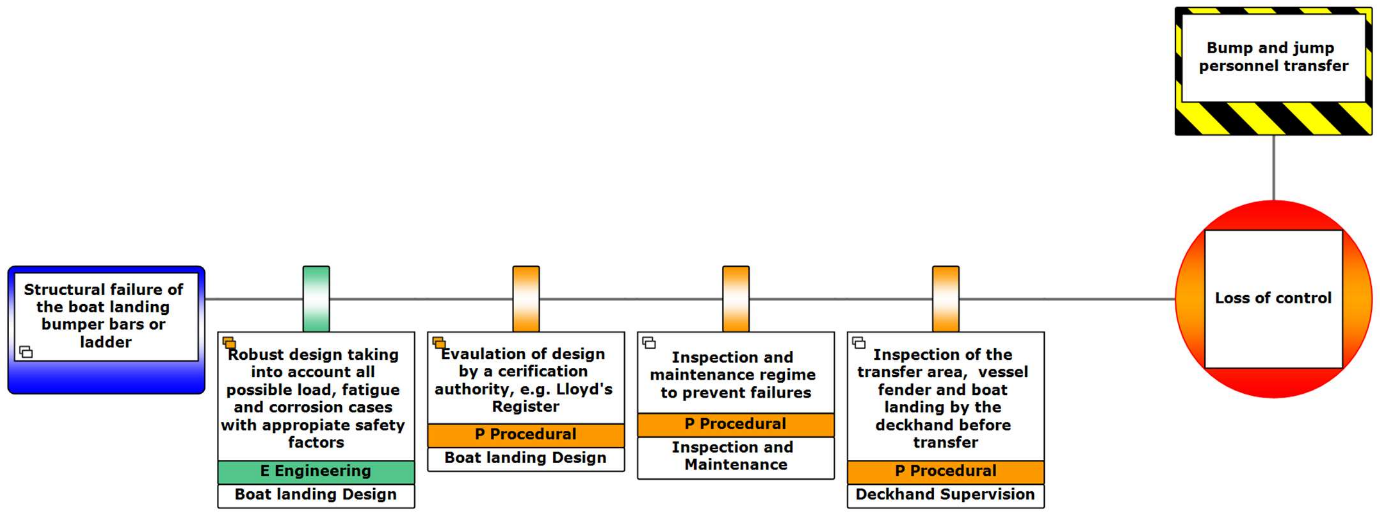
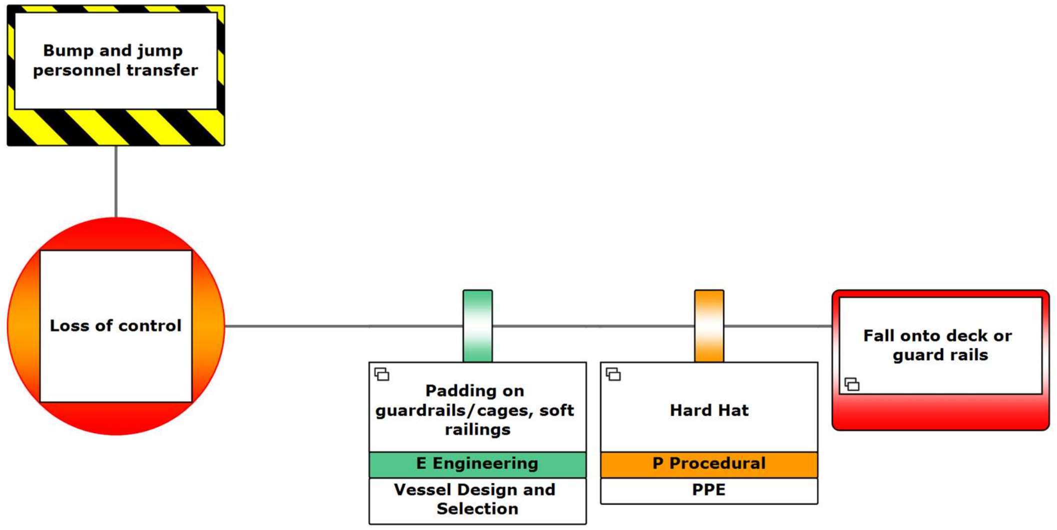

Trip or slip when on the vessel deck/fender (prior to ascent or after descent)
Deck and fender design is steppable and non-slip; handrails assist and provide stability
E Engineering
Vessel Design and Selection
Deckhand is within a caged area on the vessel or hooked-on while supporting transfer
E Engineering
Vessel Design and Selection
Minimal obstructions / trip hazards on deck and fender
P Procedural
Safety Culture
Inspection of the transfer area, vessel fender and boat landing by the deckhand before transfer
P Procedural
Deckhand Supervision
GWO Basic Safety Training for all transferees
P Procedural
Training
Personnel equipped with well fitted gloves and footwear with good grip
P Procedural
PPE
Deckhand supervision, guidance and coaching during the transfer process
HP Human Performance
Deckhand Supervision
Transferee fitness (offshore health certificate) and procedures to minimise fatigue and seasickness
P Procedural
Fitness
Transferee competence incl. site-specific induction training and tool-box talk before initiating transfer
HP Human Performance
Competence
Bump and jump personnel transfer
Loss of control
Personnel has inadequate or the wrong type of PPE
PPE procurement process
P Procedural
Competence
Buddy checks to determine adequacy and correct usage of PPE before transfer
P Procedural
Safety Culture
Deckhand makes an error - gives the command 'ADVANCE' during unsafe conditions
Deckhand competence incl. STCW certification and site-specific induction training
P Procedural
Competence

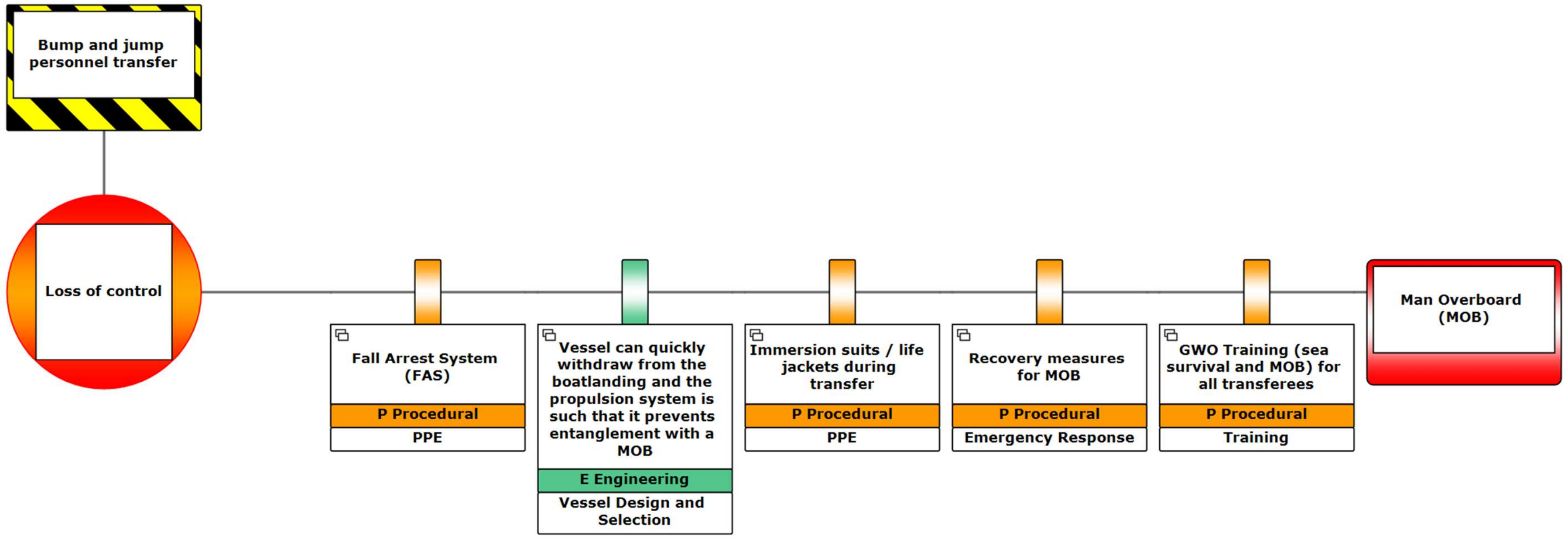

Bump and jump personnel transfer
Mistimed step (from the vessel to the ladder or vice versa)
GWO Basic Safety Training for all transferees
P Procedural
Training
Deckhand supervision, guidance and coaching during the transfer process
HP Human Performance
Deckhand Supervision
Transferee fitness (offshore health certificate) and procedures to minimise fatigue and seasickness
P Procedural
Fitness
Transferee competence incl. site-specific induction training and tool-box talk before initiating transfer
HP Human Performance
Competence
Loss of control
Deckhand makes an error - gives the command 'TRANSFER' during unsafe conditions
Deckhand competence incl. STCW certification and site-specific induction training
P Procedural
Competence

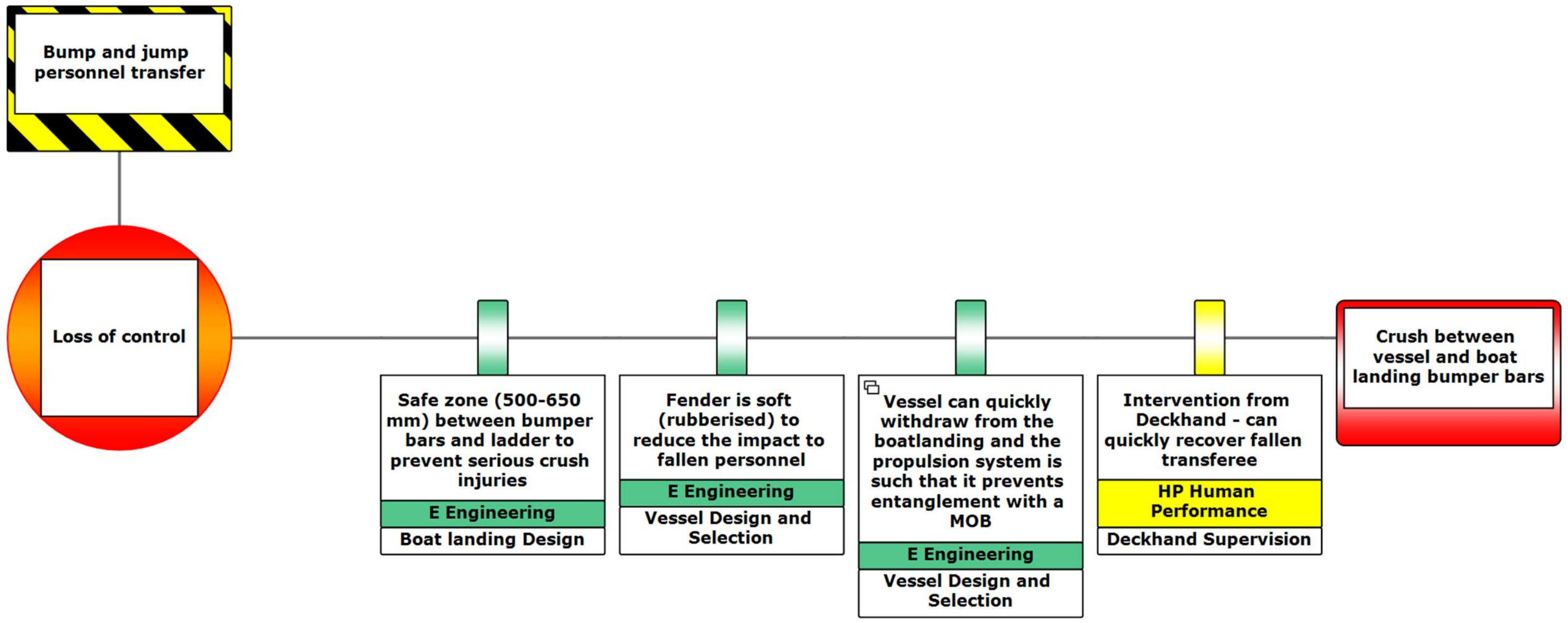

Slip on ladder during ascent or descent
Design of boatlanding is ergonamic and provides grip to climb
E Engineering
Boat landing Design
Personnel equipped with well fitted gloves and footwear with good grip
P Procedural
PPE
Transferee fitness (offshore health certificate) and procedures to minimise fatigue and seasickness
P Procedural
Fitness
Bump and jump personnel transfer
Loss of control
Marine growth or ice on ladder rungs
Assessment of ladder for marine growth / ice prior to transfer and adjustments accordingly
P Procedural
Inspection and Maintenance
Personnel has inadequate or the wrong type of PPE
PPE procurement process
P Procedural
Competence
Buddy checks to determine adequacy and correct usage of PPE before transfer
P Procedural
Safety Culture

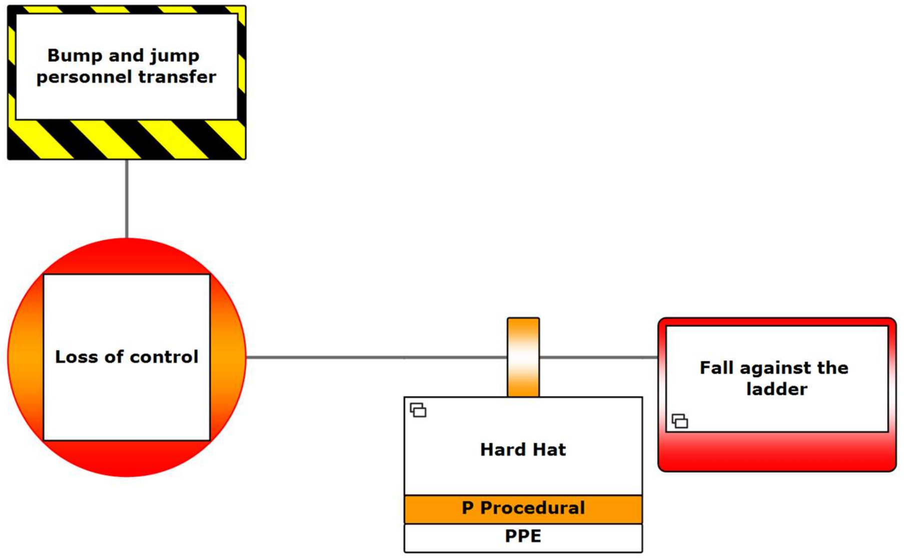

Unpredictable and violent vessel movement
Design of fender to interlock with the boat landing bumper bars, minimizing movement
E Engineering
Vessel Design and Selection
Vessel propulsion system control capable of ensuring adequate stability and minimal movement from the bumper bars without causeing excessive friction.
E Engineering
Vessel Design and Selection
Long-range weather forecasting and schedulling of offshore activities in safe weather conditions
P Procedural
Weather Management
Assessment of weather day to day through use of wave radar, CCTV and short -range weather forcasts
P Procedural
Weather Management
Continous assessment of weather conditions on site by Coxswain
HP Human Performance
Competence
Transferee is empowered to refuse transfer if they consider the conditions to be unsafe
HP Human Performance
Safety Culture
Coxswain competence to control the vessel and minimise effects caused by an unpredictable heave or sway
HP Human Performance
Competence
Personnel equipped with well fitted gloves and footwear with good grip
P Procedural
PPE
Deck and fender design is steppable and non-slip; handrails assist and provide stability
E Engineering
Vessel Design and Selection
Deckhand is within a caged area on the vessel providing additional support
E Engineering
Vessel Design and Selection
Bump and jump personnel transfer
Loss of control
Personnel has inadequate or the wrong type of PPE
PPE procurement process
P Procedural
Competence
Buddy checks to determine adequacy and correct usage of PPE before transfer
P Procedural
Safety Culture

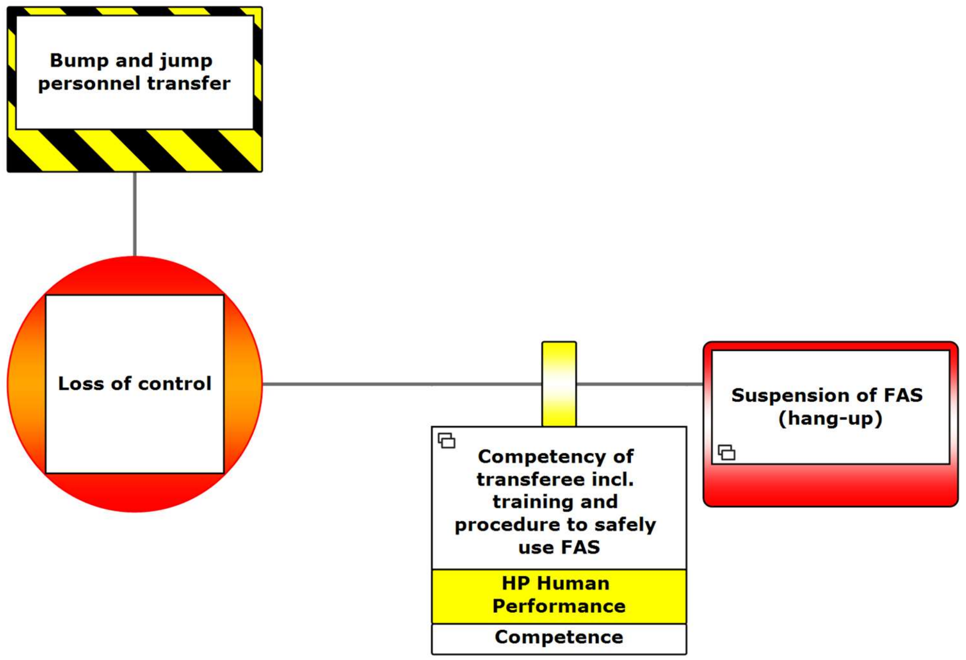

Structural failure of the boat landing bumper bars or ladder
Robust design taking into account all possible load, fatigue and corrosion cases with appropiate safety factors
E Engineering
Boat landing Design
Evaulation of design by a cerification authority, e.g. Lloyd's Register
P Procedural
Boat landing Design
Inspection and maintenance regime to prevent failures
P Procedural
Inspection and Maintenance
Inspection of the transfer area, vessel fender and boat landing by the deckhand before transfer
P Procedural
Deckhand Supervision
Bump and jump personnel transfer
Loss of control

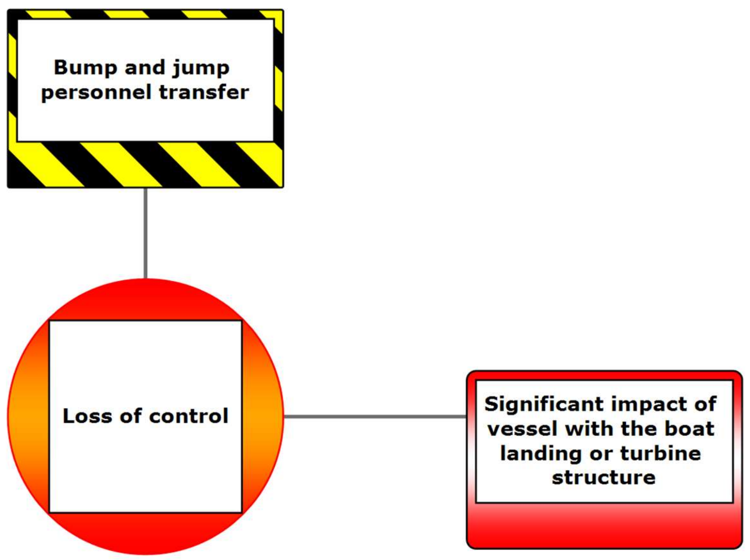

Bump and jump personnel transfer
Loss of control
Padding on guardrails/cages, soft railings
E Engineering
Vessel Design and Selection
Hard Hat
P Procedural
PPE
Fall onto deck or guard rails

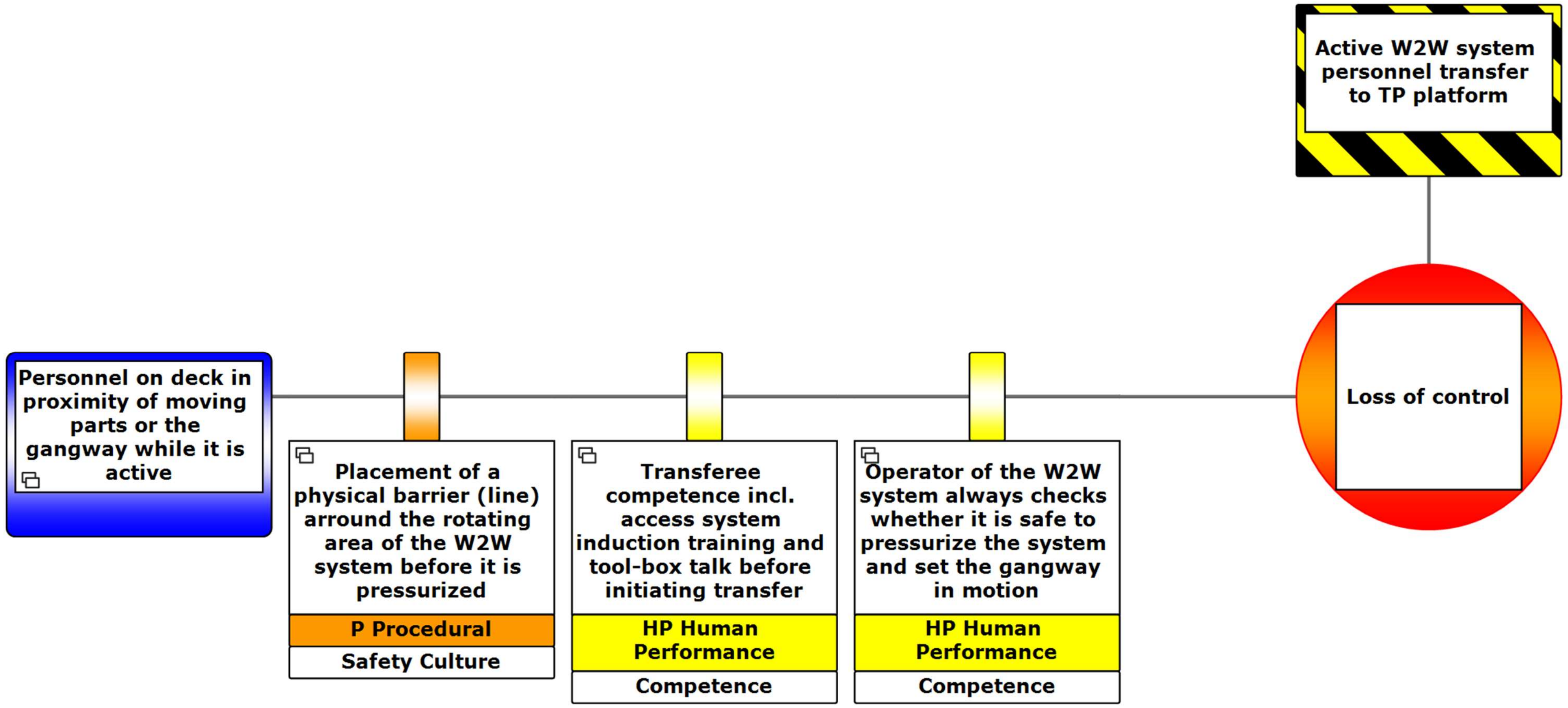

Bump and jump personnel transfer
Loss of control
Fall Arrest System (FAS)
P Procedural
PPE
Vessel can quickly withdraw from the boatlanding and the propulsion system is such that it prevents entanglement with a MOB
E Engineering
Vessel Design and Selection
Immersion suits / life jackets during transfer
P Procedural
PPE
Recovery measures for MOB
P Procedural
Emergency Response
GWO Training (sea survival and MOB) for all transferees
P Procedural
Training
Man Overboard (MOB)

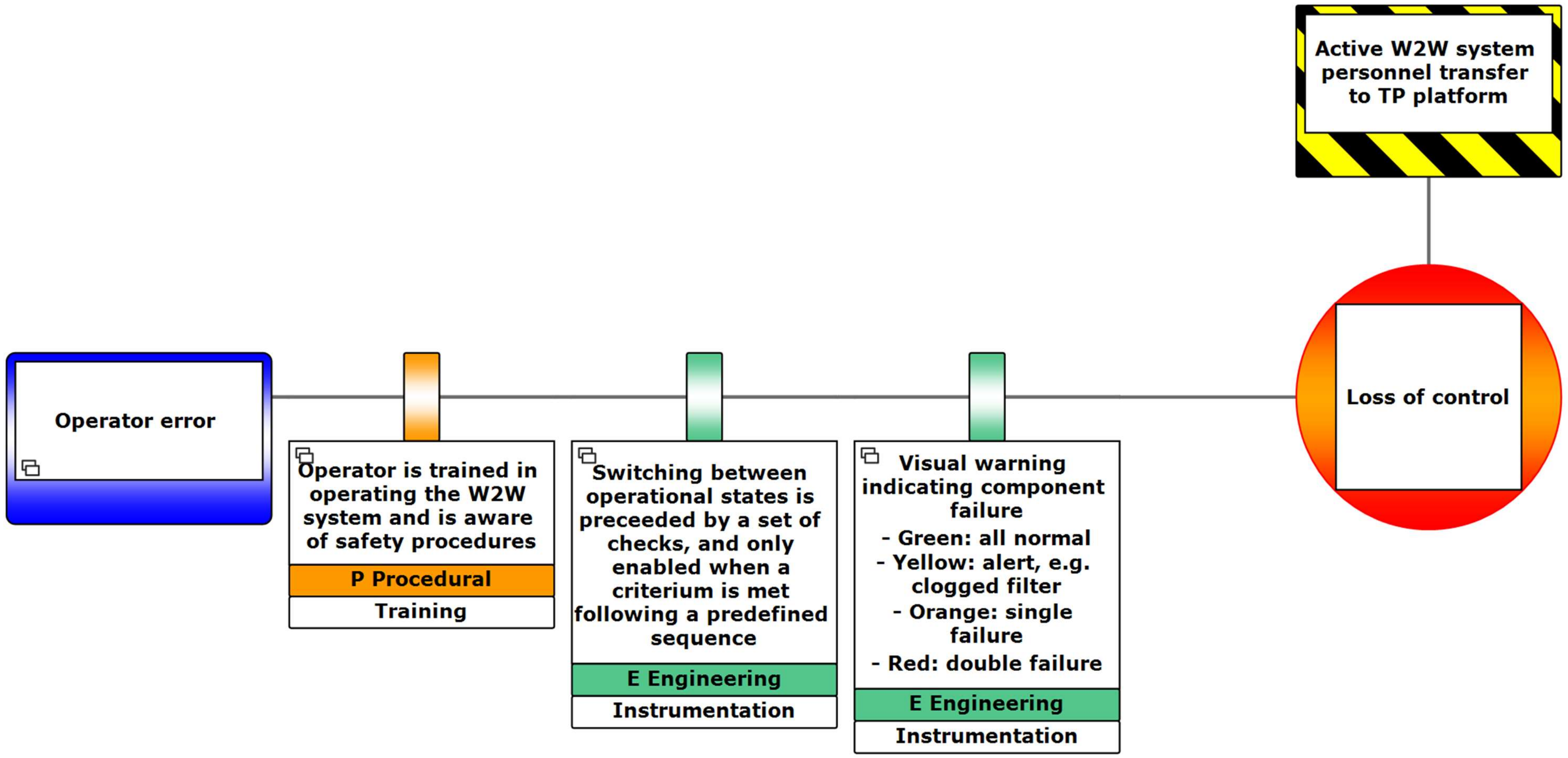

Bump and jump personnel transfer
Loss of control
Safe zone (500-650 mm) between bumper bars and ladder to prevent serious crush injuries
E Engineering
Boat landing Design
Fender is soft (rubberised) to reduce the impact to fallen personnel
E Engineering
Vessel Design and Selection
Vessel can quickly withdraw from the boatlanding and the propulsion system is such that it prevents entanglement with a MOB
E Engineering
Vessel Design and Selection
Intervention from Deckhand - can quickly recover fallen transferee
HP Human Performance
Deckhand Supervision
Crush between vessel and boat landing bumper bars

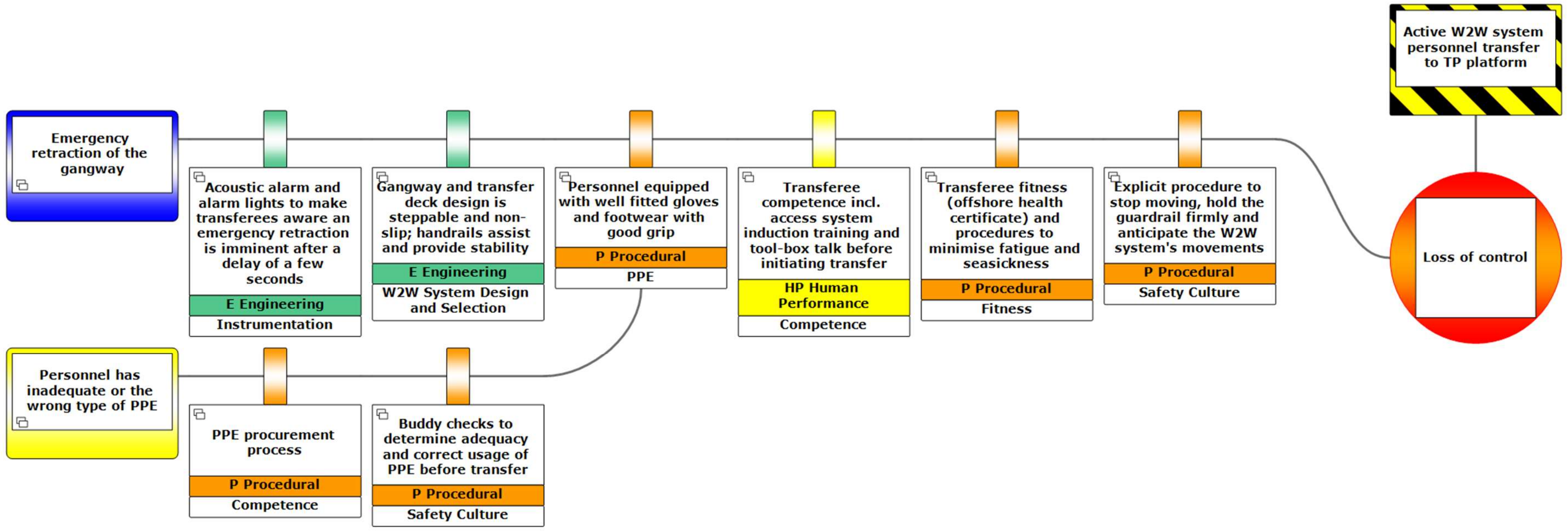

Bump and jump personnel transfer
Loss of control
Hard Hat
P Procedural
PPE
Fall against the ladder

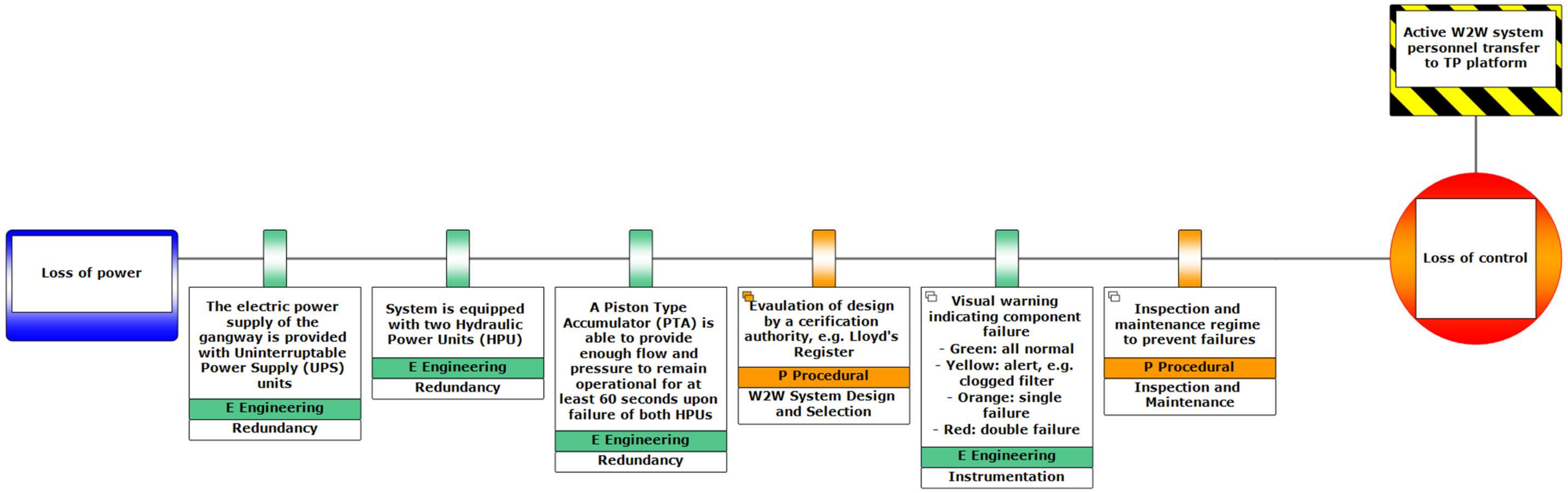

Bump and jump personnel transfer
Loss of control
Competency of transferee incl. training and procedure to safely use FAS
HP Human Performance
Competence
Suspension of FAS (hang-up)

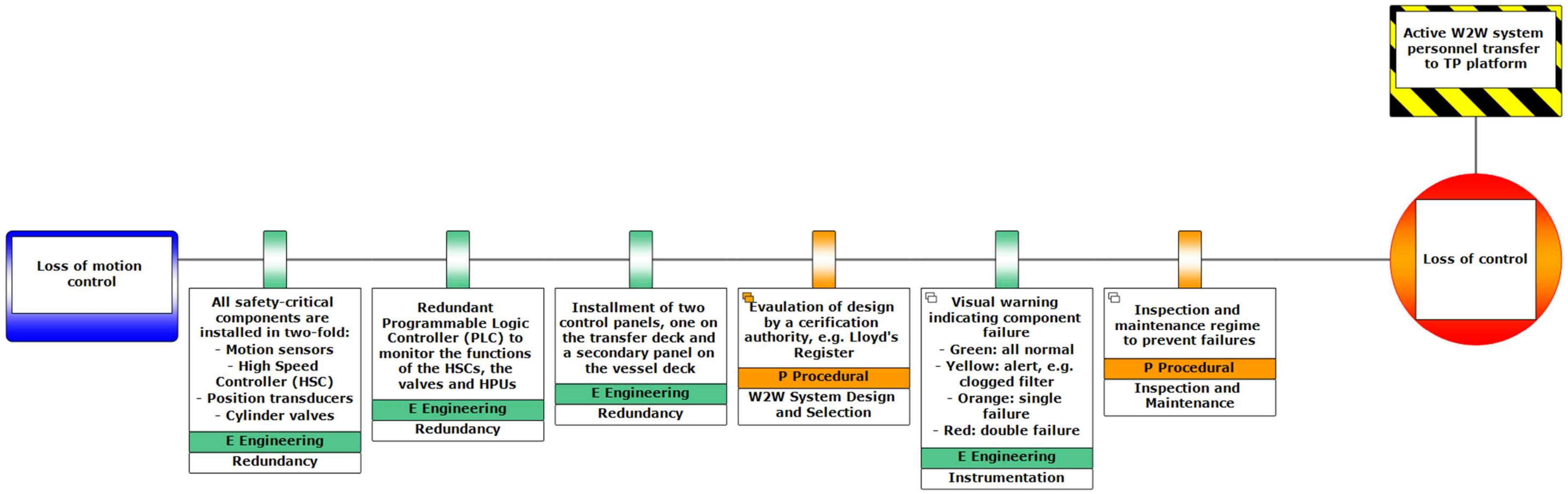

Bump and jump personnel transfer
Loss of control
Significant impact of vessel with the boat landing or turbine structure

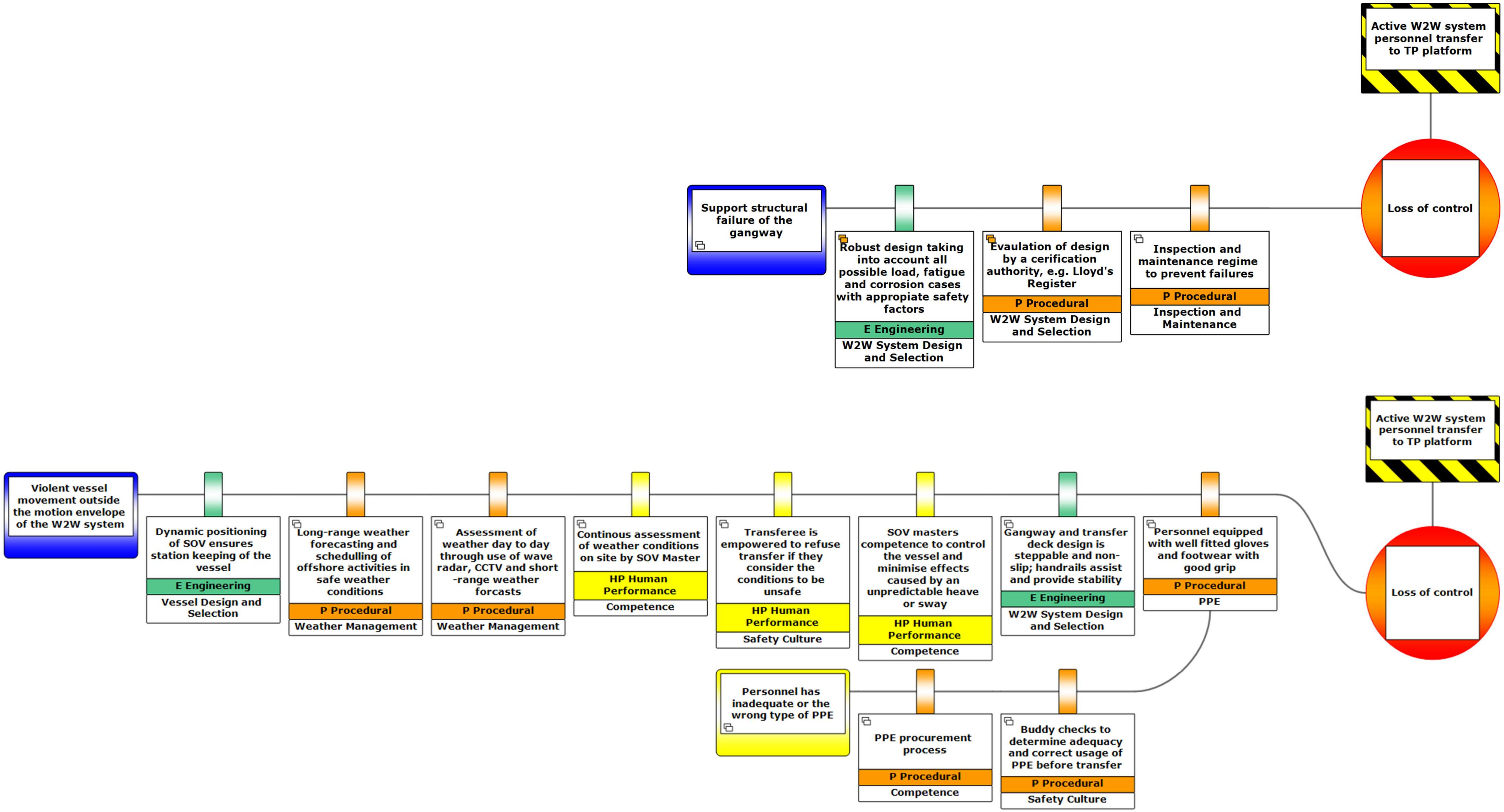

Active W2W system personnel transfer to TP platform
Loss of control
Personnel on deck in proximity of moving parts or the gangway while it is active
Placement of a physical barrier (line) arround the rotating area of the W2W system before it is pressurized
P Procedural
Safety Culture
Transferee competence incl. access system induction training and tool-box talk before initiating transfer
HP Human Performance
Competence
Operator of the W2W system always checks whether it is safe to pressurize the system and set the gangway in motion
HP Human Performance
Competence


Active W2W system personnel transfer to TP platform
Loss of control
Operator error
Operator is trained in operating the W2W system and is aware of safety procedures
P Procedural
Training
Switching between operational states is preceeded by a set of checks, and only enabled when a criterium is met following a predefined sequence
E Engineering
Instrumentation
Visual warning indicating component failure
- Green: all normal
- Yellow: alert, e.g. clogged filter
- Orange: single failure
- Red: double failure
E Engineering
Instrumentation

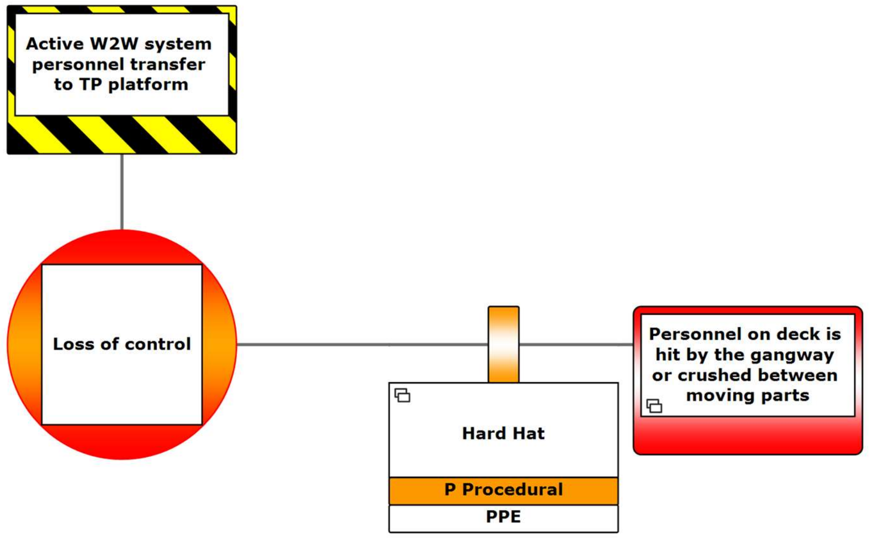

Emergency retraction of the gangway
Acoustic alarm and alarm lights to make transferees aware an emergency retraction is imminent after a delay of a few seconds
E Engineering
Instrumentation
Gangway and transfer deck design is steppable and non-slip; handrails assist and provide stability
E Engineering
W2W System Design and Selection
Personnel equipped with well fitted gloves and footwear with good grip
P Procedural
PPE
Transferee competence incl. access system induction training and tool-box talk before initiating transfer
HP Human Performance
Competence
Transferee fitness (offshore health certificate) and procedures to minimise fatigue and seasickness
P Procedural
Fitness
Explicit procedure to stop moving, hold the guardrail firmly and anticipate the W2W system's movements
P Procedural
Safety Culture
Active W2W system personnel transfer to TP platform
Loss of control
Personnel has inadequate or the wrong type of PPE
PPE procurement process
P Procedural
Competence
Buddy checks to determine adequacy and correct usage of PPE before transfer
P Procedural
Safety Culture

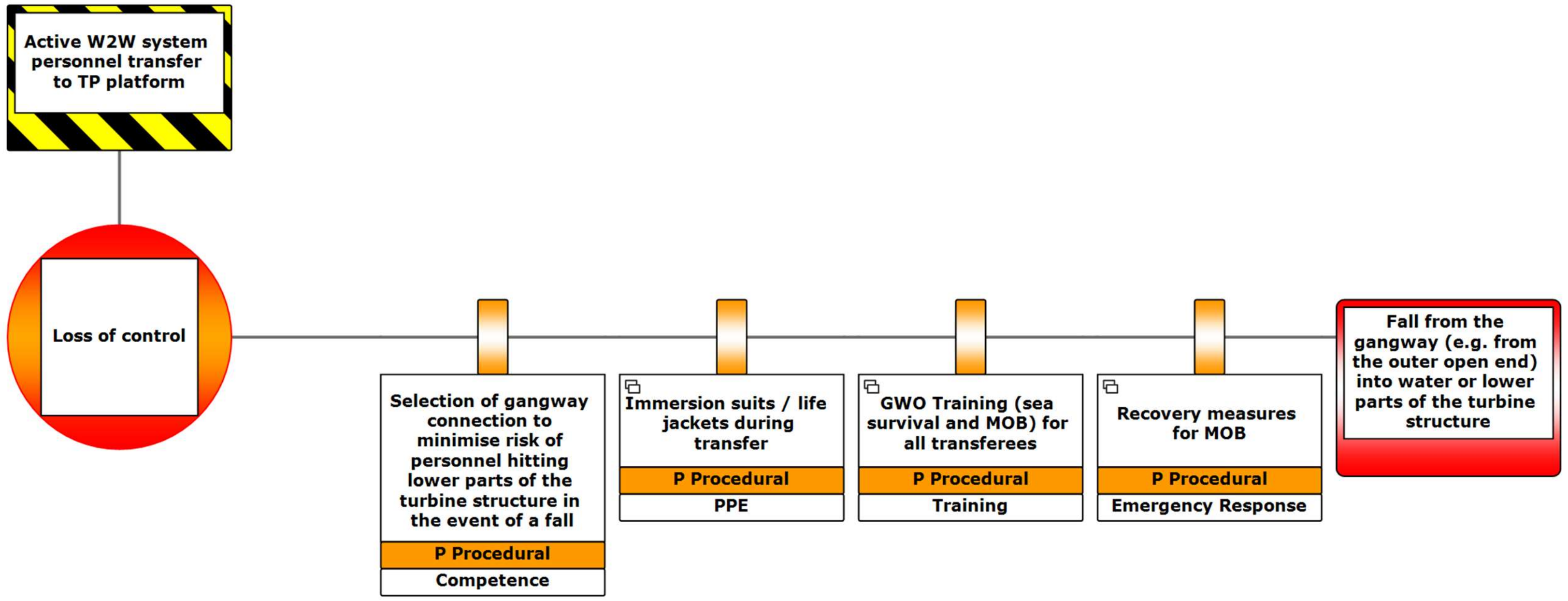

Loss of power
The electric power supply of the gangway is provided with Uninterruptable Power Supply (UPS) units
E Engineering
Redundancy
System is equipped with two Hydraulic Power Units (HPU)
E Engineering
Redundancy
A Piston Type Accumulator (PTA) is able to provide enough flow and pressure to remain operational for at least 60 seconds upon failure of both HPUs
E Engineering
Redundancy
Evaluation of design by a cerification authority, e.g. Lloyd's Register
P Procedural
W2W System Design and Selection
Visual warning indicating component failure
- Green: all normal
- Yellow: alert, e.g. clogged filter
- Orange: single failure
- Red: double failure
E Engineering
Instrumentation
Inspection and maintenance regime to prevent failures
P Procedural
Inspection and Maintenance
Active W2W system personnel transfer to TP platform
Loss of control

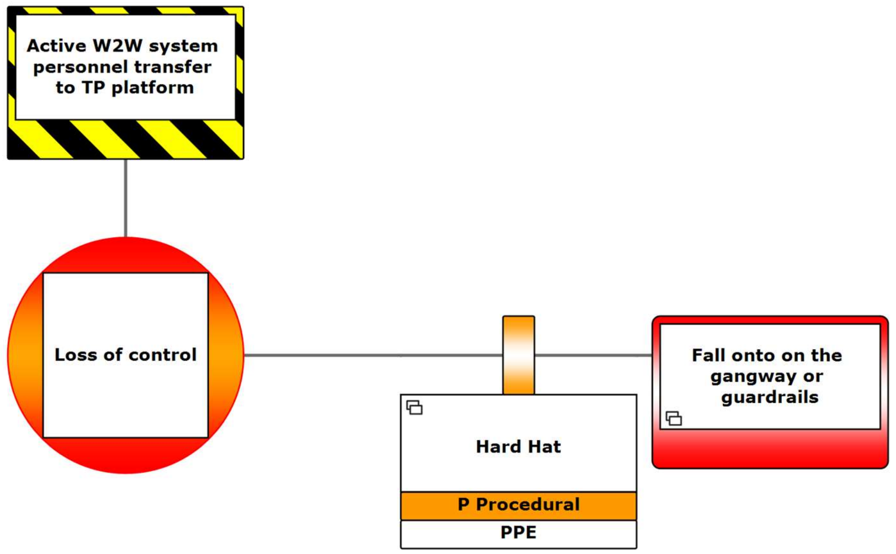

Loss of motion control
All safety-critical components are installed in two-fold:
- Motion sensors
- High Speed Controller (HSC)
- Position transducers
- Cylinder valves
E Engineering
Redundancy
Redundant Programmable Logic Controller (PLC) to monitor the functions of the HSCs, the valves and HPUs
E Engineering
Redundancy
Installment of two control panels, one on the transfer deck and a secondary panel on the vessel deck
E Engineering
Redundancy
Evaluation of design by a cerification authority, e.g. Lloyd's Register
P Procedural
W2W System Design and Selection
Visual warning indicating component failure
- Green: all normal
- Yellow: alert, e.g. clogged filter
- Orange: single failure
- Red: double failure
E Engineering
Instrumentation
Inspection and maintenance regime to prevent failures
P Procedural
Inspection and Maintenance
Active W2W system personnel transfer to TP platform
Loss of control

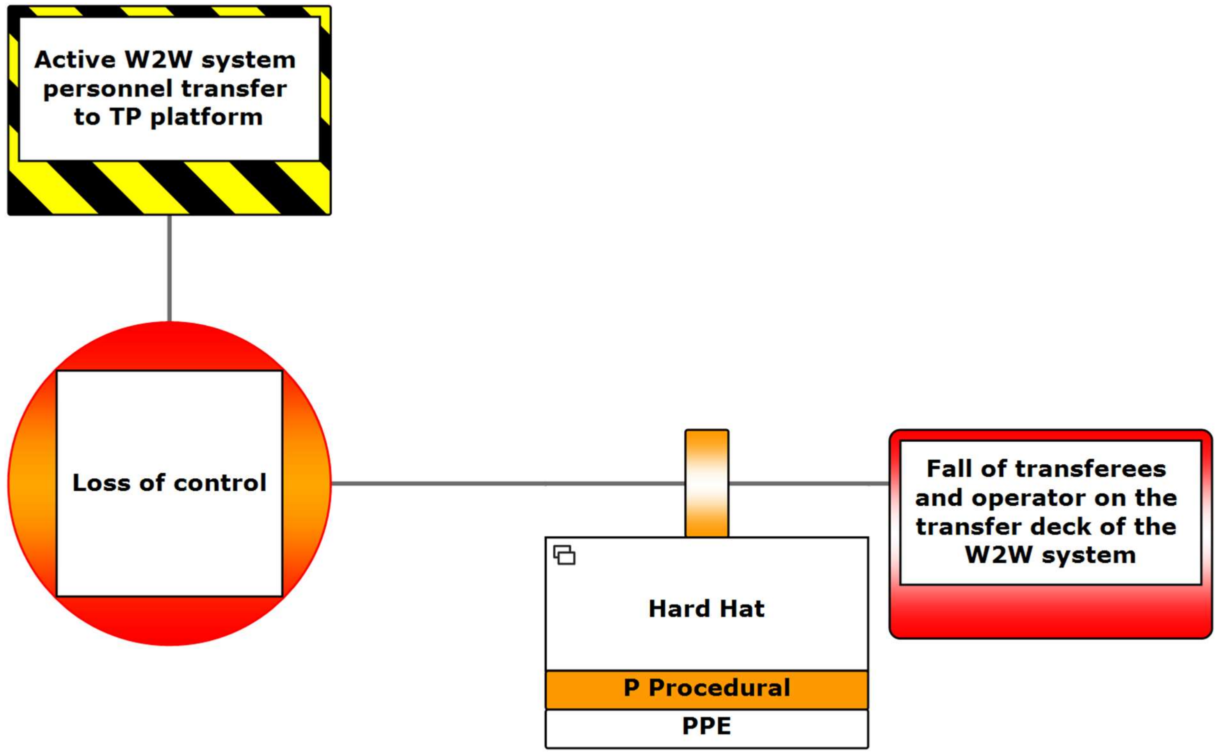


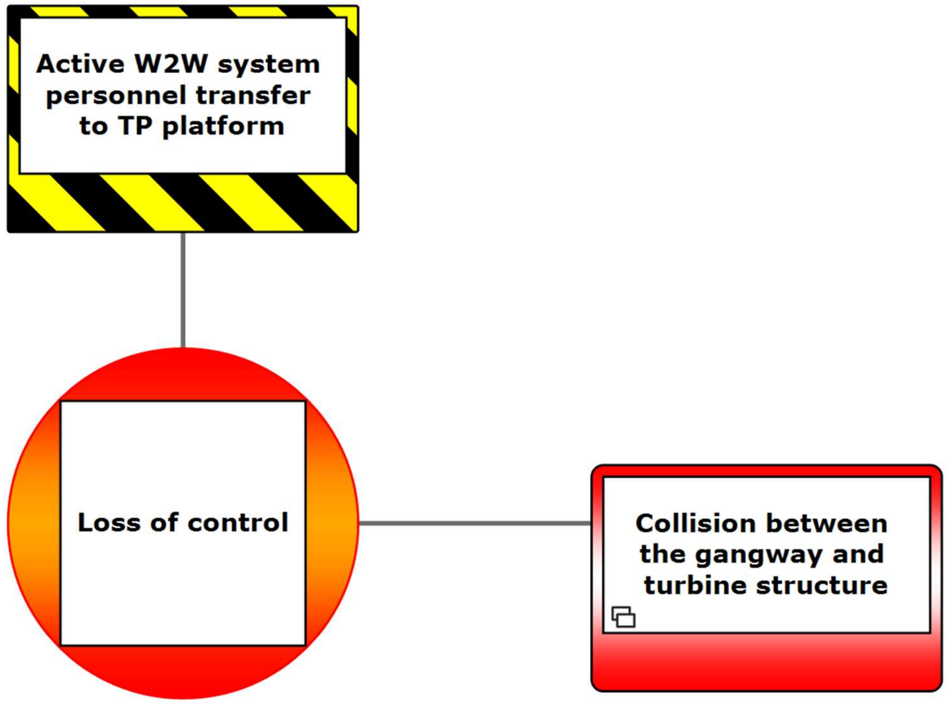
Active W2W system personnel transfer to TP platform
Loss of control
Support structural failure of the gangway
Robust design taking into account all possible load, fatigue and corrosion cases with appropiate safety factors
E Engineering
W2W System Design and Selection
Evaulation of design by a cerification authority, e.g. Lloyd's Register
P Procedural
W2W System Design and Selection
Inspection and maintenance regime to prevent failures
P Procedural
Inspection and Maintenance
Active W2W system personnel transfer to TP platform
Loss of control
Violent vessel movement outside the motion envelope of the W2W system
Dynamic positioning of SOV ensures station keeping of the vessel
E Engineering
Vessel Design and Selection
Long-range weather forecasting and schedulling of offshore activities in safe weather conditions
P Procedural
Weather Management
Assessment of weather day to day through use of wave radar, CCTV and short -range weather forcasts
P Procedural
Weather Management
Continous assessment of weather conditions on site by SOV Master
HP Human Performance
Competence
Transferee is empowered to refuse transfer if they consider the conditions to be unsafe
HP Human Performance
Safety Culture
SOV masters competence to control the vessel and minimise effects caused by an unpredictable heave or sway
HP Human Performance
Competence
Gangway and transfer deck design is steppable and non-slip; handrails assist and provide stability
E Engineering
W2W System Design and Selection
Personnel equipped with well fitted gloves and footwear with good grip
P Procedural
PPE
Personnel has inadequate or the wrong type of PPE
PPE procurement process
P Procedural
Competence
Buddy checks to determine adequacy and correct usage of PPE before transfer
P Procedural
Safety Culture

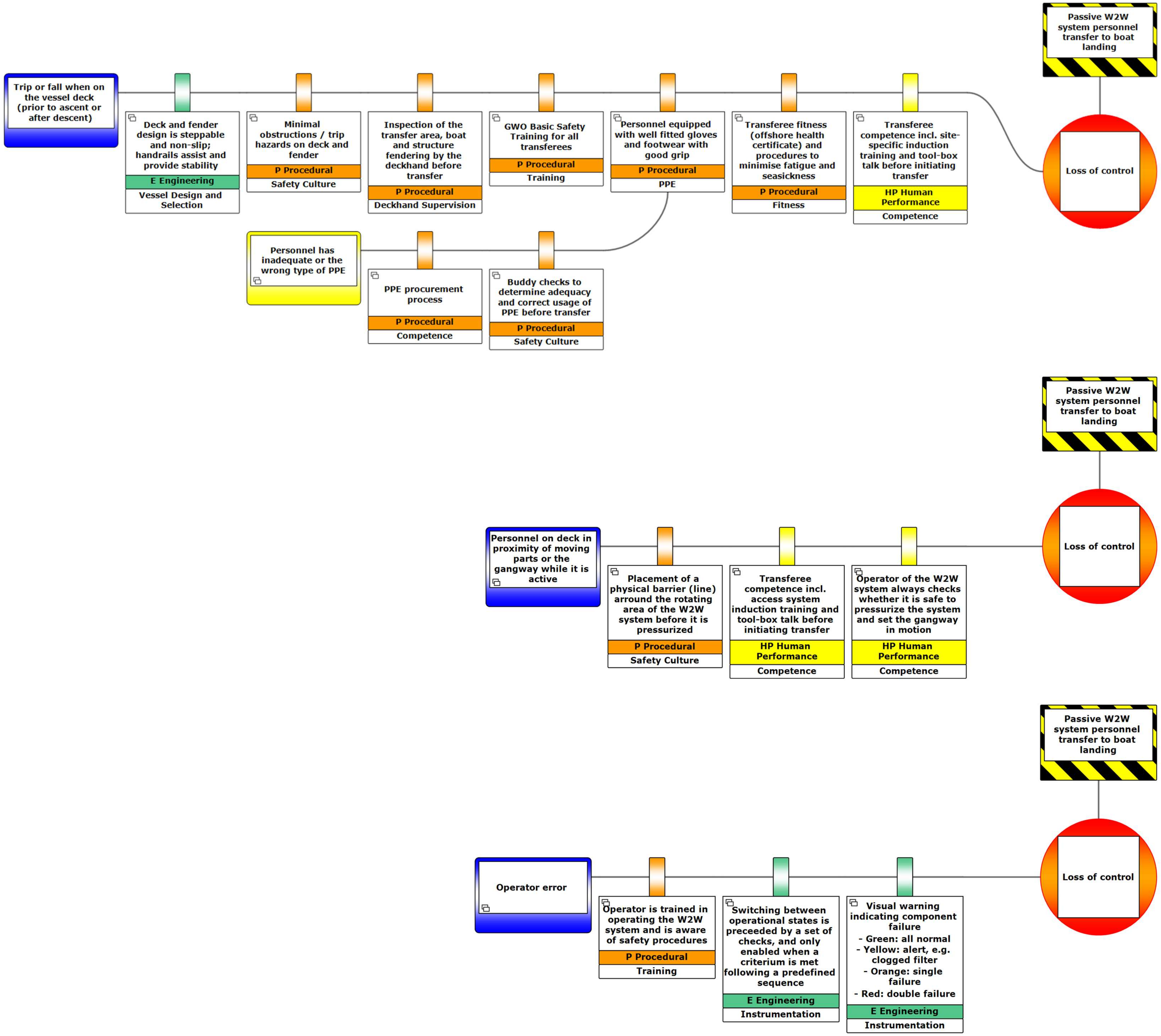

Active W2W system personnel transfer to TP platform
Loss of control
Hard Hat
P Procedural
PPE
Personnel on deck is hit by the gangway or crushed between moving parts

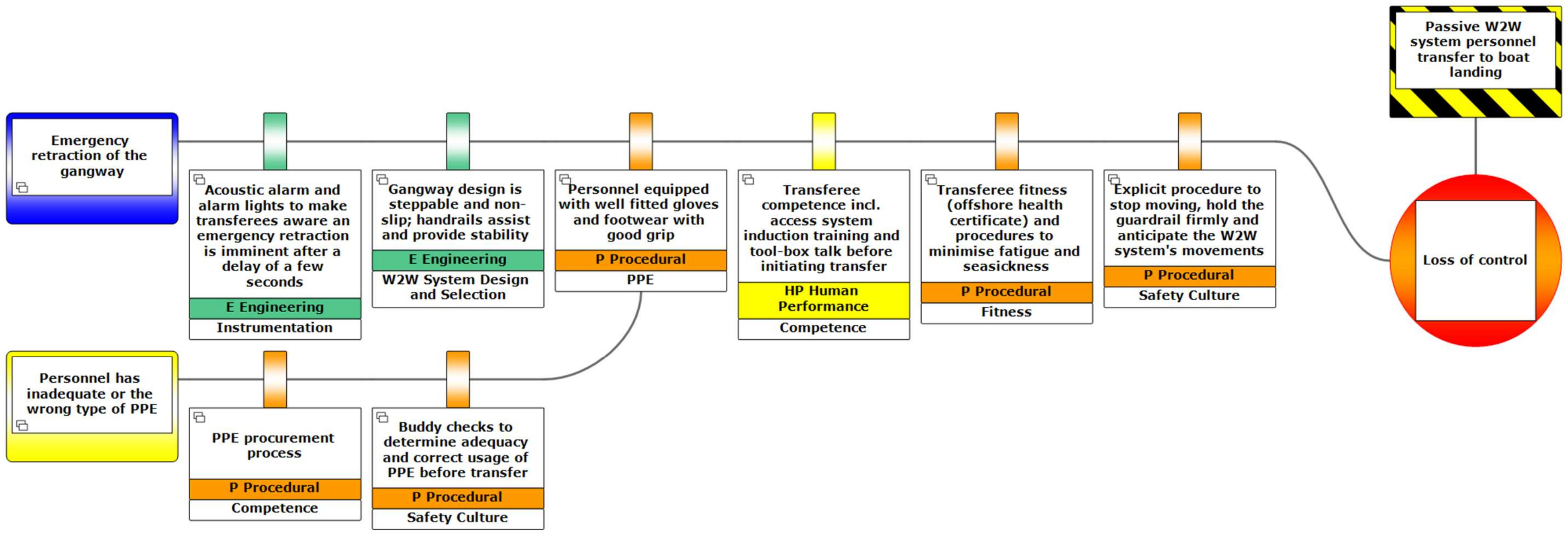

Active W2W system personnel transfer to TP platform
Loss of control
Selection of gangway connection to minimise risk of personnel hitting lower parts of the turbine structure in the event of a fall
P Procedural
Competence
Immersion suits / life jackets during transfer
P Procedural
PPE
GWO Training (sea survival and MOB) for all transferees
P Procedural
Training
Recovery measures for MOB
P Procedural
Emergency Response
Fall from the gangway (e.g. from the outer open end) into water or lower parts of the turbine structure

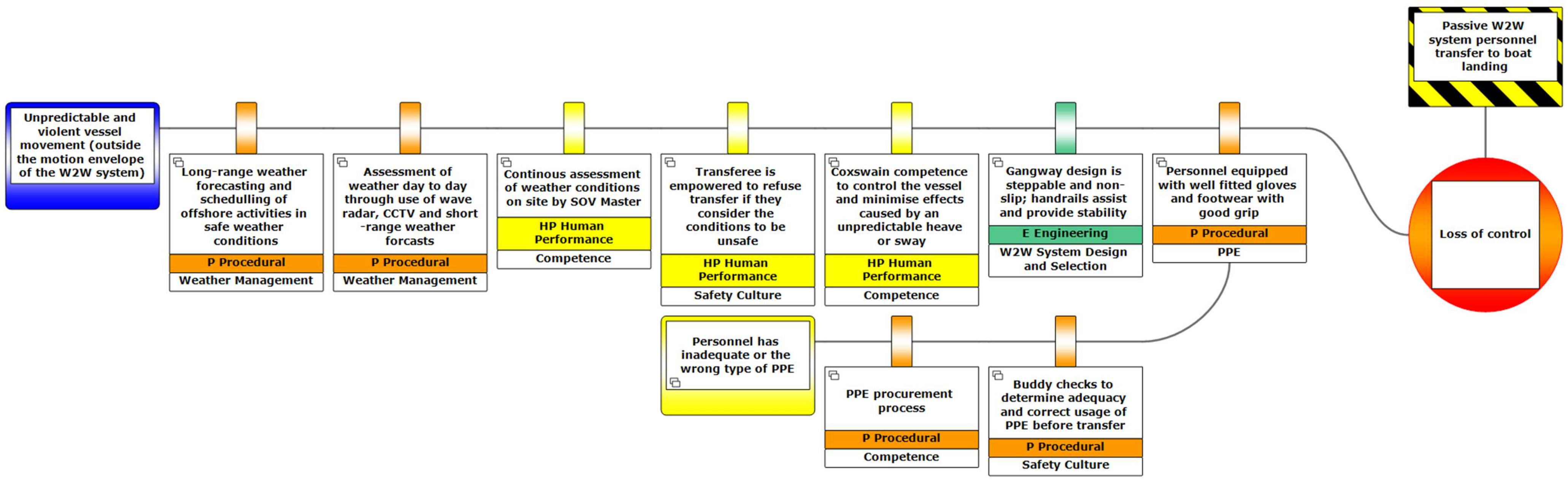

Active W2W system personnel transfer to TP platform
Loss of control
Hard Hat
P Procedural
PPE
Fall onto on the gangway or guardrails

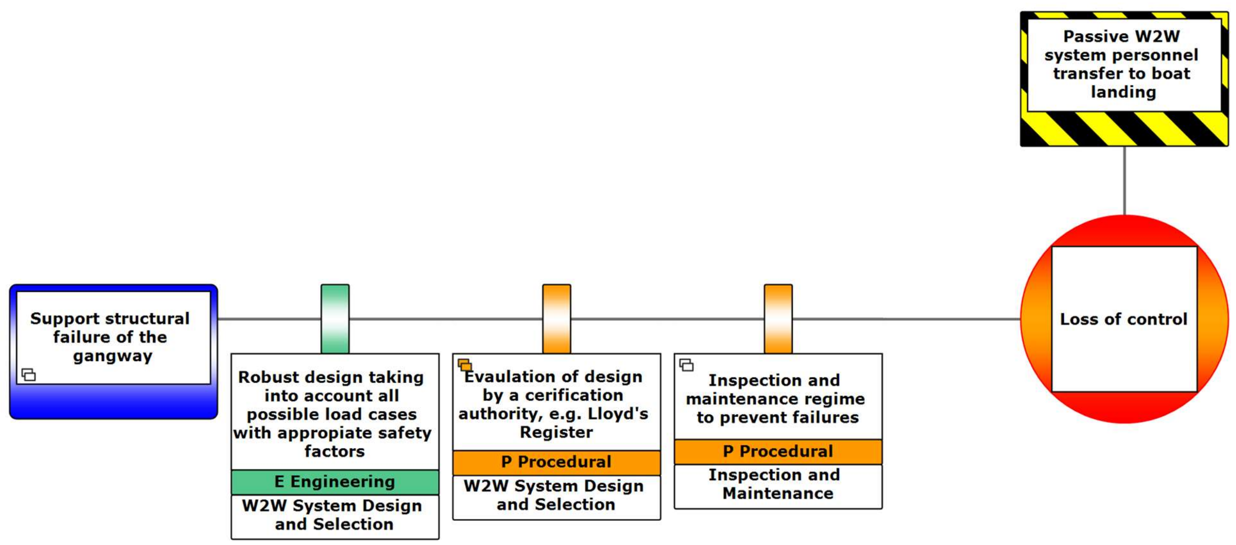

Active W2W system personnel transfer to TP platform
Loss of control
Hard Hat
P Procedural
PPE
Fall of transferees and operator on the transfer deck of the W2W system

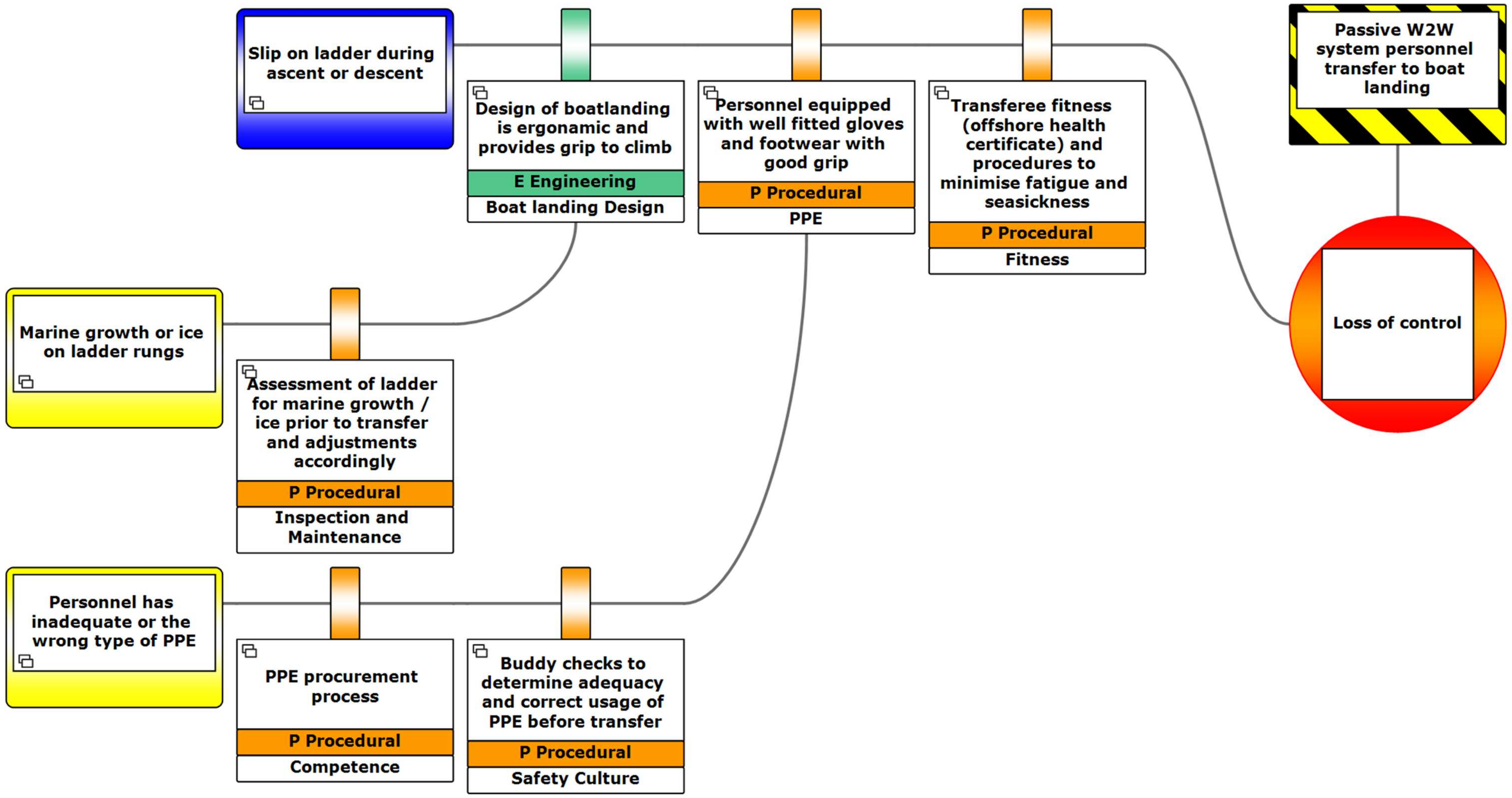

Active W2W system personnel transfer to TP platform
Loss of control
Collision between the gangway and turbine structure

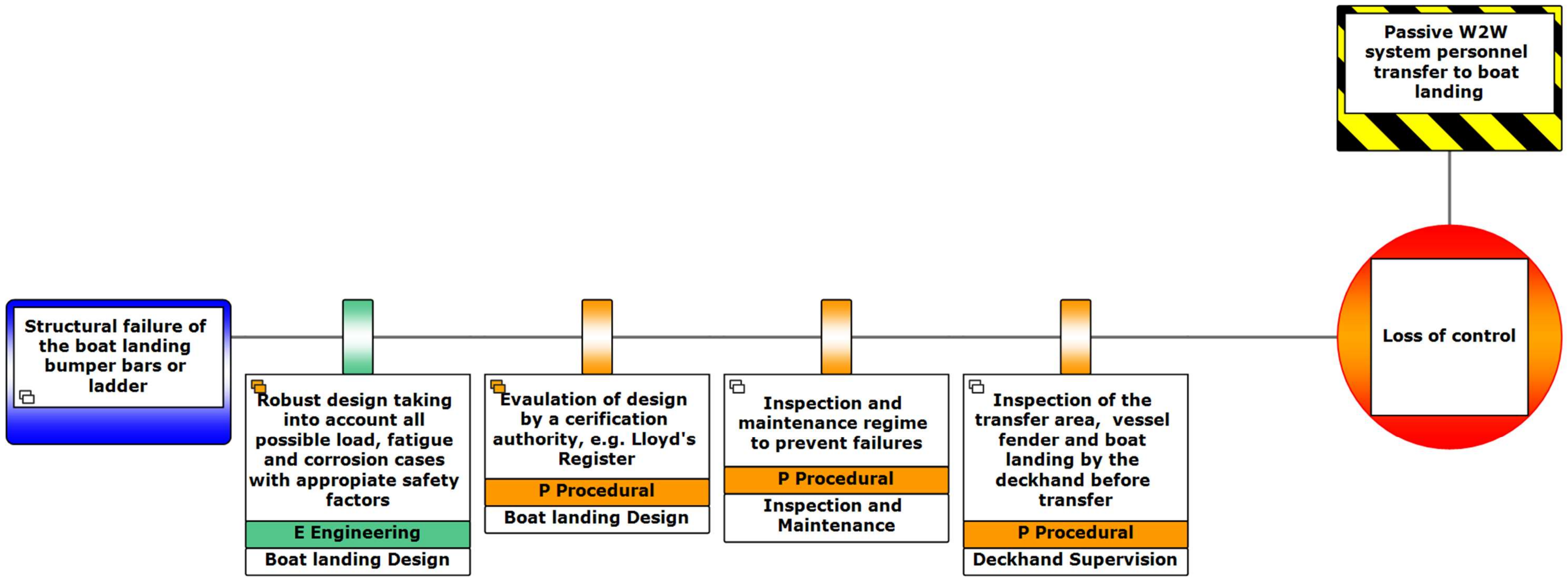

Passive W2W system personnel transfer to boat landing
Loss of control
Trip or fall when on the vessel deck (prior to ascent or after descent)
Deck and fender design is steppable and non-slip; handrails assist and provide stability
E Engineering
Vessel Design and Selection
Minimal obstructions / trip hazards on deck and fender
P Procedural
Safety Culture
Inspection of the transfer area, boat and structure fendering by the deckhand before transfer
P Procedural
Deckhand Supervision
GWO Basic Safety Training for all transferees
P Procedural
Training
Personnel equipped with well fitted gloves and footwear with good grip
P Procedural
PPE
Transferee fitness (offshore health certificate) and procedures to minimise fatigue and seasickness
P Procedural
Fitness
Transferee competence incl. site-specific induction training and tool-box talk before initiating transfer
HP Human Performance
Competence
Personnel has inadequate or the wrong type of PPE
PPE procurement process
P Procedural
Competence
Buddy checks to determine adequacy and correct usage of PPE before transfer
P Procedural
Safety Culture
Passive W2W system personnel transfer to boat landing
Loss of control
Personnel on deck in proximity of moving parts or the gangway while it is active
Placement of a physical barrier (line) arround the rotating area of the W2W system before it is pressurized
P Procedural
Safety Culture
Transferee competence incl. access system induction training and tool-box talk before initiating transfer
HP Human Performance
Competence
Operator of the W2W system always checks whether it is safe to pressurize the system and set the gangway in motion
HP Human Performance
Competence
Passive W2W system personnel transfer to boat landing
Loss of control
Operator error
Operator is trained in operating the W2W system and is aware of safety procedures
P Procedural
Training
Switching between operational states is preceeded by a set of checks, and only enabled when a criterium is met following a predefined sequence
E Engineering
Instrumentation
Visual warning indicating component failure
- Green: all normal
- Yellow: alert, e.g. clogged filter
- Orange: single failure
- Red: double failure
E Engineering
Instrumentation

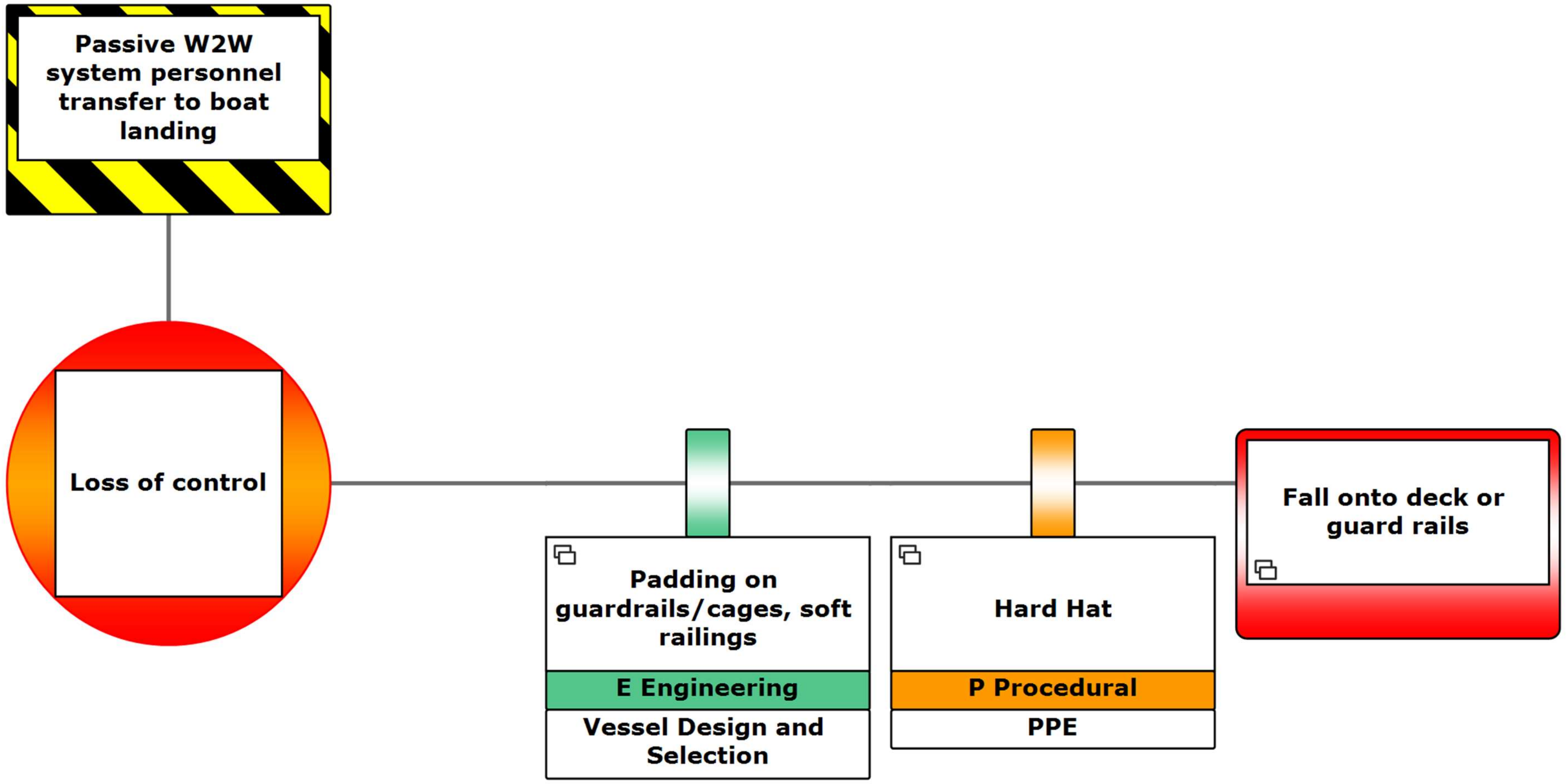

Emergency retraction of the gangway
Acoustic alarm and alarm lights to make transferees aware an emergency retraction is imminent after a delay of a few seconds
E Engineering
Instrumentation
Gangway design is steppable and non-slip; handrails assist and provide stability
E Engineering
W2W System Design and Selection
Personnel equipped with well fitted gloves and footwear with good grip
P Procedural
PPE
Transferee competence incl. access system induction training and tool-box talk before initiating transfer
HP Human Performance
Competence
Transferee fitness (offshore health certificate) and procedures to minimise fatigue and seasickness
P Procedural
Fitness
Explicit procedure to stop moving, hold the guardrail firmly and anticipate the W2W system's movements
P Procedural
Safety Culture
Passive W2W system personnel transfer to boat landing
Loss of control
Personnel has inadequate or the wrong type of PPE
PPE procurement process
P Procedural
Competence
Buddy checks to determine adequacy and correct usage of PPE before transfer
P Procedural
Safety Culture

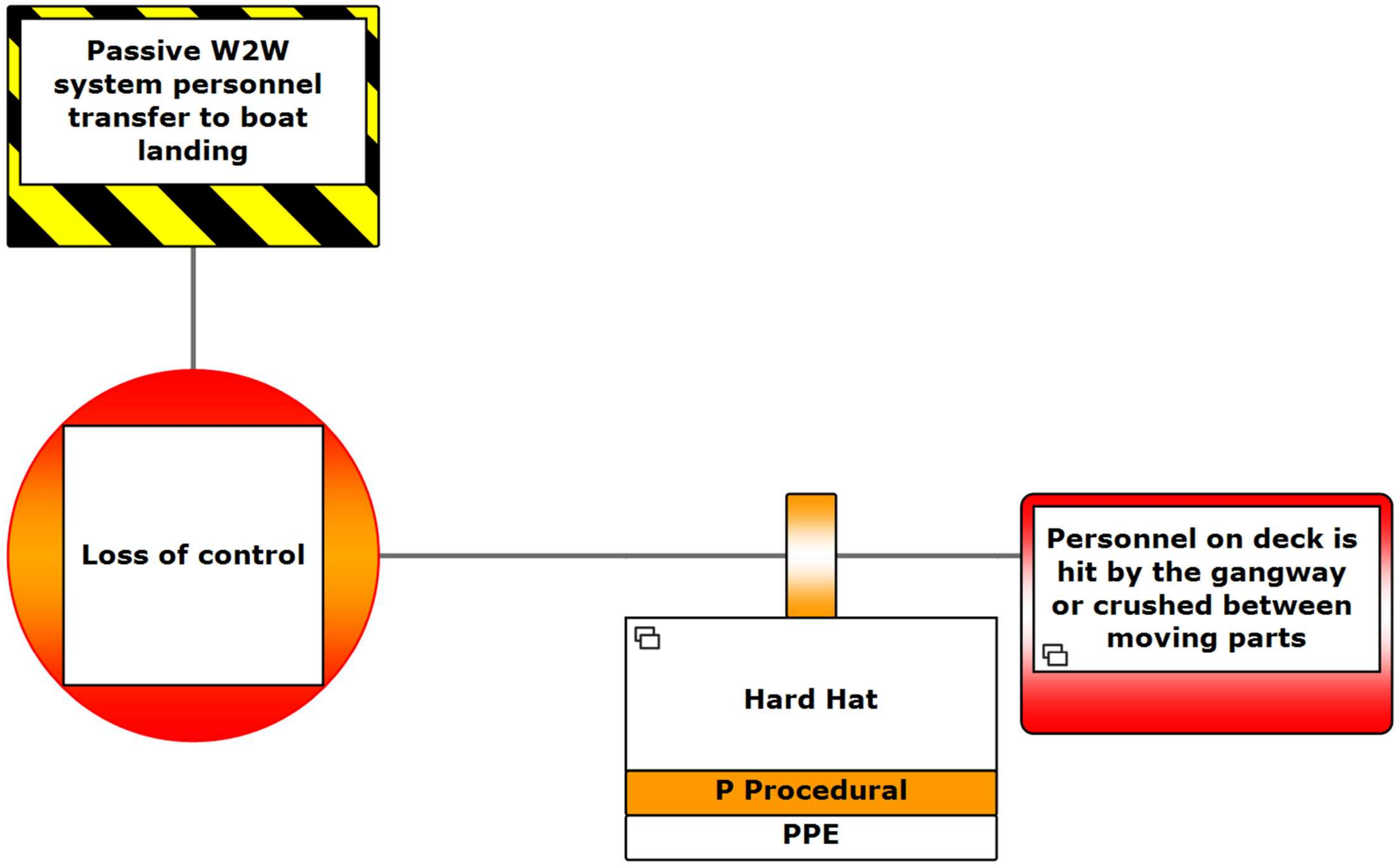

Unpredictable and violent vessel movement (outside the motion envelope of the W2W system)
Long-range weather forecasting and schedulling of offshore activities in safe weather conditions
P Procedural
Weather Management
Assessment of weather day to day through use of wave radar, CCTV and short -range weather forcasts
P Procedural
Weather Management
Continous assessment of weather conditions on site by SOV Master
HP Human Performance
Competence
Transferee is empowered to refuse transfer if they consider the conditions to be unsafe
HP Human Performance
Safety Culture
Coxswain competence to control the vessel and minimise effects caused by an unpredictable heave or sway
HP Human Performance
Competence
Gangway design is steppable and non-slip; handrails assist and provide stability
E Engineering
W2W System Design and Selection
Personnel equipped with well fitted gloves and footwear with good grip
P Procedural
PPE
Passive W2W system personnel transfer to boat landing
Loss of control
Personnel has inadequate or the wrong type of PPE
PPE procurement process
P Procedural
Competence
Buddy checks to determine adequacy and correct usage of PPE before transfer
P Procedural
Safety Culture

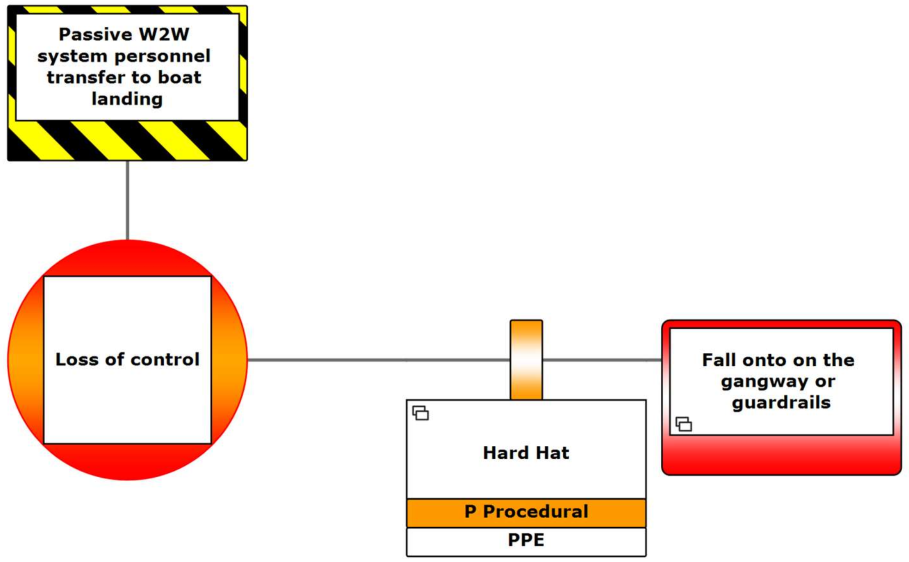

Support structural failure of the gangway
Robust design taking into account all possible load cases with appropriate safety factors
E Engineering
W2W System Design and Selection
Evaulation of design by a cerification authority, e.g. Lloyd's Register
P Procedural
W2W System Design and Selection
Inspection and maintenance regime to prevent failures
P Procedural
Inspection and Maintenance
Passive W2W system personnel transfer to boat landing
Loss of control

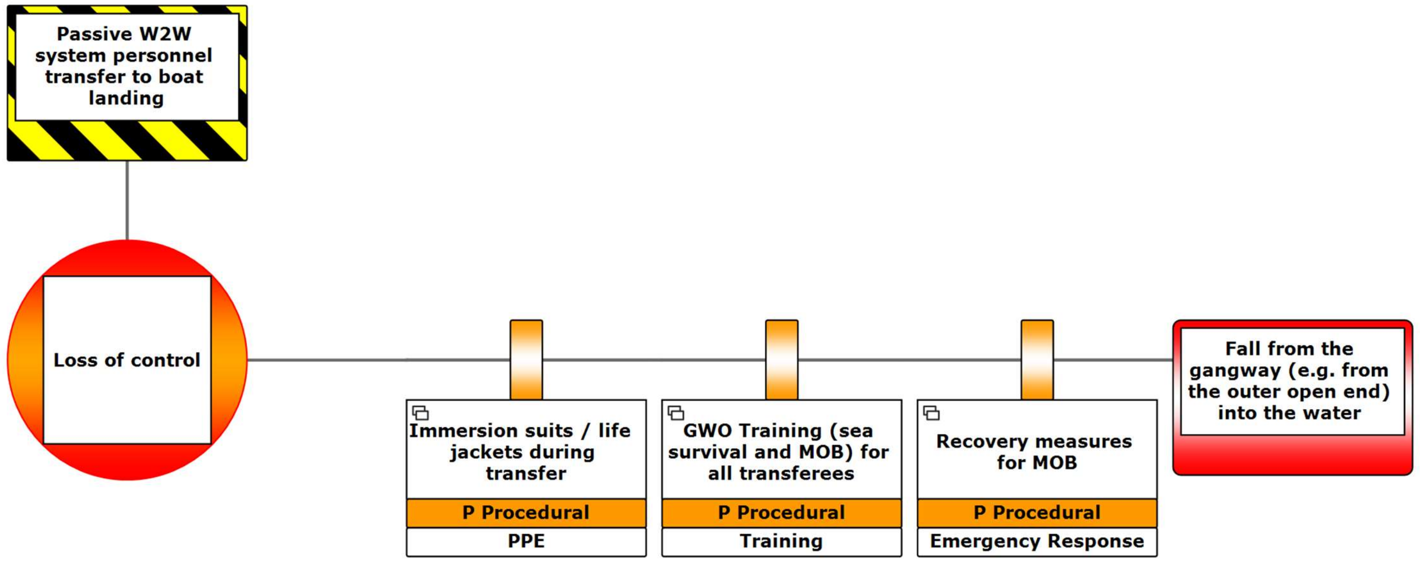

Slip on ladder during ascent or descent
Design of boatlanding is ergonomic and provides grip to climb
E Engineering
Boat landing Design
Personnel equipped with well fitted gloves and footwear with good grip
P Procedural
PPE
Transferee fitness (offshore health certificate) and procedures to minimise fatigue and seasickness
P Procedural
Fitness
Passive W2W system personnel transfer to boat landing
Loss of control
Marine growth or ice on ladder rungs
Assessment of ladder for marine growth / ice prior to transfer and adjustments accordingly
P Procedural
Inspection and Maintenance
Personnel has inadequate or the wrong type of PPE
PPE procurement process
P Procedural
Competence
Buddy checks to determine adequacy and correct usage of PPE before transfer
P Procedural
Safety Culture

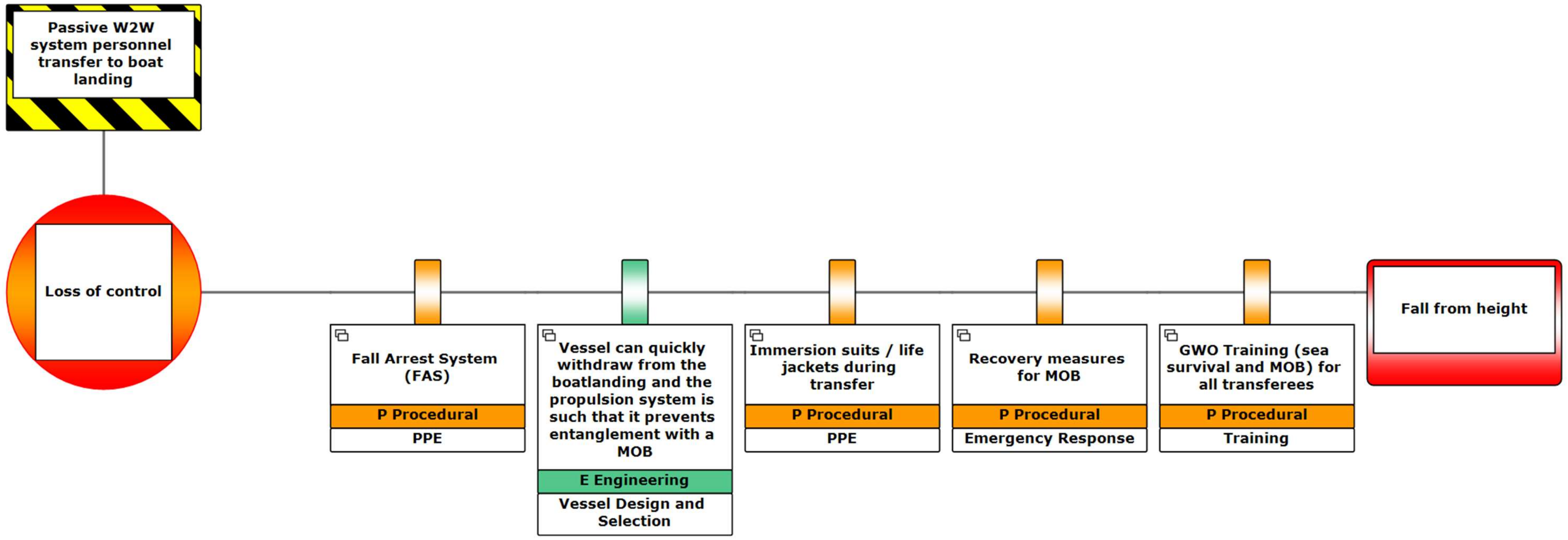

Passive W2W system personnel transfer to boat landing
Structural failure of the boat landing bumper bars or ladder
Robust design taking into account all possible load, fatigue and corrosion cases with appropiate safety factors
E Engineering
Boat landing Design
Evaulation of design by a cerification authority, e.g. Lloyd's Register
P Procedural
Boat landing Design
Inspection and maintenance regime to prevent failures
P Procedural
Inspection and Maintenance
Inspection of the transfer area, vessel fender and boat landing by the deckhand before transfer
P Procedural
Deckhand Supervision
Loss of control

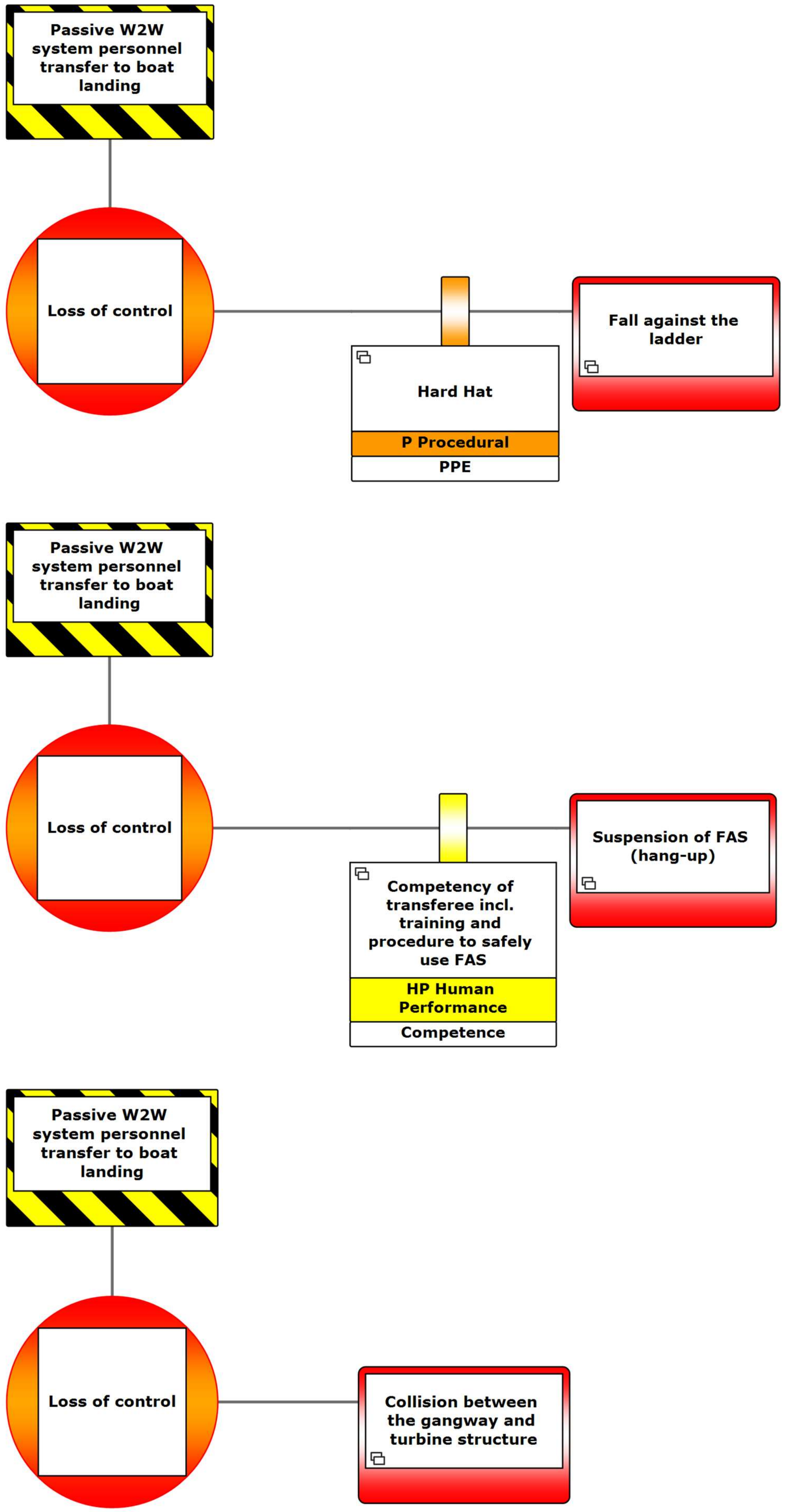

Passive W2W system personnel transfer to boat landing
Loss of control
Padding on guardrails/cages, soft railings
E Engineering
Vessel Design and Selection
Hard Hat
P Procedural
PPE
Fall onto deck or guard rails


Passive W2W system personnel transfer to boat landing
Loss of control
Hard Hat
P Procedural
PPE
Personnel on deck is hit by the gangway or crushed between moving parts

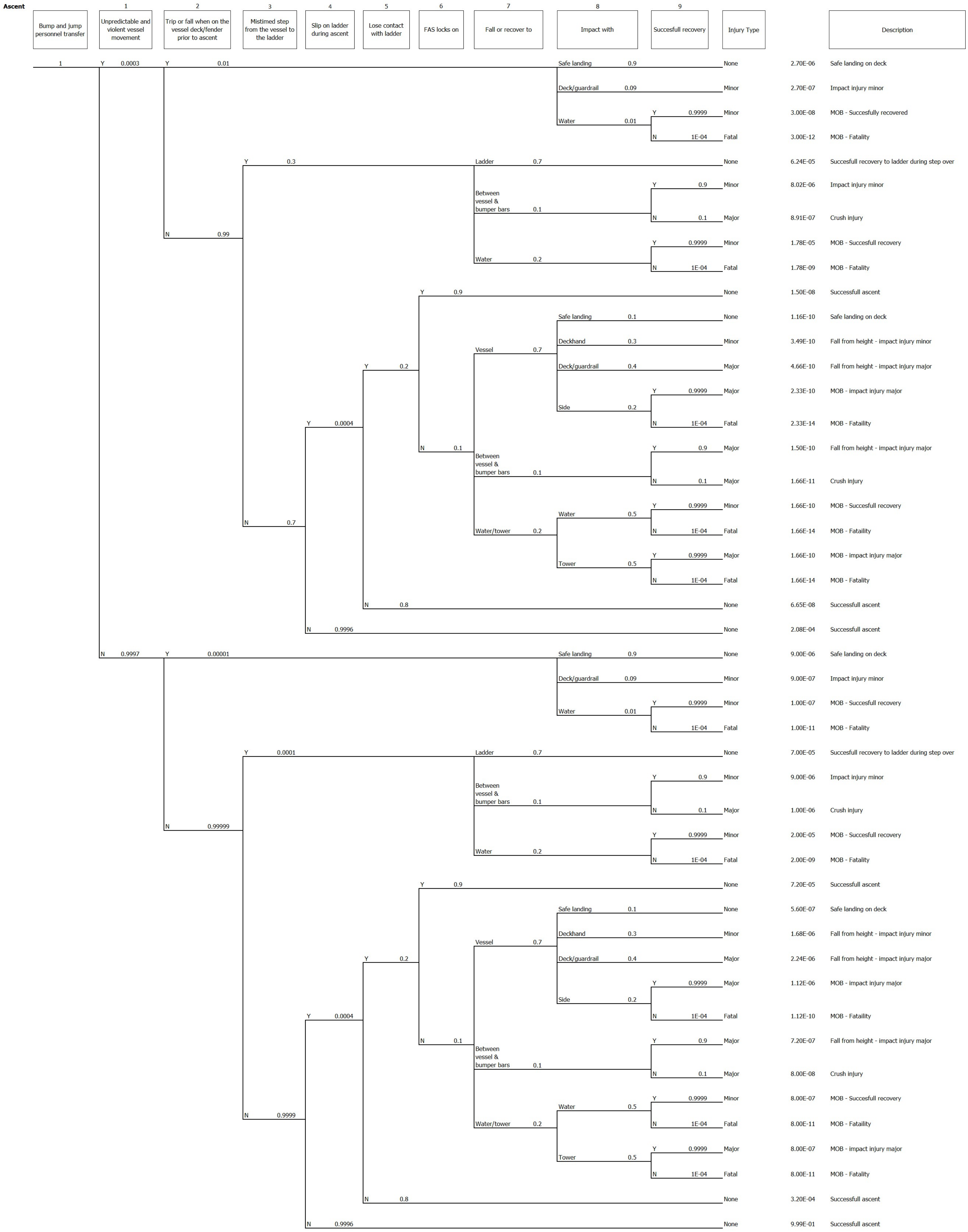

Passive W2W system personnel transfer to boat landing
Loss of control
Hard Hat
P Procedural
PPE
Fall onto on the gangway or guardrails


Passive W2W system personnel transfer to boat landing
Loss of control
Immersion suits / life jackets during transfer
P Procedural
PPE
GWO Training (sea survival and MOB) for all transferees
P Procedural
Training
Recovery measures for MOB
P Procedural
Emergency Response
Fall from the gangway (e.g. from the outer open end) into the water

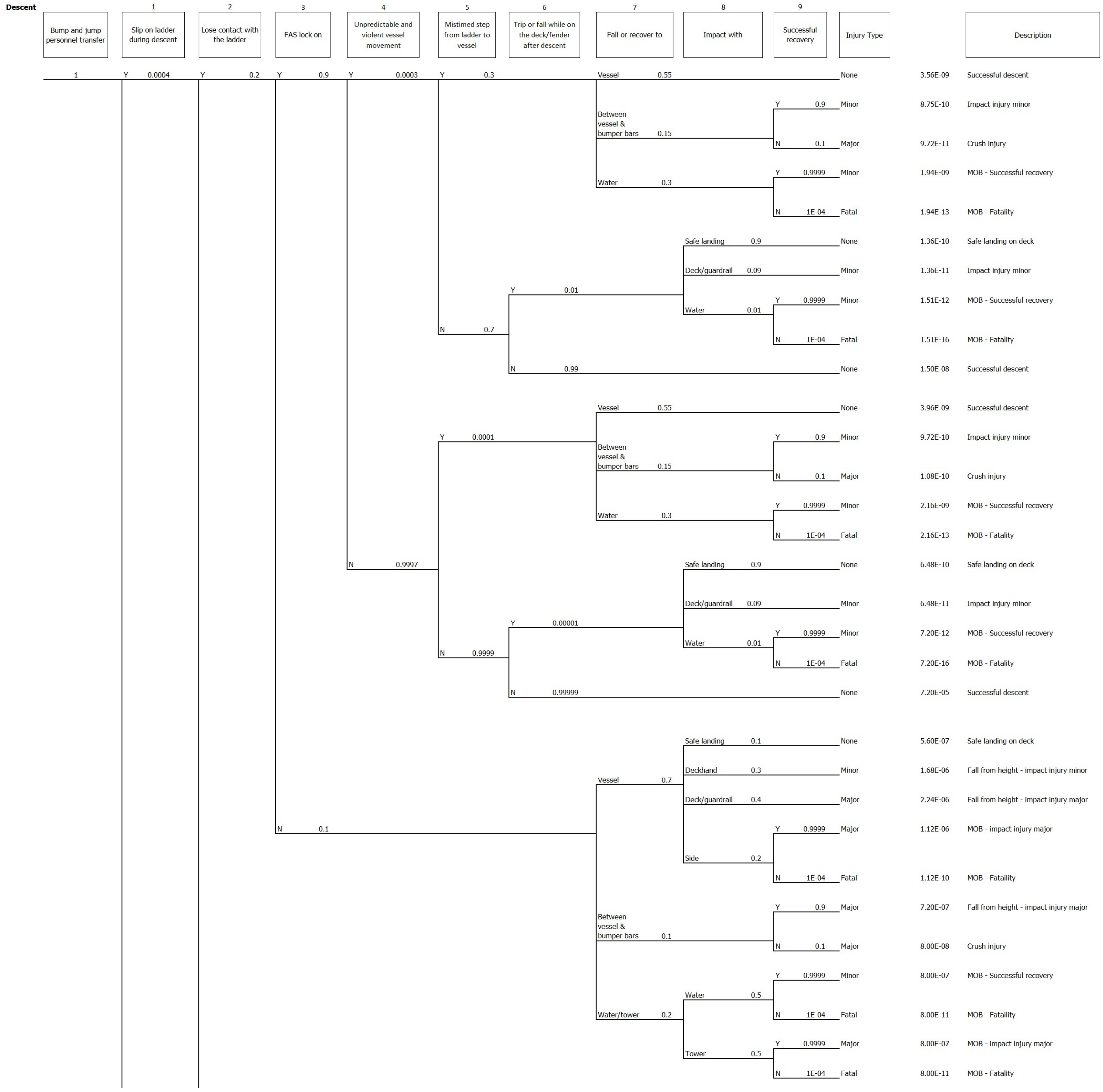

Passive W2W system personnel transfer to boat landing
Loss of control
Fall Arrest System (FAS)
P Procedural
PPE
Vessel can quickly withdraw from the boatlanding and the propulsion system is such that it prevents entanglement with a MOB
E Engineering
Vessel Design and Selection
Immersion suits / life jackets during transfer
P Procedural
PPE
Recovery measures for MOB
P Procedural
Emergency Response
GWO Training (sea survival and MOB) for all transferees
P Procedural
Training
Fall from height


Passive W2W system personnel transfer to boat landing
Loss of control
Hard Hat
P Procedural
PPE
Fall against the ladder
Passive W2W system personnel transfer to boat landing
Loss of control
Competency of transferee incl. training and procedure to safely use FAS
HP Human Performance
Competence
Suspension of FAS (hang-up)
Passive W2W system personnel transfer to boat landing
Loss of control
Collision between the gangway and turbine structure

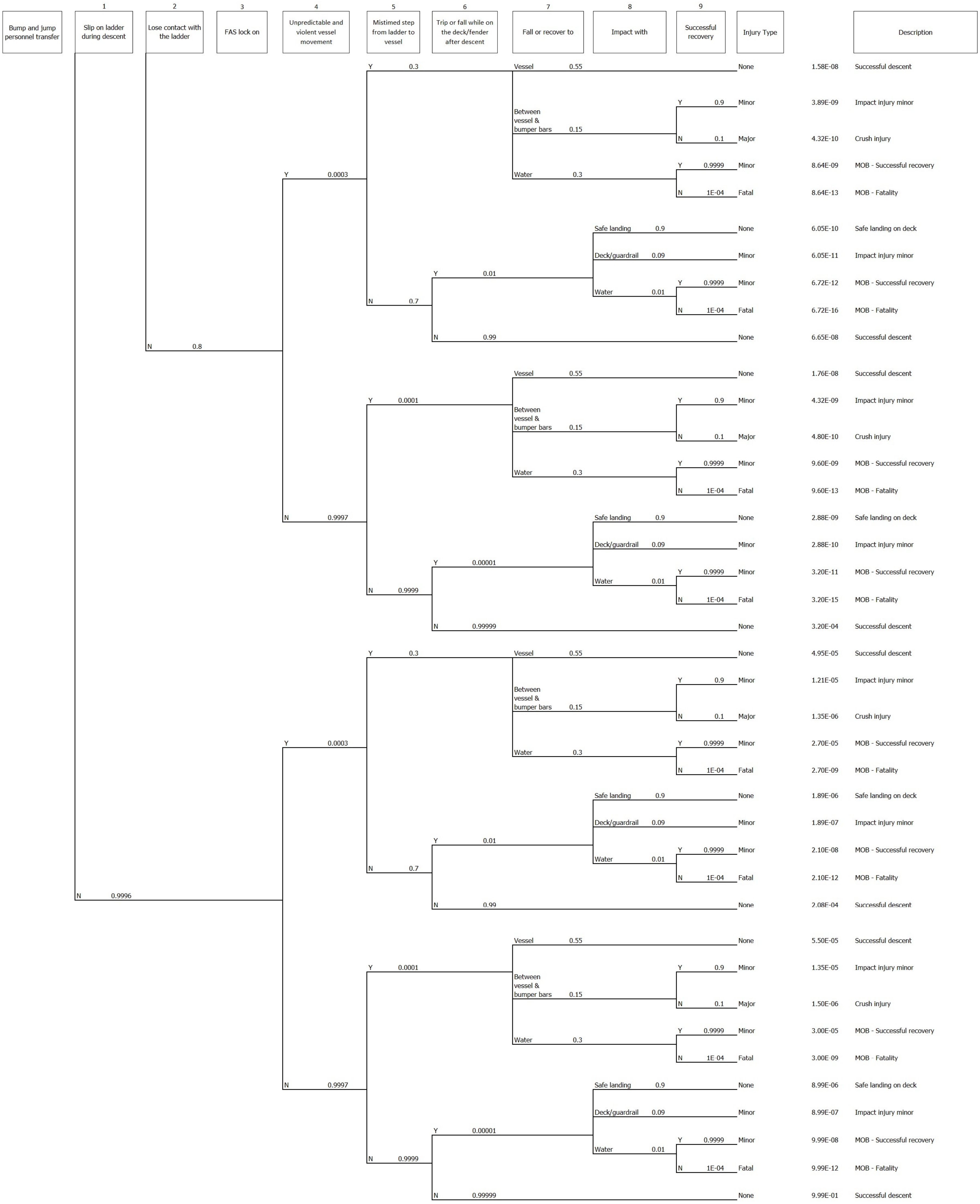
APPENDIX B


Ascent
Bump and jump personnel transfer
1 Unpredictable and violent vessel movement
2 Trip or fall when on the vessel deck/fender prior to ascent
3 Mistimed step from the vessel to the ladder
4 Slip on ladder during ascent
5 Lose contact with ladder
6 FAS locks on
7 Fall or recover to
8 Impact with
9 Succesfull recovery
Injury Type
Description
None 2.70E-06 Safe landing on deck
Minor 2.70E-07 Impact injury minor
Minor 3.00E-08 MOB - Succesfully recovered
Fatal 3.00E-12 MOB - Fatality
None 6.24E-05 Succesfull recovery to ladder during step over
Minor 8.02E-06 Impact injury minor
Major 8.91E-07 Crush injury
Minor 1.78E-05 MOB - Succesfull recovery
Fatal 1.78E-09 MOB - Fatality
None 1.50E-08 Successfull ascent
None 1.16E-10 Safe landing on deck
Minor 3.49E-10 Fall from height - impact injury minor
Major 4.66E-10 Fall from height - impact injury major
Major 2.33E-10 MOB - impact injury major
Fatal 2.33E-14 MOB - Fataility
Major 1.50E-10 Fall from height - impact injury major
Major 1.66E-11 Crush injury
Minor 1.66E-10 MOB - Succesfull recovery
Fatal 1.66E-14 MOB - Fataility
Major 1.66E-10 MOB - impact injury major
Fatal 1.66E-14 MOB - Fatality
None 6.65E-08 Successfull ascent
None 2.08E-04 Successfull ascent
None 9.00E-06 Safe landing on deck
Minor 9.00E-07 Impact injury minor
Minor 1.00E-07 MOB - Succesfull recovery
Fatal 1.00E-11 MOB - Fatality
None 7.00E-05 Succesfull recovery to ladder during step over
Minor 9.00E-06 Impact injury minor
Major 1.00E-06 Crush injury
Minor 2.00E-05 MOB - Succesfull recovery
Fatal 2.00E-09 MOB - Fatality
None 7.20E-05 Successfull ascent
None 5.60E-07 Safe landing on deck
Minor 1.68E-06 Fall from height - impact injury minor
Major 2.24E-06 Fall from height - impact injury major
Major 1.12E-06 MOB - impact injury major
Fatal 1.12E-10 MOB - Fatality
Major 7.20E-07 Fall from height - impact injury major
Major 8.00E-08 Crush injury
Minor 8.00E-07 MOB - Succesfull recovery
Fatal 8.00E-11 MOB - Fataility
Major 8.00E-07 MOB - impact injury major
Fatal 8.00E-11 MOB - Fatality
None 3.20E-04 Successfull ascent
None 9.99E-01 Successfull ascent

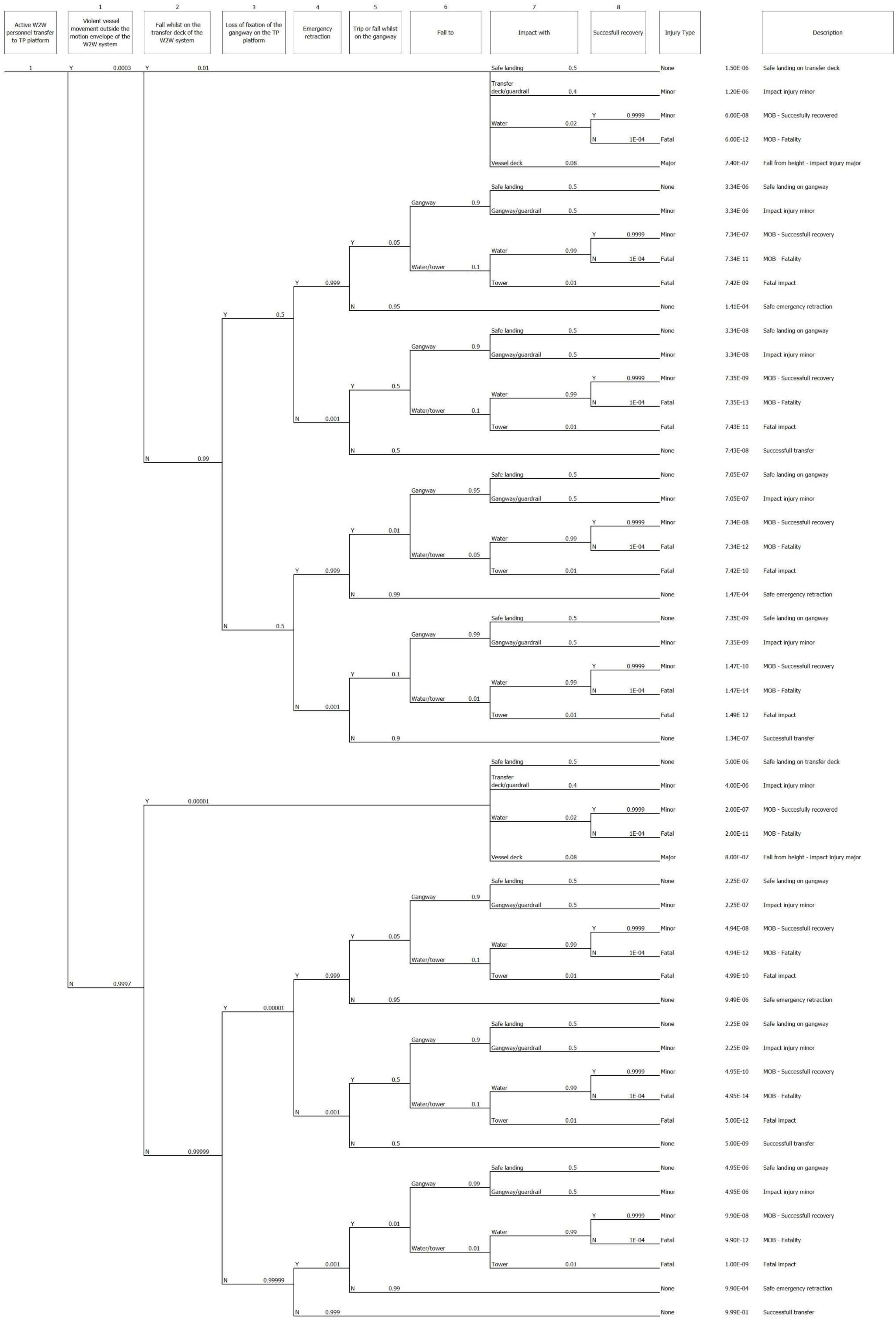
APPENDIX C


Descent
Bump and jump personnel transfer
1 Slip on ladder during descent
2 Lose contact with the ladder
3 FAS lock on
4 Unpredictable and violent vessel movement
5 Mistimed step from ladder to vessel
6 Trip or fall while on the deck/fender after descent
7 Fall or recover to
8 Impact with
9 Successful recovery
Injury Type
Description
1 Y 0.0004 Y 0.2 Y 0.9 Y 0.0003 Y 0.3 Vessel 0.55 None 3.56E-09 Successful descent
Between vessel & bumper bars 0.15
Y 0.9 Minor 8.75E-10 Impact injury minor
N 0.1 Major 9.72E-11 Crush injury
Water 0.3
Y 0.9999 Minor 1.94E-09 MOB - Successful recovery
N 1E-04 Fatal 1.94E-13 MOB - Fatality
N 0.7 Y 0.01
Safe landing 0.9 None 1.36E-10 Safe landing on deck
Deck/guardrail 0.09 Minor 1.36E-11 Impact injury minor
Water 0.01
Y 0.9999 Minor 1.51E-12 MOB - Successful recovery
N 1E-04 Fatal 1.51E-16 MOB - Fatality
N 0.99 None 1.50E-08 Successful descent
N 0.9997 Y 0.0001 Vessel 0.55 None 3.96E-09 Successful descent
Between vessel & bumper bars 0.15
Y 0.9 Minor 9.72E-10 Impact injury minor
N 0.1 Major 1.08E-10 Crush injury
Water 0.3
Y 0.9999 Minor 2.16E-09 MOB - Successful recovery
N 1E-04 Fatal 2.16E-13 MOB - Fatality
N 0.9999 Y 0.00001
Safe landing 0.9 None 6.48E-10 Safe landing on deck
Deck/guardrail 0.09 Minor 6.48E-11 Impact injury minor
Water 0.01
Y 0.9999 Minor 7.20E-12 MOB - Successful recovery
N 1E-04 Fatal 7.20E-16 MOB - Fatality
N 0.99999 None 7.20E-05 Successful descent
N 0.1 Vessel 0.7
Safe landing 0.1 None 5.60E-07 Safe landing on deck
Deckhand 0.3 Minor 1.68E-06 Fall from height - impact injury minor
Deck/guardrail 0.4 Major 2.24E-06 Fall from height - impact injury major
Side 0.2
Y 0.9999 Major 1.12E-06 MOB - impact injury major
N 1E-04 Fatal 1.12E-10 MOB - Fataility
Between vessel & bumper bars 0.1
Y 0.9 Major 7.20E-07 Fall from height - impact injury major
N 0.1 Major 8.00E-08 Crush injury
Water/tower 0.2
Water 0.5
Y 0.9999 Minor 8.00E-07 MOB - Successful recovery
N 1E-04 Fatal 8.00E-11 MOB - Fataility
Tower 0.5
Y 0.9999 Major 8.00E-07 MOB - impact injury major
N 1E-04 Fatal 8.00E-11 MOB - Fatality

Descent

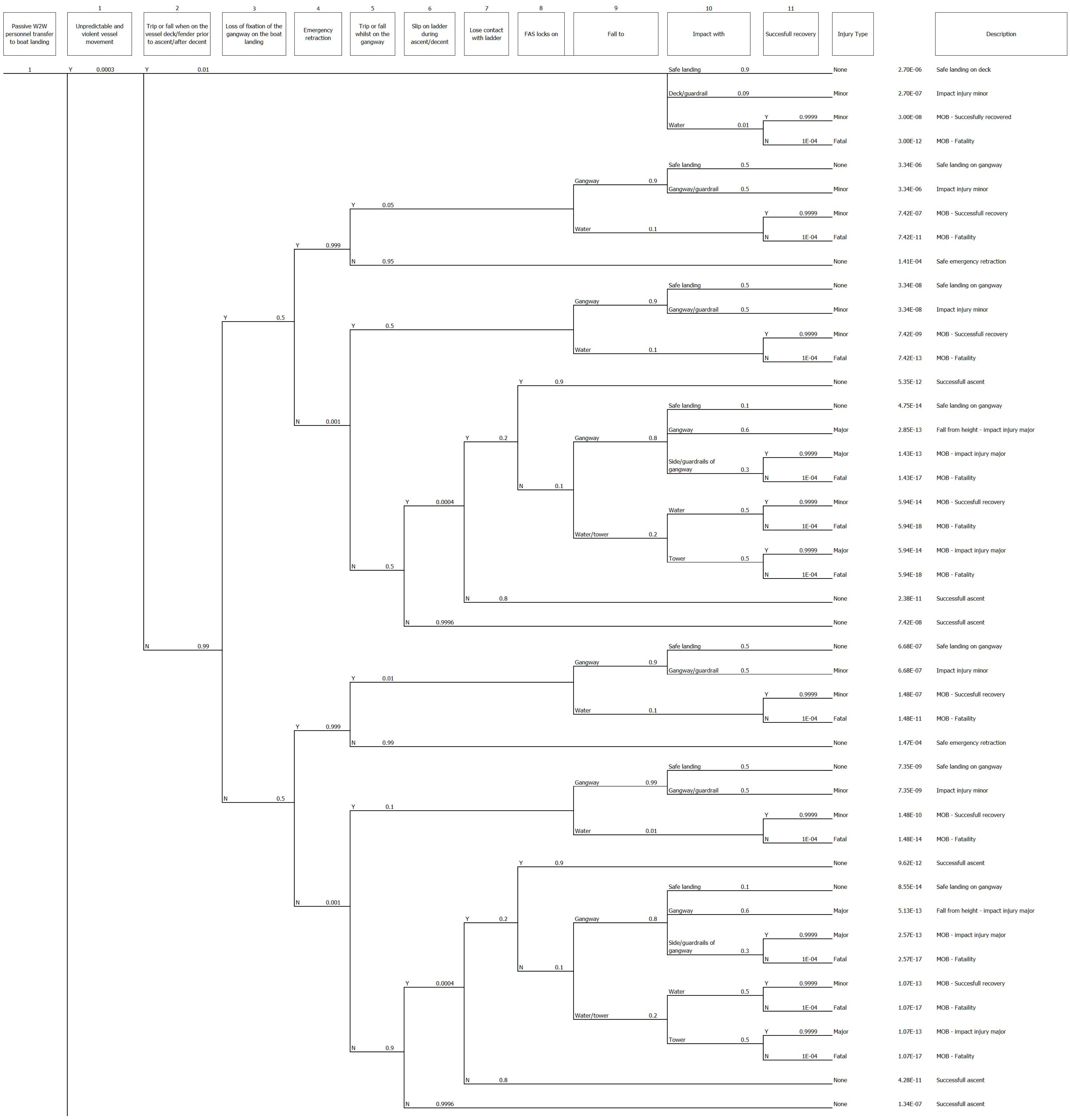

Bump and jump personnel transfer
1
Slip on ladder during descent
2
Lose contact with the ladder
3
FAS lock on
4
Unpredictable and violent vessel movement
5
Mistimed step from ladder to vessel
6
Trip or fall while on the deck/fender after descent
7
Fall or recover to
8
Impact with
9
Successful recovery
Injury Type
Description
None 1.58E-08 Successful descent
Minor 3.89E-09 Impact injury minor
Major 4.32E-10 Crush injury
Minor 8.64E-09 MOB - Successful recovery
Fatal 8.64E-13 MOB - Fatality
None 6.05E-10 Safe landing on deck
Minor 6.05E-11 Impact injury minor
Minor 6.72E-12 MOB - Successful recovery
Fatal 6.72E-16 MOB - Fatality
None 6.65E-08 Successful descent
None 1.76E-08 Successful descent
Minor 4.32E-09 Impact injury minor
Major 4.80E-10 Crush injury
Minor 9.60E-09 MOB - Successful recovery
Fatal 9.60E-13 MOB - Fatality
None 2.88E-09 Safe landing on deck
Minor 2.88E-10 Impact injury minor
Minor 3.20E-11 MOB - Successful recovery
Fatal 3.20E-15 MOB - Fatality
None 3.20E-04 Successful descent
None 4.95E-05 Successful descent
Minor 1.21E-05 Impact injury minor
Major 1.35E-06 Crush injury
Minor 2.70E-05 MOB - Successful recovery
Fatal 2.70E-09 MOB - Fatality
None 1.89E-06 Safe landing on deck
Minor 1.89E-07 Impact injury minor
Minor 2.10E-08 MOB - Successful recovery
Fatal 2.10E-12 MOB - Fatality
None 2.08E-04 Successful descent
None 5.50E-05 Successful descent
Minor 1.35E-05 Impact injury minor
Major 1.50E-06 Crush injury
Minor 3.00E-05 MOB - Successful recovery
Fatal 3.00E-09 MOB - Fatality
None 8.99E-06 Safe landing on deck
Minor 8.99E-07 Impact injury minor
Minor 9.99E-08 MOB - Successful recovery
Fatal 9.99E-12 MOB - Fatality
None 9.99E-01 Successful descent

APPENDIX D

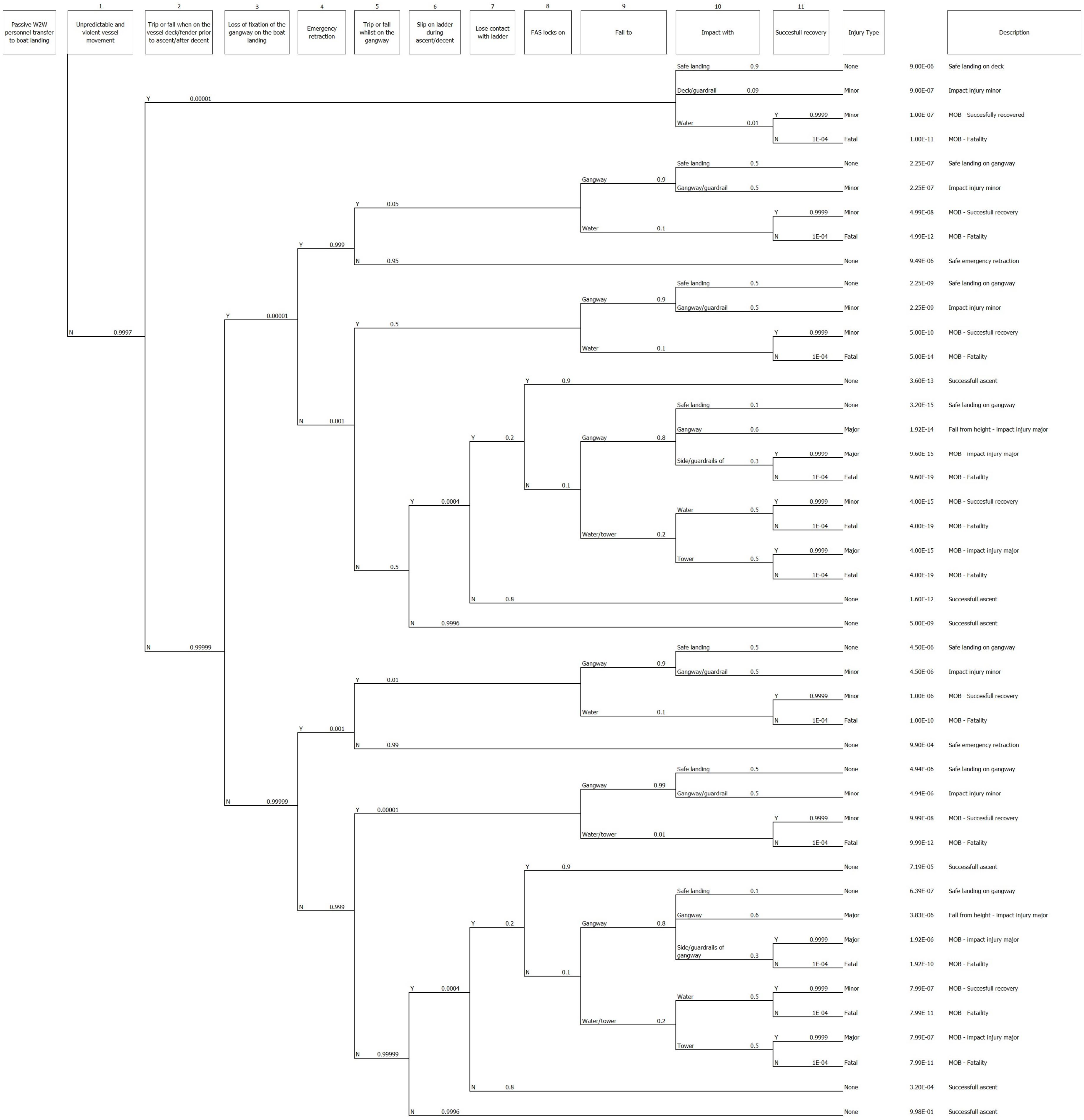


Active W2W personnel transfer to TP platform
1 Violent vessel movement outside the motion envelope of the W2W system
2 Fall whilst on the transfer deck of the W2W system
3 Loss of fixation of the gangway on the TP platform
4 Emergency retraction
5 Trip or fall whilst on the gangway
6 Fall to
7 Impact with
8 Succesfull recovery
Injury Type
Description
None 1.50E-06 Safe landing on transfer deck
Minor 1.20E-06 Impact injury minor
Minor 6.00E-08 MOB - Succesfully recovered
Fatal 6.00E-12 MOB - Fatality
Major 2.40E-07 Fall from height - impact injury major
None 3.34E-06 Safe landing on gangway
Minor 3.34E-06 Impact injury minor
Minor 7.34E-07 MOB - Successfull recovery
Fatal 7.34E-11 MOB - Fatality
Fatal 7.42E-09 Fatal impact
None 1.41E-04 Safe emergency retraction
None 3.34E-08 Safe landing on gangway
Minor 3.34E-08 Impact injury minor
Minor 7.35E-09 MOB - Successfull recovery
Fatal 7.35E-13 MOB - Fatality
Fatal 7.43E-11 Fatal impact
None 7.43E-08 Successfull transfer
None 7.05E-07 Safe landing on gangway
Minor 7.05E-07 Impact injury minor
Minor 7.34E-08 MOB - Successfull recovery
Fatal 7.34E-12 MOB - Fatality
Fatal 7.42E-10 Fatal impact
None 1.47E-04 Safe emergency retraction
None 7.35E-09 Safe landing on gangway
Minor 7.35E-09 Impact injury minor
Minor 1.47E-10 MOB - Successfull recovery
Fatal 1.47E-14 MOB - Fatality
Fatal 1.49E-12 Fatal impact
None 1.34E-07 Successfull transfer
None 5.00E-06 Safe landing on transfer deck
Minor 4.00E-06 Impact injury minor
Minor 2.00E-07 MOB - Succesfully recovered
Fatal 2.00E-11 MOB - Fatality
Major 8.00E-07 Fall from height - impact injury major
None 2.25E-07 Safe landing on gangway
Minor 2.25E-07 Impact injury minor
Minor 4.94E-08 MOB - Successfull recovery
Fatal 4.94E-12 MOB - Fatality
Fatal 4.99E-10 Fatal impact
None 9.49E-06 Safe emergency retraction
None 2.25E-09 Safe landing on gangway
Minor 2.25E-09 Impact injury minor
Minor 4.95E-10 MOB - Successfull recovery
Fatal 4.95E-14 MOB - Fatality
Fatal 5.00E-12 Fatal impact
None 5.00E-09 Successfull transfer
None 4.95E-06 Safe landing on gangway
Minor 4.95E-06 Impact injury minor
Minor 9.90E-08 MOB - Successfull recovery
Fatal 9.90E-12 MOB - Fatality
Fatal 1.00E-09 Fatal impact
None 9.90E-04 Safe emergency retraction
None 9.99E-01 Successfull transfer

APPENDIX E



Passive W2W personnel transfer to boat landing
1 Unpredictable and violent vessel movement
2 Trip or fall when on the vessel deck/fender prior to ascent/after decent
3 Loss of fixation of the gangway on the boat landing
4 Emergency retraction
5 Trip or fall whilst on the gangway
6 Slip on ladder during ascent/decent
7 Lose contact with ladder
8 FAS locks on
9 Fall to
10 Impact with
11 Succesfull recovery
Injury Type
Description
None 2.70E-06 Safe landing on deck
Minor 2.70E-07 Impact injury minor
Minor 3.00E-08 MOB - Succesfully recovered
Fatal 3.00E-12 MOB - Fatality
None 3.34E-06 Safe landing on gangway
Minor 3.34E-06 Impact injury minor
Minor 7.42E-07 MOB - Successfull recovery
Fatal 7.42E-11 MOB - Fataility
None 1.41E-04 Safe emergency retraction
None 3.34E-08 Safe landing on gangway
Minor 3.34E-08 Impact injury minor
Minor 7.42E-09 MOB - Successfull recovery
Fatal 7.42E-13 MOB - Fataility
None 5.35E-12 Successfull ascent
None 4.75E-14 Safe landing on gangway
Major 2.85E-13 Fall from height - impact injury major
Major 1.43E-13 MOB - impact injury major
Fatal 1.43E-17 MOB - Fataility
Minor 5.94E-14 MOB - Succesfull recovery
Fatal 5.94E-18 MOB - Fataility
Major 5.94E-14 MOB - impact injury major
Fatal 5.94E-18 MOB - Fatality
None 2.38E-11 Successfull ascent
None 7.42E-08 Successfull ascent
None 6.68E-07 Safe landing on gangway
Minor 6.68E-07 Impact injury minor
Minor 1.48E-07 MOB - Succesfull recovery
Fatal 1.48E-11 MOB - Fataility
None 1.47E-04 Safe emergency retraction
None 7.35E-09 Safe landing on gangway
Minor 7.35E-09 Impact injury minor
Minor 1.48E-10 MOB - Succesfull recovery
Fatal 1.48E-14 MOB - Fataility
None 9.62E-12 Successfull ascent
None 8.55E-14 Safe landing on gangway
Major 5.13E-13 Fall from height - impact injury major
Major 2.57E-13 MOB - impact injury major
Fatal 2.57E-17 MOB - Fataility
Minor 1.07E-13 MOB - Succesfull recovery
Fatal 1.07E-17 MOB - Fataility
Major 1.07E-13 MOB - impact injury major
Fatal 1.07E-17 MOB - Fatality
None 4.28E-11 Successfull ascent
None 1.34E-07 Successfull ascent



Passive W2W personnel transfer to boat landing
1 Unpredictable and violent vessel movement
2 Trip or fall when on the vessel deck/fender prior to ascent/after decent
3 Loss of fixation of the gangway on the boat landing
4 Emergency retraction
5 Trip or fall whilst on the gangway
6 Slip on ladder during ascent/decent
7 Lose contact with ladder
8 FAS locks on
9 Fall to
10 Impact with
11 Succesfull recovery
Injury Type
Description
None 9.00E-06 Safe landing on deck
Minor 9.00E-07 Impact injury minor
Minor 1.00E-07 MOB - Succesfully recovered
Fatal 1.00E-11 MOB - Fatality
None 2.25E-07 Safe landing on gangway
Minor 2.25E-07 Impact injury minor
Minor 4.99E-08 MOB - Succesfull recovery
Fatal 4.99E-12 MOB - Fatality
None 9.49E-06 Safe emergency retraction
None 2.25E-09 Safe landing on gangway
Minor 2.25E-09 Impact injury minor
Minor 5.00E-10 MOB - Succesfull recovery
Fatal 5.00E-14 MOB - Fatality
None 3.60E-13 Successfull ascent
None 3.20E-15 Safe landing on gangway
Major 1.92E-14 Fall from height - impact injury major
Major 9.60E-15 MOB - impact injury major
Fatal 9.60E-19 MOB - Fatility
Minor 4.00E-15 MOB - Succesfull recovery
Fatal 4.00E-19 MOB - Fatality
Major 4.00E-15 MOB - impact injury major
Fatal 4.00E-19 MOB - Fatality
None 1.60E-12 Successfull ascent
None 5.00E-09 Successfull ascent
None 4.50E-06 Safe landing on gangway
Minor 4.50E-06 Impact injury minor
Minor 1.00E-06 MOB - Succesfull recovery
Fatal 1.00E-10 MOB - Fatality
None 9.90E-04 Safe emergency retraction
None 4.94E-06 Safe landing on gangway
Minor 4.94E-06 Impact injury minor
Minor 9.99E-08 MOB - Succesfull recovery
Fatal 9.99E-12 MOB - Fatality
None 7.19E-05 Successfull ascent
None 6.39E-07 Safe landing on gangway
Major 3.83E-06 Fall from height - impact injury major
Major 1.92E-06 MOB - impact injury major
Fatal 1.92E-10 MOB - Fatility
Minor 7.99E-07 MOB - Succesfull recovery
Fatal 7.99E-11 MOB - Fatality
Major 7.99E-07 MOB - impact injury major
Fatal 7.99E-11 MOB - Fatality
None 3.20E-04 Successfull ascent
None 9.98E-01 Successfull ascent