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Occupational Risk Assessment of Bunkering Operations on Merchant Marine Vessels

Ανάλυση Ασφάλειας σε Πλοία του Εμπορικού Ναυτικού κατά τον Ανεφοδιασμό Καυσίμων

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Abstract

Globalization is constantly increasing the need to transport raw materials and products between countries; a substantial proportion of world trade, almost 90%, is carried out by sea. As bunkering is one of the most basic functions of ships, its importance is readily apparent.

In the period from 2014 to 2022, 542 cases of pollution were reported: 290 (53.5%) cases for cargo ships, 86 (15.9%) for fishing vessels, 82 (15.1%) for service ships, 71 (13.1%) for passenger ships, and 13 (2.4%) for other types of vessels (European Maritime Safety Agency 2023).

What is common about these accidents is the fact that they are not due to the leakage of cargo oil. Instead, marine pollution by ship's bunkers (fuel) and other pollutants (e.g., cargo residues, lubricating oils, or hydraulic oils) corresponded to 64.2% of all pollution. From 2014 to 2018, an unsettling trend has been observed by many P&I clubs: the majority, an estimated 18%, of all pollution incidents handled by their claims teams were caused by bunker spills (Gard 2019) (UK P&I 2018) (Japan P&I Club 2021). This figure represents the majority of oil spills due to marine casualties. It is evident that, while the measures currently in place have steadily reduced the occurrence of accidents, there is still room for improvement regarding the understanding and implementation of a safety-oriented mindset.

In this study, an occupational safety hazard analysis of the bunkering process will be conducted by utilizing the method of hierarchical task analysis and visualizing the results via bowtie diagrams to illustrate the inherent risks of the procedure, the preventive measures currently applied, and their efficacy. Finally, the findings will be applied to a number of case studies to verify the results of the thesis.

Terminology

- **Bunker:** fuel supplied to a vessel for its propulsion and/or operation. (ISO 21562:2020)
- **Bunker agreement:** contractual terms applying to a bunker transfer. (ISO 13739:2020)
- **Bunker Delivery Note (BDN):** official document from the supplier providing information on the quantity of the bunker(s) delivered to the vessel and limited information on the quality. (ISO 13739:2020)
- **Bunkering facility (or "facility"):** system designed to be used to transfer bunkers to a vessel. It may consist of a floating, shore-based, fixed, or mobile fuel-supply facility, such as a bunker vessel, terminal, or road tanker. (ISO/TS 18683:2021)
- **Bunker tank:** a tank containing or scheduled to contain bunkers. (Not standardized)
- **Bunker tanker (or "tanker"):** bunker barge or tanker used for the supply of bunkers to the vessel. (ISO 13739:2020)
- **Bunkering facility operator (or "facility operator"):** company that operates the bunker tanker. (ISO 13739:2020)
- **Chief engineer:** person authorized to receive bunkers and sign the associated documentation. (ISO 13739:2020)
- **International Safety Management (ISM) Code:** The International Management Code for the Safe Operation of Ships and for Pollution Prevention. (ISM Code 2010)
- **List:** inclination of a vessel expressed in degrees port or starboard away from the vertical. (ISO 13739:2020)
- **Material Safety Data Sheet (MSDS):** document that provides information on the properties of hazardous chemicals, how they affect health and safety in the workplace and how to manage the hazardous chemicals in the workplace. (ISO/TR 13329:2012)
- **Nominated tank:** tank from which bunkers are delivered. (ISO 13739:2020)
- **Non-nominated tank:** tank not nominated for current delivery. (ISO 13739:2020)
- **Road tanker:** truck used for the supply of bunkers to the vessel. (ISO 13739:2020)
- **Safety management system (SMS):** a structured and documented system enabling personnel to effectively implement the safety and environmental protection policy. (ISM Code 2010)
- **Sample:** bunker specimen defined by time, location and method of sampling. (ISO 13739:2020)
- **Sample seal:** tamper-evident device that uniquely identifies the origin of the sample and prevents the unauthorized loosening or removal of the sample container closure. (ISO 13739:2020)
- **Shipboard Oil Pollution Emergency Plan (SOPEP):** a document detailing the appropriate emergency response procedures to the event of oil pollution on a case-by-case basis. Each vessel is required to have its own plan drafted and implemented (Resolution MEPC 54(32))
- **Shore pipeline:** shore connection point for the supply of bunkers to a vessel. (ISO 13739:2020)
- **Supplier:** company whose name appears on the bunker delivery note. It is possible that the supplier is not the actual seller of the bunkers. (ISO 13739:2020)
- **Supplier's representative**: individual who is appointed by the supplier to be responsible for the delivery of bunkers to the vessel and for the completion of the documentation. (ISO 13739:2020)
- **Trim:** difference between the fore and aft draught of the vessel. When the aft draught is greater than the forward draught, the vessel is said to be trimmed by the stern. When the aft draught is less than the forward draught, the vessel is said to be trimmed by the head. (ISO 13739:2020)

Chapter I: Introduction

Definition of the term “bunkering”

The word “bunker” is derived from the Scottish word “bunk,” which means a reserved seat or bench. The term “bunker” is also used extensively in the armed forces’ terminology to define an area to store and safeguard personnel and supplies, such as fuel, ammunition and food (Wankhede 2019).

In the shipping industry, the word bunker is used for fuel and lube oils, which are intended to be used for machinery operation only. If a vessel is carrying marine fuel or lube oil to discharge it to another port, it will not be called "bunker." If, on the other hand, the vessel or truck is carrying it to transfer to another vessel for use in its machinery, it will be termed "bunker,” and the operation can be labeled "bunkering.”. When the vessel receives any kind of oil for use in its machinery, it is called bunker fuel or bunker oil.

Bunker fuel can be supplied to a vessel in a variety of ways. The mode or method may vary depending on the grade or type of fuel being delivered to the vessel. There are three main types of bunkering operations depending on the location and method of fuel transfer:

- Ship-to-ship (STS) bunkering: This method involves transferring fuel between two ships while anchored or in proximity. It is commonly used for offshore bunkering operations or when vessels are unable to access port facilities.
- Shore-to-ship bunkering: In this type of bunkering, fuel is transferred from onshore storage facilities to ships berthed at ports. Shore-based bunkering infrastructure, including pipelines and loading arms, facilitates the fuel transfer.
- Truck-to-ship bunkering: This method involves using road tanker trucks to transport fuel to vessels. It is commonly used in situations where shore infrastructure is limited, if the quantity of the bunkers to be delivered is not substantial enough to warrant delivery via higher capacity means, or when vessels are berthed in areas without dedicated bunkering facilities.

Regulatory framework for the safe bunkering of vessels

The International Maritime Organization (IMO) has issued rules on pollution of the marine environment with the "International Convention on the Prevention of Pollution from Ships" (MARPOL) and the International Chamber of Shipping has issued an International Safety Guide for Oil Tankers and Terminals (ISGOTT n.d.), which gives clear instructions with check lists for the bunkering process depending on the class of ship in order to reduce the chances of accidents.

In addition to the IMO regulations, it is seen that individual states and/or ports have their own regulatory regimes covering bunkering operations. At the same time, many owners have their own specific requirements, instructions and procedures related to such operations, which are laid out in the ship`s Safety Management System (SMS) and the Shipboard Oil Pollution Emergency Plan (SOPEP). Based on these guidelines, ship owning companies are free to draw up their own bunkering plan, which is described in detail in a special chapter in the ISM Code, to define the personnel involved in the process and the distribution of their tasks, the maximum volume of bunkers for each tank, the method of measuring the tank temperature, and all the individual stages to ensure the correct materialization of the procedure.

Presidential Decree 293 (ΦΕΚ Α' 1986) applies to oil transfer operations of Greek and foreign ships conducted within Greek ports and territorial waters, as well as to Greek ships refueled in foreign ports, regardless of any additional requirements provided for in these ports.

According to this decree, depending on the mode of supply, the Master of the barge, the designated person of the shore installation, or the driver of the road tanker are designated as the supplier's representative, and the Master and Chief Engineer of the ship receiving the fuel are designated as the fuel receipt officers. It also specifies the responsibility of the Port Authorities for the control of ships being refueled, their fire safety measures and necessary equipment, the time allowed for bunkering, safety measures during anchoring and mooring, preparation for bunkering, and measures during bunkering.

In many cases, the local port authorities, such as the Central Port Authority of Mytilene, Gytheio, et cetera further specify the general principles of the bunkering procedure defined by the legislation, considering the conditions prevailing in their areas of responsibility and factors such as vessel and ship traffic density, adjacent areas, vessels, available personnel to conduct inspections, normal weather conditions, et cetera.

Safety regulations and protocols make the bunkering procedure rather convoluted and inevitably create a burdensome amount of bureaucracy. The cost of the procedure is not limited solely to the price of the bunkers. The distance from the port of refueling to the vessel's target destination and the time in standby at the port of refueling must also be considered. Also, reliable communication with the local agent and the supplier must be established so that the operation can be conducted without any delay. The pressure created by these factors often urges the parties involved to act on the mentality that "time is money" rather than "safety first." Consequentially, safety protocols are bypassed, with very adverse effects.

Hazards in the process of bunkering

Bunkering, like other seafaring tasks, encompasses inherent risk. While most bunkering procedures are carried out and finished without incident, there is always the possibility that something may go wrong. Because of the possibility of bunker tank overflows, the bursting of defective bunker hoses, or leaking from poor bunker manifold connections, these procedures create a higher-than-average risk. Due to the crucial nature of these procedures, even tiny mistakes might snowball into serious risks.

Such occurrences may cause significant oil contamination in port or coastal waters, resulting in third-party property damage, economic loss claims, high clean-up expenses, vessel delays, and possibly criminal negligence penalties. The environmental effect may be devastating, with long-term consequences for marine life and coastal ecosystems. In summary, a commonplace procedure may swiftly devolve into a shipowner's and shipmaster's nightmare.

Compounding these factors is the relentlessly rising price of oil and its derivatives, coupled with an ever-increasing awareness of marine environmental protection. This evolving landscape has transformed the bunkering of ships from a relatively low-skill, low-value activity into a highly focused shipboard operation demanding stringent regulatory compliance and rigorous quality and quantity assurance.

Human error usually takes center stage in bunkering incidents, ranging widely from incorrect hose connections and improper valve operations to miscommunications between the vessel's crew and bunker barge personnel. Comprehensive training and clear communication protocols are essential to minimize the probability of such errors appearing. Regular drills and assessments can help ensure that crew members are well-prepared and understand their roles and responsibilities during bunkering operations.

Another culprit for these types of events can often be equipment failures such as ruptured hoses, faulty valves, and malfunctioning pumps. These failures can stem from inadequate maintenance, wear and tear, or manufacturing defects. Such incidents can be avoided by ensuring that all equipment used in bunkering operations is regularly inspected and maintained and, moreover, that high-quality, certified equipment is being used.

External factors, such as weather conditions, may also disrupt the smooth operation of the bunkering process. For instance, high winds might cause strain on the attached bunkering hose, while rough seas can destabilize the vessel, making precise operations more challenging and changing the vessel's trim and list, thus reducing the tanks' and save-alls' effective capacity. The nature of the fuel itself adds another layer of problems. Distinct types of bunker fuel have varying degrees of volatility, viscosity, and potential for environmental damage or harm to human lives. Heavier fuels are more challenging to manage and clean up in the event of a spill, while lighter, more volatile fuels can pose higher fire and explosion risks.

Overall, it is evident that the process of bunkering is fraught with various hazards. The first and most crucial step in mitigating the impact of these hazards is to recognize their existence. Recognizing and respecting the complexity and potential dangers inherent in bunkering can lead to more informed and cautious practices, ultimately safeguarding the marine environment and the interests of those involved in maritime operations. Each aspect, from environmental risks and technical failures to human error and external conditions, plays a critical role in the overall safety of the bunkering process, and as such, the safety measures that are put in place must be properly understood and well respected by all responsible parties.

Chapter II: Breakdown of a Bunkering Operation

Throughout this chapter, a comprehensive overview of an ordinary bunkering procedure will be laid out. The purpose of this chapter is to lay the groundwork for the reader to familiarize themselves with the bunkering process, to the extent that the much more detailed Hierarchical Task Analysis that follows does not feel "out of their depth". This chapter is by no means an exhaustive description of the entire procedure and should not be considered as such. Having said all that, below are some key steps to the successful completion of the bunkering process.

Planning the Bunkering Operation

The planning phase of the bunkering operation is of critical importance, yet it can often be overlooked due to the frequency with which it is conducted by a vessel's personnel. It is important to remember that there can be drastic differences between bunkering operations, and, as such, the methodology of each operation must be adapted to the conditions that are prevalent at a given time.

In the preliminary phase of the bunkering operation, the Chief Engineer is tasked with creating a pre-loading plan. The volume of bunkers to be received, the loading sequence of the bunker tanks, and the correct final ullage of each tank must be written down. The Chief Engineer must also designate the personnel that are required to take part in the bunkering operation and clarify each person's role and responsibilities throughout the procedure. Finally, a detailed bunkering checklist must be created, outlining the step-by-step process that must be followed to safely and effectively conduct the operation.

After the pre-loading plan and bunkering checklist have been hatched, the Chief Engineer must conduct a meeting with the crew to familiarize the designated personnel and establish the proper way to conduct the routine and emergency procedures that they may have to undertake. After the theoretical training, an oil spill drill must be conducted to better prepare personnel to mitigate such an event should the occasion arise.

Figure II-A: A crew meeting is conducted prior to the operation

Aside from the crew, the equipment necessary for undertaking the procedure must be ensured to be in good working order. The bunker pipelines must be pressure-tested at least once every six months, according to most shipping companies' SMS. Additionally, the remote level gauges and overflow alarms should be activated and ensured to be working via soundings and mock overflow tests. All crew must be equipped with properly working transceivers to facilitate communication. Personnel must also learn certain hand signals as a secondary means of communication (Ships Business 2015).

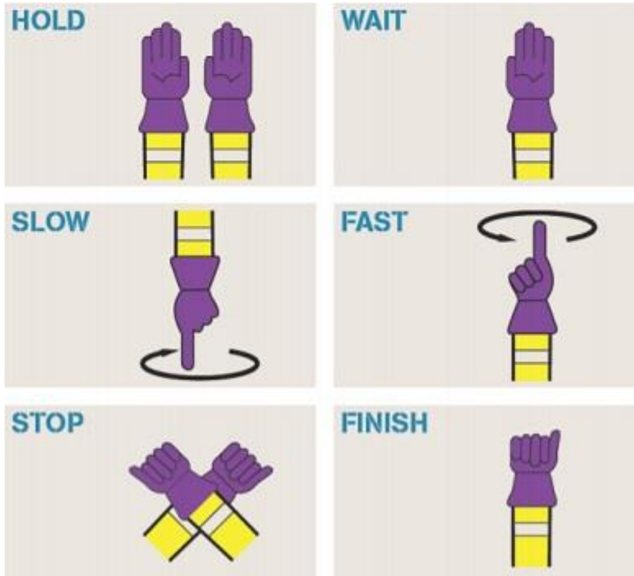

Figure II-B: Basic hand signals for the bunkering

For the safety of the personnel in the event of a bunker spill, all the external doors and ports of the accommodation deck must be closed and remain as such throughout the procedure. This way, the accommodation deck will remain uncontaminated by hazardous materials and can function as a safe space for personnel and a base of operations for the mitigating procedures that must take place. The hatch lids of the vessel's cargo space and bunker tanks must also be sealed shut for a similar reason.

If the vessel does not have a designated overflow tank, the Chief Engineer must nominate one, ensure that it is empty and that no other type of liquid is routed towards said tank, and connect it directly to the bunker line in such a way that, if an excess quantity of bunkers is supplied, said bunkers will automatically be routed towards the designated overflow tank.

Before the Bunkering Operation

Prior to commencing the operation, personnel must strive to ensure that all applicable safety and precautionary measures have been implemented. All the bunker manifolds that are not in use must be blanked off to prevent bunkers from escaping through them in the event of an overflow. In the same spirit, all the overboard discharge valves must be closed, and the scuppers and save-alls of the vessel must be plugged. Drip trays should be placed underneath the bunker hose connection and all the other potential points of leakage throughout the bunker line system.

Figure II-C: Personnel must plug all scuppers and save-alls of the vessel

On the nominated bunker manifold, personnel must fit all fuel oil sampling equipment, alongside a pressure gauge, a thermometer, and, optionally, a viscometer. SOPEP emergency cleanup gear must be strategically placed in high-risk areas of the vessel and be ready for use at any point. Responsible personnel must ensure that all the valves that are critical to the operation function properly and align them in a proper way for the bunker line to be routed towards the first receiving bunker tank.

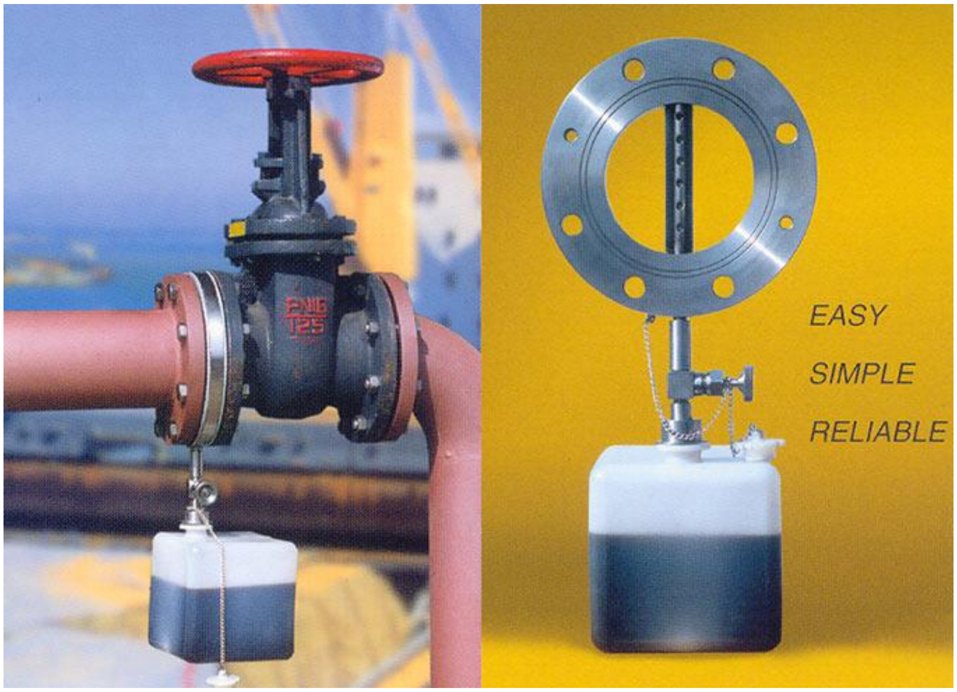

Figure II-D: Drip line sampling valve fitted on a bunker manifold, collecting fuel sample.

To connect the bunkering hose, the vessel must be safely berthed to the bunkering facility beforehand. Throughout this thesis, the term bunkering facility is used as an umbrella term for all the means of delivering bunkers, primarily a bunker tanker, a shore pipeline, or a road tanker. In the case of the bunker tanker, it must be safely berthed on the receiving vessel while the latter is either at anchor or berthed ashore, while the other two methods can only be conducted while the vessel is berthed ashore.

Figure II-E: The bunker tanker is berthed onto the receiving vessel.

After the berthing procedure is successfully completed, the supplier's representative must board the vessel to discuss with the Chief Engineer the details of the oncoming bunkering procedure. During this pre-bunkering meeting, both parties must agree on the quantity and type of bunkers that are to be supplied, the minimum and normal pumping rate of the operation, and the means of communication between the two parties while the process is ongoing.

Aside from the technicalities of the procedure, the two parties must also implement safety measures, such as each party's emergency shut-down procedure. The supplier's representative must also present to the Chief Engineer an MSDS with detailed safety precautions and handling instructions for the bunkers that are to be supplied.

A representative of the vessel should board the bunkering facility for a thorough inspection. During that inspection, the personnel of the facility should be called upon to sound the nominated tanks in order to verify the actual quantity of bunkers within them. The nominated tanks should contain a quantity that can fulfill the vessel's order in the least. Any non-nominated tanks within the facility must also be sounded to later verify that no amount of bunkers have been rerouted there. The representative should also inspect the bunkering hose that is to be used in the operation to ensure its integrity.

Once everything is in order, the bunkering hose can be attached to the manifold, either by the vessel's or the supplier's crew. Prior to beginning the transfer of bunkers, a no-smoking notice must be posted, with designated safe smoking areas identified, while any hot work must cease. All the radars must be switched off, the radio transmitters must be grounded, and the VHF transceivers must be switched to a low-power mode.

Figure II-F: The bunkering hose is connected to the vessel's manifold

During the Bunkering Operation

The Chief Engineer must appoint a watchman to be present at the bunkering station throughout the procedure. It is the responsibility of this watchman to observe any leakages from the bunkering manifold or the connected hose and to ensure that the drip line sampler is working properly and without any tampering. Oftentimes, the watchman is presented with an emergency stop button from the facility. Should he observe any abnormality, he is tasked with pressing the button, which will in turn stop the supply of bunkers immediately on the facility's side.

Figure II-G: An appointed watchman must always be present at the bunkering

Another watchman is tasked with roaming around the deck, keeping an eye out for any signs of bunker leakages from pipelines, tanks, and overboard valves. This watchman will not have access to any means that can stop the procedure immediately. Instead, he must rely on communicating with the Chief Engineer and the supplier's representative directly via a two-way radio.

After a thorough communications check between all parties, the Chief Engineer then gives the go-ahead for beginning the supply of bunkers. During the start of the bunkering, the pumping rate is kept low; this is done to check that the oil is routed to the intended tank. Personnel must perform a sounding of the receiving bunkering tank, but also of all the tanks that are not involved in the operation, to ensure that the bunkers are not involuntarily diverted.

After the completion of all the preliminary checks, the pumping rate is increased to the agreed-upon normal pumping rate. It is recommended that only one tank be filled at a time because monitoring multiple tanks at a time bisects the attention of personnel and, thus, increases the chances of a man-made error occurring. Soundings must be performed regularly, and with higher frequency, the closer the tank gets to being full. Many vessels have tank gauges that show each tank's level in the control room, but personnel should not rely solely on them in case any malfunction occurs.

Figure II-H:Personnel sounding a tank

Once the tank being filled reaches the maximum allowable quantity of 90% of the available capacity, the bunkering facility operator is told to reduce supply to the agreed-upon low pumping rate to top up the tank. Then the valve of the next receiving bunker tank is opened, and the process begins anew, however many times it is necessary to fill all the receiving bunker tanks with the intended quantity.

Finally, after the final bunker tank has been filled, the Chief Engineer informs the facility operator to blow high-pressure air through the bunkering hose with the aim of securely depositing any residual bunkers within the system in the tank. This operation can be particularly tricky since the pressurized air will seek to decompress through any available opening in the system. It is especially important to close and adequately secure all the sounding pipe caps; otherwise, bunkers could potentially overflow through them.

After the Bunkering Operation: Wrap-up

Once the bunkering procedure is finished, the vessel's manifold valve must be closed for safety reasons, but the bunkering hose should not be disconnected just yet. Some time must be allowed to pass for the surface of the received bunkers to stabilize and for the air bubbles mixed with the bunkers to separate and rise to the surface. Once the liquid level has settled, personnel must measure the quantity of the bunkers received in the presence of the supplier's representative. In case of any discrepancy between the agreed-upon amount and the actual amount received, the supplier may agree to compensate for the shortfall and thus may have to resume the bunkering operation.

To verify the quantity of the bunkers received, the chief engineer must sign the bunker receipt (BDN), which serves as proof of delivery. If the actual amount received is contested between the two parties, the chief engineer should write down on the BDN what is considered the correct amount, sign it, and issue a letter of protest against the supplier.

The drip line sample that was taken throughout the procedure is evenly distributed in four sampling bottles. Two samples are kept onboard: one as proof for the vessel in case of future claims and another one to be presented to port authorities or inspectors on behalf of IMO. The third sampling bottle is given to the supplier’s representative, and the last one is sent ashore to a lab for analysis.

After everything is settled, the hose connection is removed. The operation mode of the vessel’s lines and valves is returned to normal, the SOPEP gear is stowed away, and the scuppers and drains are unplugged. The chief engineer makes an entry about the operation in the vessel’s oil record book along with the received BDN. The new bunkers should be kept in the receiving tanks and not used until the report from the lab returns and the results are normal.

Chapter III: Risk Assessment Tools – Methodology

A comprehensive overview of the Hierarchical Task Analysis method

The complexity and risk involved in certain tasks can be highlighted effectively via the conduct of an ergonomic analysis. Through the ergonomic work analysis, the following can be determined:

- The correct planning of a project.
- The distribution of roles between the personnel involved.
- The skills personnel involved should have and the training they should receive.
- Whether automation should be used or not.
- Which safeguards should be used and when.

Furthermore, alternative approaches to the problem can be evaluated and a manual for the correct execution of the task at hand can be created. Such a study can also be conducted in cases where a failure or a dangerous event has occurred to pinpoint gaps or weak points in the implemented safety measures of the routine procedure of the task at hand. From the results of the ergonomic analysis some improvements in the implementation of the procedure can be made to avoid such instances in the future.

Multiple methods of ergonomic work analysis have been developed throughout the years. The most suitable method of analysis may differ, depending on the type of work under consideration and the points of focus of its users. For example, different methods should be chosen between a routine task that aims to better manage employees' time and a new project where it is important to draw up an action plan, taking into account the available resources.

For the needs of this thesis, an ergonomic analysis will be conducted using the method of Hierarchical Task Analysis (H.T.A). A brief description of the method is presented below.

The foundation of what is known today as H.T.A. was laid by Annet et al (Training for Perceptual Skills 1966). Later, it was amended and further developed by Shepherd (Hierarchical Task Analysis 2000). It is a method suitable for tasks where the application of certain actions under certain conditions can be expected to yield the same results, thus allowing the formulation of a repetitive pattern.

In this method, a complex task is broken down into smaller, more manageable subtasks, which can in turn be broken down to the point where everything can be assumed to be self-explanatory to the person who will be called upon to perform the task. A rule of thumb is usually followed: a subproject need not be further analyzed when the probability of making a mistake multiplied by the cost of the mistake is below a specified threshold. Of course, each sub-project, depending on its gravity, can be treated as an independent object of a new Hierarchical Task Analysis. Apart from the final main objective and the individual objectives (task-subtask), a second key characteristic of this method is the description of the structure of the sub-tasks, their hierarchy, in which order they should be executed, and the alternatives followed under different circumstances. It is taken into consideration:

- If a sequence of subtasks must be followed strictly in order.
- If some subtasks are to be executed only under certain conditions.
- If there is a time dependency between subtasks.
- If a subtask should be conducted repetitively.

- If certain subtasks should be conducted simultaneously.

Initially, H.T.A. was used to create manuals and train staff, since it made it easier for instructors to describe in a straightforward way the step-by-step process of completing a task. Today, this method has seen success in a wide variety of fields, such as the design of software for human-computer interaction applications. H.T.A. can be rendered either as a tree diagram or as a table. The former method is exceptionally helpful when used for the analysis of a task in simpler subtasks, while, in the latter, a greater volume of more detailed information can be captured.

For H.T.A. to be an effective tool, it requires the active participation of all involved parties, both during the collection of the necessary information and its implementation. The analyst needs to obtain information, such as the context of the work, the collaboration necessary for its completion, the specific way some tasks must be handled, et cetera The active participation in the process also helps to convince its intended users that the proposed method of execution is the most foolproof. This reduces the chances of its users skipping the steps of execution of sub-tasks for the sake of ease and comfort.

A comprehensive overview of the Bowtie Analysis

The conclusions of a hazard assessment study can be presented via a "risk-barrier-impact" diagram, best known as a bowtie diagram. The bowtie diagram constitutes a structured method of qualitative analysis, in cases where a quantitative approach is difficult or unnecessary.

Bowtie diagrams have a simple format and can be easily understood even by non-experts. A hazard, in this case referred to as a “top event”, is represented by a circle occupying the central position of the diagram. To the leftmost part of the diagram the causes or threatening events of the hazard are placed, and the possible consequences are placed at the rightmost part. The measures that can be taken to prevent the occurrence of the top event, mostly referred to as “preventive barriers”, are shown between the “root causes” and the “top event”. If the preventative barriers fail, whether they are not properly implemented, hampered by other factors or simply not as effective as expected, the top event is triggered. The protective measures to avoid or minimize the effects, called “mitigating barriers”, are depicted between the “top event” and the “consequences”.

The preventative and the mitigating barriers are not themselves impervious to external factors that may render them inefficient. For that reason, when a bowtie diagram is created, the “threats” that would hinder a barrier are also listed and, in turn, the barriers that are in place to prevent such an event from happening are placed on the line that connects the “threat” to the barrier that is being affected.

These diagrams are widely used in occupational risk assessment in certain workplaces, where the threatening factors for the safety of workers and the safety measures that can be taken to prevent accidents at work, as well as measures to mitigate the effects of such accidents, can be identified.

Methodology

In this chapter, the methodology implemented in the conduct of this study is being laid out in a brief and concise manner.

To form a spherical understanding of the basics of the bunkering procedure, reference was made to multiple shipping companies’ documents that are crucial to the creation of a pre-bunkering checklist prior to the conduct of the relevant procedure. More specifically, source material from bunkering check lists, Chief Engineers’ standing orders, Risk Assessment studies by the companies, as well as the institutional framework set by the competent authorities, i.e., the IMO, classification societies, port authorities, and P&I clubs.

Based on the knowledge gained from the records, although it is impossible to include all the factors to be taken into account for a foolproof checklist, the creation of what should be a typical bunkering check list was attempted. That said, it should be stated that the parameters of each individual check list can be largely affected by the type of vessel, the cargo onboard, the prevailing weather conditions, and the location where the operation is conducted. Nevertheless, the bunkering checklist that has been created should be able to portray satisfyingly the majority of the bunkering operations taking place on a daily basis.

For the next step, with the help of the created checklist and by utilizing the method of H.T.A., a tree diagram of the bunkering process is created. The purpose of the tree diagram is to break down each of the main tasks into multiple smaller subtasks, until the complexity of each subtask is simple enough for a person with adequate engineering skills, but unfamiliar with the bunkering process to understand. The related hierarchical tree subsequently formed will be highly explanatory, albeit admittedly complex.

From this hierarchical tree, the riskiest subtasks of the procedure will be singled out. Due to the limitations of the HTA in the tree diagram form, namely the conciseness that is necessary to group together such volume of information, the identified critical subtasks will be further developed with the use of the HTA in table form to portray the full picture of the complexity of these seemingly simple tasks. The table will include time constraints, limitations of various types, equipment limitations, personnel limitations, control measures, and hazards.

Through the above-mentioned table, it will be made possible to derive the main risks (top events), the root causes, and the possible outcomes of certain precarious situations. For each of these hazards, with the help of the HTA tree diagram that was initially created, the preventive barriers, i.e., the barriers that prevent the occurrence of the main event, as well as the mitigating barriers, i.e., those that prevent the deterioration of the situation, will be identified, and, in turn, the hazards that may affect those barriers will be inspected upon in similar fashion.

This procedure will be presented in the form of bowtie diagrams, a useful tool that helps the reader better visualize the link between every event and barrier. These diagrams are a powerful tool that demonstrates skillfully, even to the untrained eye, the chain of events that can cause the most minor occurrence to spiral out of control. Thus, it highlights the importance of the existence of each subtask and their crucial role in the safe operation of the vessel.

Finally, all the findings of this thesis will be put to use by analyzing some indicative case studies. Through these tools, the shortfalls and mistakes made by personnel will come to the surface. Hopefully, by the end of this thesis, the reader will be equipped with precious knowledge that will help recognize shortcomings in the way a bunkering procedure is conducted, and occurrences such as the ones mentioned in the case studies will become an even rarer event.

Chapter IV: Hierarchical Task Analysis of the Bunkering Procedure

The bunkering procedure is a complex task that requires the synergy of most crew members throughout. To better understand said procedures, the conduct of an H.T.A. is in order. The first step of the analysis is the division of the main task into four critical subtasks, which will in turn be broken down into subtasks until the level of detail achieved in the analysis is sufficient to accurately portray the root causes of the dangers to personnel, the vessel, its cargo, and the environment. The current analysis breaks down the main task into four subtasks that are to be conducted consecutively. Conducting any part of these separate tasks concurrently would be a breach of the established procedure and increase the possibility of an accident taking place. The four subtasks are the following: (1) Plan out the operation. (2) Prepare the vessel for bunkering. (3) Start the bunkering. (4) Wrap up the bunkering operation.

(1) Planning out the bunkering operation

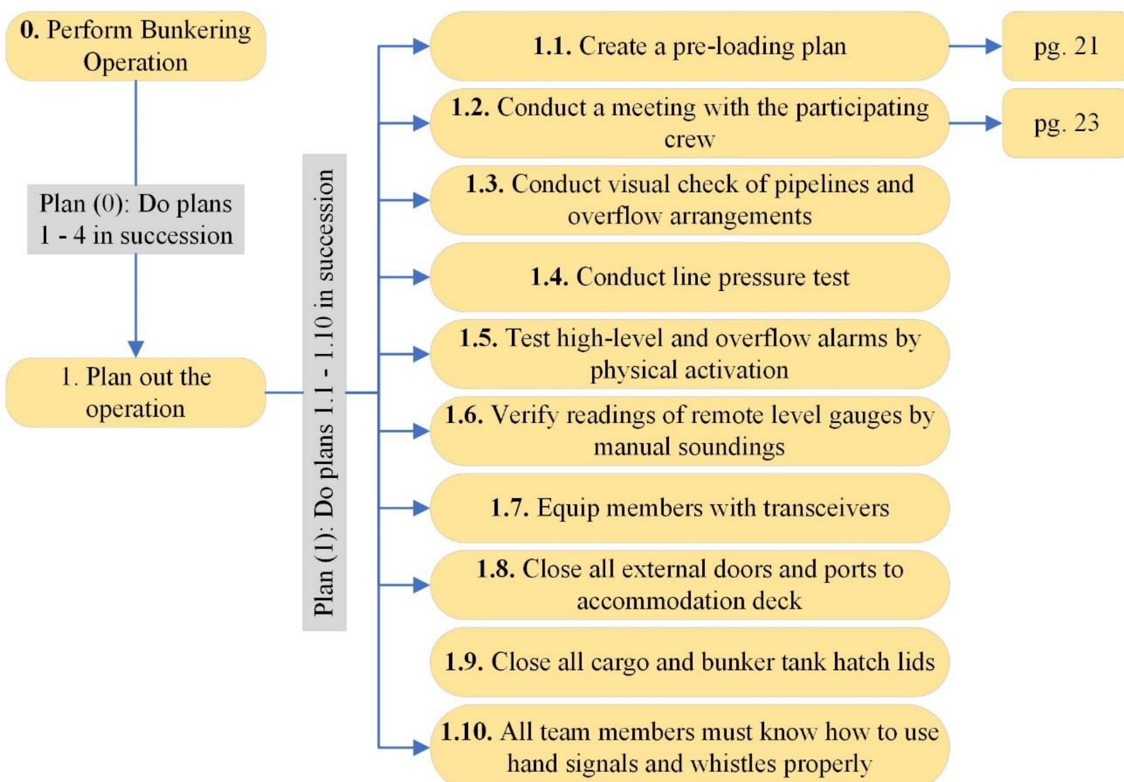

Figure IV-A:Plan out the operation (1)

During the planning phase (1), the chief engineer is deemed responsible for creating a pre-loading plan (1.1) that contains a step-by-step breakdown of the operation and assigns each specific task or set of tasks to an appointed member. A pre-bunkering meeting is to take place in the presence of all the participating crew (1.2) with the purpose of familiarizing them with the pre-loading plan and the responsibilities of each person involved.

After the plan is established and made clear to personnel, a series of checks should be performed. Namely, the system of pipelines should be visually inspected (1.3), and a pressure test should be conducted (1.4) at least once every six months. All the high-level and overflow alarms must be checked by physical activation (1.5), and the readings of the remote level gauges must be verified through manual soundings of the corresponding tanks (1.6). All personnel involved must be equipped with transceivers or have access to inboard phones (1.7) and have adequate training in communicating using hand signals and whistles as a backup (1.10).

All doors and ports leading to the accommodation deck must be closed and remain shut throughout the procedure (1.8). This ensures that in case of an accident, the living quarters of the personnel will not be contaminated and can function as a safe space from hazardous materials and vapors, as well as an operating base for the crew conducting emergency response procedures. In the same spirit, all cargo and bunker tank hatch lids should be closed (1.9) to prevent any contamination of the cargo or the bunkers of the vessel.

(1.1) Creating a pre-loading plan

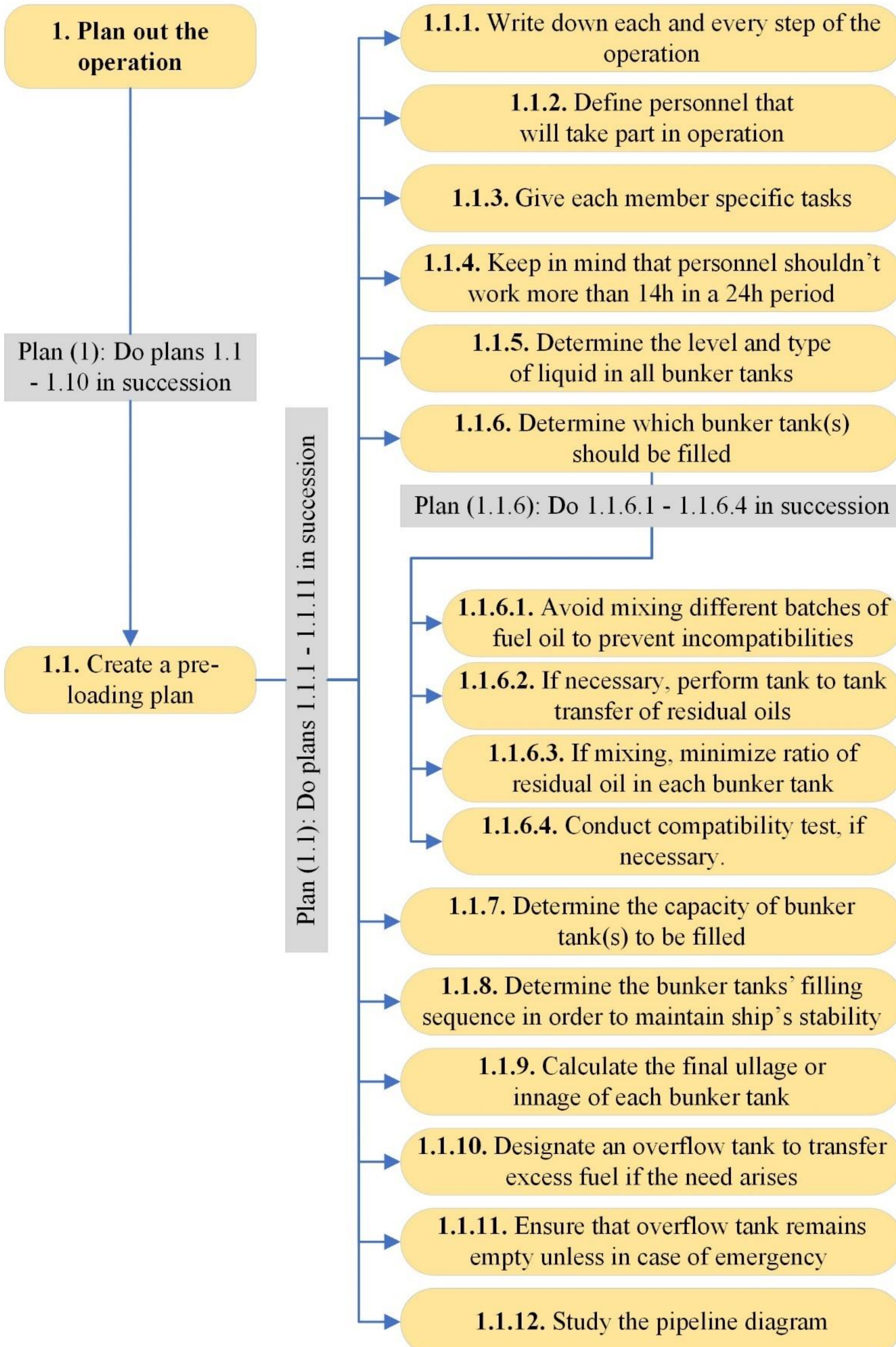

Figure IV-B: Create a pre-loading plan (1.1)

It is of utmost importance for the smooth completion of the operation that a full-proof, concise, and comprehensible pre-loading plan be outlined. A proper pre-loading plan is a powerful tool to be used both by responsible officers and personnel on duty, while a hastily created or non-existent pre-loading plan is often the precursor to accidents and an improper response to emergency situations.

To effectively create a pre-loading plan, the responsible officers must write down the operation step-by-step (1.1.1), study the pipeline diagram (1.1.12), define the personnel that will take part in the operation (1.1.2), and give each member specific duties to uphold (1.1.3). It is important to keep in mind that exhausted personnel increase the probability of human error, and as such, it is required by law for the participating crew to work no more than 14 hours in a 24-hour period (1.1.4), unless in case of an emergency. If the operation is expected to last longer than that, the responsible officers must plan and designate backup personnel.

A precise calculation of the level and type of liquid in all the vessel's bunker tanks (1.1.5) should take place, which will determine which bunker tank or set of tanks will be filled (1.1.6). It should be noted that mixing different batches of fuel poses significant risk and should be avoided at all costs (1.1.6.1). The composition of each bunker batch may differ from port to port or even from the same port on different dates. Mixing incompatible bunker batches may create sludge, which in turn can damage critical machinery and equipment. Although it is preferred that each bunker batch occupies a different tank or set of tanks, if there are not enough empty tanks to accommodate the new batch, a tank-to-tank transfer of the residual oils in the same tank(s) may be in order (1.1.6.3). If the overall tank capacity does not allow for the accommodation of the new batch, the residual oils should be poured in equal percentage into the receiving tanks, but only after a compatibility test has been conducted between the bunker batches that are to be infused (1.1.6.4).

The responsible officer(s) must determine the capacity of the designated bunker tanks (1.1.7) and calculate the final ullage or innage that the soundings should read (1.1.9) before changing over tanks or terminating the procedure. Any reading above the determined limit should trigger an emergency response to all personnel since there is an elevated risk of the tank overflowing. It is important that the filling of the tanks does not affect the vessel's stability, since that could create a plethora of problems that are to be further analyzed in an upcoming chapter. Thus, a tank filling sequence that maintains the vessel's stability must be determined (1.1.8). Most of the newer ships have a predetermined overflow arrangement that automatically reroutes any excess oil to a slack tank or distributes it equally to adjacent bunker tanks. For the older vessels, it is important to designate an overflow tank into which the excess bunker will be rerouted manually in case the receiving bunker tank fills above the established safe level (1.1.10). Said overflow tank should be emptied and remain empty in preparation of an emergency (1.1.11).

(1.2) Conducting a meeting with the crew

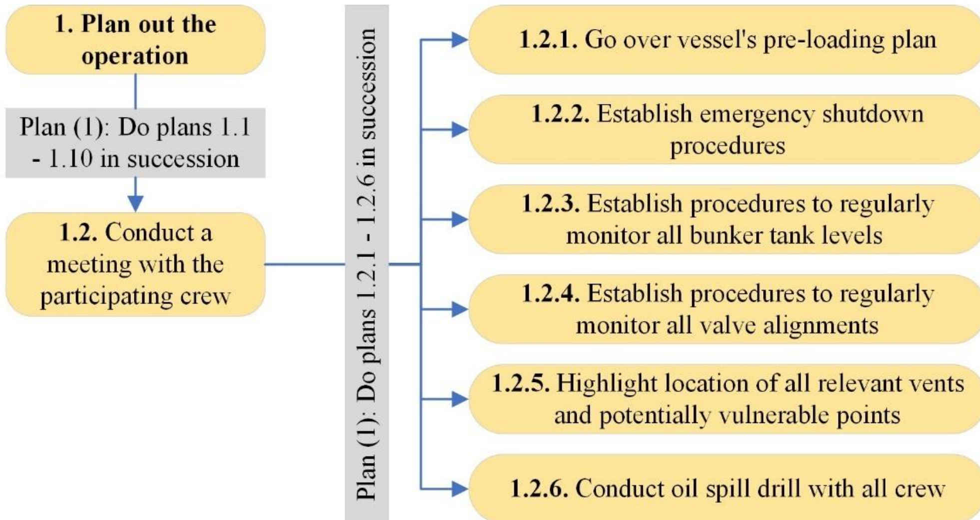

Figure IV-C:Conduct a meeting with the crew (1.2)

After the pre-loading plan has been created, a pre-bunkering meeting should take place between all concerned personnel. The purpose of this meeting is to familiarize personnel with the pre-loading plan (1.2.1) and go over the vessel's emergency shutdown procedures (1.2.2), which must be known and well understood by all the crew. The officers should establish procedures for the personnel to regularly monitor the level of all bunker tanks (1.2.3) and check that all valves remain in the correct alignment (1.2.4) throughout the procedure. All the vulnerable points of the system should be highlighted, especially the vents from which a tank overflow might occur (1.2.5). Finally, all the vessel's crew should conduct an oil spill drill (1.2.6) to confirm readiness and familiarity with the vessel's SOPEP.

(2) Preparing the vessel for bunkering

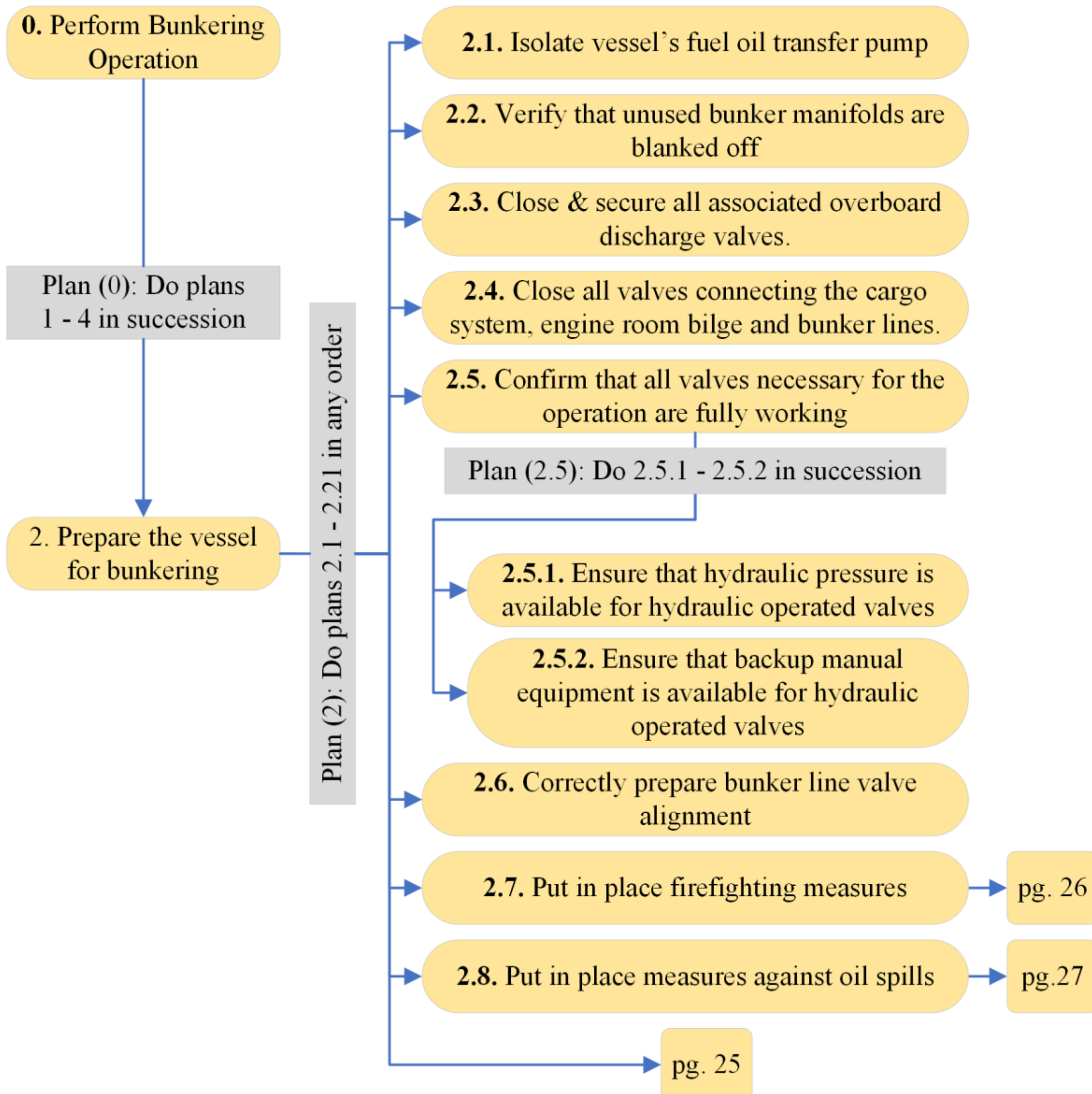

Figure IV-D: Prepare the vessel for bunkering pt.1 (2)

Prior to connecting the vessel with the bunkering facility, the crew must make certain preparations that are necessary for the smooth and safe conduct of the operation. In the case of fuel bunkering, the fuel oil transfer pump must be turned off (2.1). The same principle applies to all different types of bunkers as well. As a safety precaution, the unused bunker manifolds should be blanked off (2.2), and any overboard discharge valve should be closed and secured (2.3), to prevent the accidental discharge of liquids during a worst-case scenario. Additionally, any valves connecting the cargo system and the engine room bilge to the bunker lines should also be closed (2.4).

Responsible personnel should confirm that all the valves that are necessary for the operation are properly functioning (2.5) and correctly prepare the bunker line valve alignment that leads to the first tank or set of tanks that is due to be filled (2.6). The appropriate firefighting measures should be put in place (2.7), as well as measures against oil spills, in accordance with the vessel's SOPEP (2.8). Appointed personnel should also check that each bunker tank's air vent is unobstructed and fully operational (2.9).

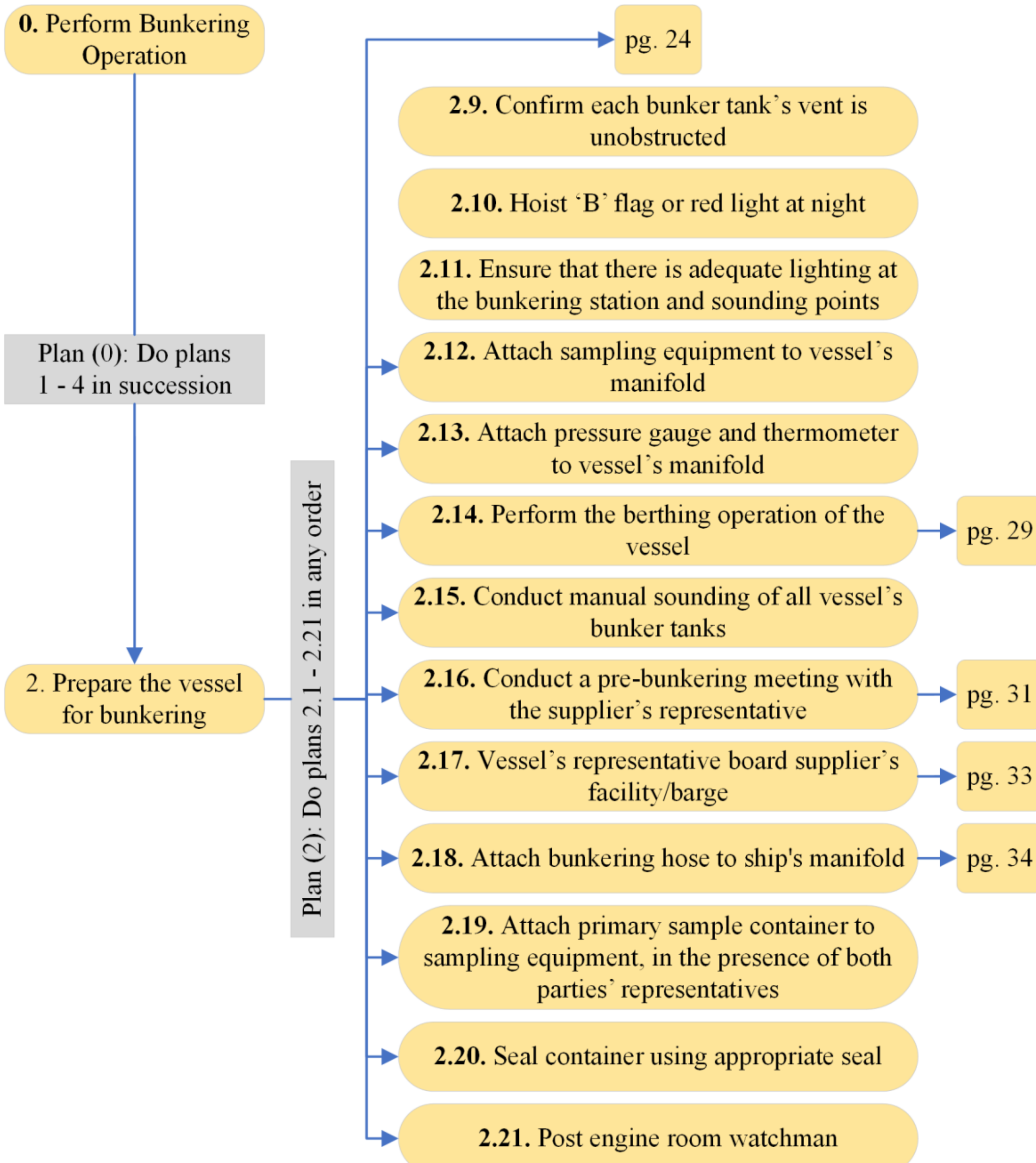

Figure IV-E: Prepare the vessel for bunkering pt.2 (2)

The vessel must hoist a 'B' flag that signals to all nearby vessels and facilities that a bunkering operation is ongoing (2.10). At night, instead of the flag, a red light must be turned on at the mast of the vessel. Adequate lighting must be provided to the bunkering station and the sounding points throughout the procedure (2.11), to facilitate the smooth conduct of the operation and prevent crew errors due to low visibility. The bunkering manifold that is to be used must be retrofitted with a drip line sampling valve (2.12), a pressure gauge, a thermometer (2.13), and, optionally, all other measuring instruments available, such as a viscometer.

After the preparations are complete, the vessel is now ready to conduct a berthing operation with the facility (2.14). The supply of bunkers is most commonly conducted by a bunker tanker that berths on the side of the vessel where the bunkering manifold is prepared while the vessel is anchored mid-sea near a port. Oftentimes, while the vessel is berthed at a port, bunkers can be supplied via a shore pipeline or by road tankers. For the sake of simplicity, the analysis of the thesis revolves mostly around the method of bunkering by bunker tanker, the reason being that it is a more complex operation than bunkering by shore pipeline or road tankers, while the steps to be conducted remain essentially the same, with a few minor adaptations.

Appointed personnel should conduct a manual bunkering of all vessel tanks (2.15) to confirm the measurements of the pre-loading plan. Said pre-loading plan is to be discussed with the supplier's representative during the pre-bunkering meeting of the two parties' responsible officers (2.16). After the pre-bunkering meeting is completed, the vessel should appoint a representative to board the bunkering facility and make some key observations (2.17).

After going through the previous steps, it is now time to attach the bunkering hose to the vessel's designated manifold (2.18). Prior to starting the transfer of bunkers, responsible personnel must attach the primary sample cubitainer to the manifold's sampling equipment (2.19) and then seal the container using an appropriate seal in the presence of both parties' responsible officers (2.20). The vessel must appoint an engine room watchman (2.21) to monitor the reading of the remote level gauges of all tanks and the control room's emergency alarms throughout the procedure.

(2.7) Putting in place firefighting measures

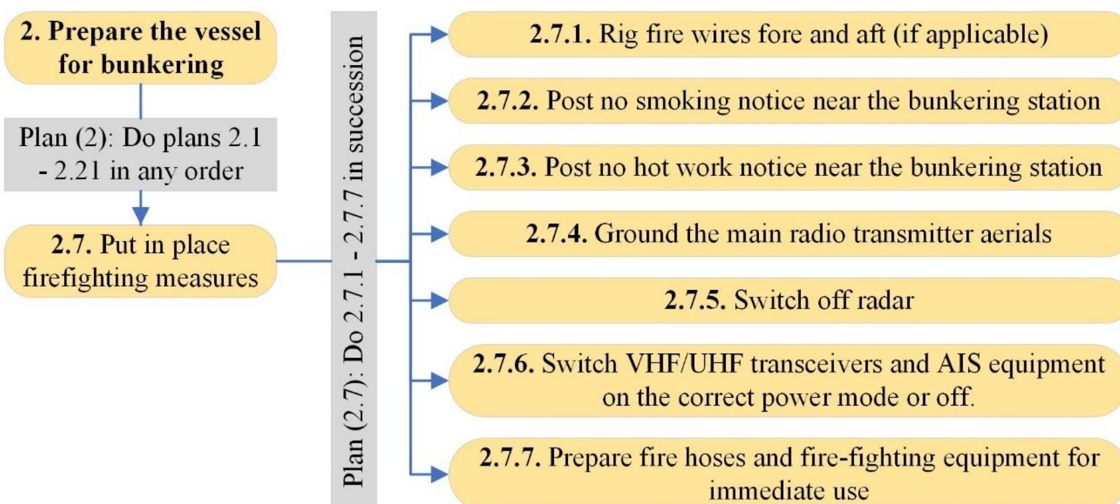

Figure IV-F:Put in place firefighting measures (2.7)

It is no secret that bunkers are highly flammable, whether it be MGO, MDO, LO, or any other type of liquid. Therefore, it is of utmost importance to implement and uphold strict firefighting measures. It is common for some types of vessels, especially those carrying flammable cargo, to rig fire wires fore and aft (2.7.1). A fire wire is a wire that can withstand the force applied to it while towing the vessel and is invulnerable to fire and elevated temperatures. Should the fire onboard a vessel become unquenchable and pose a threat to surrounding vessels, facilities, or personnel, a tow boat could become attached to a fire wire and drag the vessel engulfed by flames further away from its current position.

It is important to prevent the presence of naked flames or sparks on a vessel that is undergoing a bunkering operation for fear of an oil spill occurring and being accidentally ignited. That is why a no smoking notice (2.7.2) and a no hot work notice (2.7.3) should be posted for the area near the bunkering station. The main radio transmitter aerials should be grounded (2.7.4), the radar should be switched off (2.7.5), and the transceivers and AIS equipment should be switched to the correct power mode or off (2.7.6). Fire hoses and other firefighting equipment should be deployed and ready for use near the bunkering manifold (2.7.7). The hoses should be connected to a water supply line beforehand, and their length must be adequate for use around the intended areas. Personnel should confirm that their condition is satisfactory and that they do not become entangled while being deployed.

(2.8) Putting in place measures against oil spills

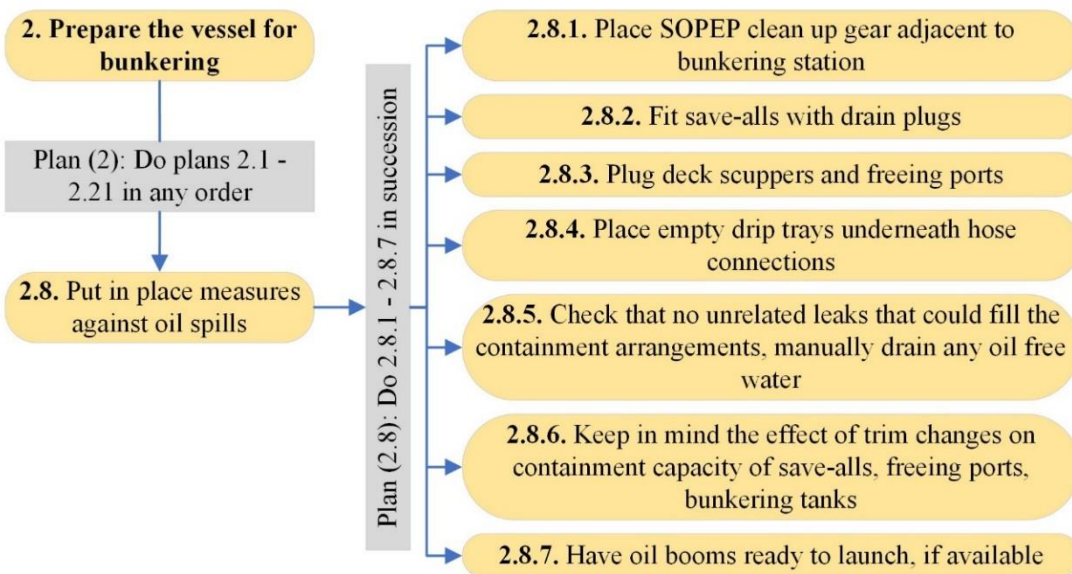

Figure IV-G: Put in place measures against oil spills (2.8)

An oil leak or oil spill is the most common type of accident that occurs during a bunkering operation. For this reason, countermeasures against such occurrences are well thought out and meticulously planned. It is required of all vessels to have a SOPEP crafted to cater to each singular vessel's idiosyncrasy. The plan goes further into detail about the emergency procedures that are to be followed after an event has occurred. The purpose of this thesis is to study the measures that are taken before the occurrence of an event; therefore, a large part of the SOPEP is beyond its scope, but there are still some major takeaways from said document.

The first step to preparing the vessel against oil spills is to place cleanup gear stipulated by SOPEP near the bunkering station (2.8.1) and any place where there is an elevated risk of an oil spill. Some common items of this nature are sawdust, rags, oil absorbents, oil solvents, and disposal barrels. Afterwards, responsible personnel should fit the save-alls with drain plugs (2.8.2), plug all the scuppers and freeing ports on the deck (2.8.3), and place empty drip trays underneath the hose connection as well as any pipeline connections that are at risk of causing an oil leak (2.8.4).

For these measures to be effective, it is important to constantly check that there are no leaks of other types of liquids, such as rainwater or a leaking waterpipe, that could feel the containment arrangements, namely the save-alls, the drip trays, and the vessel's coaming. If an accumulation of such liquids is observed, it should be drained manually (2.8.5). Another major factor to be considered is the effect of trim changes on the capacity of all containment arrangements but also of the bunker tanks that are due to be filled (2.8.6). An excessive list or trim may "tip to the side" said arrangements, meaning that a filled or mostly filled arrangement could spill some of its content under these circumstances.

A final, more "desperate" countermeasure is to have oil booms ready to launch in case an oil spill into the vessel's surrounding waters is imminent or underway (2.8.7). An oil boom, also known as an oil fence or oil float, is a sort of "fence" that floats on the surface of the water. Since oil is lighter than water, it also floats above surface level and can thus be partially contained within the oil boom's confines.

(2.14) Performing the birthing operation of the vessel

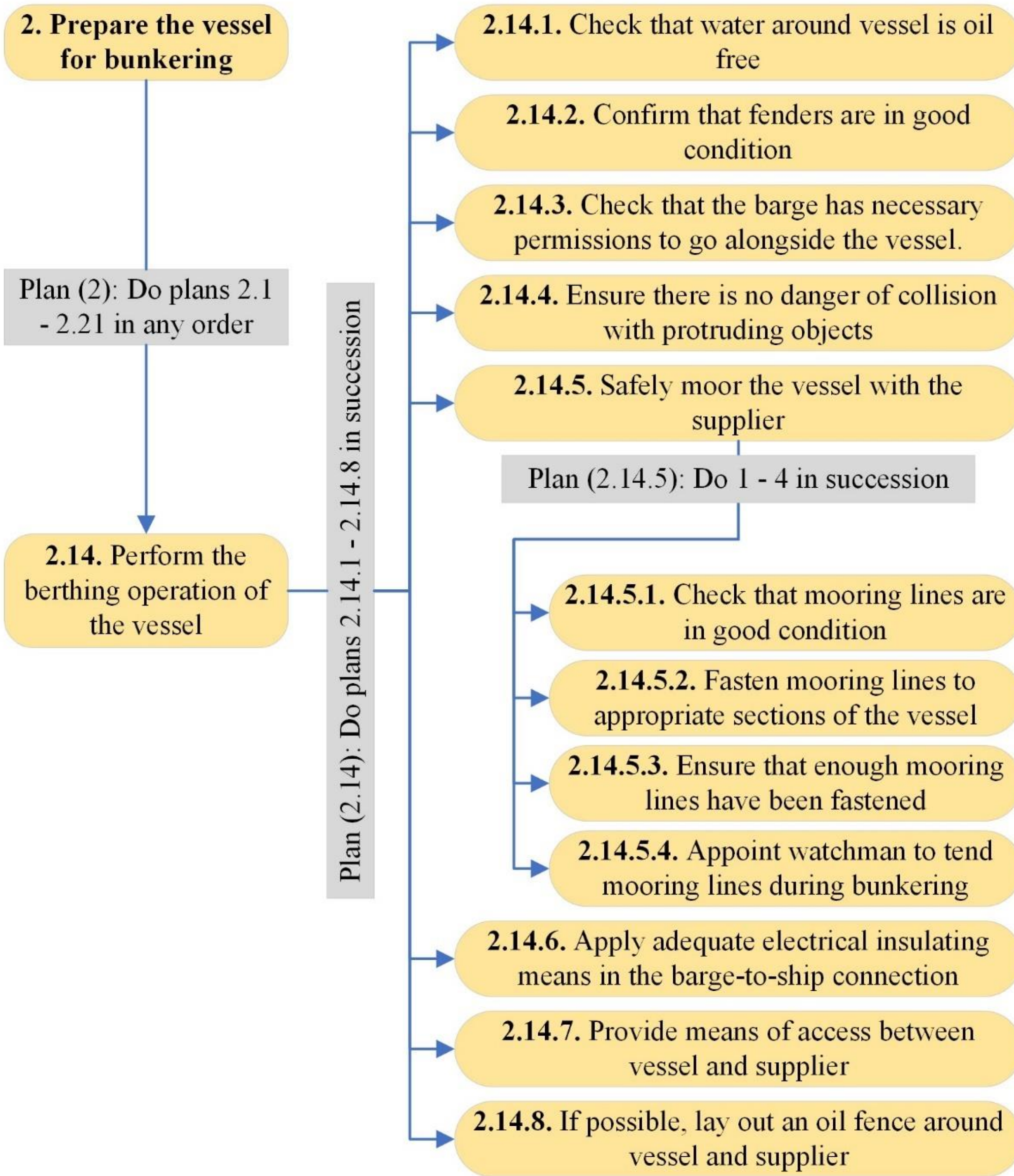

Figure IV-H: Perform the birthing operation of the vessel (2.14)

Prior to berthing, while the vessel is in proximity to the bunkering facility, personnel should be on the lookout for any indications of oil pollution in the water (2.14.1). The fenders of the bunkering facility should be in good condition (2.14.2) to prevent metal-to-metal contact and absorb the shock from any minor collision between the two parties. It should be ensured that there are no objects protruding, either from the vessel or the facility, that pose a threat of collision (2.14.4). After the previous checks are completed, the mooring of the barge to the vessel (or of the vessel to the port) is in order (2.14.5).

The mooring lines to be used must be in good condition (2.14.5.1) and fastened to appropriate sections of the ship (2.14.5.2) to avoid damage to the vessel (bending or breaking of the mooring point) and the possibility of the mooring line coming loose. A sufficient number of mooring lines must be fastened (2.14.5.3) to prevent free movement between barge and facility (2.14.5.3). Adverse weather conditions may increase the number of mooring lines necessary for the task. A watchman should be appointed to tend to the mooring lines at all times (2.14.5.4).

Electrical insulating means must be applied between the two parties (2.14.6) to prevent the creation of sparks. The vessel's pilot ladder should be used to provide physical access between the two parties, unless deemed impossible by the officers in charge, in which case some other means of access that comply with the guidelines of SOLAS must be deployed (2.14.7). If the responsible officers determine access is not safe due to weather or sea state, then sole reliance on communication by radio or secondary means of communication should be allowed. As a precaution, an oil fence can be laid out around the vessel and the bunkering facility (2.14.8).

(2.16) Conducting a pre-bunkering meeting with the supplier's representative

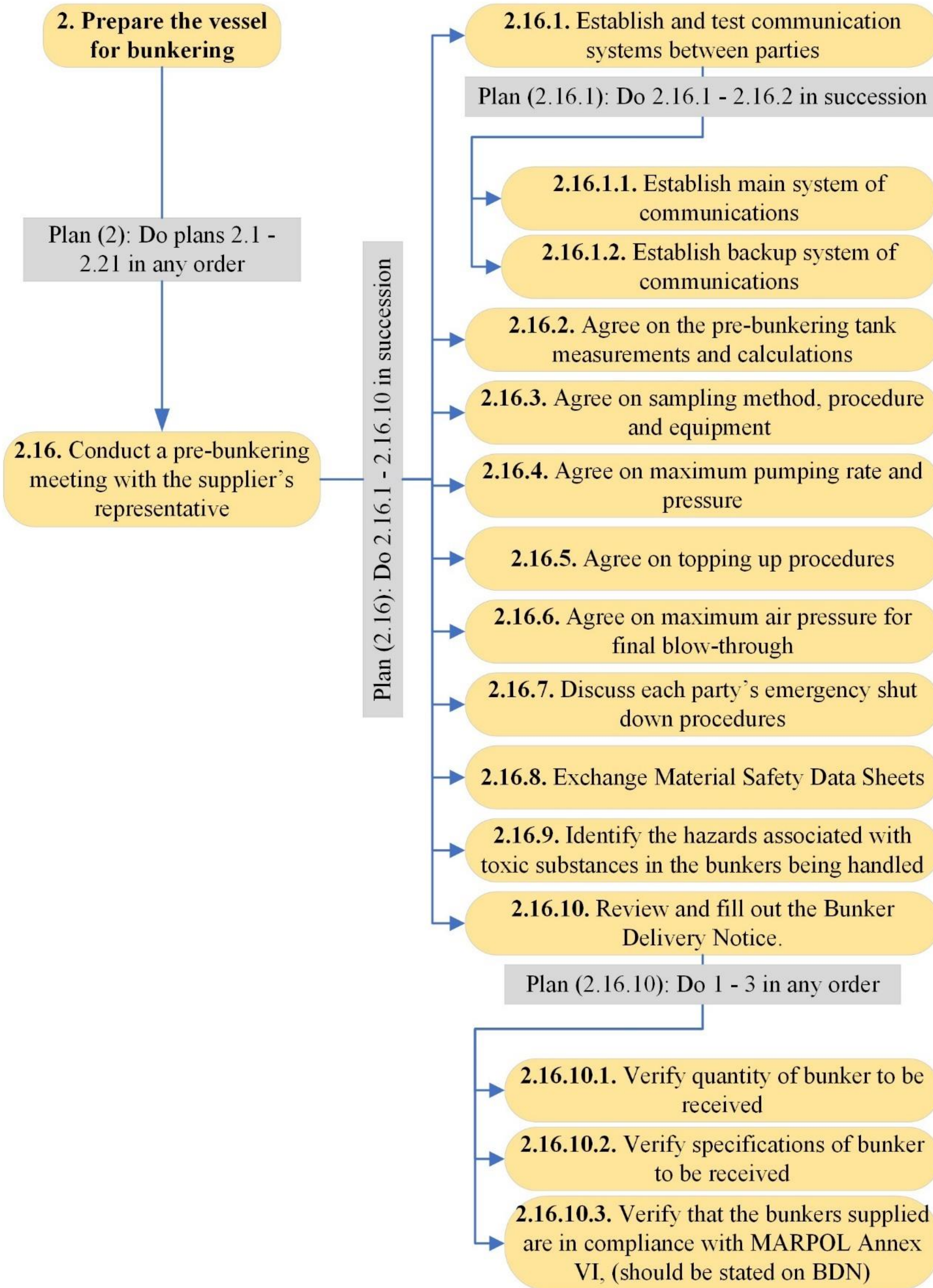

Figure IV-I: Conduct a pre-bunkering meeting with the supplier's representative (2.16)

During the pre-bunkering meeting, communication systems must be established and tested (2.16.1). Communication is mainly achieved through radio, although if the main system of communication fails, the parties must be able to communicate immediately and effectively through other means, such as hand signals, lights, flags, or verbally.

It is also important for the parties to agree on the vessel's tank measurements (2.16.2), on the maximum safe pumping rate and pressure (2.16.4), as well as the air pressure that is to be achieved for the final blow-through (2.16.6). A high pressure in the bunker piping arrangement could create problems such as leakages or, even worse, the parting of the bunker hose. By agreeing on the vessel's bunker tank measurements, the supplier can better calculate the amount of bunkers to provide, and a concise pumping rate ensures that the exact agreed-upon amount of bunkers will be delivered.

Another key point of the meeting is the bilateral agreement on the bunker tank topping-up procedures (2.16.5) since there is an elevated risk of the bunker tank overflowing if proper due diligence is not applied. An emphasis should also be placed on each party's emergency shutdown procedures (2.16.7), which may need the cooperation of both parties to be effective to their fullest extent.

It must be noted that insufficient communication between parties during emergency shutdown procedures may further exacerbate the problem at hand or create an entirely new one. The most prominent example of such a case is the vessel's crew closing against incoming bunkers without notifying the supplier's crew to stop pumping. Such an instance would strain the bunkering line and hose with excessive pressure and may even cause the parting of the hose or bunker line leakage. With that said, such a scenario is less likely in modern times because most bunkering facilities present the receiving vessel with an emergency stop button on the vessel's manifold that immediately stops the pumping on the facility's behalf if pressed.

For the operation to be in compliance with international maritime laws, but also to prevent fraud against either side, a sample of the fuel must be taken throughout the bunkering. Both parties must sign off on the technicalities of said procedure (2.16.3). Oftentimes, the supplier's representative may insist that the sampling equipment be attached to their end of the bunkering hose, but such a proposition must be strongly objected to since it does not comply with international laws and may facilitate tampering with the sampling equipment.

Finally, it is crucial that the proper paperwork is filled out by or exchanged between both parties. Namely, the vessel must be supplied with the bunkers' MSDS (2.16.8), which, amongst others, provides crucial information on the hazards associated with toxic substances in the bunkers (2.16.9). But by far the most important document is the BDN (2.16.10), which officializes the quantity (2.16.10.1) and quality (2.16.10.2) of the bunkers that are to be received but also verifies that, to the knowledge of the vessel's chief engineer, the bunkers received from the supplier are in compliance with MARPOL Annex VI (2.16.10.3).

(2.17) Vessel's representative boards the bunkering facility

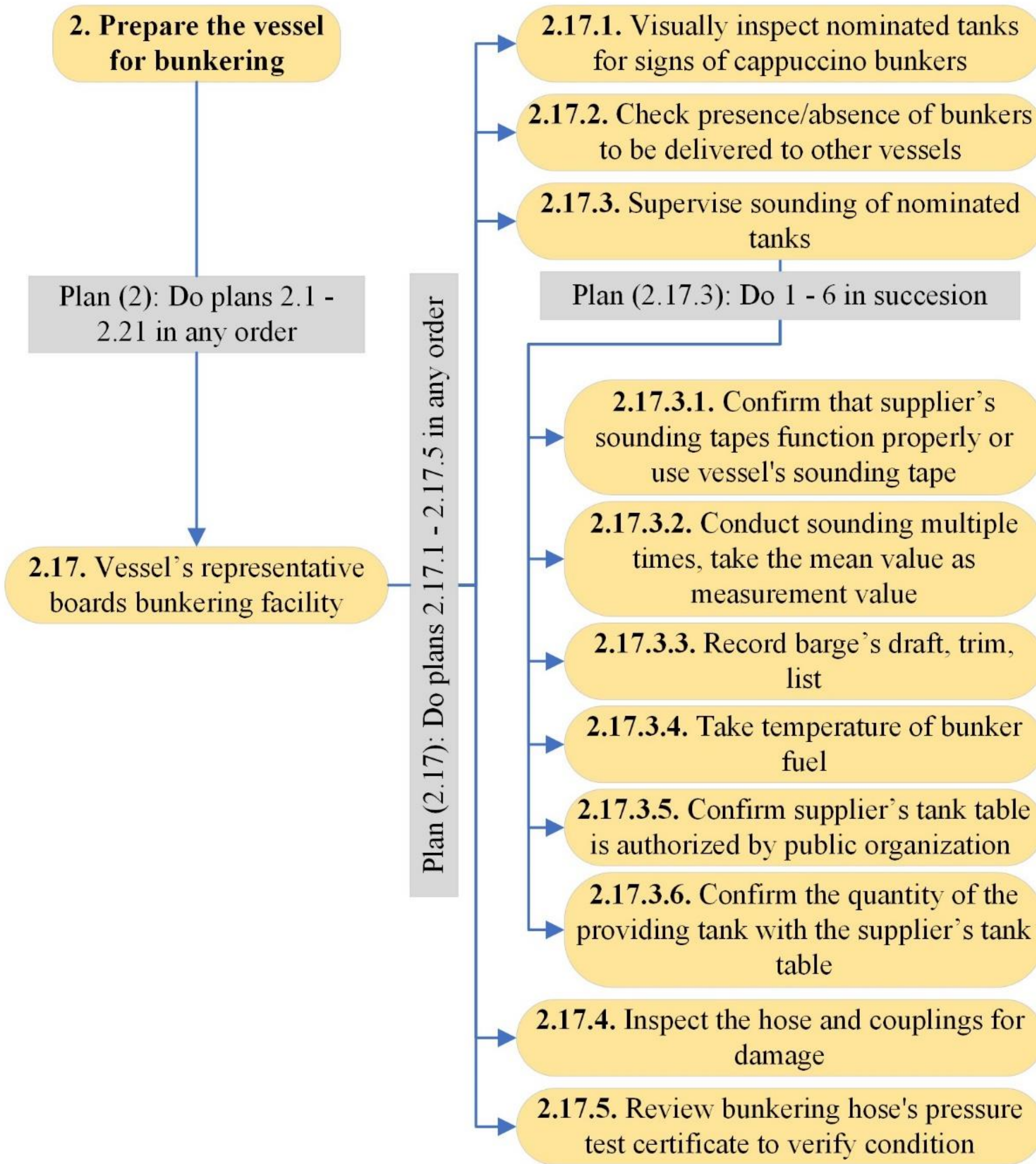

Figure IV-J: Vessel's representative boards the bunkering facility (2.17)

A representative of the vessel must be present at the bunkering facility to witness the sounding of the supplier's nominated tanks (2.17.3) and ensure that said procedure is done correctly and methodically. To rule out the possibility of foul play, the representative should also visually inspect the nominated tanks for signs of cappuccino bunkers (2.17.1) and check on the overall quantity of bunkers and free space available on the barge / facilities (2.17.2).

A common fraud perpetrated by some suppliers is to route some of the bunkers intended for the vessel to other tanks on the facility. That way, once the bunkering is over, they will dismiss the vessel's assertion of a short supply of bunkers by pointing out that the nominated tank or set of tanks that was confirmed to contain the intended amount of bunkers beforehand is empty afterwards. Even if the missing amount gets found in a different tank on the supplier's premises, it will be hard to ascertain that it was in fact originally intended for the vessel if the representative has not checked on all the other tanks and kept a record of their contents beforehand.

While on board the bunkering facility, the representative should also inspect the bunkering hose and its couplings for signs of wear and tear (2.17.4). If, after the visual check, the representative deems it necessary, he may ask for the bunkering hose pressure test certificates from the supplier (2.17.5).

(2.18) Attaching the bunkering hose to the vessel's manifold

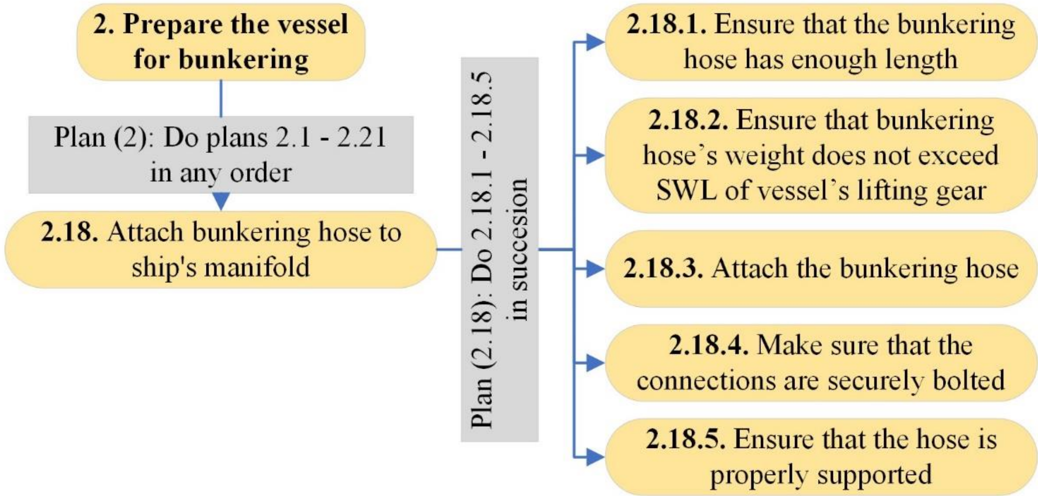

Figure IV-K: Attach the bunkering hose to the vessel's manifold (2.18)

Although on the surface it seems like an easy task, it is of critical importance to follow the due process while attaching the bunkering hose to the vessel's manifold. The bunkering hose must be of enough length (2.18.1) to not only be able to reach from the facility to the manifold but also to withstand the independent pitching of each. Prior to lifting the bunkering hose from the facility, it should be ensured that its weight does not exceed the safe working load of the vessel's lifting equipment (2.18.2); otherwise, the hose could become detached, posing a threat to personnel, the vessel, or the environment. Once the hose has been lifted, it should be properly attached to the manifold (2.18.3) and properly supported (2.18.5) to ensure that it stays in place and to prevent any accidental kinking. The connections must be securely bolted (2.18.4) to prevent any minor leaks during the supply of bunkers through the system.

(3) Starting the transfer of bunkers

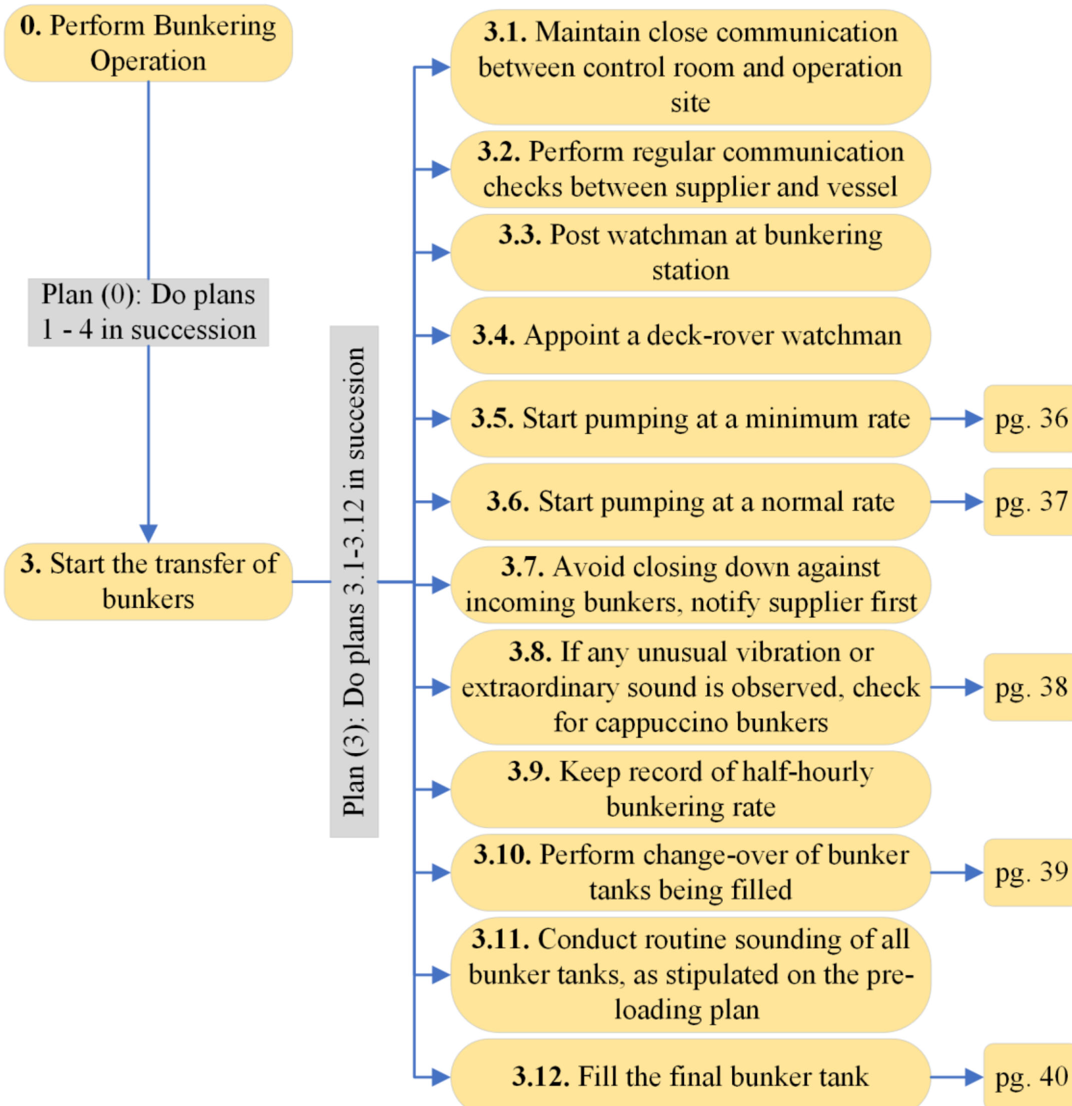

Figure IV-L: Start the transfer of bunkers (3)

Once all the preceding steps are completed, it is time to begin the focal task of the procedure, the transfer of bunkers. While the transferring process is ongoing, close communication must be maintained, both between the operation site and control room (3.1) and between the vessel and the bunkering facility (3.2). A watchman must always be present at the bunkering station (3.3), while another appointed watchman must rove around the deck (3.4), keeping an eye out for signs of oil leaks along the bunkering arrangement and the pipelines and valves all around the vessel, as well as checking the sea surface for oil spills.

While the transfer of bunkers (3.5), (3.6), (3.10), and (3.12) is ongoing, some important checks must be conducted over predetermined periods of time. First and foremost, personnel should always keep in mind that, as previously stated, closing down against incoming bunkers without notifying the operator is strictly forbidden (3.7), especially in the case of an emergency. If at any time personnel observe any unusual vibrations or extraordinary sounds on and near the bunkering hose, then suspicion of cappuccino bunkers must be raised and acted upon (3.8). A record of the half-hourly bunkering rate must be maintained (3.9) to approximate more accurately the received volume and document any abnormalities. Most importantly, appointed personnel must conduct routine soundings of all tanks as per the pre-loading plan (3.11).

(3.5) Pumping at a minimum rate

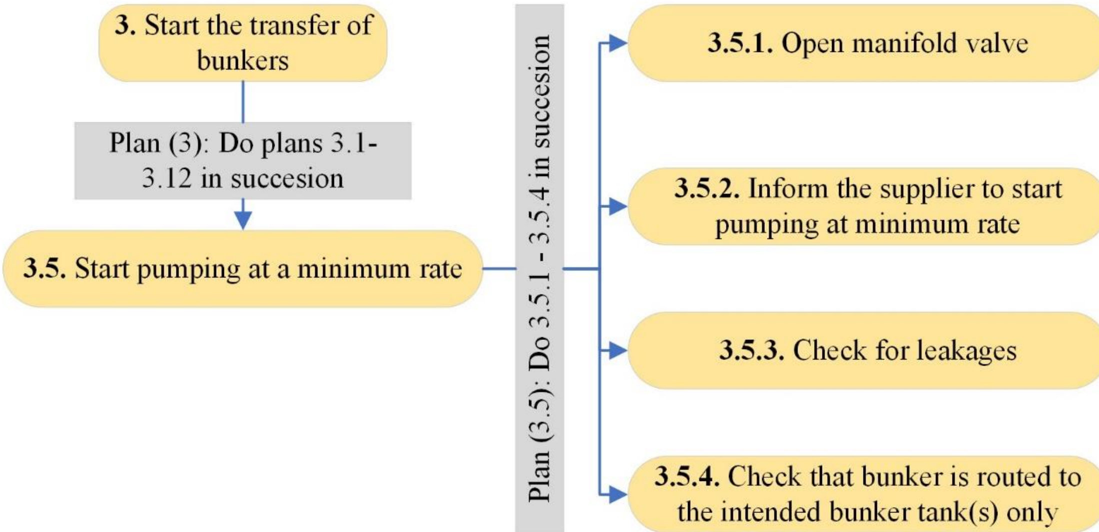

Figure IV-M: Start pumping at a minimum rate (3.5)

Once it is time to start the transfer of bunkers, the order to fully open the manifold valve is given (3.5.1). Prior to initiating the transfer of bunkers at the agreed-upon pumping rate, the chief engineer must inform the bunkering facility operator to start pumping at a minimum rate (3.5.2). During this time, personnel should carefully inspect the bunker line arrangement for any leakages (3.5.3) and check that the bunkers are routed to the intended tank(s) and that there are no bunkers being accidentally delivered to any unintended tanks (3.5.4). After all inspections are completed, the chief engineer can give permission for the operators' crew to start pumping bunkers at a normal rate.

(3.6) Pumping at a normal rate

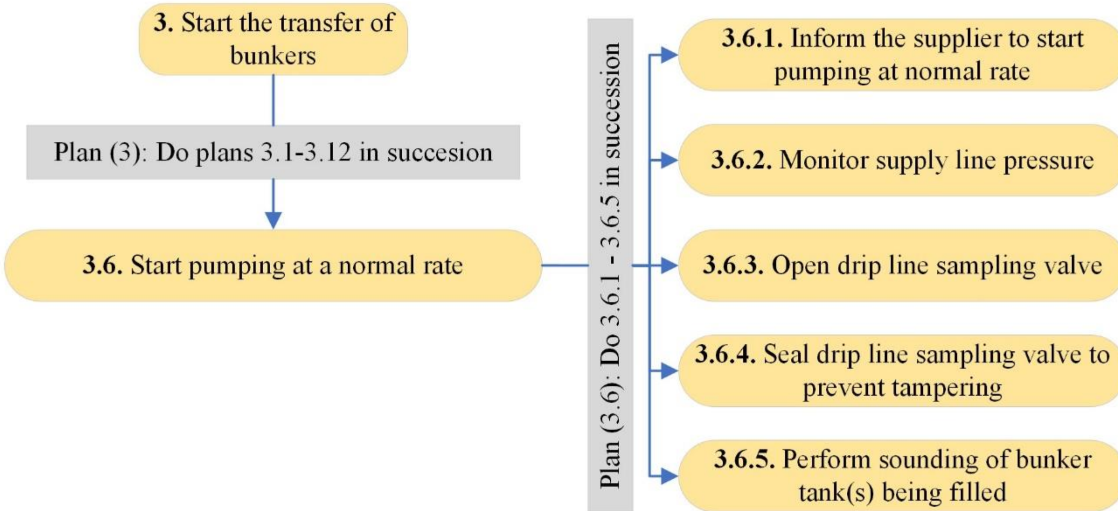

Figure IV-N: Start pumping at a normal rate (3.6)

Once the facility operator starts pumping at a normal rate (3.6.1), personnel should monitor the pressure of the supply line through the attached pressure gauge (3.6.2). The fuel sampling shall begin by opening the drip line sampling valve (3.6.3) and attaching a seal to the valve in the presence of both parties' representatives to prevent it from being operated afterwards without breaking the valve (3.6.4). If it is determined after the application of the seal that the drip rate is insufficient or excessive, the vessel's chief engineer must break the seal in front of the supplier's representative, recalibrate the valve, and then attach a new seal to it.

While pumping at the normal rate, personnel should conduct routine soundings of the bunker tank(s) being filled (3.6.5), as stipulated on the pre-loading plan. Even though in modern times there are multiple remote level gauges and overflow alarms in place on many of the vessels, the proper functioning of such equipment is not guaranteed. Improbable as it may seem, the possibility of an event circumventing all automated systems still exists. That is why, by conducting manual soundings, personnel place another barrier to the occurrence of an accident.

(3.8) Checking for cappuccino bunkers

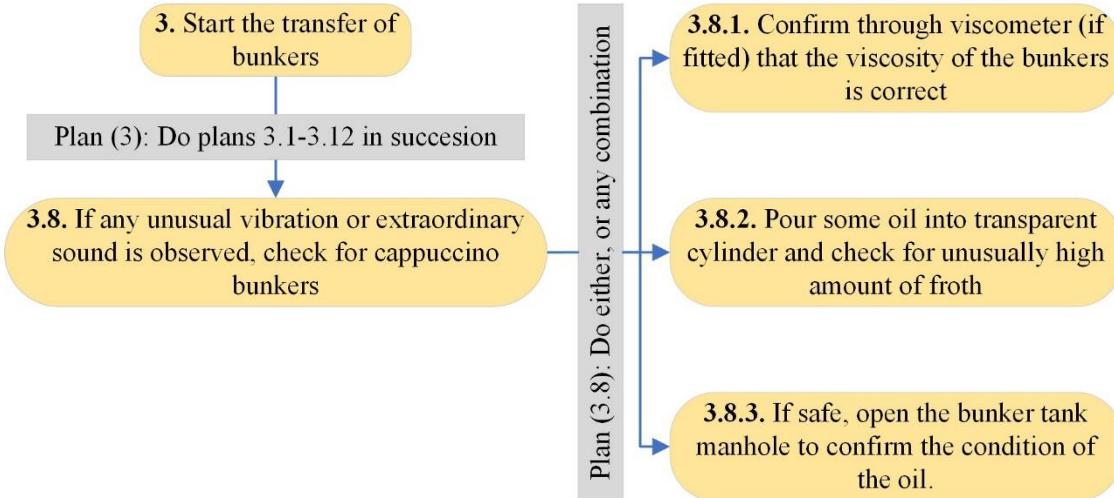

Figure IV-O: Check for cappuccino bunkers (3.8)

Cappuccino bunkers refers to a common malpractice during bunkering operations, often done to defraud the receiving vessel's responsible personnel in regard to the received quantity of bunkers but may also happen by accident. For the cappuccino bunkers to occur, the bunkers must be infused with air, thus creating a frothy appearance (hence the name) and increasing the volume of the original bunkers. For the mixture to happen, air could be blown into the bunkers while in the facility's nominated tank(s), or the bunkers could be supplied under excessive pressure, thus creating bubbles in the liquid supplied. After a while, the air separates from the bunkers, revealing the actual supplied quantity, but by then it might be too late for the unsuspecting receiving vessel's personnel. Aside from the financial damage this fraud might cause, the supply of bunkers under excessive pressure can cause a multitude of problems for the operating equipment and the piping arrangement of the vessel. For these reasons, all personnel should be on the lookout for signs of cappuccino bunkering, such as unusual vibrations or extraordinary sounds coming from the bunkering hose and the piping arrangement.

If a case of cappuccino bunkering is suspected, personnel should first confirm through the viscometer attached to the bunkering manifold that the viscosity of the bunkers is correct (3.8.1). A viscometer would quickly confirm or debunk any suspicion of cappuccino bunkers, but such an instrument might not be fitted during the operation. Another, more rudimentary, way of checking for cappuccino bunkers is by pouring some oil into a transparent container and then visually checking if there is an unusually high amount of froth in the liquid (3.8.2). A small amount of air bubbles is inevitable, so an experienced eye should be trusted to make that distinction.

If none of the previous methods have helped determine conclusively the responsible officers' suspicions, as a last resort and only if allowed by the authorities under which the operation is conducted, the manhole of the bunker tank being supplied can be opened to confirm the condition of the oil (3.8.3). Such a drastic measure should be avoided for fear of an overflow occurring through the opened manhole.

(3.10) Changing over bunker tanks

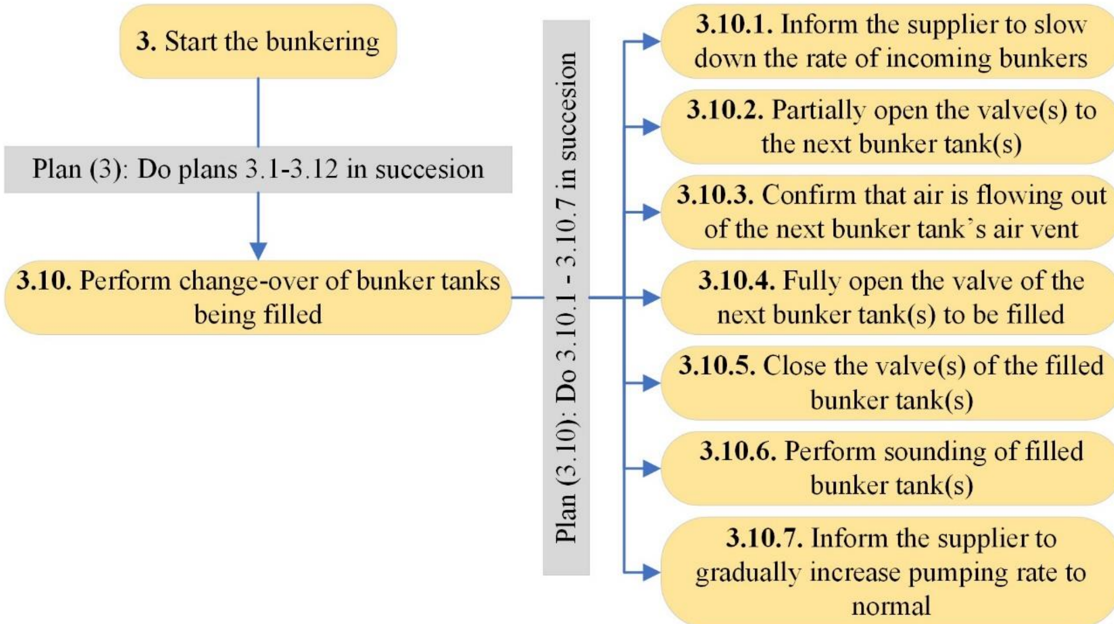

Figure IV-P: Perform change-over of bunker tanks (3.10)

When a bunker tank is close to full, and if there is another bunker tank due to be filled next, the vessel's crew must perform a change-over of bunker tanks. Said procedure starts by informing the facility operator to slow down the rate of incoming bunkers (3.10.1). Next, responsible personnel must partially open the valves to the next designated bunker tank (3.10.2) to ensure that the oil can flow without any problems or obstructions. Personnel must also confirm that the air from inside the tank can be adequately displaced through the air vent (3.10.3). A malfunction of the air vent may trap the air inside the tank or hinder the air flow, and as such, it may increase the internal pressure of the tank, increasing the risk of an accident happening. The same danger can occur from an excessive pumping rate, which would fill the bunker tank with oil faster than the air can escape through the vent.

When all the preliminary checks are completed, responsible personnel should fully open the valves of the designated bunker tank(s) (3.10.4) and close the valves of the filled bunker tank(s) (3.10.5). A sounding must be performed on the filled bunker tanks (3.10.6) to ensure that they have been completely closed off, and as such, no new bunkers are supplied to them. Finally, the chief engineer can give permission to the facility operator to increase the pumping rate back to normal (3.10.7).

(3.12) Filling the final bunker tank

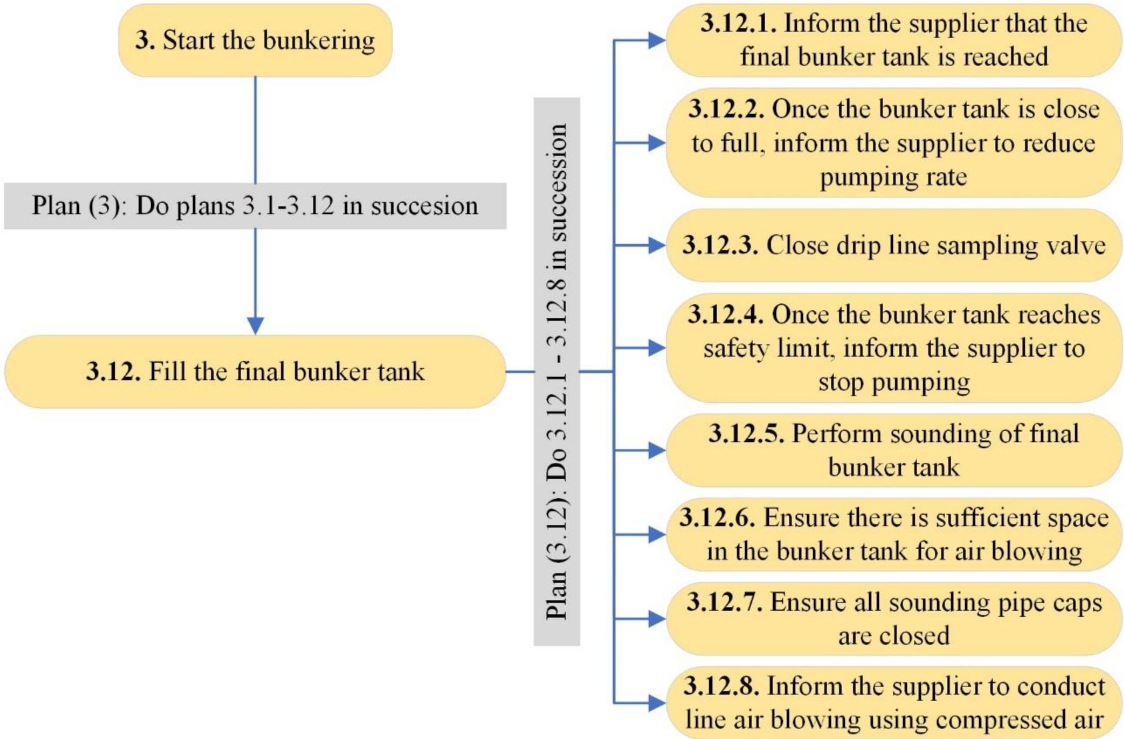

Figure IV-Q: Fill the final bunker tank (3.12)

When the final bunker tank is reached, the facility operator must be informed (3.12.1) to be more alert during the procedure. Once the bunker tank is close to full, responsible personnel should order the facility operator to reduce the pumping rate (3.12.2) and close off the drip line sampling valve (3.12.3). Once the tank's safety limit has been reached, the facility operator must be informed to stop pumping (3.12.4). Responsible personnel must perform sounding of the bunker tank (3.12.5) to ensure that the flow of bunkers towards the tank has stopped and to confirm that there is enough space left in the tank for the final blow-through (3.12.6) and for the expansion of the oil due to temperature changes. Prior to giving the go-ahead to the facility operator to conduct the bunker line air blowing (3.12.8), personnel must check that all the sounding pipe caps are closed and firmly in place. An unsecured sounding pipe of a tank might allow for the discharge of oil mist in the air, or worse yet, a tank overflow, during the final blow-through.

(4) Wrapping up the bunkering operation

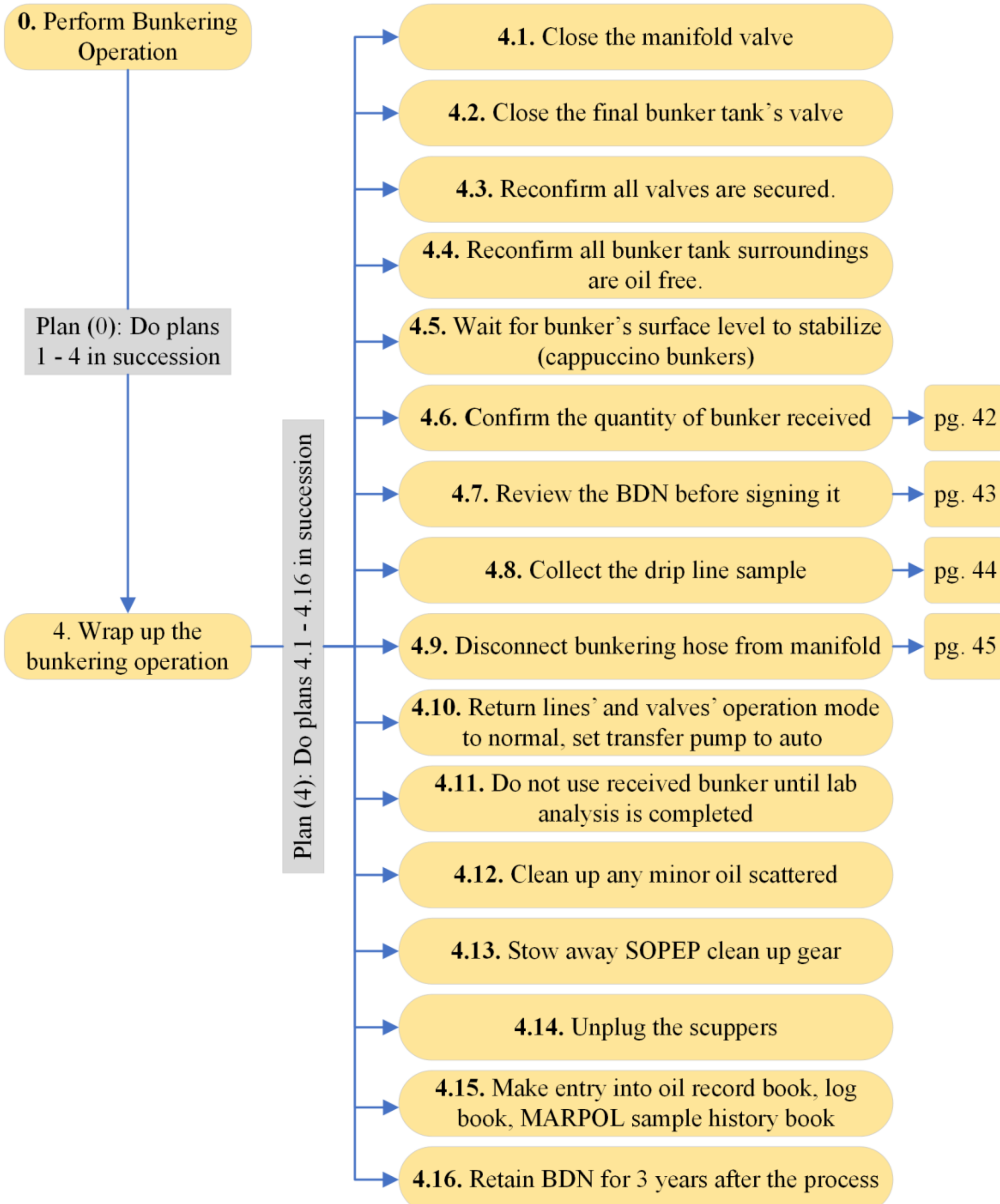

Figure IV-R: Wrap up the bunkering operation (4)

After the final blow-through has been conducted, the manifold valve must be closed (4.1), but the bunkering hose is not to be detached yet. Responsible personnel must close the valves of the final bunker tank (4.2) and ensure that all the valves used are completely closed off (4.3). The deck-rover watchman must do one final check that all the bunker surroundings and containment arrangements are free of oil (4.4). Prior to measuring the actual quantity of the received bunkers (4.6), some time must pass for the bunker's surface level to stabilize (4.5) and for any air bubbles formed inside to separate.

Representatives from both parties must be present in the collection of the drip line sample (4.8). The chief engineer must refrain from signing the BDN prior to confirming that the stated quantity of bunkers matches the actual quantity delivered (4.7). If the chief engineer concludes that the bunkers are short supplied, they may require the supplier's representative to commence the transferring process once again or to subtract the missing quantity from the bill. Only after it is ensured that no more transfer of bunkers is to take place can the bunkering hose be disconnected from the manifold (4.9).

The used valves and lines' operation mode should be set back to normal, and the transfer pump must be turned back to auto (4.10). Until the sample has been analyzed by a laboratory, it is best to refrain from using the new batch of bunkers (4.11). Personnel should clean up any minor oil spills found scattered around the vessel (4.12). Even though all precautions may be upheld, it is nearly impossible to eliminate all sources of oil contamination. For that reason, personnel should keep in mind that even the smallest amount of oil spilled can contribute to major environmental pollution in the long run. After the clean-up procedures have concluded, the SOPEP gear must be stowed away (4.13) in a safe and orderly manner, and the scuppers can be unplugged (4.14).

The chief engineer must make a new entry containing pertinent information about the bunker batch into the oil book, the vessel's logbook, and the MARPOL sample history book (4.15). Such information may be of critical importance in the future, for example, when considering the mixture of a new batch of bunkers with the old one or when issuing a letter of protest against a supplier. Competent authorities, such as the IMO or the port authorities, may also request access to said information at any point. According to international law, the BDN must be kept on board for at least three years after the process (4.16).

(4.6) Calculating the quantity of the received bunkers

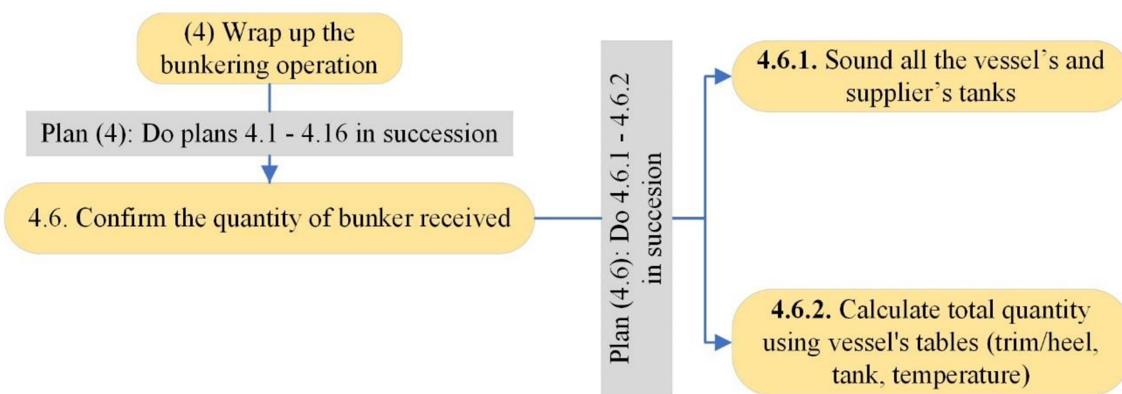

Figure IV-S: Confirm the quantity of received bunkers (4.6)

To properly calculate the quantity of bunkers received, responsible personnel should sound all the vessel's bunker tanks that have been filled, as well as the facility's nominated tanks (4.6.1). After taking the measurements, personnel should use each tank's tables to determine the actual quantity received (4.6.2).

(4.7) Signing the BDN

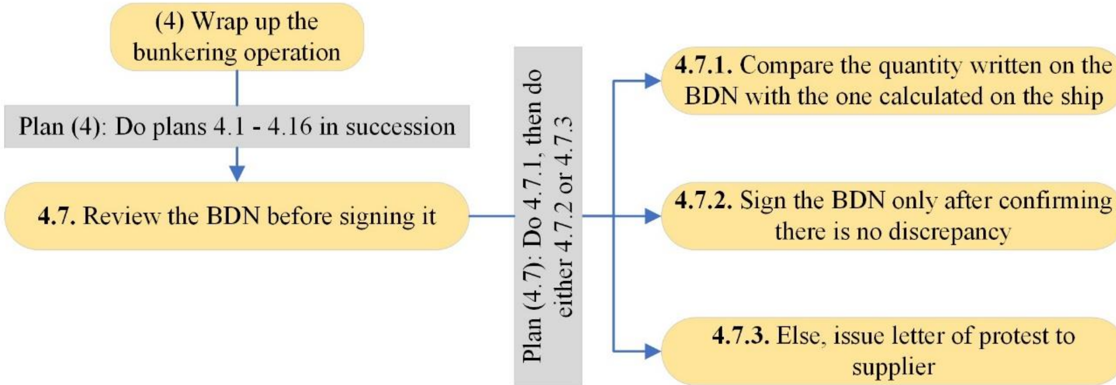

Figure IV-T: Review the BDN before signing it (4.7)

The BDN is a document of utmost importance for the bunkering operation. On it are written the quantity of bunkers received, the composition of said bunkers, the date and place where bunkering takes place, et cetera. For that reason, the chief engineer should make sure that all the information written on the BDN is correct before signing it. After signing the BDN, holding the supplier accountable for any malpractice becomes increasingly difficult.

The composition of the bunkers is to be determined by lab analysis, hence the drip line sample. The quantity, however, is to be determined by the vessel's responsible personnel, as described previously, and signed on by the vessel's officers, who should check for a discrepancy between the quantity written on the BDN and the one calculated on site (4.7.1). If the two values match, then the BDN should be signed (4.7.2). Otherwise, a letter of protest should be issued to the supplier instead (4.7.3).

(4.8) Collecting the drip line sample

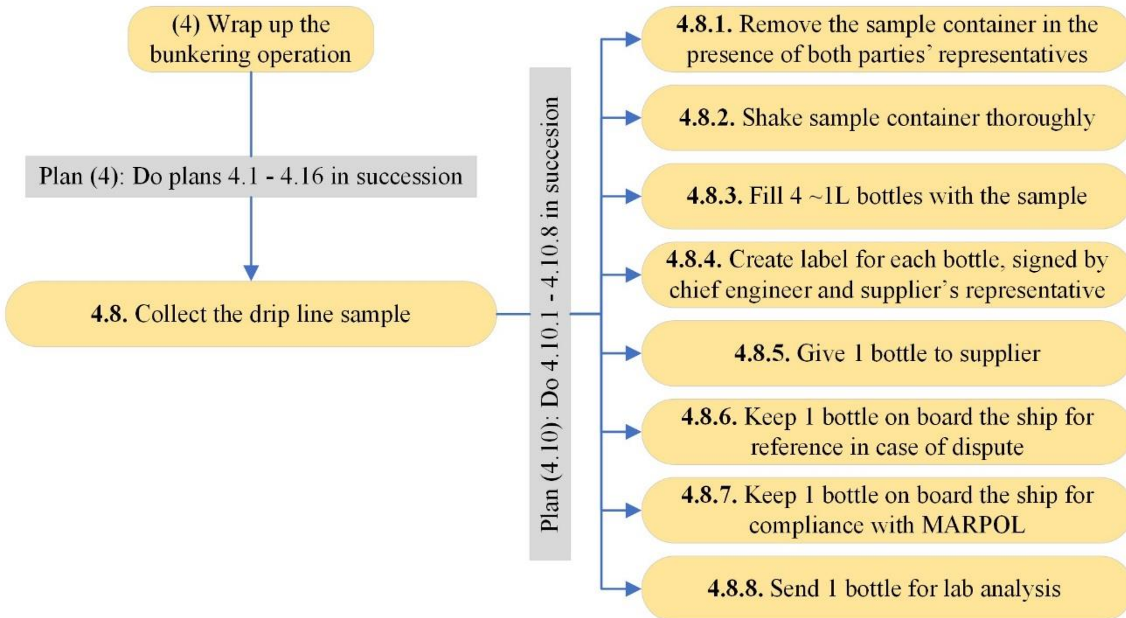

Figure IV-U: Collect the drip line sample (4.8)

Both parties' responsible officers are to be present during the collection of the drip line sample to legitimize the sample's lab results further down the line. The seals are to be broken and the cubitainer removed (4.8.1). The sample container should be thoroughly shaken (4.8.2), and four ~1L bottles should be filled (4.8.3). Each bottle should be labeled and signed by the chief engineer and the supplier's representative (4.8.4). One bottle goes to the supplier (4.8.5), one bottle is sent for lab analysis (4.8.8), and two bottles are kept on board the vessel. One bottle is meant to be kept for reference in case a dispute arises in regard to the bunker quality (4.8.6), while another bottle is kept onboard to be presented as proof that the received bunker follows the MARPOL guidelines (4.8.7) should an inspection by competent authorities take place.

(4.9) Disconnecting the bunkering hose from the manifold

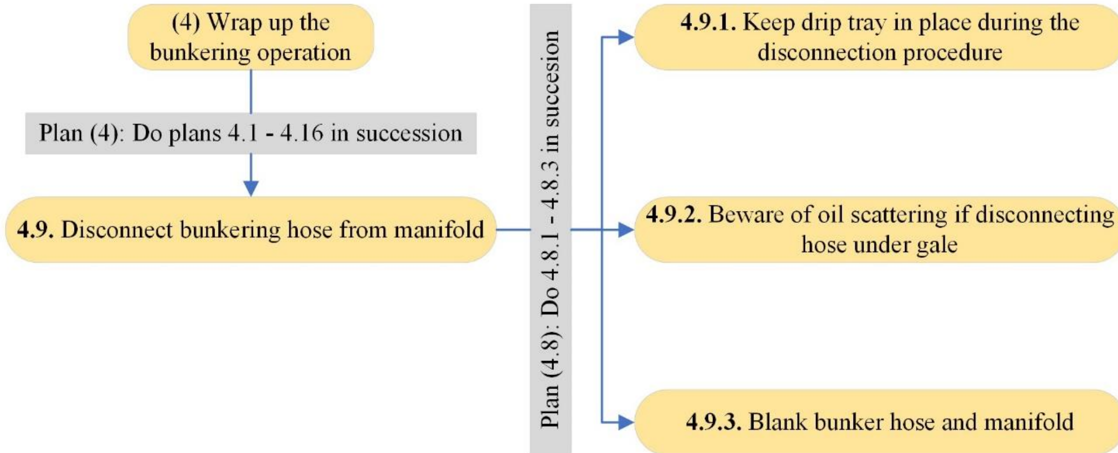

Figure IV-V: Disconnect the bunkering hose from the manifold (4.9)

Even after pressurized air has blown through the bunkering hose, small quantities of oil may still be present in it. That is the reason drip trays should be kept in place during the disconnection procedure (4.8.1), and crew should beware of oil scattering during the hose disconnection if done so under a gale (4.8.2). After the hose has been disconnected from the bunkering manifold, both should be blanked off (4.8.3) to avoid any leakage.

Chapter V: Hierarchical Task Analysis tables of the critical subtasks

During the previous chapter, the bunkering procedure was broken down to multiple subtasks that must be conducted to achieve the completion of the process. With the knowledge gained from the aforementioned analysis, it is now possible to identify certain subtasks from the entire procedure that can be considered as more likely to pose a threat if done incorrectly. Those tasks are called critical subtasks, and through a more careful inspection, they can give an insight into the weak spots of the current safety measures applied.

An important aspect of the procedure's subtasks is the time frame within which they are to be conducted. If a task is done out of order, a safety gap could be created, or even worse, an instigating event. Many examples come to mind when it comes to improper timing, such as closing the manifold valve prior to stopping the transfer of bunkers or deploying a pilot ladder to board the supplier's representative prior to safely mooring the barge to the vessel. It is understood that the consequences of any such mistake can be devastating, and, as such, a strict chronological order must be followed.

Time limitations aside, there are multiple other factors that can compromise the integrity of the operation. The limitations of each subtask vary, from the condition of the equipment used to the minimum resting hours of the personnel. As such, the general category of limitations catalogs the "weak points" of the critical subtasks in the following table analysis.

The "equipment" section lists all the equipment necessary to complete a critical subtask. Missing, malfunctioning, or subpar equipment is oftentimes the root cause of an accident. In such cases, personnel might be compelled to find a workaround, which may result in devastating results. For example, a nonfunctioning crane may be "patched" by tying a rope around the nozzle of the bunkering hose and pulling on the rope to lift it. Even if such improvised solutions do not end up in disaster, they instill a false sense of security and disregard for the rules among personnel, a mentality that is sure to cause problems in the future.

During the bunkering operation, personnel are assigned certain tasks that must be conducted. These tasks must be clearly defined for each crew member and leave no room for diffusion of responsibility (the bystander effect). Additionally, an overbearing workload for any one crew member is one of the leading causes of human errors, not only in the shipping industry but also in general. As it is evident, the proper allocation of tasks and responsibilities to personnel plays a pivotal role in the safe conduct of the procedure.

Conducting a task properly is exceedingly difficult without any feedback on the actions performed. This is why responsible officers do not rely on volumetric equations for the progress on the filling of the tanks but primarily on the sounding measurements that take place frequently in addition to the remote level gauges positioned in the engine control room. For that reason, the existence and observation of control measures are also considered for the table analysis.

Finally, each subtask carries inherent risks that can be manifested into hazards if actualized. Personnel should be alert and ready for the negating procedures of each event that may occur during the engagement of a subtask. An immediate response to a threat can prevent the exacerbation of the problem, while a delayed response can turn even the most minor event into a major accident with severe implications. As such, the list of hazards for each subtask is also included in the table analysis.

Task	Critical subtasks	Time	Limitations	Equipment	Personnel	Control Measures	Hazards
Create a pre-loading plan	Write down each and every step of the operation	Before the bunkering operation	Must be comprehensive and detailed	Example bunkering checklist	Personnel involved in operation must be familiarized with preloading plan and well trained	Training exercises and emergency response drills	Ineffective bunkering checklist
	Define personnel that will take part in operation		Give each member specific tasks	Duty assignment table			Overworked personnel
			Personnel shouldn't work more than 14h in a 24h period				
	Determine the level and type of liquid in all bunker tanks		Be thorough with sounding procedure	Tank tables, sounding tape, oil record book		Tank sounding	Error in selection of appropriate tanks
	Determine which bunker tanks should be filled		Avoid mixing different batches of fuel oil	Compatibility test, if necessary.		-	Incompatibility of different batches
			If mixing is unavoidable, minimize ratio of residual oil in each bunker tank				
	Determine the capacity of bunker tanks to be filled		Calculate the final ullage or innage of each bunker tank	Tank tables		-	Capacity miscalculation
			If necessary, perform tank to tank transfer of residual oils	Oil transfer pumps			
	Determine the bunker tanks' filling sequence		Beware of impact in vessel's stability	Water ballast tanks		-	Excessive trim / heel /list
	Designate an overflow tank to transfer excess fuel if the need arises		Ensure that overflow tank remains empty for emergency use	Overflow tank		-	Overflow tank rendered useless

Task	Critical subtasks	Time	Limitations	Equipment	Personnel	Control Measures	Hazards
Put in place firefighting measures	Rig fire wires fore and aft (if applicable)	Before the bunkering operation	Must be capable of towing the ship	Fire wires, tow boat	Responsible personnel	-	Fire wire breaks during towing
	Post no smoking notice near the bunkering station		Must be strictly enforced and designated smoking areas should be established	-		-	Source of open flame
	Post no hot work notice near the bunkering station		Must be strictly enforced	-		-	
	Ground the main radio transmitter aerials		-	Main radio transmitter		-	Possible creation of spark
	Switch off radar		-	Radar		-	
	Switch VHF/UHF transceivers and AIS equipment on the correct power mode or off.		-	VHF/UHF transceivers, AIS equipment		-	
	Prepare fire hoses and fire-fighting equipment for immediate use		Must be in proper working condition	Fire fighting equipment		-	Inability to combat fire

Table 1:HTA table pt.1

Task	Critical subtasks	Time	Limitations	Equipment	Personnel	Control Measures	Hazards
Put in place measures against oil spills	Place oil spill clean up gear adjacent to bunkering station	Before the bunkering operation	Must be in accordance with SOPEP	Sawdust, rugs, oil absorbents, dispersants, PPE, waste containers	Responsible personnel	-	Clean up efforts rendered inefficient
	Fit save-alls with drain plugs		Must be effectively sealed	Drain plugs		-	Spilled oil escapes from containment and causes water pollution
			Ensure that no non-bunkering related leaks could fill the containment arrangements				
	Plug deck scuppers and freeing ports		Must be effectively sealed			-	
			Ensure that no non-bunkering related leaks could fill the containment arrangements				
	Have oil booms ready to launch, if available	Before oil spreads extensively	Better to be deployed as a preacaution	Oil booms	Emergency response personnel	-	

Task	Critical subtasks	Time	Limitations	Equipment	Personnel	Control Measures	Hazards
Perform the berthing operation of the vessel	Check that water around vessel is oil free	Prior to mooring	-	-	Responsible personnel	Visual check	Oil pollution goes unnoticed
	Ensure there is no danger of collision		Watch out for protruding objects	-			Collision, damage to vessel
			Confirm that fenders are in good condition	Fenders			
	Safely moor the vessel with the supplier	-	Mooring lines must be in good condition	Mooring lines	Appoint watchman to tend mooring lines during bunkering	-	Failure of mooring lines
			Mooring lines must be fastened to appropriate sections of the vessel				Damage to vessel
			Enough mooring lines should be fastened				Failure of mooring lines
	If possible, lay out an oil fence around vessel and supplier	After mooring	Oil fence should surround the vessel and the supplier	Oil fence	Vessel or supplier	-	Oil pollution further exacerbated

Table 2:HTA table pt.2

Task	Critical subtasks	Time	Limitations	Equipment	Personnel	Control Measures	Hazards
Attach bunkering hose to manifold	Ensure that the bunkering hose has enough length	Prior to attaching bunkering hose	-	-	Vessel's representative on supplier's facility	-	Hose damaged or disconnected during vessel's pitching / rolling
	Ensure that the bunkering hose's weight does not exceed the SWL of the vessel's lifting gear		-	-		-	Lifting gear failure
	Attach the bunkering hose	-	Make sure the connections are securely bolted	Crane, bunkering hose, torque wrench, bolts	Place watchman to manifold	Manual check	Hose disconnection
	Ensure that the hose is properly supported	After attaching bunkering hose	Hose must be supported appropriately to prevent kinking, bending, excessive stress	Hose floats, hose supports			Hose damaged, submerged
Task	Critical subtasks	Time	Limitations	Equipment	Personnel	Control Measures	Hazards
Start pumping at minimum rate	Open manifold valve	After bunkering hose securely connected	Manifold valve must be fully open	Manifold valve	Responsible personnel	Manual check, readings of attached gauges	Increase in pressure inside bunkering hose
	Inform the supplier to start pumping at minimum rate	After opening manifold valve	Backup communication must be established as a safeguard	Transceivers, visual signals, sound signals, mobile/ satellite phones	Responsible officer(s)	Regular communication checks	Misunderstanding in pumping rate could create overpressure
	Check for leakages.	While pumping at minimum rate	Even minor leaks can contribute to pollution if ignored	Drip trays, save-alls	All watchmen	Visual confirmation	Pipeline leakage
	Check that bunker is routed to the intended bunker tank(s) only.	Regularly	Check that valves are operational, do not assume wrong tanks are not being filled	Pipeline and tank valves	Responsible personnel	Routine sounding of all tanks	Filling of the wrong tank
			Be thorough with sounding procedure	Tank tables, sounding tape			

Table 3:HTA table pt.3

Task	Critical subtasks	Time	Limitations	Equipment	Personnel	Control Measures	Hazards
Perform change-over of bunker tanks being filled	Inform the supplier to slow down the rate of incoming bunkers.	Once tank level is close to safety limit	Backup communication must be established as a safeguard	Transceivers, visual signals, sound signals, mobile/ satellite phones	Responsible officer(s)	Regular communication checks	Tank overflow
	Partially open the valve(s) to the next bunker tank(s)		Check that valves are operational, do not assume they are working properly	Pipeline and tank valves, tank tables, sounding tape	Responsible personnel	Sounding of newly opened tank(s)	
	Confirm that air is flowing out of the next bunker tank's air vent.	Once new tank starts to fill	Do not assume that air vents are functional	Tank air vents	Deck rover watchman	Manual inspection	Tank overpressure
	Fully open the valve(s) of the next bunker tank(s) to be filled.		Check that valves are operational, do not assume they are working properly	Pipeline and tank valves, tank tables, sounding tape	Responsible personnel	Sounding of newly opened tank(s)	Filling of the wrong tank
	Close the valve(s) of the filled bunker tank(s)					Sounding of filled bunker tank(s)	
	Inform the supplier to gradually increase pumping rate to the one agreed upon.	After filled tank is confirmed closed	Backup communication must be established as a safeguard	Transceivers, visual signals, sound signals, mobile/ satellite phones	Responsible officer(s)	Regular communication checks	System overpressure

Task	Critical subtasks	Time	Limitations	Equipment	Personnel	Control Measures	Hazards
Fill the final bunker tank	Inform the supplier that the final bunker tank is reached.	Once final tank is reached	Backup communication must be established as a safeguard	Transceivers, visual signals, sound signals, mobile/ satellite phones	Responsible officer(s)	Regular communication checks	Miscommunication between parties
	Inform the supplier to reduce pumping rate	Once final bunker tank is close to full	Backup communication must be established as a safeguard	Transceivers, visual signals, sound signals, mobile/ satellite phones	Responsible officer(s) / personnel	Regular communication checks	
			Be thorough with sounding procedure	Tank tables, sounding tape		Tank sounding	
	Inform the supplier to stop pumping	Once final tank reaches safety limit	Backup communication must be established as a safeguard	Transceivers, visual signals, sound signals, mobile/ satellite phones	Responsible officer(s) / personnel	Regular communication checks	Tank overflow
			Be thorough with sounding procedure	Tank tables, sounding tape		Tank sounding	
	Ensure there is sufficient space in the bunker tank for air blowing	Once pumping has stopped		Tank tables, sounding tape	Responsible personnel	Sounding of final bunker tank	
	Ensure all sounding pipe caps are closed	Before air blowing	-	Sounding pipe caps		Manual inspection	Escape of oil during air blowing
	Inform the supplier to conduct line air blowing using compressed air	After everything else is completed	Final air blowing pressure must be upheld	Transceivers, visual signals, sound signals, mobile/ satellite phones	Responsible officer(s)	Regular communication checks	System overpressure

Table 4:HTA table pt.4

Chapter VI: A Bowtie Analysis of the most common events

Thanks to the hierarchical task analysis that has been conducted in the previous chapters, it is now easier to identify the "weak spots" of the bunkering procedure. From the table form of the analysis, the instigating events of the most common types of accidents can be deduced, and through the tree diagram, the main preventative and mitigating barriers can be examined thoroughly. Equipped with that information, relative Bowtie diagrams have been created with the purpose of delving into the effectiveness of the implemented safety measures throughout the bunkering process.

Each Bowtie diagram starts out by listing multiple threats that can lead to the same or a similar accident (top event). A line is drawn from the threat to the top event, being interrupted by the preventative barriers that have been put in place. The effectiveness of some barriers can vary depending on their implementation. Some other threats, represented by a slightly milder color, can impede, or render useless the implemented preventative barriers. That is why, in turn, some preventative barriers have been placed to safeguard against those threats as well.

If the preventative barriers prove ineffective, then the top event occurs, thus creating a perilous situation that has the potential to be further exacerbated. At that point, mitigating procedures are set in motion, and the mitigating barriers are placed in anticipation of such an event. For the purposes of this paper, the mitigating procedures are beyond the scope of research since they are mostly implemented after the occurrence of an event, and their effectiveness relies mostly on the active engagement of the crew. Any reader interested in researching this subject more thoroughly is encouraged to read *IMO: Guidelines for the Development of Shipboard Marine Pollution Emergency Plans (2010 Edition)* and its subsequent amendments, the 1974 *International Convention for the Safety of Life at Sea (SOLAS)*, and its subsequent amendments.

In a worst-case scenario where a hazard cannot be restrained, leading to a top event where all the mitigating barriers fail, grave consequences occur. These consequences usually fall into one of two categories: casualties or pollution.

A casualty is defined as an occurrence that leads to the damage / destruction of the vessel and/or its surrounding vessels / facilities or results in bodily harm to personnel, with the severity ranging from the most minor instances even up to death. From the scope of this paper are excluded the casualties that can occur independently from the bunkering procedures, such as falls from heights or the grounding of the vessel.

The term pollution is used in this instance to describe the consequences of the failure to contain bunkers within the vessel's premises, which in turn leads to contamination of the surrounding environment. The most common aftermath of such cases is the creation of an oil spill on the waters surrounding the vessel, threatening the marine environment and the quality of life of the local population, assuming the event occurs near a port or a coastline. Pollution is the most common outcome of a bunkering accident, and bunkering accidents are the biggest contributors to marine pollution.

Below are listed the Bowtie diagrams for the events of tank overflow, disconnection of bunkering hose, creation of pressure within a tank, leakages in the bunkering system, and an unexpected oil spill. With the information available throughout this thesis, a thorough analysis of each diagram is due.

Tank overflow: threats and preventative barriers

When discussing bunkering accidents, the event of a tank overflow is the first to come to mind, and for a good reason. A tank overflow is an event that can occur easily, and its consequences can be dire if an effective and timely response is not met. The most common cause of such events is the human factor, whether it is in combination with other factors or not. There are two distinctive ways a tank overflow can occur: either a bunker tank is filled beyond its containment capacity, or a tank is filled by bunkers unwillingly. In either case, the end results are the same.

To avoid the overfill of a bunker tank, multiple criteria must be met. While creating a pre-loading plan, the chief engineer must correctly calculate the remaining capacity of the bunker tanks. To do that, they must refer to each tank's capacity table, which projects the remaining tank capacity in accordance with its sounding measurements and the vessel's trim and list. It is important to remember that any change to the vessel's trim and list impacts the tanks' available capacity.

A safety limit of about 90% of the bunker tank's capacity is established in each vessel's SMS. The company may elect to establish an even lower, but not a higher, safety limit if they choose to do so. The tank's level is monitored by the engine room watchman at all times through a remote gauge and double-checked by appointed personnel conducting manual soundings at regular intervals. To diminish the probability of human error, the personnel involved must be well-trained and well-rested. Personnel should not work more than 14 hours in a 24-hour period, unless in the case of an emergency.

Since the pumping rate is regulated by the bunkering facility operator, a loss of communication between the two parties may prove devastating. For that reason, not only a primary but also a secondary means of communication must be established prior to beginning the transfer. The primary means of communication is usually achieved through transceivers or radio. On the contrary, a secondary means of communication can be hand signals, whistles, or shouts.

It is not an uncommon occurrence that the wrong tank is filled due to a routing error in the piping arrangement or the malfunction of a valve. Personnel may open the wrong valve if the valves are not clearly marked on site as well as on the vessel's diagrams. To counteract said threat, all valves are checked regularly to be in the correct order, and while pumping slowly, responsible personnel must check that the bunkers are routed to the intended tanks and them only, both by visual confirmation as well as regular soundings of all the vessel's tanks. If the valve alignment is correct but bunkers flow to another tank as well, that may indicate a valve malfunction. In addition to preliminary valve checks, there must also be countermeasures against a malfunctioning valve, such as secondary operating equipment.

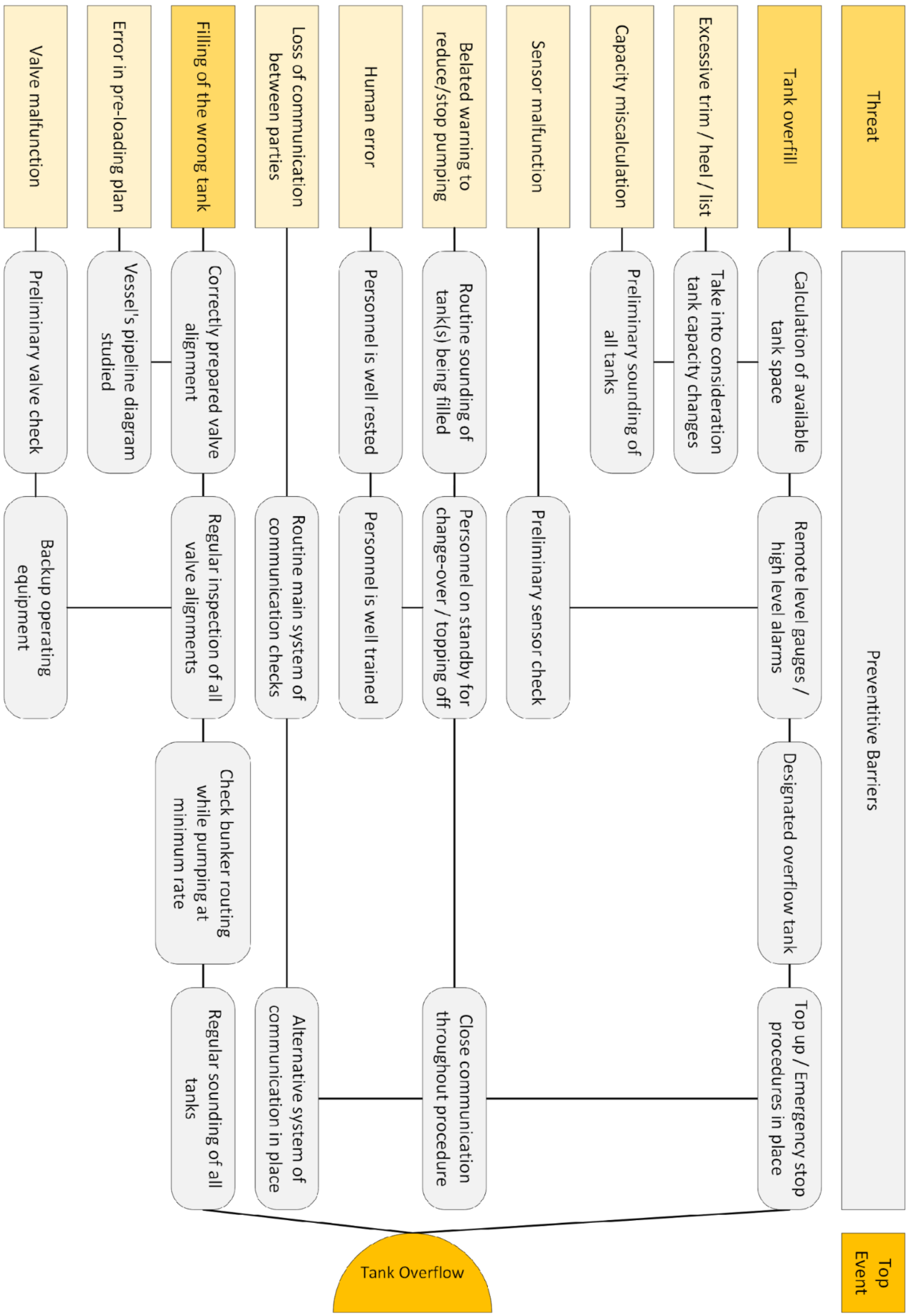

Figure VI-A:Tank overflow - threats and preventative barriers

Tank overflow: mitigating barriers and consequences

If the applied preventative barriers fail, the threat that has been presented manifests itself in the top event: a tank overflow. After the occurrence of the top event, it is crucial to safeguard human lives, the property, and the environment around the affected area to prevent the spread of the destruction even further and to initiate mop-up procedures. Measures that have been taken as a precaution prior to the top event are of crucial importance towards achieving the previously mentioned goals. These are called mitigating barriers, and the extent of the consequences of the top event depends greatly on their effectiveness. In the event of a tank overflow, as is the case with most bunkering accidents, there are two different unwelcome outcomes. The first is the cause of pollution in the waters around the vessel and in the environment in general. The second is the contingency of a casualty, whether that be the destruction of assets of the vessel or third parties or, most importantly, the injury or loss of life of active personnel and bystanders.

The prevention of oil pollution relies primarily on a timely and effective response to the event. The responsibility for the expedient observation lies mostly on the deck-rover watchman, whose duty it is to beware of any signs of oil spills on the premises of the vessel and the surrounding waters. That does not mean that anyone else witnessing any such event can remain idle. Once an oil spill has been reported, the chief engineer must activate an emergency alarm, inform the bunkering facility, and commence emergency stopping procedures in coordination, based on the plan laid out during the representative's pre-bunkering meeting. After the bunkering procedure has stopped and the danger of further oil contamination has been addressed, emergency cleanup procedures must take place. The SOPEP gear that has been strategically placed around the vessel plays a vital role in the cleaning operations that must be undertaken. The plugged scuppers and save-alls around the vessel will help contain the oil spill onboard the vessel for an increased period of time, given that they have been put in place to begin with and that the trim and list of the vessel do not reduce their containment capacity tremendously. As a last resort, an oil boom (or oil fence), if placed around the vessel, limits the contamination area if any amount of oil ends up in the surrounding water.

Due to the bunkers' flammable properties, the vessel and the crew are exposed to the risk of a fire or explosion after a tank overflow. To prevent the ignition of the spilled bunkers, a series of restrictions have been placed on everyone onboard the vessel, such as a ban on smoking outside of a few designated safe areas, the deactivation of the vessel's radar and other radiocommunications that can create electric sparks, and the banning of hot work. Additionally, the vessel and the facility are electrically insulated. Firefighting equipment is strategically placed around the vessel to put out the fire should an ignition occur. As a last resort, on vessels that carry flammable or explosive materials, fire wires are fitted on the fore and aft of the vessel. Should a fire erupt and spiral out of control, a tow boat can use the fire wire to transport the vessel a safe distance away from people, facilities, and other vessels.

Personnel partaking in the operation are obligated to wear personal protective equipment at all times, as is usual on a daily basis. Prior to commencing the bunkering procedure, the MSDS must be studied to properly equip personnel against any toxic substances incorporated in the bunkers. The doors and windows to the accommodation deck must be always closed. This will prove essential in the protection of personnel against toxic vapors from an oil spill. During such an event, a contamination-free accommodation deck can function as a safe space for personnel as well as a base of operation for the emergency procedures that must take place. On a similar note, the hatches and valves leading to the cargo deck must be closed to prevent the contamination of cargo with oil. Although not as critical as in previous instances, damaged cargo can lead to monetary compensation for the owner as well as damage to the reputation of the company.

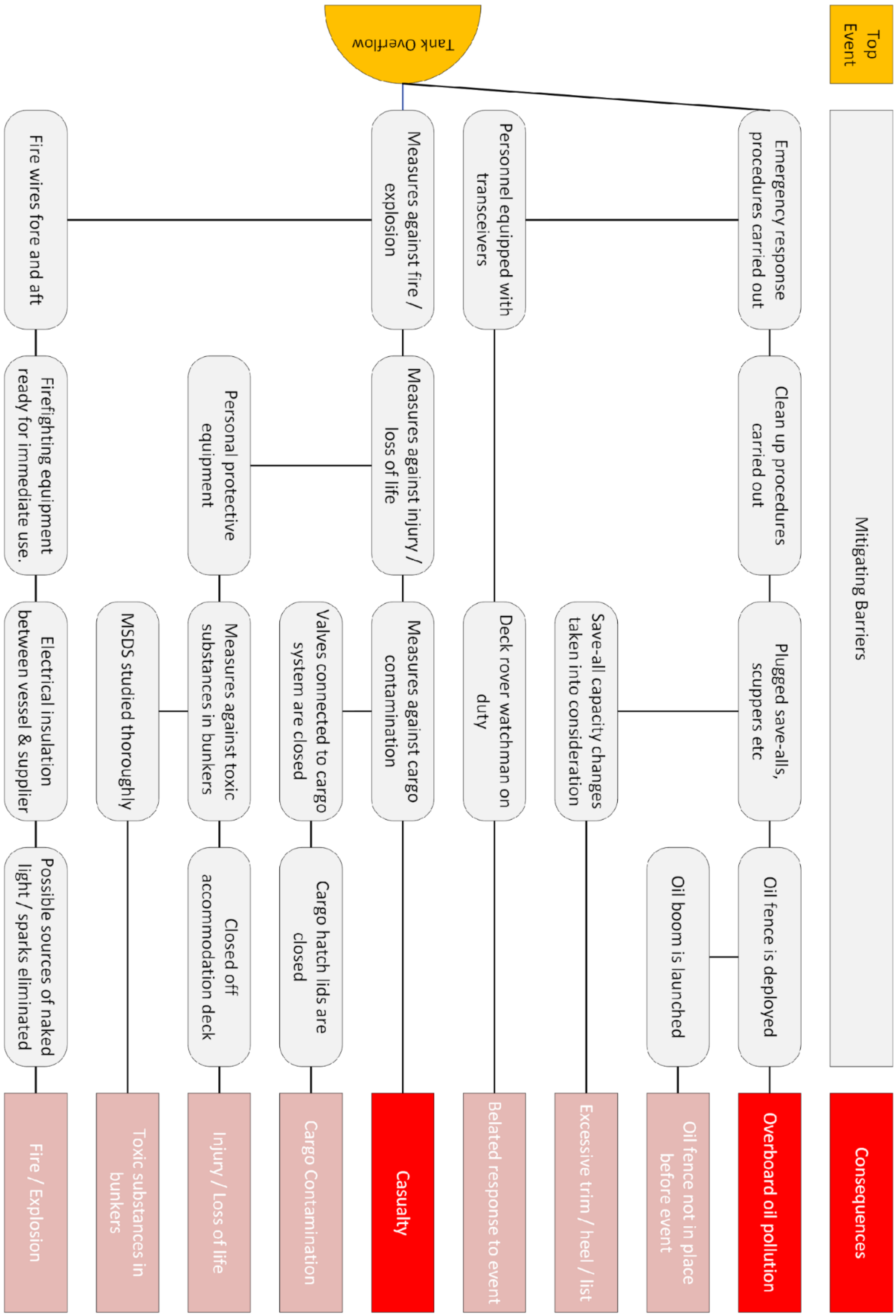

Figure VI-B: Tank overflow - mitigating barriers and consequences

Disconnection or parting of the bunkering hose: threats and preventative barriers

Whether the bunkering hose disconnects or parts, the results can be similar and equally devastating. A hose in poor condition may not be able to withstand the pressure applied to it during the bunkering procedure. For that reason, the vessel's representative must perform a visual check on the bunkering hose while onboard the bunkering facility and, if needed, ask the facility operator to view the hose's pressure test certificate. Even if the bunkering hose is in adequate good condition, excessive or fluctuating pressure may cause the hose to part nonetheless. A deviation from the agreed-upon operating pressure may occur from a partially or fully closed valve, such as the manifold valve. For that reason, the crew must perform routine checks on all valves involved in the operation and ensure that none are malfunctioning. Even in case of an emergency, the manifold valve must not be closed while the facility operator provides bunkers.

The agreed-upon pumping rate must be maintained at all times. Personnel must routinely check the manifold's pressure gauge to confirm that everything is in order. The facility operator may elect to pump at a higher rate to finish the operation more quickly or, sometimes, to create the frothing effect on the bunkers, also known as cappuccino bunkers. Under no circumstances should this be allowed to happen. An excessive pumping rate equals excessive pressure on the bunkering hose, not to mention the theft of bunkers paid for by the company. On the topic of cappuccino bunkers, the facility operator may supply cappuccino bunkers formed inside their nominated tank, thus eliminating the need for excessive pumping rates. But this practice is also perilous since air has a different compressibility and viscosity than any other liquid. This means that the supply of cappuccino bunkers can cause abnormal vibrations in the hose, maybe serious enough to cause parting. For that reason, personnel must keep an eye out at all times for signs of such a case.

Aside from the pressure applied to the bunkering hose, external factors can also cause parting or disconnection, such as the different relative motions of the vessel and the bunkering facility. The probability of such an occurrence increases as the weather conditions worsen, but other variables can factor in as well. Worn-out mooring lines, for example, may snap under tension, unberthing the vessel from the bunkering facility. For these reasons, personnel must visually check the condition of the mooring lines prior to using them. In harsh weather conditions, the chief engineer may elect to order the use of additional mooring lines for the berthing operation. Throughout the operation, a watchman must be placed to observe the mooring lines and notify the chief engineer should something go wrong.

During the process of attaching the bunkering hose to the manifold, a multitude of things can go wrong. The bunkering hose may prove too heavy for the vessel's lifting equipment. If the SWL of the crane is exceeded, it might snap midair, sending the bunkering hose into a freefall. Such a mistake can easily be avoided if personnel ensure that the crane used can safely lift the bunkering hose from the facility. To properly support the weight of the bunkering hose, an appropriate amount of hose supports must be placed. To prevent the hose from sinking in the water in case of an accident, purpose-built buoys must be placed along the entirety of the hose. The specifications of the bunkering hose may also fail to meet demands regarding the appropriate minimum length. Even if the bunkering hose is long enough to reach the vessel's manifold, an unexpected motion between the two parties may overstretch it to the point of the hose parting under tension.

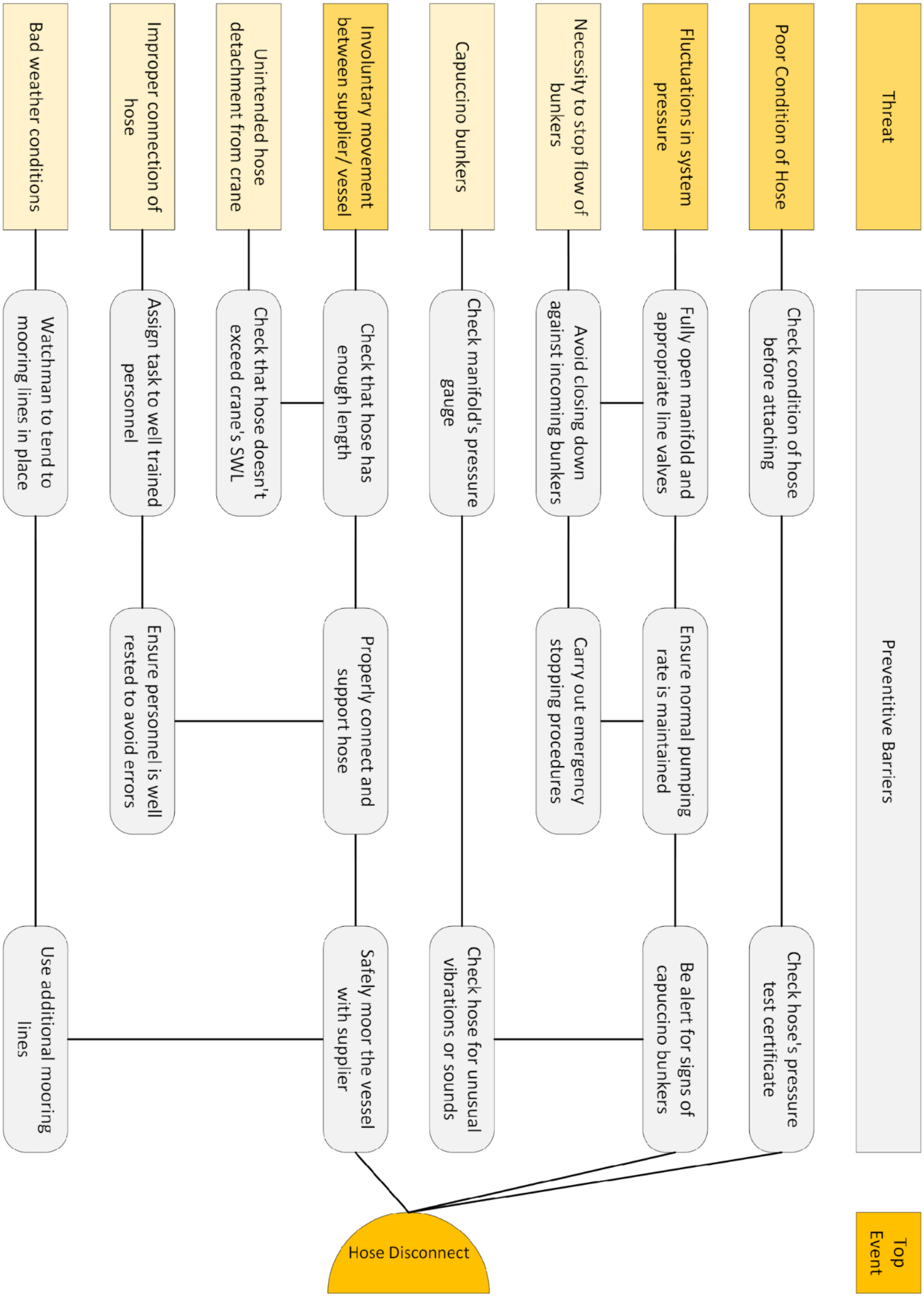

Figure VI-C: Disconnection or parting of the bunkering hose - threats and preventative barriers

Disconnection or parting of the bunkering hose: mitigating barriers and consequences

In the unlikely event that the bunkering hose disconnects from the manifold, either by parting or by detaching, swift action must be taken to prevent the deterioration of the situation. Especially if the disconnection occurs during the transfer of bunkers, the facility can pump copious quantities of oil directly into the sea prior to performing emergency stopping procedures. But even if the disconnection happens at a time when bunkers are not being transferred, residues of oil from the inside of the pump will be introduced to the surrounding waters. It is apparent that the disconnection of the hose is a serious threat to the marine environment.

After the hose has been disconnected, it is important to initiate the emergency stopping procedures and the emergency cleanup procedures as soon as possible. If the hose has been properly supported, and with a lot of luck, the hose may discharge the bulk of its contaminants onboard the vessel, where, even though it is still a serious event, the containment of the bunkers and the cleanup procedures are easier to perform. If, on the other hand, the bunkering hose ends up in the water, the only way of containment is an oil fence, which of course is effective only temporarily. The hose floats, if fitted, keep the hose on top of the surface, making it easier and faster to retrieve, thus reducing the contamination caused.

For the human factor, the disconnection of the hose mid-transfer can prove extremely dangerous, especially towards personnel around the manifold at the time of the event. The bunkers may be launched directly at personnel, causing irritation of the eyes and skin, inhalation of hazardous vapors, chemical burns, or even thermal burns. For that reason, personnel must wear personal protective equipment such as goggles, gloves, and overalls at all times, and even respiratory protective gear if deemed necessary in the MSDS.

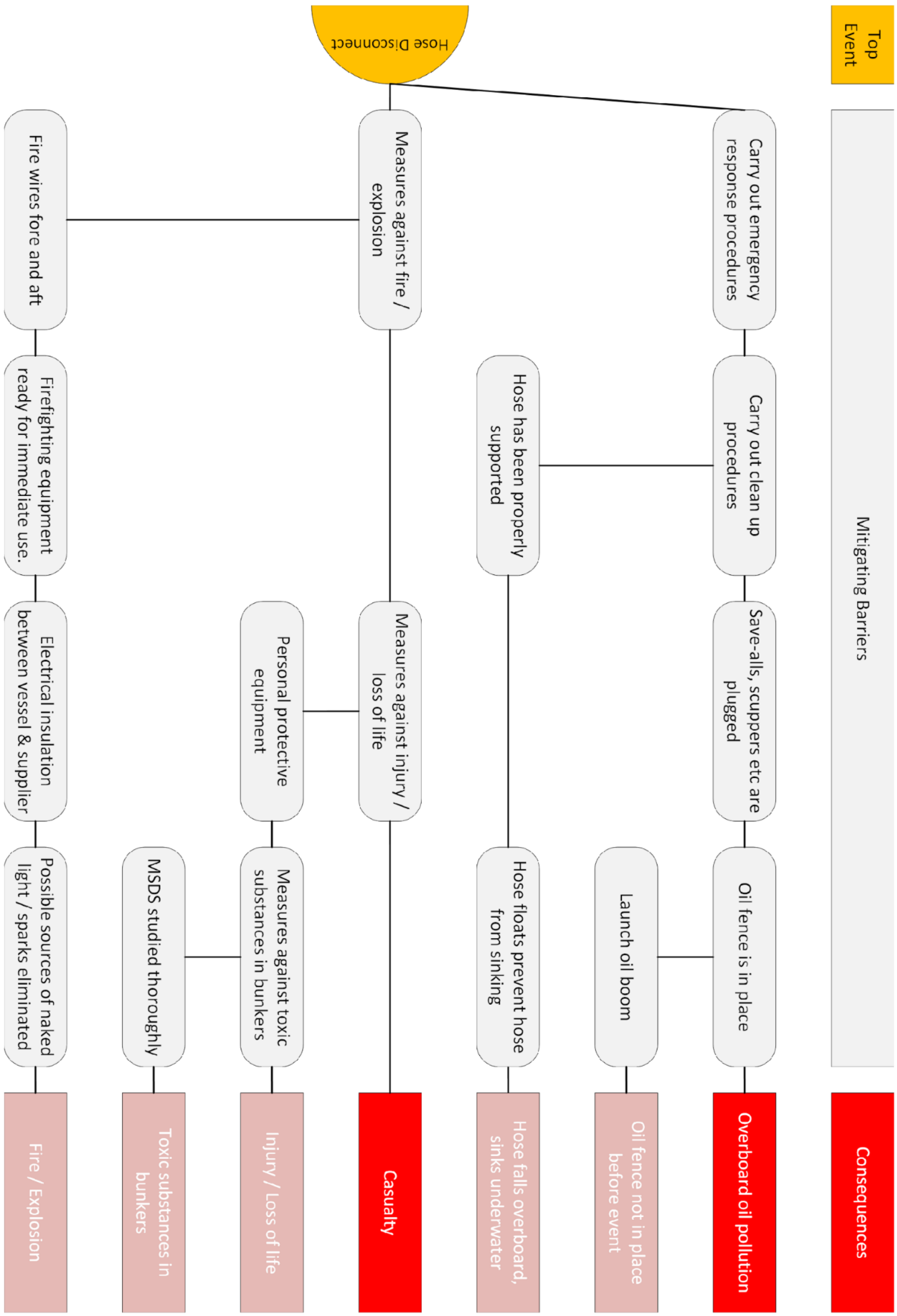

Figure VI-D: Disconnection or parting of the bunkering hose - mitigating barriers and consequences

Pressure buildup in bunker tank: threats and preventative barriers

When air gets trapped inside a bunker tank, its pressure increases the more the tank gets filled, causing the creation of a pressurized air pocket. This event may lead to the abrupt release of the trapped air through an opening, usually the air vent, in the meantime discharging oil mist in the air. There is also the unlikely possibility of the tank becoming deformed or even ruptured from the pressure applied to it, but that is a much rarer instance, since the tanks have strict construction and maintenance standards.

To avoid the creation of air pockets, the Chief Engineer must calculate in the pre-loading plan a tank filling sequence that does not disturb the vessel's balance, therefore increasing its trim and list. An excessive trim or list may cause the received bunkers to block the tank's air vents, thus preventing the air inside the tank from escaping in a safe manner. The same principle applies to bunkering operations under adverse weather. The forces applied to the vessel from the waves and winds may tilt the vessel, similarly to when the filled tanks displace the vessel's weight center.

It is also possible for a tank's air vent(s) to malfunction in some shape or form. A vent might be obstructed by foreign objects, or the opening valve may not work properly. Either way, a tank with a closed air vent has no way of displacing the air inside it, effectively creating an air bubble. For that reason, it is stipulated on the pre-loading plan that all the air vents of the bunker tanks to be filled must be checked to be unobstructed and in proper working order prior to commencing the operation, and then again when it is time for each individual tank to be filled.

But even if the previously stated criteria are met, there is also the possibility of the air pressure inside the bunker tank increasing due to an excessive pumping rate or an increased blow-through pressure. Each tank's air vent has its own physical limitations regarding the volume that can be transferred at a time. If the bunker tank fills faster than that limit, the air pressure inside the tank increases temporarily, and that can cause similar results to the previous threats stated. For that reason, the maximum pumping rate and the final blow-through rate were agreed upon by both parties during the pre-bunkering meeting and must not be exceeded under any circumstances.

Pressure buildup in bunker tank: mitigating barriers and consequences

If the pressure inside a bunker tank increases past a safety limit, then the overflow arrangement comes into play. Excessive air pressure is diffused in the designated overflow tank through the activation of the bunkering tank's pressure relief system. By rerouting the pressurized air into the overflow tank, it is ensured that a mist of bunkers will not be sprayed outside through the air vent.

It is important that the pressurized air not be allowed to escape through other means, most commonly unsecured sounding pipes. For that reason, personnel are instructed to close the sounding pipe caps after conducting a sounding and especially prior to the final air blow-through, where the volume of air inside that tank increases rapidly and the air vents may be unable to keep the pressure inside the tank at the atmospheric level, at least temporarily.

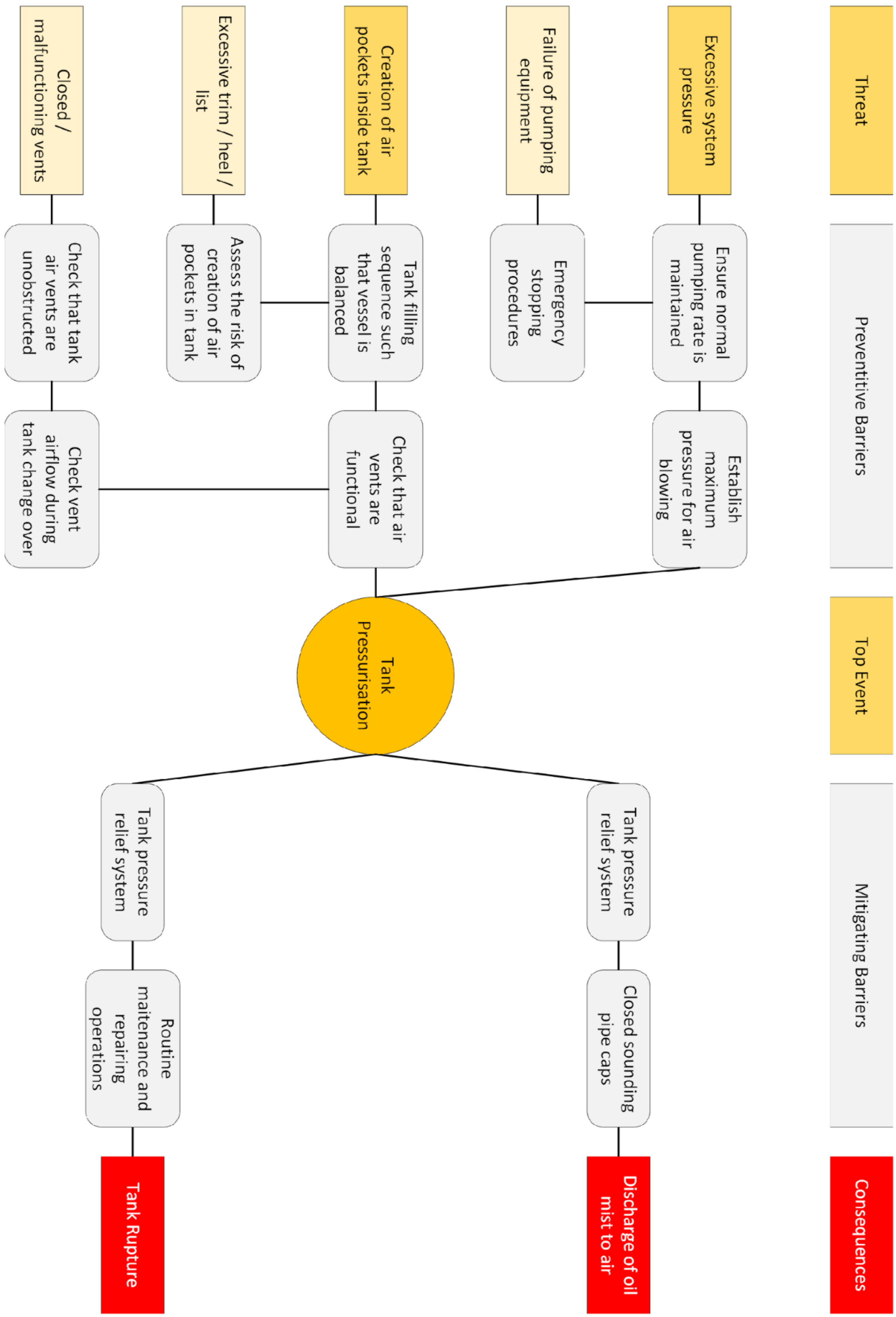

Figure VI-E: Pressure buildup in bunker tank

Bunker line leakage: threats and preventative barriers

It is not uncommon for lesser amounts of bunkers to leak from the bunker line, usually in places where there is a bottleneck in the flow of bunkers, such as pipe corner joints or valves, but all the pipeline fittings are points of concern. The main culprits for such an occurrence are excessively high pressure inside the bunker line and poor line maintenance. Throughout this thesis, the causes and effects of excessive line pressure have been presented thoroughly. If pressure inside the system is built up, it can be partially relieved by leaking fuel through the line's joint connections.

But even under normal circumstances, the bunker line may leak in parts if the proper maintenance procedures have not been conducted prior to the bunkering operation. It is important for the pipelines to undergo routine visual inspection for any loose, damaged, or rusty parts and for any such imperfections to be repaired in due time. Rust is not to be underestimated. At the initial stages, no deterioration of the rusty part's properties and functions may be observed, but with time, it can cause fragility, malfunction of the valves, and even punctures. A pipeline pressure test must be conducted every six months to ensure that the bunker line can withstand the amount of pressure it is usually subjected to, increased by an additional safety threshold.

Bunker line leakage: mitigating barriers and consequences

No amount of oil pollution is a safe amount of oil pollution. Even the most minor oil leakages must be addressed immediately. Personnel should place drip trays underneath points of concern to collect any oil that may leak, and the deck-rover watchman must remain vigilant for signs of oil spills on deck. If an oil spill is discovered, personnel must clean it up using SOPEP gear such as rags and sawdust; if not immediately, then right after the procedure is finished.

A line leakage is also a point of concern because it reveals a weak spot in the bunker line system, meaning that the leaking part may be the first to give in under pressure, creating a major threat of oil pollution onboard or at sea. For that reason, everyone must remain vigilant and check the points of leakage intermittently. If the amount of oil leaking from a point of concern increases, it is an indication that the situation is worsening, and it is up to the discretion of the Chief Engineer whether to pause the bunkering procedure or not.

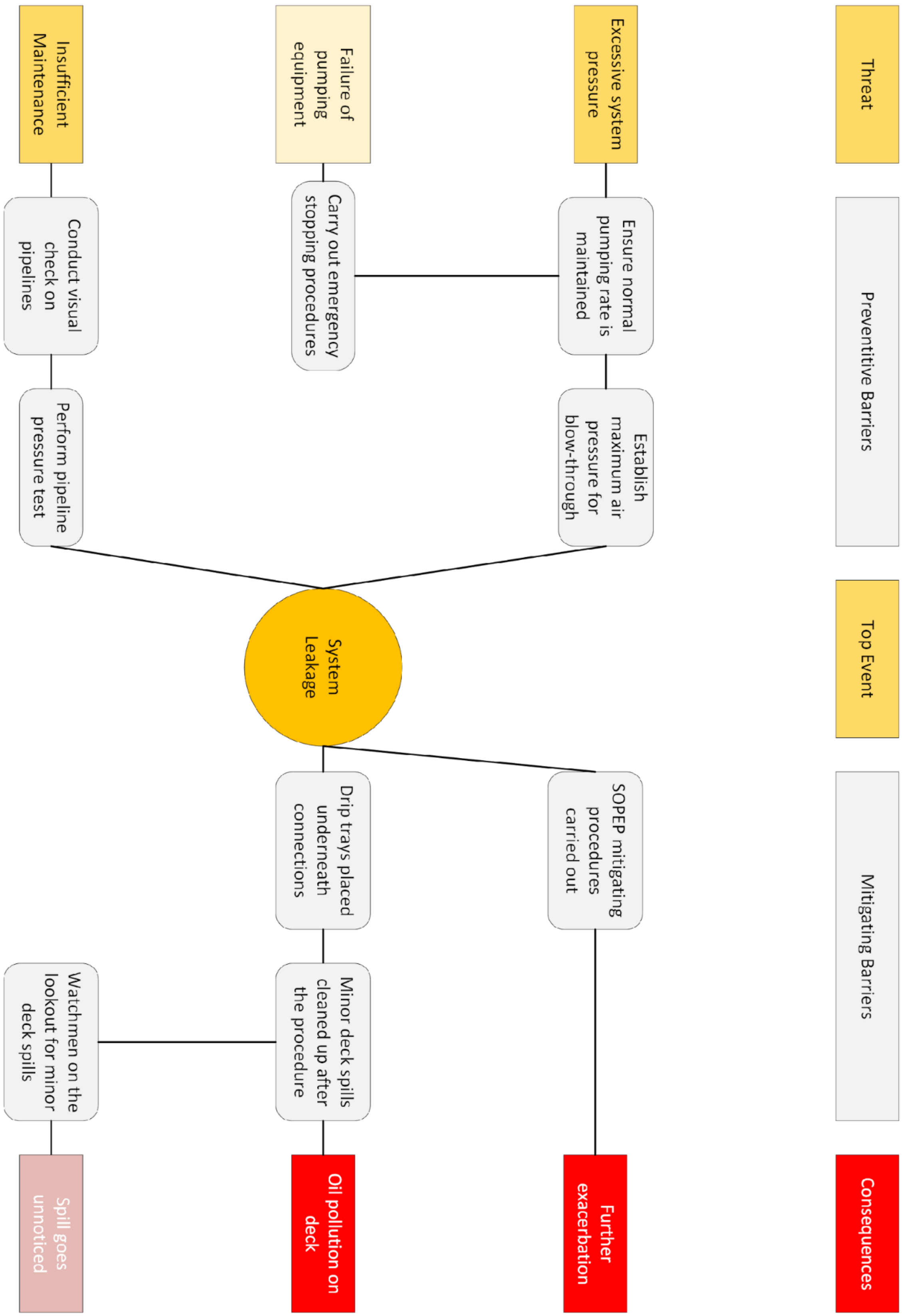

Figure VI-F: Bunker line leakage

Unforeseen discharge of oil at sea

The oil pollution of the sea is one of the most threatening events that can take place, mainly because of the extremely limited reaction time window. If the spill goes by unnoticed, water currents can spread leaked oil in all directions in a matter of minutes, if not seconds. The leak can originate from a number of places and for various reasons.

If the bunker line has been routed incorrectly, the received bunkers could end up being discharged at sea through one or some of the vessel's overboard valves. This is a rare occasion, but one that cannot be overlooked. The main goal of risk assessment and hazard analysis, after all, is to preemptively identify and help prevent all the threats that are inherent to a procedure. To prevent such an event from happening, the chief engineer must study the vessel's pipeline diagram and establish the proper bunker line route in the pre-loading plan. Personnel must then line up the pipeline arrangement as stated in the plan, but also close and secure the overboard discharge valves of the vessel in preparation for the bunkering procedure.

In the event of a casualty, most commonly the collision of the vessel with a foreign object, minor damage to the vessel's hull, could create small holes in the vessel's exterior that, in a "perfect storm" type of scenario, can lead to the leakage of bunkers at sea. Marine vessels undergo thorough examination and repairs to rule out the possibility of such an event. Case in point: all vessels undergo a dry-docking procedure at least once every five years. During that time, inspectors from multiple regulatory bodies must witness the state of the vessel's hull and confirm that it is in a satisfactory condition. To prevent the collision of the vessel during the bunkering operation, the berthing process must be conducted in a proper manner to prevent free movement between the vessel and the bunkering facility.

If a discharge of oil at sea occurs, the only safety measure that can help mitigate the situation is an oil fence. However, it is not mandatory for an oil fence to be deployed beforehand, or to have an oil fence ready for deployment, for that matter. Even if an oil fence has been deployed beforehand or launched after the oil spill is discovered, the time that it can contain the spilled oil is very limited, and the situation can be exacerbated under harsh weather. If the two parties do not manage to contain the oil spill in time, heavy fines are issued towards the responsible personnel, the vessel, and the owner company, not to mention the environmental damage that occurs.

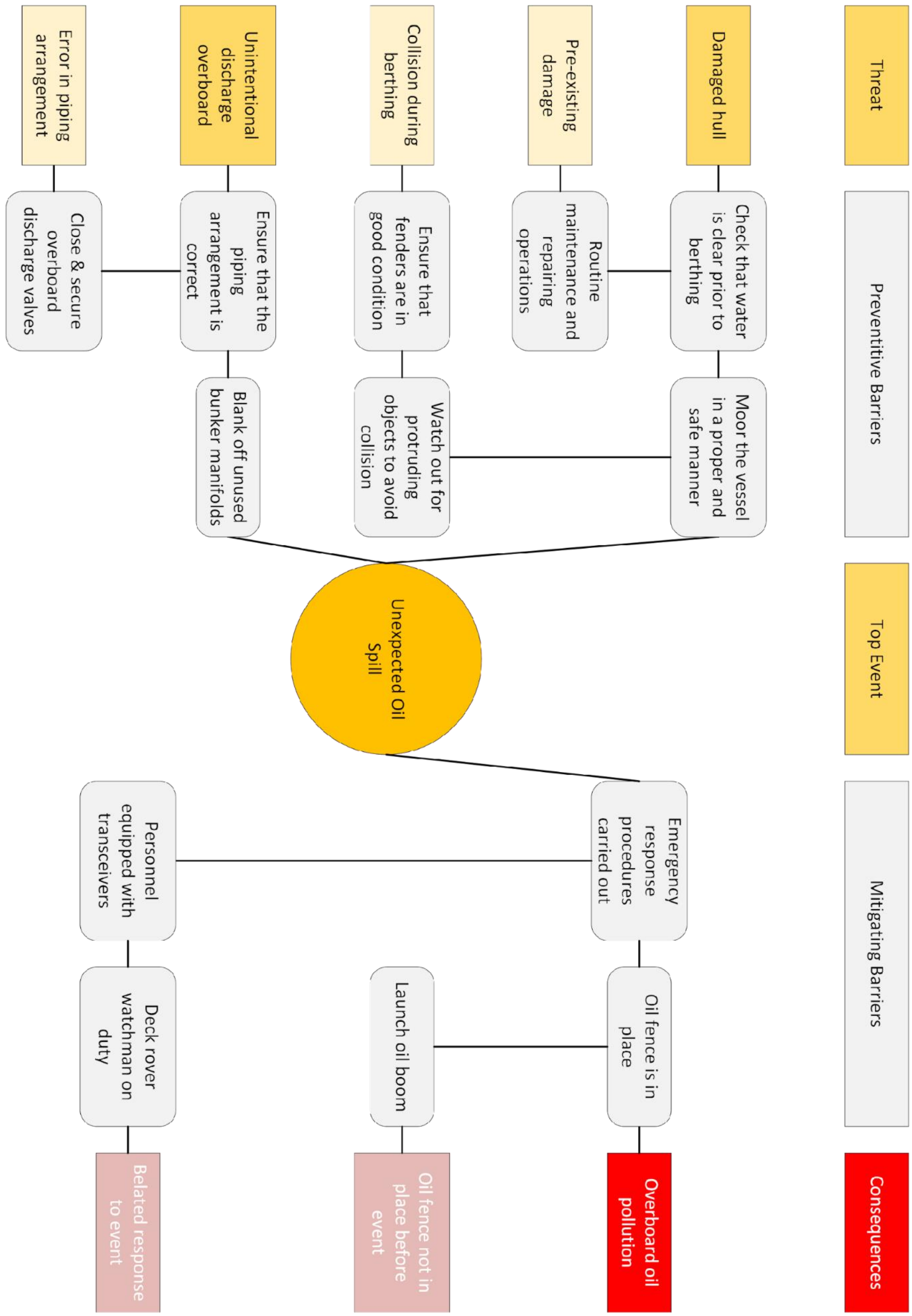

Figure VI-G: Unforeseen discharge of oil at sea

Chapter VII: Case Studies

Case Study: Overflow while bunkering (The Swedish Club 2021)

It was morning in the middle of summer and a vessel was loading alongside on the starboard side. The Chief Engineer had ordered a fuel truck to bunker marine diesel oil. The Second Engineer had asked one of the oilers to prepare the manifold for receiving fuel. The fuel checklist had been completed by the Third Engineer and all scupper plugs on deck were in place. However, there was no risk assessment for the bunkering operation and no toolbox meeting was held before the bunkering took place.

The bunkering began at 09.00 and the oiler and Third Engineer were monitoring the operation by the starboard side bunker station. The Second Engineer was carrying out maintenance in the engine room. The Third Engineer was in radio contact with the Chief Engineer who was in the engine control room. As there was no radio contact with the truck driver ashore, the Third Engineer and the truck driver had agreed to use hand signals.

An hour later an AB was walking on the port side to the mess for a coffee break when he saw oil overflowing from the port side bunker station. He called on the radio that there was oil overflowing into the harbor and ran to the starboard side and informed the Third Engineer.

Oil was overflowing from a blind flange on the port side bunker station. The Third Engineer waved to the fuel truck driver to stop pumping, and he also pushed the emergency stop by the bunker station. The fuel truck driver stopped immediately. The Chief Engineer had heard the AB over the radio and closed the valves to the tank. He had not noticed anything unusual on the gauges and had not suspected that oil was overflowing. The Third Engineer and the oiler ran over to the port side with absorbent pads from the Shipboard Oil Pollution Emergency Plan (SOPEP) equipment. However, there was too much oil, and it was spreading into the harbor. Fortunately, there were favorable winds which pushed the oil back towards the vessel and berth.

The Master informed the VTS and coast guard about the oil spill. The local fire department arrived at the scene within 20 minutes and launched oil booms around the vessel. They worked all day and didn't finish until late in the evening. They continued the following morning, and the task was completed by lunchtime.

It was estimated that one tonne of fuel had escaped into the harbor. When the engineers investigated the port bunker station, they found that bolts on the blind flange were loose. This allowed the oil to overflow. Both the port side and starboard side bunker lines are connected and there is no valve in-between; this is a common system. It is however very important to check that the flange bolts and valves for the bunker station not being used are closed and secured.

The bolts for the blind flange were re-tightened. The line was pressure tested and found not to be leaking. The oily water in the harbor was pumped into immediate bulk container (IBC) tanks which were supplied by the authorities. The vessel was fined and had to pay for the entire cleaning operation. The vessel was not detained and was allowed to sail after the hull had been cleaned.

Lessons Learned

The conduct of a bunkering procedure is commonplace in most marine vessels currently in service. Regularity brings familiarization, which in turn brings a sense of overconfidence to experienced personnel, which sometimes results in the negligent execution of the procedure's steps. The human factor is the most common root cause of most bunkering accidents. It is important for all personnel to remember that, even though the bunkering procedure is conducted frequently and the chances of an accident happening is small, the consequences of such an accident are tremendous.

In the aforementioned case study, the relaxed attitude of the vessel's personnel in charge is apparent. No pre-bunkering meeting took place prior to the procedure, nobody was appointed as a deck-rover watchman, nobody checked that the blanked manifolds were sufficiently secured and, most importantly, nobody conducted sounding measurements throughout the supply on bunkers. Instead, the Chief Engineer was overseeing the procedure from the engine control room, having assumed that the remote level gauges were in proper working order, while simultaneously conducting maintenance in the engine room. The Chief Engineer did not bother to establish reliable communication with the road tanker driver, which could be easily achieved by equipping them with a radio receiver.

Once the tank overflow was discovered by chance, the mitigating barriers were insufficient in containing the spill on board. Even though the vessel's scuppers were plugged, an emergency stop button was provided to personnel near the receiving bunker manifold and SOPEP gear was readily available for use, the delayed detection and, consequently, the delayed response to the oil spill degraded their effectiveness. It was by pure lack that the oil was not scattered in the surrounding waters and the oil booms could be deployed to contain the pollution.

This case study highlights how important a proper pre-loading plan and a pre-bunkering meeting is. During these meetings, the Chief Engineer must appoint all personnel involved in their respective workstations, study the vessel's piping system, and highlight its vulnerable points. Had the Chief Engineer emphasized that the bunker lines of the port and the starboard manifold were interconnected, with no valve that can isolate each of them, personnel might have double checked if the unused bunker manifold was properly blanked off.

Case Study: Lessons learnt from bunker fuel contamination incident (UK P&I 2017)

The UK P&I Club has issued guidance about a bunker fuel contamination incident which occurred onboard a general cargo ship during loading a bulk cargo. The Club has provided details of what happened and highlights the important lessons learned.

This vessel was loading bulk cargo in two of the vessel's lower holds. During the loading operation, the vessel bunkered 500 MT of HFO into no.'s 2 port and starboard fuel oil side tanks. Shortly after the completion of bunkering operations, the Chief Engineer (C/E) noticed the level of no.2 port fuel oil tank was decreasing from observation of the remote gauging system.

Upon investigation, the C/E found a large quantity of fuel oil in no.3 cargo hold ladder trunk and immediate measures were taken to transfer fuel from no.2 port to other bunker tanks. It was calculated that about 60 MT of fuel had leaked into no.3 cargo hold containing about 2,200 MT of cargo. Further investigation revealed that the oil was leaking from an inadequately secured tank access cover. Approximately 200 MT of cargo was contaminated, which was segregated, packed in bags and discharged.

The vessel was a newbuilding, and it was the first time that no.2 port fuel oil tank had been filled since departing the shipyard. It was apparent that one of the tank access lids had not been properly closed at the time of delivery as a large number of securing nuts were found to be slack after the incident.

Although the damaged cargo was sold to a local salvage buyer at a depreciated value, a very large amount of time and expense was consumed in handling and storing the damaged cargo as well as in thoroughly cleaning the contaminated cargo holds.

Lessons Learned

This case study highlights the reason all unused manifolds, cargo and tank hatch covers must be confirmed as tightly closed prior to initiating the bunkering procedure. Any unsecured opening is a probable point of leakage or overflow of excess bunkers. In the event of an overflow, an unsecured cargo hatch lid may lead to the bunkers spilling in the vessel's cargo compartment and contaminating the merchandise. For the same reason, all access points and air vents from the vessel's manifold to the accommodation deck. In case of an emergency, the crew will have to retreat to the accommodation deck to protect themselves from any harmful substances spilled and their fumes. Small, insignificant in appearance, measures such as these can save human lives and shield from extensive property damage.

From the narration of the events, it is made clear that an inadequate pre-loading plan was hatched from the chief engineer prior to the operation. A pre-bunkering plan must include the quantity to be received by each tank, as well as the normal transfer rate of the bunkers. With these two pieces of information, it is easy to approximate the time it takes for a bunker to be filled. Since the bunkering facility pumped an additional sixty metric tons with the chief engineer being none the wiser, it can be assumed that the received quantity of tankers was not being carefully measured and monitored. If any such action had been taken, the leakage would have been noticed earlier, and the damage caused might have been minimized.

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