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EVALUATING LNG BUNKERING AUTOMATION TECHNOLOGY

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ABSTRACT

Automation technology has gained much traction over the last few years and its applicability to the maritime industry offers diverse opportunities, such as improved bunkering of Liquefied Natural Gas. To showcase this, an analysis is conducted in this research, starting with an outline of the current state of the art, which is then extended to consider future developments and implementations of automated solutions for LNG bunkering. It is argued that automation technologies and their progression in being accepted by industry will help to attain sustainable growth. Thereby, in order to save time and improve staff productivity in terminals there are factors that must be considered. Crucial factors that have been identified and thus, need be taken into account are among other things: fuel transfer flow, which includes the gasification and re-gasification characteristics; ship status; LNG tanks and their capacities; as well as methods of conventional bunkering that are currently applied in practice. In this context, reliable measurements are required to ensure trustworthiness for such risk factors involved in LNG bunkering.

Keywords: LNG bunkering; Risk factors; Automation technology; Building automation system; Marine industry.

1. INTRODUCTION

Challenges and opportunities that are involved in automated liquefied natural gas (LNG) bunkering procedures are analysed and evaluated in this present study. The development of automated LNG technology is argued to provide advantages that are influenced by peripheral technologies developments, such as: low temperature actuators, sensors, controllers, Programmable Logic Controllers (PLCs), Direct Digital Controllers (DDCs), Emergency Shut-down system (EMS), Human Machine Interface (HMI) control panels, Building Automation System (BAS) as well as precision of transfer valves and low temperature pneumatic valves. In this paper, particular focus is on BAS in order to consider the risks involved in implementing automated LNG bunkering technology.

A Monte Carlo simulation method is conducted for risk analysis assessment. We analyse and compare various technical approaches based on automation technology involving LNG bunkering by using Low Temperature Actuator especially from the FESTO model, the Standard Cylinder DSBC ISO 15552 for the fuel transfer set-up for the Ship-to-Shore bunkering of LNG (FESTO @ http://www.Festo.com).

In the next Section, the findings from the conducted literature review are showcased. In Section 3, the methodology is presented, followed by Section 4, which describes the LNG bunkering process. In Section 5, a description of LNG automated bunkering solutions is set out, which is then evaluated in Section 6 within a risk analysis conducted to weigh on the potential

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opportunities in adopting automated LNG solutions. The paper rounds up with a conclusion incl. recommendations in Section 7.

2. LITERATURE REVIEW

In 2014, the European Commission helped to clearly explain the alternative fuel needs in order to achieve sustainability – especially by using LNG as an eco-fuel for efficient shipping in the European Union (EU). This overview provides directions on the universal protocols and identifies the benefactors for employing LNG as fuel. Accordingly, LNG has been recognised as one of transitional measures, alternative strategies and business opportunities in maritime shipping and the entire transportation and energy system (Gerlitz et al., 2017). Moreover, it is argued that LNG is the most promising alternative shipping fuel technology in the short to medium term, especially for Short Sea Shipping and inland waterway transport (Madjidian, 2017). Nevertheless, especially in Europe, the needed LNG infrastructure is still in creation and causes high investment costs especially in ports (Philipp et al., 2018).

Accordingly, the following literature is introduced as it supports our proposal in using automation in LNG bunkering. Published research on using simulation technique(s) is presented as it has proven to be the best means for analysing and testing.

Martin-Soberon et al. (2014) presented the concept of automation and port container terminal. In addition, the paper addresses general considerations vis-à-vis automation in different types of port facilities. The paper further advances the current knowledge on this topic by introducing an automation philosophy that adapts the implementation of automation technologies currently available on the market to the particular needs of each port or terminal. Finally, a summary of the main advantages and challenges regarding the automation of ports and terminals is explained.

Zeng and Yang (2008) presented their research on a simulation optimization method for scheduling loading operations in container terminals. This method integrates the intelligent decision mechanism of optimization algorithm and evaluation function of simulation model, whereby the procedures are: initializing container sequence according to certain dis-patching rule, then improving the sequence through genetic algorithm, using simulation model to evaluate objective function of a given scheduling scheme.

The work by Noh et al. (2014) proposed a technique that joins dynamic procedure re-production (DPS) and Monte Carlo re-enactment (MCS) to assist in decision-making on the outline weight of fuel stockpiling tanks on LNG-energized ships. Since the weight of such tanks changes with time, DPS is utilized to anticipate the weight profile. Despite the fact that gear disappointment and consequent repair influence transient weight improvement, it is difficult to execute these components specifically in the process reproduction because of the irregularity of the disappointment. To anticipate the weight conduct sensibly, MCS is joined with DPS. In MCS, discrete occasions are produced to make a lifetime situation for a framework. The use of MCS with long haul DPS uncovers the recurrence of exceeding weight. This is especially adding value, since the exceeding weight can cause a hazard.

Maidstone (2012) stated that the initial simulation modelling in operational research provides a valuable tool for approximating real-life behaviour and hence can be used for testing scenarios. In addition, the art of constructing the model itself may lead the modeller to greater understanding of the real system, such as in the present case of LNG bunkering. When simulating there exist three main methods in use: Discrete Event Simulation, System Dynamics and Agent Based Simulation.

Parola and Sciomachen (2003) presented a discrete event simulation modelling approach that is related to the logistic chain as a whole in the North-Western Italian port system. They analysed the potentiality of the system by giving particular attention to the land transport and the modal split re-equilibrium with the aim of evaluating a possible future growth of the container flows. Some simulation models were analysed for highlighting both features and problems of the logistic activities of the intermodal network. In particular, the first experiment was performed according to the present configuration for validating the model itself and setting the parameters; successive models were developed for evaluating possible different scenarios of the land infrastructures in a 2012 vision.

Domingues et al. (2016) provided the fundamental concepts and requirements of Building Automation (BA) systems by defining each aspect based upon established literature standards. By using these aspects as guidelines, the main BA technology specifications available were then reviewed with respect to their coverage of features. The authors proceeded by showing that none of the analysed specifications were able to cover totally the expected standard functionality span of BA. Despite the popularity of the subject, one surprising aspect of building automation (BA) is the scarcity of authoritative literature references regarding the topic. This situation hampers communication between developers and contributes to the well-known problem of heterogeneity where there is difficulty in integrating solutions from different manufacturers with each other.

3. METHODOLOGY

A qualitative approach was conducted by the usage of a literature survey technique in which reviewed scientific articles were studied. In addition, interviews with domain experts assisted in removing any ambiguities that emerged from the literature findings after the reviews. A quantitative aspect of the present research is the use of the Monte Carlo simulation method. Using a Monte Carlo simulation model can be viewed as a good tool when conducting a study on risks. This model especially shows that evaluating the safety in efficient bunkering without any sort of dangerous risks is similar to gambling at the casinos in Monte Carlo, Monaco, for which the simulation tool acquired its name. These games at the casino are 'games of chance', such as dice, slot machines, roulette wheels, etc. (Rubinstein & Kroese, 2017).

4. LIQUIFIED NATURAL GAS BUNKERING

Bunkering relates to the transfer of LNG from a supply installation to a receiving vessel. The supplied LNG has the sole purpose of being used as a fuel. It is important to note that LNG bunker procedures may vary greatly between projects, ships, and bunker facilities. The use of standardized procedures and checklists from existing projects may be helpful as guidance. However, vessel-specific procedures of bunkering operations should be developed due to the unique characteristics of particular bunkering facilities, receiving vessels or environmental conditions. In the following, a simplified bunker operation sequence is described. Actual sequences can vary depending on the supplier's and receiver's equipment and capabilities.

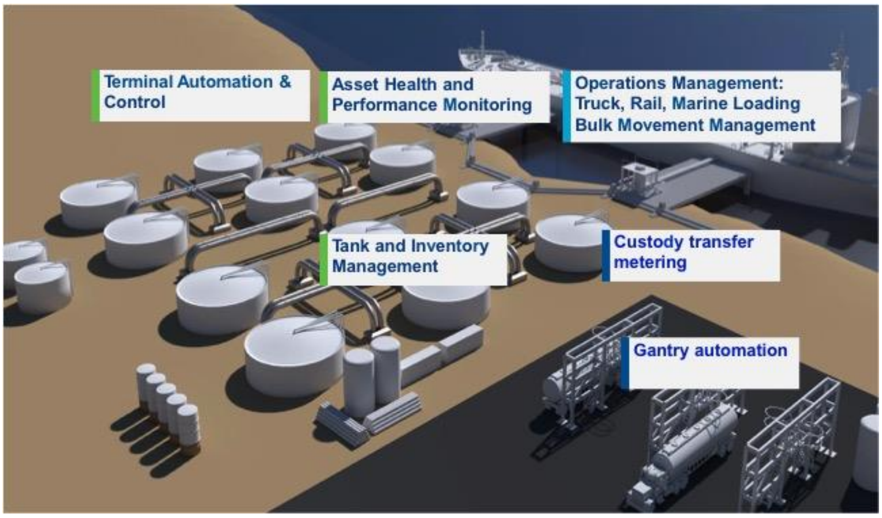
The first task in the LNG bunkering process is the notification of port authorities' intent to bunker LNG. Among other things, this requires the confirmation of compatibility between the supplier and receiver regarding equipment, procedures and protocols. Then, the receiving ship moors alongside the quay or pier, or bunker vessel moors alongside receiving ship. Accordingly, security and safety zones are established. Any pre-bunkering checklist, procedures, and communication protocols are completed and agreed between the supplier and receiver. Moreover, persons-in-charge are designated and communications, monitoring and ESD links are established.

Accordingly, the ESD needs to be tested. The supplier evaluates tank pressure and temperature - depending on tank types and bunker procedure. Generally, firefighting equipment is readied for immediate use and all safety systems, such as gas detection and alarms, are operational and have been tested. Furthermore, sufficient lighting is established or ensured and all involved personnel must put on required personal protective equipment (PPE). In addition, weather and sea conditions must fit to or comply within established limits and electrical isolation or bonding connections, as applicable, are confirmed.

The next step is for water spray curtains and drip trays, as applicable, are to be in place. Then, supplier's bunker hoses or transfer arms are connected between the supplier's and receiving ship's manifolds. The supplier and/or receiver should inert and then gas up and cool down all required bunker lines and equipment that will be utilized. Accordingly, the LNG transfer can start.

During this transfer, a number of items are monitored, such as tank levels, tank pressures and temperatures. In addition, the pump transfer rates are monitored and the pump flow rates adjusted as necessary. Generally, the top spray and bottom fill rates are adjusted as necessary to control tank pressure. Simultaneously the mooring lines and bunker hoses and arms are monitored and/or adjusted as necessary while the integrity of security and safety zones is always maintained and potentially changing weather and sea conditions are taken into account.

Figure 1: Intelligent LNG Terminal operations and processes that can be automated



Source: Emerson (2016).

When the LNG transfer stops, the LNG in the lines is allowed to vaporize and the remaining liquid is returned back to the tanks. Both the supplier and receiver inert all bunker lines and bunker hoses utilized during the bunker operation. Supplier's bunker hoses, communications, monitoring, ESD and electrical isolation or bonding connections are disconnected from the receiving ship's manifold. Receiving ship unmoors from the quay or pier, or bunker vessel unmoors from the receiving ship and notifies port authority.

Building upon the described simplified bunker operation sequence, in Figure 1, we present a possible full-automated LNG terminal solution that can improve performance and operations, whereby the opportunities for improved terminal scheduling and network optimisation are highlighted.

4.1 Methods for LNG bunkering

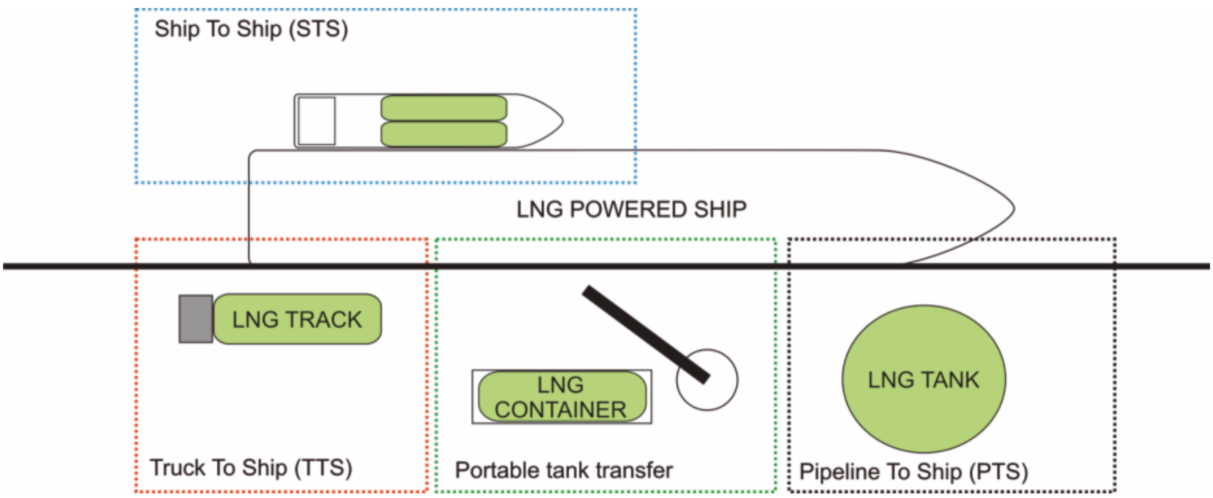
To obtain a general overview of the existing rule framework of LNG bunkering for gas-fuelled vessels, a number of LNG bunker operations and the related LNG supply modes are identified in this sub-chapter.

The transport and handling of LNG as cargo on land and sea have been proven for many years. In Europe, in terms of LNG bunkering for gas-fuelled vessels, some experience with smaller vessels operating in the Norwegian and the Baltic Seas has been gained in recent years. Due to the small number and size of gas-fuelled vessels, the current demand for LNG and the required bunker rates are mostly handled by LNG tank trucks – using Truck to Ship transfer (TTS), i.e. LNG transfer from the truck to receiving vessel. The following are the possible LNG supply modes that we have illustrated in Figure 2:

- Ship to Ship transfer (STS),
- Truck to Ship transfer (TTS), and
- Terminal/Pipeline to Ship transfer (PTS).

In case of using portable tank systems, empty tanks are replaced by full portable tanks. In comparison to the above-mentioned procedures, the reception of LNG as fuel consists of loading / unloading and connection / disconnection of the port-able tank systems (Langfeldt & Pewe, 2013).

Figure 2: Terminal/Pipeline to Ship transfer (PTS), Truck to Ship transfer (TTS), Ship-to-Ship transfer (STS)



Source: MarTech LNG (2014).

4.2 Vessel compatibility and confirmation requirements

One of the key steps in safe LNG bunkering is verifying that the supplying vessel or facility and the receiving vessel are compatible. Compatibility covers a wide range of topics and because of the complexity of LNG bunkering, it is more important to confirm compatibility than in case of oil fuel bunkering. A vessel compatibility assessment must be carried out prior to LNG bunkering operations. Compatibility is normally agreed and confirmed in written form prior to the start of bunkering as part of the bunkering procedures. An easy and widely accepted way to do this is to fill in a checklist to confirm compatibility before each bunkering operation starts (Det Norske Veritas 2012).

A compatibility review should address all shore-to-ship, ship-to-ship, etc. considerations. Confirmation that the receiving ship – and supply ship, if applicable – can be safely moored and that adequate spacing is provided between the ships or to the facility to prevent damage. Any restrictions on length should be noted. Moorings should be sufficient to keep the ships(s) restrained for anticipated wind, tide and weather conditions, and any expected surges from passing vessels.

The relative freeboard of the ships(s) or facility should allow hoses to reach from the bunker supply connection to the bunker receiving connection with sufficient slack to allow for any expected relative motion. Any restrictions on freeboard should be noted and if necessary initiate counter measures. The manifold arrangements, spill containment systems, and hose connections for the supply source and the receiving vessel must be checked and monitored. The possibility for a potential emergency release (e.g. hose breakaway) with minimal gas release should be ensured as well.

The measures to prevent electrical arcing at the manifold needs to be assessed. Confirmation that the supply source and receiving ship have compatible emergency shutdown connection, defined emergency procedures and safety systems is also required. In addition, an auditing regarding the size and scope of the hazardous areas on the supply source and the receiving ship is crucial as well.

The objective should be to keep any sources of ignition from the supplier or receiving ship. A confirmation is also needed whether volume, pressure and temperature of the supply source are compatible with the tanks on the receiving ship. If the receiving ship requires vapour return, confirmation is required that the supply source can accept returned vapour and that the vapour return systems are compatible. Furthermore, confirmation regarding inerting and purging capabilities are in place at both the supply source and receiving ship is crucial. Lastly, confirmation is needed that communications equipment is compatible and the required connections and interfaces are provided so that the bunker supplier and receiver can monitor the bunkering operation, as well as can initiate an emergency shut-down of the complete transfer operation at all times, if any problems occur.

4.3 LNG bunkering regulations and recommendations for vessels

The IMO has been assisting in the development of regulations, recommendations and requirements for LNG powered ships involved in international voyages. There are specific references that apply to LNG fuelled vessels in the two primary IMO regulations applicable to vessels: International Convention for the Safety of Life at Sea (SOLAS) and International Convention for the Prevention of Pollution from Ships (MARPOL). However, the primary regulations and recommendations addressing ships that have LNG on board are found in the IMO Codes and Guidelines identified as follows (Styliadis & Koliousis, n.d., p. 54):

- IGC Code: The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) is the mandatory code for LNG carriers regardless their size, including those of less than 500 gross tonnage. The IGC Code is relevant to any internationally trading bunker supply ship to which SOLAS is applicable or if necessary to be applied by class, national or port regulations.
- MSC.285(86): In June 2009, IMO issued this resolution as an interim measure to provide guidance for the LNG fuelled ships. The resolution is voluntary and can be used by flag states.
- IGF Code: The International Code of Safety for Ships using Gas or Other Low Flashpoint Fuels (IGF Code) represents an international standard for ships, other than vessels covered by the IGC Code, that operate with gas or low-flashpoint liquids as fuel. The code provides mandatory criteria for the arrangement and installation of machinery, equipment and systems for ships that operate with gas or low-flashpoint liquids as fuel to minimize the risk to the vessel, its crew and the environment.

5. BACKGROUND ON BUILDING AUTOMATION SYSTEMS FOR AUTOMATED LIQUIFIED NATURAL GAS BUNKERING

In this section, we provide arguments supporting the opportunities for automated LNG bunkering. Concepts from Building Automation Systems (BAS) provide a theory on how such automation solutions for LNG bunkering could be successfully achieved (cf. Domingues et al., 2016).

A BAS comprises of a framework introduced in structures that controls and screens building administrations in charge of warming, cooling, ventilation, aerating, lighting, shading, life wellbeing, caution, security, etc. Furthermore, it is useful for mechanizing assignments in innovatively empowered situations, organizing various electrical and mechanical objects interconnected in an appropriate way by method for hidden control systems. These frameworks might be send in mechanical bases, for instance: production lines, big business structures and shopping centres, or even in the household area. Building computerization has become prominent in recent years due to its high potential for increased utilization and encouraging building operation, checking and support, while enhancing client fulfilment. These frameworks accomplish such tasks by using an extensive variety of sensors (e.g. for detecting temperature, CO_2 fixation, zone wind current, light levels, etc.), by what crucial data is provided, which enables basic decision making on how the building hardware will be controlled, accompanied by sink costs while maintaining client services.

These general principles present and bind together the essential and basic ideas of building computerization frameworks. Unfortunately, in configuring systems to work with each other in order to execute tasks there exist some common problems, such as:

- objects are not able to work with other vendor's products thus locking costumers to particular product offerings,
- too intricate to ever be utilized by non-specialised staff or persons, regardless whether they are end-clients or framework designers,

- only perform attractively in the accurate conditions they were customized for, not performing successful if the workplace changes, therefore inadequate with regards to adaptability, and
- do not cover all functionalities expected in a BAS.

By dissecting data models of standard BA advances, we presume that none can completely cover the usefulness anticipated from BAS, and that particular innovations are required with a specific end goal to make a completely useful framework. Nonetheless, the interoperability of these innovations is hampered, since various ideas cannot be mapped between them. As an immediate result of this fact, manufactures have been directed to make their own exclusive expansions, which intensifies the issue of heterogeneity.

Many researcher in their published works that are active in BAS discussions have a few hazy definitions and wordings that – over the long haul – intensifies heterogeneity among BA innovations. This study refers to fundamental sources to systematize major ideas of BAS that comply with the ISO 16484-3 and EN 15232 standards, and describes the extent of usefulness anticipated from the classical BAS that will be utilized to assess the scope of every innovation standard. Hence, according to our understanding and broadly speaking, a BAS is a circulated framework situated to the electronic control and administration of building administrations, additionally alluded to as building mechanization and control framework (BACS). The design of such a related and appropriated framework can be segmented into three layers (ibid.):

- field layer, where the communication with field objects (e.g. sensors, actuators) takes place;
- automation layer, where estimations are handled, control circles are executed and cautions are enacted; and
- management layer, in which framework information tasks (e.g. sending, logging, authenticate, etc.) occur.

6. RISK ANALYSIS LNG BUNKERING AUTOMATION TECHNOLOGY

Risk assessment methods may be qualitative or quantitative and should follow recognized standards, such as ISO 31010; Risk Management – Risk Assessment Techniques (ABS, 2014). The basic risk assessment of the bunkering operation should consider details of both the bunker supplier and the receiving ship. The bunker supplier could be a vessel, truck, portable tank or a fixed facility (cf. sub-chapter 4.1). If it is a facility or LNG terminal, the scope of the related risk assessment study may be for bunkering only or the study could be part of other risk assessment studies carried out for the entire entity or facility, such as a siting, fire risk assessment (FRA), waterway suitability assessment (WSA), or overall security assessment study.

Section 6 of the report from ABS (2014), “Bunkering of Liquefied Natural Gas-fuelled Marine Vessels in North America”, offers more details on the different types of studies that may be required for an LNG supply facility or terminal, particularly in North America. In the same report, Appendix A – “Risk Assessment Workshop Templates” contains a suitable reference on the details on how to carry out a risk assessment study (ibid.). A detailed description of risk assessment methodology also can be found in ISO/TS 18683:2015.

As already abovementioned, generally there exist two primary philosophies to risk assessment – qualitative or quantitative approach. Which to use depends on the level of detail required for identified hazards and potential consequences. A qualitative risk assessment evaluates identified hazards from a hazard analysis in general terms (e.g. low, medium, high) and formulates ways to reduce these risks. For instance, it may be considered for suitable bunkering operations to follow standard procedures that have already been found to offer safe operation in other bunkering operations. However, if LNG bunkering is a new operation (e.g. in a specific port environment), or a complicated bunkering operation is planned, or unusual vessels or circumstances are involved, a more detailed quantitative risk assessment may need to be performed.

Nevertheless, in some cases, an in-between analysis, referred to as a semi-quantitative risk assessment, which is less rigorous than a full quantitative assessment, could be suitable. Which approach is required depends very much on the situation and the requirements of the approving regulatory organization, plus what level of assessment will make the owners and operators of both the LNG bunker supplier and the receiving ship comfortable with the intended bunkering operations.

It is important to discuss the planned risk assessment approach with the approval organizations early in the process in order to ensure conformity and compliance of the later proposed approach. Whether a qualitative or quantitative approach is required is subjective, whereby for the same bunkering supplier or specific bunker operation some approval organizations may accept a qualitative approach, while others may request a quantitative approach, whereat usually the more stringent requirement apply, unless a consensus approach can be negotiated.

6.1 Risk concept

Risk is a function of the initiating event, the state of the system and of its environment, and the time frame. A traditional perspective for risk metric/description is presented as follows:

Risk = Probability & scenarios / (severity) consequences (R = P&C) (1)

Namely, risk is a measure of the probability and severity of adverse effects, the combination of probability and extent of consequences or magnitude/severity of consequences. The above metrics/definitions of the concept of risk indicate that risk should be analysed in both aspects of likelihood/probability of accident occurrence and associated consequences. In this paper, the following description of risk is adopted with reference to a generic i-th initialling event, which combines probabilities and consequences:

$$Risk\ i = P\ i * [\ \sum N\ = 1\ C\ i, j * q\ i, j] \quad (2)$$

where i is the index of the element of the set A of initiating events, whose generic element Ai is a specific initiating event, pi is the likelihood of occurrence of the initiating event Ai, j is the index of the possible consequences deriving from scenario Ai, Ci, j is the magnitude of the possible consequences caused by event Ai and q i, j is the conditional probability that these consequences develop, given that the accident Ai occurred.

Event Tree Analysis (ETA) is an inductive logic, graphically supported approach for identifying the various accident sequences that may result from a given initiating event (Zio et al., 2006). The probability of each accident sequence can be estimated by multiplication of the conditional probabilities of each node along the sequence from the initiating event to the end (Zio et al., 2007). Thereby, risk criteria is defined as the terms of reference by which the significance of risk is assessed and risk evaluation explains the procedure based on the risk analysis to determine whether the tolerable risk has been achieved. Accordingly, risk management describes the coordinated activities to direct and control an organization with regard to risk.

A framework of quantitative risk assessment to estimate the potential risk of LNG-fuelled vessels leakage is proposed in terms of the above-illustrated perspectives of risk and related quantitative techniques. Specifically, the framework is used for quantitative risk assessment of fire and explosion accidents in oil and gas installations, e.g. LNG-fuelled vessels, LNG terminals, oil tank trucks. The framework enables to measure the probability of accident scenarios for various initiating events by ETA, which is the likelihood of fire and explosion accidents for LNG-fuelled vessels leakage events in this paper. The severity of consequence for the accident scenarios can be also analysed and evaluated by CFD simulation with regard to the actual size and arrangement of LNG-fuelled vessel. In comparison to an alternative risk assessment framework, e.g. NORSOK standard z-013 (Norwegian Technology Centre, 2001), this framework is able to quantify the probability of accident scenarios from the initiating events to the outcome accidents, to simulate and evaluate the severity of consequences for these accident scenarios, to integrate the results from probability analysis, severity of consequence analysis, and comprehensive assess the risks of potential events like LNG-fuelled vessels leakage events.

Accordingly, this paper focuses on the risk analysis of LNG-fuelled vessel leakage, during the shipping voyage, neglecting loading and unloading processes. The consideration is for the risks to crew and third party on-board, whereas property loss or environmental damage caused by LNG leakage is out of consideration. A risk analysis model is provided below that indicates the potential of risks, which can be later used for arguing the case for implementing LNG automation technologies in order to mitigate.

Given some identified risk factors

$$= (\xi\ 1, \ldots, \xi\ 2) \text{ with a given p.d.f. } P\ (x\ 1..., x\ n) \qquad (3)$$

Given Performance Index

$$\eta = \psi\ (\xi) \qquad (4)$$

$$\psi\ (\xi) = \log\ (\xi\ 1\ \xi\ 2) + \xi\ 2 + 5.2\ \xi\ 3 \qquad (5)$$

Determine some statistical measure on the performance index:

1. Average Performance

$$E\ (\psi(\xi)) = \int \ldots \int \psi\ (x\ 1, ..., x\ n)\ P\ (x\ 1, \ldots, x\ n)\ dx\ 1, \ldots, dx\ n \qquad (6)$$

2. Tail

$$P(\psi(\xi) > C) = \int \int \psi(x\,1, \ldots, x\,n) > c\; P(x\,1, \ldots, x\,n)\, dx\,1, \ldots, dx\,n \quad (7)$$

3. Pdf

$$f\,\eta\,(y) = dp\,(\psi\,(\xi) < y)\,/\,dy \quad (8)$$

$$= d\,/\,dy \int \int \psi\,(x\,1, \ldots, x\,n) < y\; P\,(x\,1, \ldots, x\,n)\, dx\,1, \ldots, dx\,n \quad (9)$$

Normally, a study is carried out in a workshop setting by a multidisciplinary team. Its primary function is to review possible hazardous events that may occur during the planned operation based on detailed engineering information, previous accident history, and judgment of the participants. Depending on the specific methodology used (e.g., what-if, failure modes and effects analysis), the team will document what can go wrong, the related potential causes and consequences of these events, and what safety measures can prevent or mitigate the respective events. Hence, a full range of hazardous effects that could occur after a hazardous event should be considered. These include fire, explosion, injury to personnel, damage to equipment and structures, shutdown of nearby activities, and cryogenic hazards. The hazardous events and effects are normally placed into a risk matrix. Based on the risk matrix, risks can be ranked in terms of importance (from low probability, low consequence risks to high probability, high consequence risks).

6.2 Monte Carlo simulation model

A built determining model allows a look ahead into the future based on certain presumptions. These presumptions can be for example the return on a portfolio, the expense of a development, etc. To improve the credibility of the simulated system it is imperative to consider verifiable information, skills in the field, or past experience from which one can draw an appraisal. Although this is helpful for building up a model, generally they still contain some characteristic instability, since it is always an evaluation of an obscure system.

To mitigate this problem, in some cases, it is useful to estimate a range of values. For instance, in the frame of a construction project, based on some expert knowledge, an estimation of the time it will take to complete a particular job is possible – i.e. the estimation of the absolute maximum time it might take, in the worst possible case, and the absolute minimum time, in the best possible case. The same could be done for project costs. Moreover, for instance, in a financial market, the knowledge on the distribution of possible values through the mean and standard deviation of returns can be assessed. However, by using a range of possible values this helps to create a more realistic picture of what might happen in the future.

Accordingly, when a model is based on ranges of estimates, the output of the model will also be a range. This is different from normal forecasting model, in which the start with some fixed estimates – e.g. the time it will take to complete each of three parts of a project – in comparison with an end up value, result in the total time for the project. If the same model based on ranges of estimates for each of the three parts of the project, the result would be a range of times it might take to complete the project. Therefore, when each part has a minimum and maximum estimate, we can use those values to estimate the total minimum and maximum time for the project.

In this paper, we adopt a Monte Carlo simulation model to evaluate factors that may influence the system. Monte Carlo recreation, or likelihood reproduction, is a strategy used to comprehend the effect of danger and instability in money, venture administration, cost, and other anticipating models.

$$t_{i j i \rightarrow m i} = t_0 - 1 / \lambda_{i j i \rightarrow m i} \ln (1 - R_{i t, j i \rightarrow m i}) \qquad (10)$$

where

$$R_{i t, j i \rightarrow m i} \approx U [0,1) \qquad (11)$$

$t_{i j i \rightarrow m i}$ represents Time transition required for component i to go from state j i to same m i. $R_{i t, j i \rightarrow m i}$ denotes a random number. The fuel supply level (100% or 0% system operation) is determined by the state transition.

Then, the availability of the system is calculated as the mean value of the fuel supply level.

M – Specified number of times
A i – Availability of the system in the i^{th} system random walk
where i = 1, 2, …, M

$$A = \sum_{i=1}^{M} A_i / M \qquad (12)$$

In respective to the risk analysis, it is possible to conduct an analysis of the LNG tank and its heat exchange rate per second and also per day with respect to boil-off gas rate. Furthermore, in detail, it is necessary to explain the component of failure and repair events that takes place in the LNG bunkering sector to analytical prove the risk assessments. Henceforth, evolution of LNG automated bunkering will give new scope to the LNG market.

7. CONCLUSIONS AND RECOMMENDATIONS

In our paper, we have suggested to use of a framework from BAS in order to consider the strategy and the implementation of automated LNG bunkering systems. The methodology towards the use of automated bunkering with the help of automation systems yields nearly 100% reliability that is supported by a risk factor analysis.

In respective to the risk analysis, it is possible to explain the component of failure and repair events that takes place in the LNG bunkering sector to analytical prove the risk assessments. This paper advises that new evolution of LNG automated bunkering solutions will influence the LNG market.

Using the Monte Carlo simulation model to determine whether the process for the automated bunkering is possible or impossible results that automation is comparatively possible to implement. Furthermore, it is pointed out that customized automation and Human Machine Interface will play a vital role for an effective development of Automation LNG bunkering.

This is valid in the process of Ship-to-Ship bunkering and also possible for the improvement of an automated bunkering between Ship-to-Shore with the help of fixed and flexible actuators and sensor components.

In the near future, it can be expected that more vessels will be propelled by using LNG as fuel, which fosters the demand for solutions that consider employing automated bunkering, which at the same time facilitate sustainable growth in LNG bunkering.

A few arguments for the implementation of automated LNG bunkering solutions, as well as recommendations to facilitate the use of automated LNG bunkering solutions are suggested:

- Investments in automated LNG bunkering systems are required, but will lead to improved efficiency in bunkering of LNG (i.e. saves time, costs and reduce errors), which vice versa will further increase the use and thus, the demand for LNG in the market.
- In order to ensure reliability of automation, it is necessary to take into account all the potential risk factors involved.
- Qualitative and quantitative analysis of such system ensure high-level sustainable operation of the systems.

Future research should focus on further automation possibilities that arise for instance from blockchain technology incl. smart contracts, which represents among all novel technologies, one of the most promising approaches with far reaching potentials in the shipping sector as well as for ports (e.g. Philipp et al., 2019).

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REFERENCES

ABS (2014). Bunkering of Liquefied Natural Gas-fuelled Marine Vessels in North America, https://ww2.eagle.org/content/dam/eagle/publications/reference-report/LNG%20Bunkering.pdf, Accessed 10 May 2019.

Det Norske Veritas (2012) Modalities for the provisioning of LNG as shipping fuel in Flemish ports, Part II, Legal & Regulatory, Report No. 13YB7C6-3. LNG Bunkering http://www.lngbunkering.org, Accessed 10 May 2019.

Domingues, P., Carreira, P., Vieeira, R., and Kaster, Wolfgang. (2016) Building automation systems: Concepts and technology review. Computer Standards & Interfaces (45) March 2016, pp. 1-12. Elsevier Publishing.

Emerson (2016). LNG Cluster Cooperation. http://www.lngcluster.eu/files/Main/files/documents/Emerson%20for%20LT%20LNG.pdf . Accessed 9 June 2019.

EU Commission, (2014) European Commission, Clean Power for Transport – Alternative fuels for sustainable mobility in Europe, 2014. Accessed 20 April 2019.

FESTO (2017) Festo LNG. http://www.festo.com. Accessed 19 May 2019.

Gerlitz, L., Philipp, R., & Beifert, A. (2017, October). Smart and Sustainable Cross-Sectoral Stakeholder Integration into Macro-Regional LNG Value Chain. In *International Conference on Reliability and Statistics in Transportation and Communication* (pp. 112-126). Springer, Cham.

ISO Technical Committee 67 WG10 (2012) Draft Guidelines for systems and installations for supply of LNG as fuel to ships, Part 1 General Guidelines. ISO. http://ballots.api.org Accessed 9 June 2019.

Langfeldt, L., & Pewe, H (2013). Final Report: European Maritime Safety Agency (EMSA)—Study on Standards and Rules for Bunkering of Gas-fuelled Ships (No. 2012.005). Report.

Madjidian, J. (2017). Developing a strategy for LNG powered transport corridors in the Baltic Sea Region.

Maidstone, R. (2012). Discrete Event Simulation, System Dynamics and Agent Based Simulation: Discussion and Comparison. Report submitted to MRes in Statistics and Operational Research, University of Manchester, UK.

MarTech LNG (2014). LNG Fuel Bunkering Procedures in Ports and Terminals in the South Baltic Sea Region. http://www.golng.eu/files/Main/PDF/SBSR.pdf. Accessed 9 June 2019

Martin-Soberon AM, Monfort A, Sapina R, Monteverde N, Calduch D (2014) Automation in port container terminal. In proceedings of the XI Congreso de Ingeniería del Transporte (CIT 2014). Valenciaport Foundation, Valencia, Spain.

Noh Y, Chang K, Seao Y, Chang D (2014) Risk-based determination of design pressure of LNG fuel storage tanks based on dynamic process simulation combined with Monte Carlo method. Reliability Engineering & System Safety 129:76-82. doi /10.1016/j.ress.2014.04.018.

Norwegian Technology Centre (2001). NORSOK STANDARDZ-013, Risk and emergency preparedness analysis, Rev. 2, 2001-09-01, https://www.standard.no/pagefiles/955/z-013.pdf, Accessed 19 May 2019.

Parola F, Sciomachen A (2005) Intermodal container flows in a port system network: Analysis of possible growths via simulation models. International Journal of Production Economics 97: 75-88.

Philipp, R., Gerlitz, L. & Prause, G. (2018). Regional Häfen auf Digitalisierungskurs: Intelligentes Wachstum und nachhaltige Wertschöpfung entlang der kleinen und mittel-großen Häfen des Ostseeraumes, In: Cleve, Alde, Wißotzki (eds.): Proceedings of WiWiTa 2018 Conference, 77 – 86, Wismar, ISBN 978-3-942100-58-8, https://www.researchgate.net/publication/326113557, Accessed 19 May 2019.

Philipp, R., Gerlitz, L. & Prause, G. (2019, May). Smart Contracts for Entrepreneurial Collaboration in Logistics Networks. The 11th international scientific conference "New Challenges of Economic and Business Development – 2019: Incentives for Sustainable Economic Growth": Riga, Latvia, May 16-18, 2019. Proceedings. Riga: University of Latvia, 2019, pp. 652 – 663, https://www.researchgate.net/publication/336316066, Accessed 19 May 2019.

Rubinstein RY, Kroese, DP (2017) Simulation and the Monte Carlo Method, 3rd edition. John Wiley & Sons, Hoboken, NJ, US.

Styliadis T, Koliousis I (n.d.) LNG Operations: safety issues and procedures, https://businessdocbox.com/Green_Solutions/77800372-Lng-operations-safety-issues-and-procedures-styliadis-theodore-koliousis-ioannis-deparment-of-maritime-studies-university-of-piraeus.html#show_full_text. Accessed 9 June 2019

Zeng Q, Yang Z (2009) Integrating simulation and optimization to schedule loading operations in container terminals. Computer & Operations Research 36:1935-1944. doi:10.1016/j.cor.2008.06.010.

Zio E, Baraldi P, Patelli E (2006) Assessment of the availability of an offshore installation by Monte Carlo simulation. Int J Press Vessels Pip 2006; 83:312–20. doi.10.1016/j.ijpvp.2006.02.010.

Zio E, Marella M, Podofillini L (2007) A Monte Carlo simulation approach to the availability assessment of multi-state systems with operational dependencies. Reliab Eng Syst Saf 2007; 92:871–82.

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