Developments of Cargo Loss-Mitigating Strategies: A Review

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ABSTRACT

Covid-19 has stalled the growth of international seaborne trade to its nadir since the world's financial crisis of 2008-2009. In light of this, shipping companies, more than ever, have to seek beyond conventional wisdom in devising their master plans to tolerate the adverse implications levied by the pandemic. In this paper, several advancements in the maritime industry, ship-specific and non-ship-specific, formulated by the scientific community over the last two decades are presented. For ship-specific advancements, the guidelines for establishing effective monitoring systems for container ships, optimizing ship-to-ship transfer operations between Liquefied Natural Gas vessels and Floating Storage and Regasification Units, enhancing ethylene gassing-up operation for Liquefied Petroleum Gas vessels, and minimizing volatile organic compounds emission of crude oil tankers are presented. For non-ship-specific advancements, the technologies of Data-driven Analytics, Independent Automotive Damage Appraisers Intelligent Cargo Systems, and Blockchain Technology are presented. All these advancements can be leveraged by shipping companies to maximise their profits, particularly during the challenging epoch, by keeping their cargo loss at a minimal level.

***KEYWORDS**: Covid-19, Cargo Loss, Blockchain Technology, Data-driven Analytics, IADA Intelligent Cargo System*

1.0 INTRODUCTION

Global pandemic Covid-19 has caused the slowdown in the world economy and trade, which subsequently stalled the growth of international maritime trade to its lowest point since the financial crisis of 2008-2009 (UNCTAD, 2020). Moreover, the pandemic has encouraged shipping companies to foster technological solutions and keep abreast of the most recent advancements in the market as one of the strategies to tolerate the impacts of the pandemic since it has been demonstrated that shipping companies with swifter technological uptake are better at dealing with the disruptions engendered by the pandemic (UNCTAD, 2020). This paper will focus on the major advancements that the scientific community has contributed over the last two decades to help shipping companies in minimizing cargo loss and subsequently maximising their profits.

By and large, there are two forms of cargo loss; 1) cargo damage, and 2) cargo theft (Wu et al., 2017). The former form of cargo loss is particularly evident for container ships carrying perishable goods (e.g., fruits, vegetables, meat, fish, etc.). The South African fruit industry accounts for 50 per cent of the country's agricultural export (Barrientos, 2012). Moreover, the South African fruit industry generates approximately $1,02 billion per annum (Economic Research Division, 2010). However, a massive portion of this

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revenue and commodities are lost due to quality deprivation of these products before they reach their customers (Emenike et al., 2016). From this, it is fair to conclude that other nations may confront the same circumstances. This conclusion is supported by the fact that roughly 35 per cent of perishable goods, namely fruits and vegetables, are lost in the cold chain logistics (Vega, 2008). On top of that, $30 to $50 billion worth of cargo is stolen per annum (Xu et al., 2018). From these two statistics, it is manifest that shipping companies must be equipped with effective cargo loss-mitigating strategies to further improve their profits.

Cargo loss may occur due to a number of factors, for instance, it may be due to shipping companies not being equipped with efficient monitoring systems (Emenike et al., 2016). Moreover, cargo loss may arise due to a poor security system, which consequently leads to cargo theft (Xu et al., 2018). Last but not least, cargo loss may take place owing to improper cargo loading and unloading procedures (Shigunov et al., 2015). These three examples are just a few factors that may cause cargo loss. From the given examples, it is clear that the solutions to this problem must be sought from various fields of studies.

In the next section, this paper will introduce the methodology utilized in providing shipping companies with multi-faceted solutions. Subsequently, the paper will highlight a number of ship-specific strategies that shipping companies can implement to minimise their cargo loss. Afterwards, this paper will outline several non-ship-specific strategies that shipping companies can foster to further reduce their cargo loss. Ship-specific strategies are strategies that are exclusive to certain types of ships, whereas non-ship-specific strategies are strategies that can be adopted irrespective of ship types. Finally, a conclusion will be drawn as the final chapter of this paper.

2.0 METHODOLOGY

In this paper, the major contributions formulated by the scientific community over the last two decades in developing effective strategies to reduce cargo loss will be discussed. To that end, the commonly recognized and accepted PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was adopted in searching the relevant scientific publications that will fulfil this paper's objective (Moher et al., 2009).

In order to offer shipping companies with multi-faceted solutions having the capacity to comprehensively neutralize the cargo loss problem, the germane scientific publications were sought from a wide range of scientific fields (e.g., Marine Engineering, Electrical and Electronic Engineering, Environmental Engineering, Management, etc.). Inasmuch as the objective of this paper is to provide shipping companies with the advancements that were undertaken over the last 20 years, the search span was set from the year 2000 – 2021. All publications before 2000 were excluded from the search.

The following terms were used to systematically extract the relevant literature from two major scientific databases; 1) Scopus and 2) Web of Science. Other platforms (e.g., SpringerLink Journal, ScienceDirect Journal, etc.) were also utilized to obtain additional references.

"Cargo Loss*" AND (ship* OR vessel* OR marine*)

The search included journal articles, review papers, and conference papers that were published in English. Other document types were excluded (e.g., reports, case studies, letters, etc.). Articles written in languages other than English were also excluded (e.g., Chinese, Russian, Japanese, etc.)

At this stage, 76 studies were extracted from the databases. Subsequently, the studies were screened to remove duplicates. Consequently, 11 studies were excluded from the search result. Next, the abstracts of the studies were thoroughly screened for their relevance. Accordingly, 43 studies were removed from the search result. The exclusion criterion at this stage was as follows.

- Articles not related to strategies to reduce cargo loss in a maritime domain (e.g., cargo loss mitigating strategies for other forms of transportations; strategies for dealing with different problems such as ship collision, grounding, and so forth; causes of cargo loss without providing any remedies for the problem; etc.)

After excluding studies fulfilling this exclusion criterion, the full texts of the remaining 22 studies were perused, and as a result, 14 studies were removed based on the following criteria.

- On closer perusal, the study did not address the strategies to reduce cargo loss in a maritime domain at all. Two studies were removed due to this reason.
- The study proposes a solution that can only be effectively implemented by the relevant international organizations (e.g., proposal to IMO to develop ship-specific operational guidance). Two studies were removed due to this reason.
- No full text was available for closer perusal, neither from the publisher, research institution, or researcher's personal web pages, namely ResearchGate.com and Academia.edu. 10 studies were removed due to this reason.

Having completed this process, eight studies were left for discussion. Figure 1 illustrates the whole process in a flowchart.

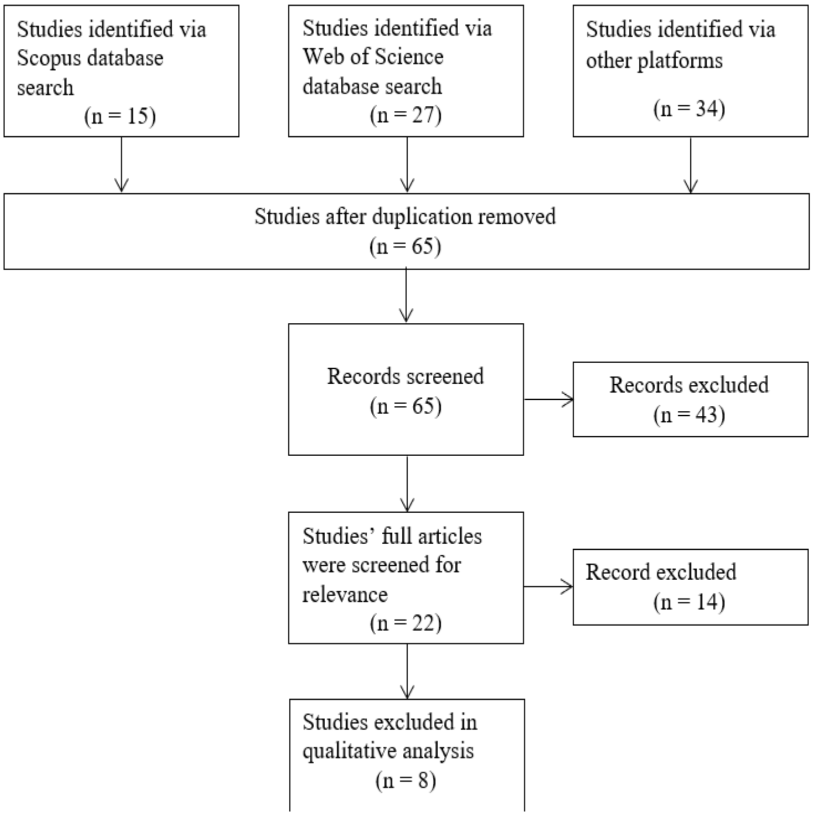


Figure 1. PRISMA flowchart of research strategy

3.0 SHIP-SPECIFIC STRATEGIES

3.1 CONTAINER SHIP

As hitherto mentioned, roughly 35 per cent of perishable goods are lost in the cold chain logistics. This problem is partially due to the lack of cost-effective monitoring systems of the good's temperature (Emenike et al., 2016). In this subsection, a solution to this problem will be discussed.

i. RFID Temperature Sensing and Predictive Modelling

The need for an improved strategy for effective in-transit cold chain management has motivated Emenike et al. (2016) to undertake a series of experiments to compile a data set that represents cold chain operations in Southern Africa. Subsequently, Emenike et al. (2016) utilized the compiled data set to train neural network models that can predict the following two parameters; 1) Current in-cargo temperatures based on the periphery's temperature, and 2) Future in-cargo temperatures based on the current temperatures. The latter parameter is particularly important in enabling proactive prevention of circumstances that may lead to cargo loss. The study has shown promising results in terms of its prediction accuracy; however, as Emenike et al. (2016) have already mentioned in their study, more focus should be given to simplifying the system's implementation method. For instance, the system may use wireless sensors in lieu of conventional sensors. This will allow this strategy to be all the more practical to be adopted by shipping companies.

3.2 GAS CARRIER

3.2.1 LNG VESSEL

The demand for Floating Storage and Regasification Units (FRSU) has been rapidly increasing since it was first inaugurated in 2005 (Wood & Kulitsa, 2018). FSRU capacity in operation had soared from approximately 35 million tonnes per annum (MTPA) to 795 MTPA in January 2017 (IGU, 2017; Wood & Kulitsa, 2018). In February 2020, the capacity reached 826 MTPA (IGU, 2020). In line with this, a significant amount of effort has been dedicated in diversifying FSRU capabilities, ranging from comparatively cheap conversion LNG vessels to larger-capacity, newly-built vessels with higher-tank-pressure ratings (Wood & Kulitsa, 2018). Given this, FSRU has opened several new markets to LNG trade (Wood & Kulitsa, 2018).

However, notwithstanding the impressive track records, a majority of the FSRU fleet is run based on operating practices developed for the lower-tank pressure ratings of LNG vessels which lead to operating inefficiencies (Wood & Kulitsa, 2018). These inefficiencies, if not treated, will lead to increments in onboard gas consumption and atmospheric emissions that consequently engender appreciable cargo loss (Wood & Kulitsa, 2018). Fortunately, a study conducted by Wood and Kulitsa (2018) has outlined several cost-effective strategies, primarily interconnected with ship-to-ship (STS) transfer procedures and LNG cargo rollover-mitigation measures, that can be fostered by shipping companies to improve their LNG trade. Moreover, the operation efficiency of FSRU can be enhanced by exploiting the standard use of the recondensing equipment (Kulitsa & Wood, 2018; Wood & Kulitsa, 2018). In this subsection, all these strategies will be discussed. It is noteworthy that all these strategies do not require any capital investments or major modifications.

i. STS Transfer Procedures

Wood and Kulitsa (2018) have proposed 12 straightforward measures to minimize gas consumption in the Gas Combustion Units (GCU) during STS transfers. These measures can be implemented individually; however, higher efficiency and lower cargo consumption can be achieved if implemented collectively (Wood & Kulitsa, 2018). These measures are as follows.

a) Ensure the LNG cargo to be transferred by the LNG carrier is as cold as possible immediately before STS transfer operations.

b) Ensure "Lowest Operating Tank Pressure" on FSRU (or receiving LNG carrier) at the beginning of STS transfer operations.

c) Avoid running safety equipment, namely GCU or steam dump, for the purpose of pre-cooling the FSRU tank's heel cargo before STS transfer operations.

d) Ensure optimum coldest state of the receiving-tank structures around the vapour space volume is attained before commencing STS transfer operations.

e) Minimize the increments of tank pressure on the receiving side during the STS transfer-lines-cool-down stage by injecting gas vapour produced during the lines-cool-down phase directly into the heel LNG cargo in lieu of the vapour space of the FSRU tank. On the whole, this measure is only effective for LNG carriers to FSRU and LNG carriers to Floating Storage Units (FSU) STS transfer operations.

f) Utilize continuous top spraying at a minimum rate to ensure the receiving tank's vapour space and the surrounding tank structure to be as cold as possible throughout the STS transfer operations.

g) Minimize the use of GCU or steam dump equipment by utilizing the upper operating limits of the particular tank designs of the receiving vessel as a pressure control reference in identifying the ideal time to start the equipment (i.e., GCU or steam dump equipment).

h) Minimize the generation of Boil-off Gas (BOG) on the discharging LNG carrier and consequently boost vapour return flow from the receiving vessel by maintaining the tank pressure of the discharging vessel close to the pressure recorded during the initial cargo survey (i.e., from the Custody Transfer Measuring System (CTMS) on that particular vessel) throughout the STS transfer operations, immediately after commencing the transfer.

i) Optimize the combined application of measures 7 and 8 by carefully coordinating the FSRU and LNG carrier to gain more savings. This combination of these measures is known as the "tandem-pressure approach", and it has the capacity to significantly increase efficiency.

j) Avoid overheating the LNG by excessive recirculation of the regasification feed pumps within the FSRU tanks.

k) Partially remove ballast water from ballast tanks that are close to the receiving vessel's LNG tanks to a certain level where the cargo tank's outer structure is not wetted by the ballast. This measure enables natural heat ingress to be minimised; however, it is limited by the ship's strength, stability, and safety limit allowances.

l) As STS transfers are nearly completed, let the expected short-lived pressure increments take place in any of the receiving vessel's tanks, up to the upper-operating-pressure limit of the tank. Maintain pressure at that point, by briefly running the GCU/steam dump or related equipment. This temporary tank-pressure increment is due to the reduced vapour return flow towards the discharging LNG carrier and it is not necessary to operate the GCU excessively to decrease the tank pressure at this stage since it will naturally decline once the STS transfer operation ends.

ii. LNG Rollover-Mitigation Measures

Wood and Kulitsa (2018) have proposed several measures to improve the rollover management of FSRU. The measures can be divided into three categories; 1) Preventative Measures, 2) Pro-Active Mitigation Measures, and 3) Reactive Mitigation Measures. These three measures are as follows.

a) Preventative Measures

In this category, several measures are proposed by Wood and Kulitsa (2018) in preventing LNG stratification on FSRU. The measures are as follows.

- Ensure one or more of the FSRU's tanks are in a near-empty state before STS transfer operations. The low LNG heel cargo in this tank will likely cause the stratification to be eliminated by itself during the operation. However, in the case of stratification that is already developed, its impacts can be minimized by top spraying.

- Load LNG into the FSRU's tank with the lowest cargo heel, at initially highest flow rates, during the initial stage of the STS transfer to boost mixing. This will slightly reduce the thickness of the top LNG layer, or may permanently eliminate stratification upon its development.

- Allocate certain FSRU tanks as "pump-out" tanks. Upon completion of STS transfer operations, the bottom-LNG layer in these tanks is subsequently removed before the development of rollover begins to occur. "Pump-out" tanks are chosen since their bottom layers are normally far smaller than the bottom layers of other tanks. These tanks are mainly used to draw in the interim LNG withdrawal for regasification feed.

b) Pro-active Mitigation Measures

In this category, several measures are proposed by Wood and Kulitsa (2018) as proactive rollover mitigation measures for FSRU. These measures are as follows.

- When the STS transfer operations are initiated, those tanks on the FSRU with the smallest LNG heel cargo must be top sprayed at maximum pump rates. This means pumping LNG from the new bottom LNG layer, introduced by the STS transfer operation, and spraying it on the top LNG layer from above, via the vapour space in the tank. This top spraying will force the densities of both LNG layers to converge all the more rapidly; hence, shortening the roll-over "incubation" period. The shorter the rollover "incubation" period the "weaker" the future rollover is likely to be. Two additional benefits of top spraying are as follows; 1) It slightly lessens the total volume of the bottom LNG layer, which also weakens the rollover; and 2) It keeps the tank structure around the vapour space cold; hence any additional cold vapour exuded during the rollover is protected from being heat up and later expand that ultimately leads to a further increment in tank pressure.

- By and large, it is better to avoid top spraying the tanks designated as "pump-out" tanks, as it would be counter-productive to the purposes of extending the rollover "incubation" period. Nonetheless, minimal top spraying may be required, in some cases, for the purpose of keeping a tank's vapour-space structure cold. This is particularly necessary when it becomes clear that the intended pump-out of the entire bottom layer is not going to be achieved and rollover becomes unavoidable. In such cases, minimal top spraying is recommended, but only when the pre-roll-over signs are conspicuous.

- STS transfer operations are often conducted at rates of 5000 to 6000 m^3/h (in some cases, 8000 to 9000 m^3/h), whilst LNG carrier and FSRU cargo lines are devised to cope with flow rates of up to 12,000 m^3/h LNG flow. This spare cargo line should be utilized whenever possible, to redistribute LNG between tanks and afterwards produce a larger number of tanks with small top LNG layers.

- Excessive recirculation of the bottom-layer LNG should be avoided to prevent unnecessary heat induction from the pumps. This is relevant to all tanks either they are designed for top spraying or pump out. This measure is particularly important to lessen BOG consumption throughout the FSRU operations.

- In the case of FSRU with membrane tanks, minimize the contact between ballast water and the outer cargo tank structure to ensure the FSRU's trim, stability and hull strength are in good condition. This measure also reduces heat ingress to the bottom-LNG layer. Moreover, this measure also contributes to small decrements in gas consumption during STS transfer operations.

c) Reactive Mitigation Measures

In this category, several measures are proposed by Wood and Kulitsa (2018) as reactive rollover mitigation measures for FSRU. These measures are as follows.

- In the case of FSRU with MARVS-250-mbarg-rated tanks, it is recommended to run the safety equipment which burns a certain amount of gas for a short time, immediately before rollover and during onset as a precautionary measure. Note that this should be only conducted when tank pressure is expected to reach the upper-operating-pressure limit. In short, the use of GCU or steam dump equipment should be limited to its essential use only to avoid unnecessary waste of the valuable cargo.

iii. Non-standard Use of an FSRU's Recondenser

Most modern FSRU are equipped with recondensers that feed condensed BOG to the regasification units and to a stream of LNG extracted from the cargo tanks (Kulitsa & Wood, 2018; Wood & Kulitsa, 2018). The utilization of the recondensers during the regasification operations reduces gas loss by inhibiting excess BOG to be consumed in GCU, steam dumps, flares, etc (Kulitsa & Wood, 2018; Wood & Kulitsa, 2018). LNG gas loss can be further reduced if recondensers are also used in the FSRU's recirculation mode (Kulitsa & Wood). However, the use of recondensers in recirculation mode is still far from common (Kulitsa & Wood, 2018; Wood & Kulitsa, 2018). Simply put, it can be concluded that the practice of using recondensers in recirculation mode is still "non-standard".

In recirculation mode, LNG is transferred from the LNG tanks to recondensing equipment, and back again to the LNG tanks. Once the regasification process is halted, not much BOG is required by the FSRU engine room; thus, the vessel has to handle this excess. By condensing the BOG to LNG and returning it to the cargo tanks, the significant volume reduction involved has caused the LNG tank pressure to rise at a slower rate due to the rising saturated vapour pressure (SVP) of the LNG in the tank as warmer LNG is sent back to the tank. Since the LNG is distributed through several cargo tanks on an FSRU, the recondenser recirculation process can be executed in cycles by switching the feed LNG and returning LNG periodically from one bank to another. This measure helps to effectively redistribute the LNG returning in the tanks in such a way that the tank pressure increment rate can be slowed down and concomitantly prolong the period without recourse to the GCU.

This measure, ultimately, will lead to appreciable decrements in gas loss and degree of emission and simultaneously improve FSRU's efficiencies, particularly during periods of low or no gas send out from the FSRU, provided that the recondensers are run within the safe operating limits. Again, note that there are no additional operating costs inasmuch as this measure consumes far less energy than sending the LNG back in the tanks via heat. Moreover, as recondensers becomes simpler to be installed, it is fair to conclude that older FSRU built without recondensers can have them retrofitted easily, and the non-standard use of recondensers outlined by Kulitsa and Wood (2018), sooner or later, will be acknowledged by shipping companies as a common practice.

In conclusion, Kulitsa and Wood (2018) have outlined comprehensive guidelines in improving the efficiencies of FSRU and reducing cargo loss. However, the studies should be supported by experimental data to gain more recognition from shipping companies.

3.2.2 LPG VESSEL

Ethylene (C2H4) is a colourless, flammable gas (National Library of Medicine, 2021). Ethylene is one of the indispensable elements of the petrochemical industry and it is primarily used to formulate plastics, polyethylene, chlorostyrene derivatives, ethanol, and higher aliphatic alcohols (McGuire, 2000; Schaller, 2012). Recently, the demand for ethylene has soared particularly in China, the Middle East, and the Far East, which has engendered an unprecedented rise in the demand for the maritime service to deliver ethylene, principally to the hitherto mentioned regions (Wieczorek, 2020). Typically, specifically built LPG vessels are used to transport ethylene (Wieczorek, 2020). In running such vessels, two of the most important operations are inerting and gassing-up operations (Wieczorek, 2020). On one hand, the inerting operation involves forming an inert atmosphere in cargo tanks to inhibit the formation of an explosive mixture between oxygen and ethylene (Wieczorek, 2020). On the other hand, the gassing-up operation involves removing an inert gas, namely nitrogen, by using ethylene vapour to prevent cargo contamination (McGuire, 2000).

Gassing-up operations are particularly challenging due to the following three reasons.

i. Both gases, ethylene and nitrogen, have very similar densities at certain temperatures (Nanowski, 2016).
ii. Ethylene is one of the most expensive cargoes to be carried by marine transports (Schaller, 2012).
iii. There are no clear guidelines for gassing-up operations on the ethylene carriers (Wieczorek, 2020).

Significant amounts of ethylene cargoes are often lost during the gassing-up operations, resulting in considerable financial loss for shipowners (Wieczorek, 2020). Approximately \$40,000 worth of ethylene is lost during the operations (Wieczorek, 2020). In view of this, Wieczorek (2020) conducted a study to optimize gassing-up operations. In this subsection, the important findings of the study will be highlighted.

Initially, Wieczorek (2020) developed a theoretical mathematical model to simulate gassing-up operations. From the model, Wieczorek (2020) proposed that gassing-up operations should be carried out with the minimum nitrogen and ethylene pressures in tanks. This will allow the gases (i.e., nitrogen and ethylene) to be separated and consequently enable the gassing-up operations to be undertaken in the shortest time with the smallest loss of ethylene cargo. Subsequently, an experimental study was conducted by Wieczorek (2020) to verify the accuracy of the findings.

The following gassing-up guidelines were applied to m/v Neptune, an ethylene carrier with four cargo tanks. The outcome of the novel procedure was then compared with other ethylene carriers (i.e., m/v Saturn and m/v Orion) that administer the conventional procedure.

i. Tanks must be gassed-up in pairs, in cascade.

ii. After the first tank of each cascade is gassed-up, it must be isolated from the other tank in the cascade, and cargo cooling must be commenced.

iii. Cold ethylene vapour must be leaded, and parallel gassing-up must be started in the other two tanks that were not gassed-up during the cascade process.

iv. The pressures of the tanks must be maintained to their minimum possible values.

v. The pressures of tanks in a cascade must be similar.

The ethylene cargo loss during the gassing-up operation of m/v Neptune was then respectively compared with a three-cargo tank carrier and a two-cargo tank carrier, m/v Saturn and m/v Orion. Note that the guidelines listed above were not applied to these two ethylene carriers since they act as control variables in this experiment.

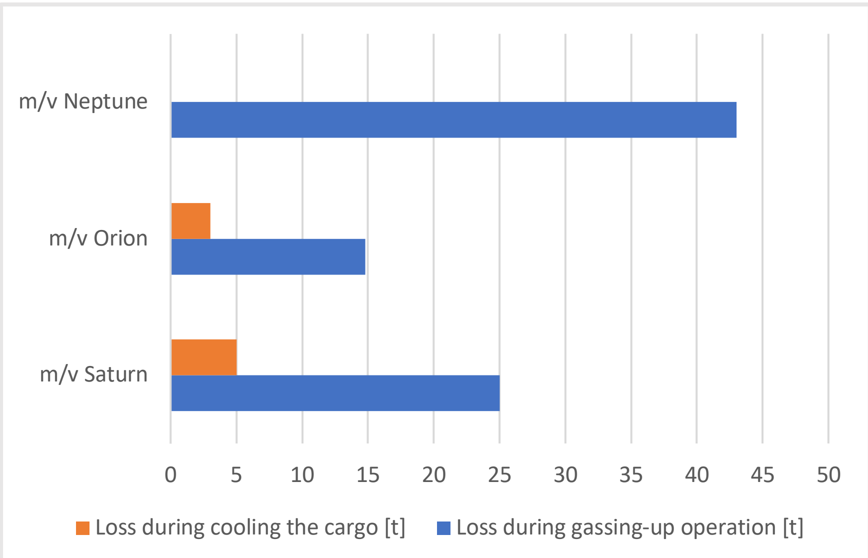


Figure 2. Comparison of ethylene cargo loss during gassing-up operations (Wieczorek, 2020)

Figure 2 demonstrates the outcome of the experiment. As shown in Figure 2, m/v Neptune experiences approximately 43 tons loss of ethylene during the gassing-up operation, the highest loss as opposed to m/v Orion and m/v Saturn. However, unlike m/v Orion and m/v Saturn, m/v Neptune experiences no cargo loss during the cargo cooling process. Moreover, no cargo compressor stopped working due to extremely high pressure on the second stage of discharge (Wieczorek, 2020). In conclusion, more studies are required to realize the conclusion obtained from the theoretical mathematical model established by Wieczorek (2020); nonetheless, this study has provided substantial insight in developing effective guidelines to reduce cargo loss during gassing-up operations of ethylene carriers.

3.3 TANKER

3.3.1 CRUDE OIL TANKER

Cargo loss in crude oil tankers is mainly due to the following events; 1) Ship Collision, 2) Grounding, and 3) Emission of Volatile Organic Compound (VOC) (Husain et al., 2003). On one hand, cargo loss due to collision and grounding has been estimated at approximately 25,000 tons per year, with occasional disastrous losses (Husain et al., 2003). On the other hand, cargo loss due to VOC emission has been estimated at roughly 1.6 million tons (Gunner, 1999).

Currently, crude oil tankers are required to ensure the ullage space to be suitably inerted and the ullage pressure must be maintained at a positive value. Concomitantly, the ullage pressure must always be below a specified value. These requirements are made to reduce cargo loss due to VOC emission. However, the requirements are not effective enough to ensure ullage mixture to reach its equilibrium state throughout a tanker’s sailing period. Consequently, VOC emission continues to occur, particularly during transit, due to frequent venting and inerting. In light of this, Husain et al. (2003) conducted a study to develop a strategy to minimize cargo loss due to VOC emission. The study was divided into two parts; 1) Analysis of crude oil under negative pressure, and 2) Minimization of VOC emission by negative pressure.

i. Analysis of Crude Oil Under Negative Pressure

Initially, Husain et al. (2003) conducted theoretical and experimental analyses to identify the vaporization properties of representative crude oil at below atmospheric pressures and at moderately elevated temperatures (i.e., typical temperatures of crude oil tankers). For experimental analysis, Husain et al. (2003) selected three crude oils; 1) 12 API, 2) 30 API and 3) 37 API. Note that API stands for American Petroleum Institute, a commonly used index to measure the density of crude oil or refined products (API, 2021; McKinsey & Company 2021). Each of the crude oils was then undergone a series of gas evolution tests at pressures of 0 psig, -2 psig, -3 psig and -5 psig at temperatures of 67 F, 80 F, and 110 F. Finally, the compositions of the liberated gas were analysed. Figure 3 and Table 1 show the schematic of equipment used in the experimental analysis and results of the evolution tests, respectively.

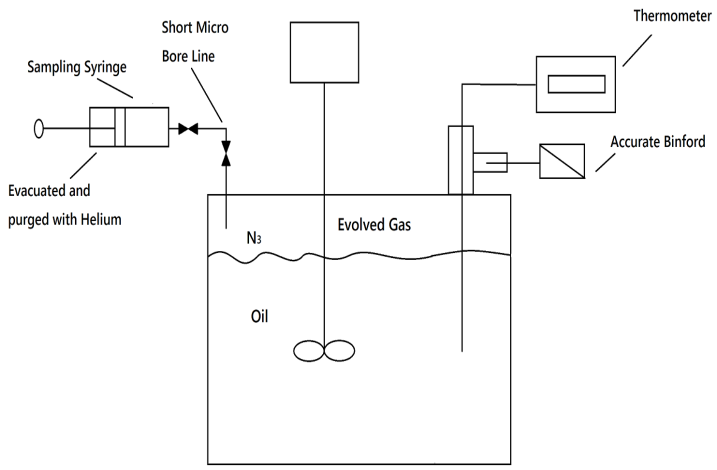


Figure 3. Equipment arrangement for experimental analysis (Husain et al., 2003)

Table 1. Results of gas evolution tests (Husain et al., 2003)

CRUDE OIL	Temperature \ Pressure	0 psig	-2 psig	-3 psig	-5psig
	F	Mole Fraction			
12 API	67	0.0013	0.0500	0.0744	0.1234
	80	0.0092	0.0568	0.0807	0.1288
	110	0.0245	0.0703	0.0933	0.1398
30 API	67	0.0009	0.0327	0.0507	0.0956
	80	0.0167	0.0535	0.0756	0.1371
	110	0.0868	0.1626	0.2240	0.5298
37 API	67	0.0007	0.0300	0.0470	0.0906
	80	0.0139	0.0479	0.0687	0.1284
	110	0.0683	0.1329	0.1837	0.4093

The following conclusions can be made from the result shown in Table 1.

- API gravity of crude oil - For heavy oils, vaporization can be considered insignificant.
- Temperature - Temperature increments boost the vaporization of intermediate components.
- Pressure - As pressure decreases below atmospheric pressure, the gas composition becomes denser with intermediate components.

ii. Minimization of VOC Emission by Negative Pressure

The data obtained from the theoretical and experimental studies were then utilized by Hashim et al. (2003) to develop an automated closed-loop control system that can limit in-transit VOC emissions by ensuring ullage pressure is maintained at a constant value. The system enables the ullage gases to be circulated in a closed-loop arrangement at sub-atmospheric pressure through a blower and seawater heat exchanger. Given this, the ullage is maintained at a constant value despite the perturbations generated by mass and heat exchange during a voyage. Most importantly, the proposed model is inexpensive and can be easily installed on tankers.

In conclusion, Hashim et al. (2003) have provided comprehensive discussion, theoretically and experimentally, on the importance of containing ullage pressure at a constant value. Moreover, Hashim et al. (2003) have proposed an automated closed-loop control system that can limit in-transit VOC emission. Needless to say, the proposed system has to be supported with experimental data to make certain of its effectiveness in limiting VOC emission. All things considered; it is fair to conclude that the study has projected a promising future for crude oil tankers.

4.0 NON-SHIP-SPECIFIC STRATEGIES

4.1 DATA-DRIVEN ANALYTICS

Cargo loss incidents not only impose financial losses to shipping companies but also disrupt the entirety of logistics systems. In addition to financial losses, cargo loss may also cause shipping companies to be susceptible to increased insurance costs, loss of business market opportunities, and degradation of companies' reputation (Burges, 2012). Given this, it is evident that cargo loss in logistics systems requires immediate attention. Notwithstanding this, in the field of logistic risk management, the number of studies dedicated to solving this issue, particularly via data-driven analytics, is rather nominal.
In consequence, Wu et al. (2017) conducted a study to develop a framework of business analytics to enable shipping companies to exploit their data to determine events that may trigger cargo loss incidents, and subsequently formulate strategies and distribute resources to prevent cargo loss in their logistics systems. The framework of business analytics is divided into three parts; 1) Descriptive Analytics, 2) Predictive Analytics, and 3) Prescriptive Analytics. Shipping companies can implement the proposed business analytics to exploit their logistics data to identify causal factors of cargo loss in their logistics systems, whilst companies without logistics data can integrate the proposed cargo loss mitigation measures into their logistic systems. Figure 4 shows the frameworks of the proposed business analytics.

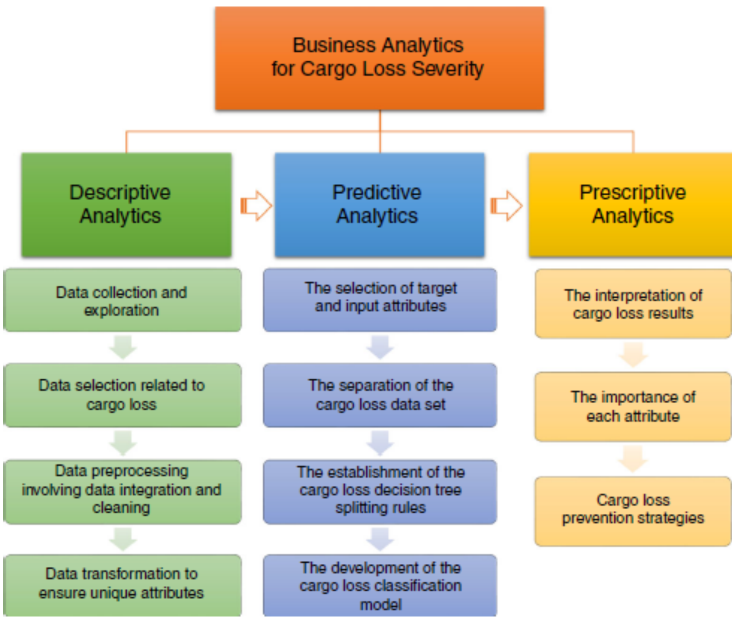


Figure 4. The proposed business analytics for cargo loss severity (Wu et al., 2017)

The applications of data-driven analytics can also be observed in other domains od the maritime industry that can be clustered into three groups; 1) Anomaly Detection Methods, 2) AIS Data Analytics, and 3) Simulation of Maritime Traffic Data (Munim et al., 2020; Sidibe & Shu, 2017; Wang et al., 2019; Yang et al., 2019).

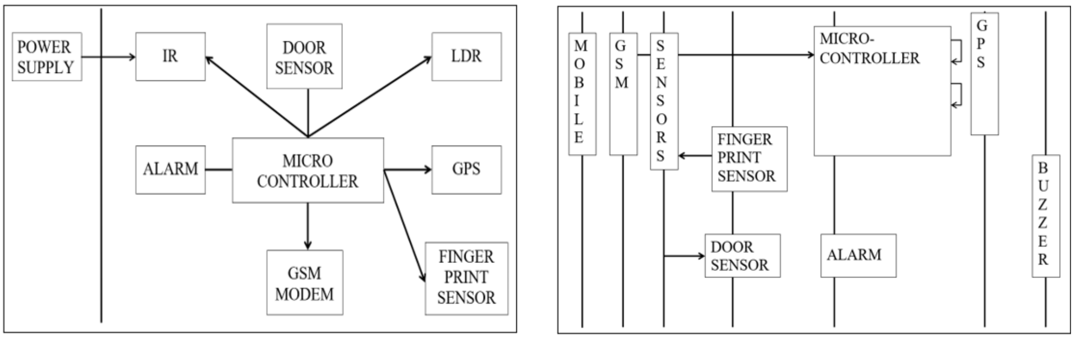
4.2 INTELLIGENT CARGO SECURITY SYSTEM

As previously mentioned, at least $30 billion worth of cargo is stolen every year. Current measures implemented by governments to prevent cargo theft, notwithstanding being strict, are highly burdensome (Xu et al., 2018). The United States Department of Homeland Security (DHS) necessitates the scanning of 100 per cent of maritime cargo entering the United States from 2012, covering roughly 11.6 million containers per year (McNeil & Zuckerman, 2010). Besides, current measures enforced by governments to make cargo systems safer are insufficient to prevent illegal practices such as tampering, load theft, terrorism, and unauthorized access, etc., from occurring (Dinesh et al., 2017). Given this, Dinesh et al. (2017) and Xu et al. (2018) conducted studies to develop intelligent cargo security systems. These systems will be discussed in this subsection.

4.2.1 IADA INTELLIGENT CARGO SYSTEM

IADA stands for "Independent Automotive Damage Appraisers". IADA acts as the final authorization centre for any type of equipment and facility to be hosted on the cargo by inspecting and customizing the cargo with the necessary components to fulfil the guidelines imposed by governments (Jijesh, 2016; Wang, 2008; Zhou, 2015). The primary objective of the system is to make certain the safety of the onboard crew members and relevant shipping operations. To further enhance the performance of the system, Dinesh et al. (2017) incorporated fingerprint and GPS modules into the system as an attempt to develop a completely standalone framework of the system.

The fingerprint module acts at the primary level of authentication to the system. Whilst, the GPS module provides uninterrupted access and location services for the system. The proposed model is claimed to enhance current IADA systems by supplementing six major benefits; 1) Saving of Labours, 2) Easy Coding and Maintenance, 3) Cost-Effective, 4) Higher Consistency and Quality, 5) Higher Accuracy, and 6) Higher Safety Rigidity (Dinesh et al., 2017). Figure 5 shows the architecture and the sequence diagram of the proposed system.



a) System Architecture b) Sequence Diagram

Figure 5. System architecture and sequence diagram of the proposed system (Dinesh, 2017)

4.2.2 BLOCKCHAIN TECHNOLOGY

Blockchain technology, which was initially used in a crypto-currency, Bitcoin, as a decentralized bookkeeping system to prevent double-spending, was leveraged by Xu et al. (2018) to enhance the current cargo security system (Nakamoto, 2009; Xu et al., 2018). By and large, blockchain has three important features; 1) Public Accessibility: All data stored with blockchain is available to the public. 2) Immutability: It is extremely difficult, if not impossible, to modify, alter, or delete information that has been fed to the blockchain when the security assumption is fulfilled. 3) Resilience: Each participant of the system possesses a complete copy of the blockchain and no single point of failure can impinge the availability of the stored data. Simply put, blockchain can provide a unified, immutable, and resilient information management portal for all maritime transportation participants and ultimately improve the transparency of the cargo flow, accelerate the inspection process and minimize fraud (Xu et al., 2018). The proposed scheme developed by Xu et al. (2018) to embed blockchain technology into the maritime cargo management system will be discussed in this subsection.

i. Participants Screening and Digital Identity Generation

The first step to secure the maritime supply chains, particularly for border-crossing cargo flows, is to screen involved participants and generate digital identities for them. An exclusive identity management system is developed to fulfil this objective, which acts as an extended public key infrastructure. A party that is involved in maritime transportation will possess a public/private key pair as its digital identity. If the party is a company, every employee involved in the cargo handling operations should possess his/her own digital identity. Fortunately, several hardware technologies have been developed to improve maritime supply chain transparency, such as smart containers, RFID tags, tracking devices, etc (Carn, 2011; Shi et al., 2011; Talukder, 2007).

ii. Checking Digital Identity

Subsequently, to make certain that a participant can only use his/her own digital identity, the system will execute the following tasks.

- Ensure both public and private keys are matched.
- Ensure the public key is valid and contains all the necessary information.
- Ensure the user is the real owner of the keys.
- Record all the activities and save them in the blockchain.

As discussed above, it is evident that blockchain technologies can be used by shipping companies to further solidify the measures committed by the governments and concomitantly streamline the cargo inspection processes. However, there are several challenges that maritime communities have to solve to fully exploit the expected benefits of blockchain technologies (Munim et al., 2021). These challenges are summarised in Table 2. Fortunately, a growing body of studies have been dedicated to resolving these challenges and all the major resolutions to these challenges are reviewed in detail by Munim et al. (2021).

Table 2. Challenges in the implementation of blockchain technologies

Challenges	Source
Lack of authority for standardization	Jovic et al. (2020), Segers et al. (2019)
Interoperability and lack of scale	Allen et al. (2019), Irannezhad (2020), Pranav et al. (2020), Shi & Wang (2018), Todd (2019)
Antitrust law and commercial privacy	Jovic et al. (2019), Todd (2019)
Environmental concern	Jovic et al. (2020)
Dispute resolution	Perkusic et al. (2019), Todd (2019)
Data tampering and hacking	Dutta et al. (2020), Kermani et al. (2020), Pranav et al. (2020), Nyugen et al. (2020), Greiman (2019)

5.0 CONCLUSION

Covid-19 has left shipping companies with no other options but to leverage recent technologies to endure the impacts subjected by the pandemic. In this paper, several advancements contributed by the scientific community over the last two decades have been discussed to assist shipping companies to minimize their cargo loss and simultaneously maximise their profits. Cargo loss can occur due to several factors such as inefficient cargo loading and unloading operations, substandard security systems, and poor goods monitoring systems, just to name but a few.

For LNG vessels, STS operations can be improved by implementing the guidelines outlined by Wood and Kulitsa (2017). For LPG vessels carrying ethylene, shipping companies can exploit the guidelines provided by Wieczorek (2020) to optimize the gassing-up operations. Moreover, crude oil tankers can reduce cargo loss by adopting closed-loop control systems to minimize VOC emissions. Furthermore, shipping companies can utilize IADA systems and blockchain technologies, as respectively proposed by Dinesh et al. (2017) and Xu et al. (2018) to improve their cargo security systems. Also, for container ships carrying perishable goods, a monitoring system proposed by Emenike et al. (2016) can be adopted to reduce cargo damage. Finally, shipping companies can exploit their logistics data, as recommended by Wu et al. (2017), to determine the factors that cause cargo loss and subsequently develop specific strategies and allocate necessary resources to prevent cargo loss.

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