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REVIEW OF THE CONTAINER SHIP LOADING MODEL – CAUSE ANALYSIS OF CARGO DAMAGE AND/OR LOSS

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ABSTRACT

As the maritime transport of containers continues to grow and container ships change in terms of design and construction, it is important to ensure the appropriate level of safety for this type of transport. Over the decades, the size and cargo capacity of container ships have been changing, and so have their manoeuvring restrictions and required stability criteria. It seems that changes in the regulations, technological development and increased stability requirements are not yielding satisfactory results – the causes of container ship accidents continue to show similar patterns. The present article refers to the problem of ensuring safety in sea container transport, with a particular focus on cargo processes. Its purpose is to determine cause-and-effect relations leading to the loss of containers at sea, and to develop a model of loading that could significantly raise the level of safety of container transport.
The article provides a general description of threats to ships related to weather conditions, loading methods or stability limitations. A statistical analysis of the occurrence of damage and/or loss of cargo from container ships was carried out and the risk of cargo loss was assessed on the basis of data from 2015–2019. A Pareto diagram was used for this purpose. The authors present the concept of the container ship loading model, which may contribute to increasing the safety of shipping in the future.

Keywords: operations process modelling, safety management, container, loss of cargo, maritime transport, means of transport

INTRODUCTION

The new standardised cargo unit, the container, revolutionised road and rail as well as sea transport. The International Maritime Organisation (IMO) does not define or specifically address container ships in its conventions. Nevertheless, the provisions of these international instruments apply to container ships, too. They are binding for container ships by defining requirements and standards for ‚cargo ships'. In most publications, a container ship is defined as a ship intended for the transport of containers, equipped with guides and designed to handle vertical loading and unloading [1, 2, 3].

Container ships are specialised ships, adapted to carry containers only. However, the various types of containers offer possibilities of carrying a wide variety of goods without changes in the ship structure [4]. The container market has been growing dynamically. Shipowners operating the largest number and size of container include A.P. Moller-Maersk Group, MSC Mediterranean Shipping Company S.A., CMA CGM S.A., China Ocean Shipping Company, Evergreen Lines, Hapag-Lloyd AG, Yang Ming Marine Transport Corporation, and United Arab Shipping Company [5, 6, 7].

To meet market requirements, operators are increasing the deadweight of container ships [8, 9]. However, due to the limited size of manoeuvring areas, it is doubtful that the main dimensions and capacities can continue to be increased. Current developments are focused on increasing the efficiency of ports, perhaps leading in the future to unmanned terminals [10, 11].

As regards long-term trends, ship sizes and total productivity by country have increased over the years, while the number of shipping companies has dropped. The number of ships and TEU capacity are manifestations of increased container trade, which, however, negatively affects the safety of navigation, particularly in restricted areas [12]. The basic convention concerning container ships is the SOLAS Convention, regarding ships of this type as not requiring specific regulations and describing typical requirements related to the construction of container ships [13]. Additional requirements are included in resolutions, e.g. MS/Circular.608, concerning requirements for open slot container ships [14]. Set forth by the IMO, mandatory stability requirements are contained in the International Code on Intact Stability. These requirements were built on experience related to ship design and analysis of marine accidents. Container ships are particularly exposed to violent gusts of wind. The parameters of the lateral windage area depend on the number of tiers (layers) of containers on board. These ships will have various heeling arms depending on the tier height. However, the fulfilment of all the stability criteria does not guarantee the total safety of the ship. Therefore, it is important to avoid adverse weather conditions that may lead to, inter alia, shipping green water, shifting cargo or increased rolling [15, 20].

For ship safety, the process of loading containers is essential. The fast process of container ship loading excludes weighing each container. The container weight data can only be found in shipping documents. Observations made during many years of maritime practice by one of the co-authors of this publication allow for an estimate that containers often weigh more than is declared in documents (by as much as 7%). In addition, information on the distribution of cargo is not available, which necessitates the assumption that the centre of gravity is at 45% of the container height, and the intersection of the longitudinal and transverse axes is exactly in the middle of the container (the difference between the adopted data and reality is up to 9%) [16, 17].

Many potential problems may arise if the container's declaration is incorrect. These include [18,19,20,21]:

- wrong decisions concerning ship loading;
- the need to relocate containers on board (and consequent delays and costs) if any of the stability parameters is found to be incorrect;
- collapse of a container stack;
- container falling overboard;
- cargo liability claims;
- damage to container bottom;
- damage to a ship;
- risk of partly lost stability due to significant load of ship;
- risk of injury or death of seafarers and port workers;
- failure of the integrity of the service schedule;
- delays in handling the supply chain for shippers of correctly declared containers;
- lost revenue and profits;
- exclusion of cargo already confirmed when the declared weight of cargo, ship's DWT capacity or maximum draft are exceeded by the real but incorrectly declared weight of cargo located on board;
- change in the planned trim and draft, causing reduced ship's efficiency, non-optimal fuel consumption and increased emissions of exhaust gases.

The IMO amended the SOLAS Convention so that a container may be loaded provided that its weight is first verified. Since 1 July 2016 the shipper has been responsible for this requirement, and a container with unverified weight cannot be loaded on board.

The container ship is particularly exposed to fire during a sea voyage due to restricted access to the cargo carried. Fire is usually caused by cargo shifting, mixing and friction inside a container due to improper securing inside the container. As containers may shift and damage each other on deck, the contents are likely to get outside the box. This is particularly dangerous if IMO-class goods are carried, as they may react with water and other substances, causing a fire or explosion. Therefore, before a container ship is loaded, containers with dangerous goods are checked for their location relative to other boxes with IMO-class goods [22]. It should also be ensured that containers containing dangerous goods are not placed near reefer containers that, in case of failure, may release large quantities of water. Due to restricted access to containers, firefighting is very difficult. Often, the only way to extinguish fire of containers located below deck is by flooding the entire hold. Fire on deck can generally be limited only by using water cannons and water curtains. All in all, fire on a container ship is a dangerous event, frequently leading to losses of cargo, and the ship itself.

One essential consequence of accidents at sea is marine environment pollution: atmosphere (fire), water and coastal beaches (fuel and lubricating oils). The impact of a container ship accident on the natural environment can be really huge [23]. Apart from pollution by cargo, a sinking container ship may spill oil. That is what happened on 10 March 2016 after the container ship *T.S. Taipei* ran aground and broke apart, spilling 441 m^3 of diesel oil into the sea, causing extensive pollution of Taiwan's shore [24].

The article aims to analyse the concept of a container ship loading model for enhancing shipping safety. Given the number of adverse events resulting in the loss of containers, it is difficult to work out solutions in safety systems that will fully satisfy existing needs. The article deals with the problem of ensuring the safety of cargo on container ships. The authors also indicate the causes and consequences of container loss.

The publication is structured as follows. "The Materials and Methods" section contains a detailed description of the objective, the scope and the research method adopted. The next section includes a statistical analysis of occurrences of damage to and/or loss of cargo from container ships and their causes using Pareto-Lorenz analysis. In the last section the authors consider the concept of a model of container ship loading, while the Conclusions refer to the presented considerations, indicating further directions of research aimed at raising safety on container ships.

MATERIALS AND METHODS

The main objective of the article is to present a concept of loading containers, with a particular focus on the causes and consequences of previous events at sea involving container ships, and indicating possible changes in cargo handling processes that may contribute to the minimisation of losses. To achieve the adopted research objective, the article specifies three stages including analyses of the subject of the research, presented in Fig. 1.

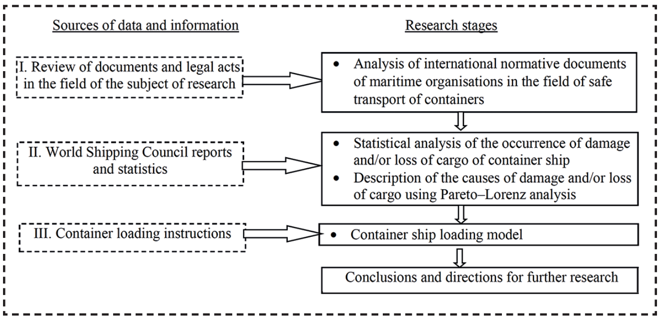

Fig. 1. Research methodology diagram. Source: Authors' study

Stage 1 consists in analysing the legal requirements for the safe transport of containers by sea. The relevant provisions of conventions addressing typical requirements for the construction of ships are taken into account.

Statistical analysis of containers lost for random causes and in catastrophic accidents is given in stage 2. The calculated weights of individual causes of damage and/or loss of containers indicate changes in the numbers of lost containers corresponding to variable weather conditions or other atypical events.

Stage 3 comprises an analysis of a container ship loading plan. It becomes clear that the creation and implementation of such a plan is a complex task, due to the restrictions of the ship itself, cargo handling gear and securing equipment, as well as weather conditions affecting the ship, human errors or incorrect declaration of cargo mass. The presented model of the loading concept introduces new elements that may contribute to greater safety and earlier determination of the actual stability of the ship.

This research makes use of various techniques and tools of data collection and analysis [25]. These include our own observations, good seamanship practice based on [13, 14, 22], analysis of source materials or statistical analysis [24]. Descriptive statistical analysis was used in the work as a summary of the data set and led to basic conclusions and generalisations of the use of containers in the port and outside the port on vessels. The total analysed data from 97 transport units was based on [21].

Descriptive statistical analysis was performed with the use of data published in the work of Van Zwijnsvoorde [26] and also by FleetMon [21]. The scope of the research covered the years 2015–2019, detailing information about accidents related to the loss of containers by a ship, divided by the location of the accident (regardless of the location of the event and in the port).

For the purposes of statistics, the main causes of damage and/or loss of containers were identified. These included:

a) In port: bad weather conditions, list, loss of stability, technical failure, collision, fire, unknown, and
b) Outside the port: loss of stability, crane collapse, failure during un/loading, crane operator's error, fire, collision, unknown.

Then, based on the information provided by the FleetMon service, the examined accidents were assigned to the given causes, bearing in mind that one accident may have many causes.

Descriptive statistics examining the issue are presented in the form of tables and graphs.

The work also includes the Pareto–Lorenz analysis. The Pareto principle, also known as the 80/20 principle, means that a small number of factors (20%) is responsible for most of the events (80%) induced by those factors. The tool allows a hierarchical arrangement of data based on their importance. Based on the Pareto–Lorenz analysis, we can determine what preventive actions should be taken to reduce the impact of major causes, and, consequently, reduce the number of accidents [25].

The construction of the diagram is performed in the following phases [25,27]: completing information about the examined process, related to a specific problem; determining the quantity that can be used to measure the result of the operation process in terms of the problem under consideration; arranging information, based on the collected data and knowledge about the operation of containers and determination of the causes, due to their considerable impact on the result of the transport process; determination of the cumulative percentages of each cause; connection with a line of points corresponding to the cumulative values; and conducting the analysis of the graph to determine the group that has the highest priority impact (weight, importance) for the sea transport of containers.

The Pareto–Lorenz analysis was used in the study to estimate the weight (importance) of individual causes of damage and/or loss of containers outside and in the port. This analysis was done on the basis of questionnaires (the size of the analysed group was 90 people), and was included in the authors' work.

Based on their experience and knowledge and the review of relevant literature [21], [28], the authors identified and presented problems related to safe handling of containers. To make the presented model with the introduced changes (in blue) feasible, all the participants in the loading process should be integrated more than before: planners, stevedores, crane operators, container-securing personnel and ship's crew.

The last part of the article formulates conclusions and indicates directions of further research, focusing on the possibilities of using the latest technologies. These may facilitate the job of an officer responsible for loading by offering better access to updated information on the cargoes to be carried, their location on the ship and actual weight, allowing quick relocation if errors are found, such as failure to meet stability requirements.

Results

Statistical analysis of the occurrence of damage and/or loss of container ship cargo

Proper loading, storage and securing of containers and the correct declaration of cargo mass is of the utmost importance for the safety of the ship, crew and cargo, as well as land-based workers, cargo handling facilities and the environment.

However, even after all the actions are executed properly, factors such as severe weather conditions, strong wind and rough sea, grounding, structural defects of hulls or collisions may lead to the loss of containers.

In the past it was virtually impossible to calculate the actual number of containers lost. For many years those figures were estimated, but not verified. It was estimated that as many as 10 000 containers were lost yearly. To obtain more accurate data, in 2011 the World Shipping Council (WSC) started a survey involving its member organisations. They operate 80% of the global capacity of container ships, so information on their losses reflects annual global losses well.

In each of the surveys conducted in 2011, 2014 and 2017, member organisations were requested to specify the number of containers lost in the previous three years. The survey conducted in 2017 involved all member companies, representing 80% of the global container capacity. For the sake of the analysis, the WSC assumes that the losses suffered by the remaining 20% operators are similar to those of the organisations participating in the survey.

Some of the companies suffered no losses in the examined periods; others had catastrophic losses that, for the purpose of this analysis, were defined as a loss of more than 50 containers at a time. Catastrophic losses are rare, but the number of containers lost in such cases exceeds half the total number lost.

The 2011 survey demonstrated that in the years 2008–2010 an average of 350 containers were lost per year. If catastrophic accidents are included, that figure increases to 675. The 2014 survey, in turn, established an average loss of 733 containers (2011–2013). With catastrophic events, the number of lost containers rose to 2,683. Such a great number was the consequence of two accidents in those years - M/V Rena in 2011 in the vicinity of New Zealand (loss of ship and 900 containers) and M/V MOL Comfort in 2013 in the Indian Ocean (loss of ship and 4,293 containers). The survey in 2017, covering the years 2014–2016, revealed the loss of 612 containers for random causes and 1390 in catastrophic accidents (Fig. 2) [29].

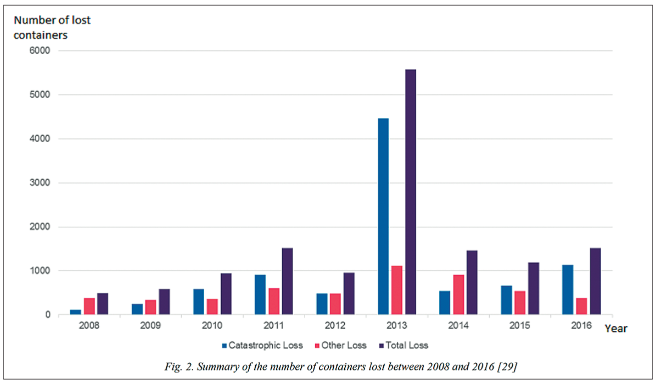

Fig. 2. Summary of the number of containers lost between 2008 and 2016 [29]

To sum up, in the years 2008–2016 the average annual loss was 568 containers. If we add disasters, the figure grows to 1582. 64% of the lost containers in the past decade resulted from catastrophic accidents, i.e. disasters.

After analysing data for 12 years (2008–2019), it was found that companies lost an average of 1,382 containers per year. Analysing the data in 3-year periods, a sudden increase in the number of lost containers in the second period is visible (MOL Comfort, M/V Rena catastrophic accidents) and then their decrease in subsequent periods (despite the SS El Faro accident and the loss of 517 containers, as well as several accidents in 2018–2019, in which more than 100 containers were lost at once) (Fig. 3) [30].

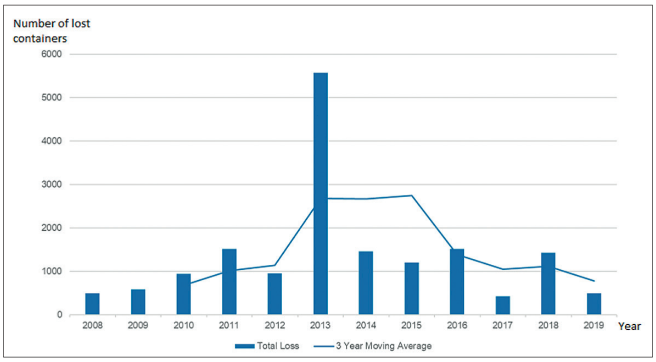

Fig. 3. Summary of the number of containers lost between 2008 and 2019 [30]

These data indicate that the number of containers lost each year differs, which is, inter alia, related to variable weather conditions or other unusual events. It can also be concluded that most of the containers were lost due to catastrophic events.

Maritime accidents in this work and consequent losses of containers are divided into two categories, following the division of the WSC: for random causes and due to catastrophic accidents (more than 50 containers lost at a time).

The analysis was based on the list of accidents presented on the FleetMon website, including accidents from all over the world. However, it should be noted that shipowners frequently fail to inform the public about container losses for random causes. This will be visible in further data.

The following analysis addresses accidents related to damage and/or loss of containers in the years 2015–2019 (Fig. 4).

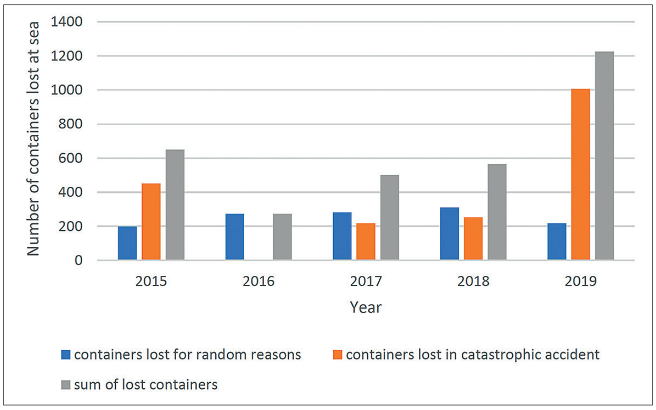

Fig. 4. Summary of container losses between 2015 and 2019. Own study based on [21]

By comparing the total number of containers lost in 2015 and 2016 with the data presented by the WSC, we can clearly see discrepancies in the number of containers lost due to random causes and those lost in catastrophic events. This may indicate that shipowners intentionally do not reveal information on the loss of containers when such incidents do not leave any trace, such as broken securing, ship damage or shifted container tiers. The differences in the number of containers lost in catastrophic accidents can also be explained in this way, if we bear in mind that in the table catastrophic accident means a case of more than 50 boxes falling overboard. This may happen in an accident for other reasons as well. Information on some of the accidents included in the WSC analysis may have not reached the public either.

Tab. 1. Comparison of the number of accidents related to the loss of containers in years 2015–2019 due to the place of their occurrence. Own study based on [21]

Accident / Year	2015	2016	2017	2018	2019
Damage and/or loss of container regardless of the location of the event	16	18	18	23	22
Damage and/or loss of container in port	5	2	2	7	7

It follows from the table that in the years 2015–2019 the average loss was 643 containers per year, of which 386 sank in catastrophic accidents. The number of containers lost in port accidents accounts for 60% of the total number lost. This outcome is in proportion to the data presented by the WSC, which proves the reliability of this research, although performed on a smaller scale.

One deviation from the average figures of previous years is the number of containers lost in catastrophic accidents in 2019. This was due to a significant loss of containers in two accidents - MSC Zoe (270) and Vietsun Integrity (285). The major cause of the former accident was considered to be adverse weather conditions, in the latter - improper stowage, leading to a list and loss of stability, and the consequent capsizing of the vessel.

Data on containers lost in ports were also analysed. They accounted for less than half of the total number of accidents (Table 1). The above data show that at the beginning of the surveyed period the number of accidents related to the loss of containers in port had a decreasing trend compared to the overall number of such accidents. In subsequent years, another growth trend can be noted (Fig. 5) However, it is not certain whether the rising trend will continue.

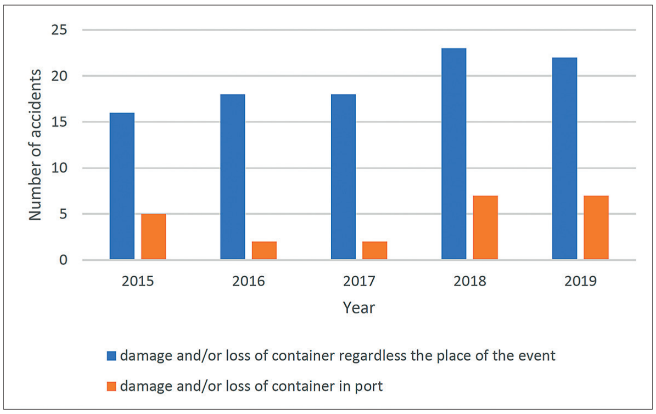

Fig. 5. Summary of container losses in port with the total number of losses in the years 2015–2019. Own study based on [21]

The analysis of accidents related to damage and/or loss of containers described on the FleetMon webpage allowed us to determine the main causes of the accidents that occurred. These include unfavourable weather conditions, ship's list, loss of stability (due to shifting of containers, flooding, technical failures (machinery, lashings and other securing elements)), collisions and fires (Fig. 6). It was also established that in some cases the probable causes of accidents were still not identified. These cases were determined as 'unknown'.

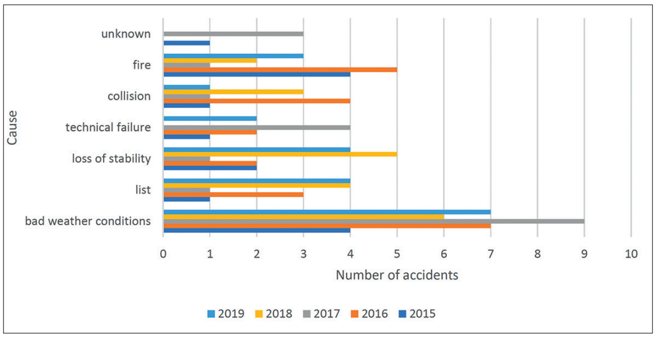

Fig. 6. Reasons for damage and/or loss of the container outside the port in years 2015–2019. Own study based on [21]

The major causes that contributed to damage and/or loss of containers are: bad weather conditions (35%), fire (16%) and loss of stability, often due to list (15%). It follows from the above diagram that the other causes also have a significant, although lower, impact. In the analysed years, the least frequent were container losses due to technical failure.

Based on the descriptions of accidents of container ships in port, the main causes of damage and/or loss of containers in such accidents could be identified (Fig. 7). These include: loss of stability, crane collapse, failure during un/loading, crane operator's error, fire and acollision (manoeuvring or unmoored ship hitting a moored ship). In this case, too, some causes were classified as 'unknown'.

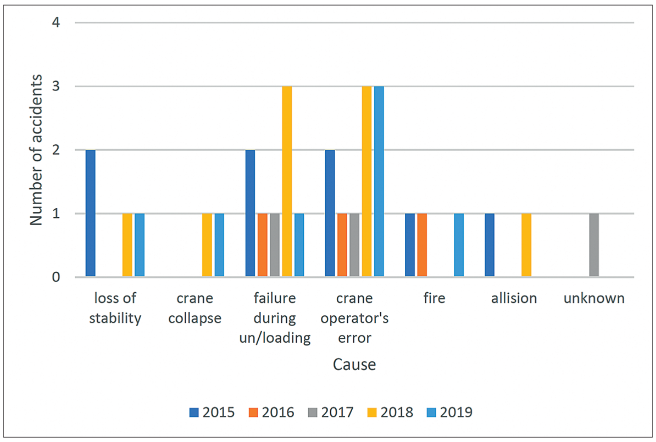

Fig. 7. Reasons for damage and/or loss of the container in the port in years 2015–2019. Own study based on [21]

Notably, in most of the examined cases a single main cause was not established. Only the most likely causes were determined. For this reason, in the above analysis more than one cause was assigned to each accident.

Description of the causes of damage and/or loss of cargo using the Pareto–Lorenz analysis

The Pareto–Lorenz diagram was used to estimate the weights of individual causes of damage and/or loss of containers outside the port, as shown in Table 2 and Figure 8.

Analysing the reasons for the loss of containers or their damage during the voyage and during the ship's stay in the port, it was found that they are repeatable. In the case of the trip, the following were classified as decisive reasons: bad weather conditions, fire, loss of stability, list, collisions and technical failure. The first two of these are not entirely related to the human factor, but the decisions made by the crew can significantly contribute to reducing the risk of losing cargo.

Tab. 2. Classification of the causes of damage and/or loss of containers outside the port according to their frequency in years 2015-2019. Own study based on [21]

Factor	Symbol	Frequency of cause occurrence	%	Cumulative values	
				Frequency of cause occurrence	Share in %
Bad weather conditions	1	33	35.11	33	35.11
Fire	2	15	15.96	48	51.06
Loss of stability	3	14	14.89	62	65.96
List	4	13	13.83	75	79.79
Collision	5	10	10.64	85	90.43
Technical failure	6	9	9.57	94	100.00

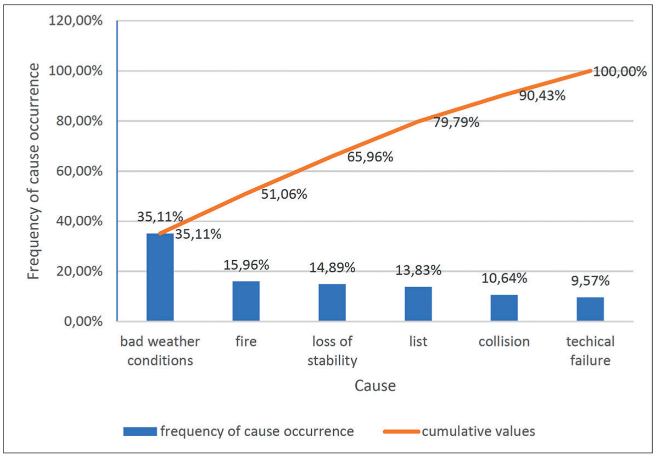

Fig. 8. Pareto-Lorenz diagram for the causes of damage and/or loss of containers outside the port in years 2015-2019 based on Table 2

The tabular data show that only four causes (approximately 80% as per the Pareto principle [25]) are major factors affecting the damage and/or loss of containers.

These include (according to Table 2 and Fig. 8):

- unfavourable weather conditions;
- fire;
- loss of stability;
- list.

These account for 83.68% of the factors contributing to damage and/or loss of containers.

In fact, adverse weather conditions and fire cannot be completely excluded as causes external to the ship. After receiving an unfavourable weather forecast, the crew of a container ship should take action to protect the cargo (check and re-fasten securings), plan weathering and, if necessary, alter the route. The prevention of fire on a ship is dependent on the correct declaration, labelling, distribution and control of containers with dangerous goods, so that in case of fire an effective firefighting action can be taken (fast sighting and identification of cargo on fire).

The main cause of accidents entirely related to the human factor is the loss of stability (usually due to the incorrect stowage plan, which, in turn, has roots in misdeclaration of the cargo weight).

Based on the Pareto-Lorenz diagram, the authors also undertook to establish the weights of individual causes of damage and/or of damage and/or loss of containers in port, as shown in Table 3 and Figure 9.

Tab. 3. Classification of the causes of damage and/or loss of containers in the port according to their frequency in years 2015-2019. Own study based on [21]

Factor	Symbol	Frequency of cause occurrence	%	Cumulative values	
				Frequency of cause occurrence	Share in %
Crane operator's error	1	10	34.48	10	34.48
Failure during un/loading	2	8	27.59	18	62.07
Loss of stability	3	4	13.79	22	75.86
Fire	4	3	10.34	25	86.21
Crane collapse	5	2	6.90	27	93.10
Collision	6	2	6.90	29	100.00

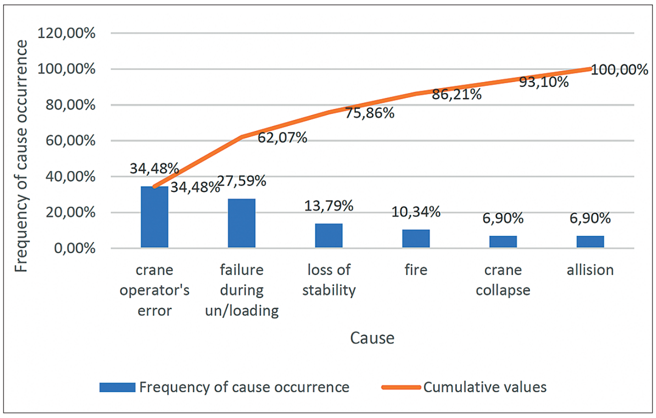

Fig. 9. Pareto-Lorenz diagram for the causes of damage and/or loss of containers outside the port in years 2015-2019 based on Table 3

The data presented above show that basically three causes mostly affect the damage and/or loss of containers in port. They represent 75.86% of the causative factors. These include (see Table 3 and Fig. 9): operator error, failure during un/loading and loss of stability.

The analysis of the above chart leads to a conclusion that the main cause of this type of accidents is operator error (34.48%), while loss of stability ranks as third (13.79); it usually arises due to incorrect calculations and misdeclaration of the cargo weight and wrong container marking. This shows that the human factor plays a major role in container-related incidents. Another important factor is a technical failure during un/loading (27.59%), referring to defective securings and cargo handling gear. This may suggest that there is a need for more frequent inspections or more effective maintenance.

Summarising the above considerations, it can be stated that the decisive influence on the damage and/or loss of containers both in port and outside the port is due to unfavourable weather conditions, fire and loss of stability, often related to the permanent heel of the ship, with the main causes of accidents in the port being operator error, failure during loading/unloading and loss of stability, usually as a result of incorrect calculations and incorrect cargo mass declaration or container labelling. Leaving a container at the scene of an accident poses an unacceptable threat to the environment, especially with regard to the substances it contains, especially when alcohol, acids, concentrated hydroxides, chemicals hazardous to health, or industrial objects or goods are released into the water. Leaving the container where it was lost may not only cause mechanical contamination of waters, but also chemical and biological hazards.

A concept of a container ship loading model for navigational safety assurance

A stowage plan for a container ship is not an easy task. It is prepared by humans under the pressure of time, by means of a computer program, often only a few hours before the ship calls at the port. In addition, large container ships require many movements of the crane in the process of loading and unloading. The relationships between loading the lowest tiers and stability requirements make it difficult to minimise the span of the cranes while preventing containers from being blocked.

The stowage planning of a container ship has two distinct phases – port planning and ship planning (Fig. 10).

In the former phase taking place between ports, planners take into account all containers to be loaded and discharged, ship data, and data on the loading port and nearest discharge ports. It seldom happens in the case of container ships that a batch of containers loaded in one port will all be unloaded in one port of discharge. Usually, the route includes a few ports of call. Therefore, the loading (stowage) plan requires cooperation between ports based on the sequence of calling at these ports to avoid container reloading within the ship.

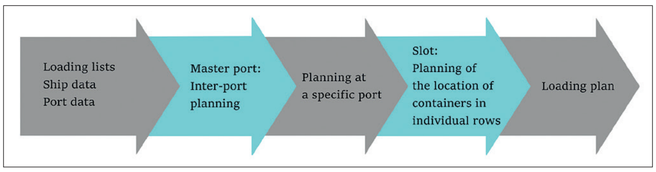

Fig. 10. Hierarchical division of scheduling "master port" and "slot". Own study based on [27]

In addition, this phase takes into account planning in the current port of loading. The order of loading and unloading is then established along with the distribution of the various types of containers in a storage yard.

Based on this distribution, the planning of container positions in specific rows is termed the slot planning phase, and the proper stowage plan is created by uploading containers into the ship model.

In this phase, the stability criteria are checked along with the possibilities of securing the planned stack of containers. There are many securing methods, depending on the ship's size and the securing equipment used on a particular ship. The method of securing a stack will be different for standard containers and those of increased height, known as high cubes.

The location of containers with special cargo should also be verified. Reefer containers should be placed near the power supply plugs. Some ships do not have such plugs in their holds, and their number on the main deck is limited, sufficient for, say, only two tiers of containers in a stack. Containers with dangerous goods should be placed following the rules of separation [31].

The efficiency of loading depends primarily on the suitable order of containers to be loaded. Most container ships have a cellular structure, designed to improve cargo storage, which imposes strong restrictions on the loading sequence. If, for instance, specific containers must be stored in the middle of a hold for the ship's stability, they should be loaded over containers to be discharged later and under containers landed earlier.

At the same time, the order of placing containers in the port's cargo storage yard should be taken into account. If containers to be loaded are located in the yard under those not to be loaded, their extraction will require extra relocation of some boxes.

Two types of container relocation exist: relocation of a row (containers placed in one stack) and relocation of a bay involving hold opening (containers placed above and below the hatch cover of a hold).

The crane operator makes 20–25 movements per hour. In the presented cases, it is clear that logistically it is easier to relocate a small number of containers than to discharge an entire bay to open a hold. For this reason, it is important to take into account the ports of destination of each container.

These considerations indicate that both the creation of a stowage plan and its implementation are complex tasks. This is due to the ship's own limitations, cargo handling facilities and securing equipment as well as weather conditions the ship is exposed to, human errors at various stages or misdeclaration of cargo weight.

Based on these factors, we can distinguish a basic model of loading corresponding to a checklist that facilitates shipboard procedures (Fig. 11).

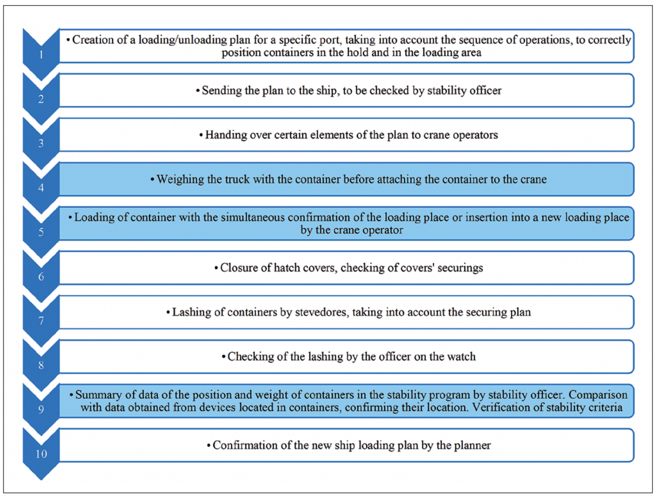

Fig. 11. Concept of container ship loading model

To make the presented model with the introduced changes (marked blue) feasible, all the participants in the loading process should be integrated more than before: planners, stevedores, crane operators, container-securing personnel and ship's crew. Each of them should be responsible for their area of work and tick off the proper performance on a list. The others could view the progress of loading operations. This would allow additional verification of whether each step was completed, which might increase the safety of the ship and cargo.

The presented model introduces new elements that may enhance safety and accelerate the assessment of the ship's actual stability. These are: weighing containers before loading, the possibility of changes made by a crane operator if a container is not placed as planned, and verification of ship stability by devices installed inside containers to confirm the real location of a container within the ship. To implement the proposed model in practice, devices should be installed in containers to enable the verification of the correct location.

To verify the weight of the cargo being shipped, container terminals could be equipped with scales for weighing the truck and its container just before moving to a gantry crane. Such devices are often fitted with a container recognition function, which would increase the certainty that the container is properly loaded in the ship. Thanks to these technologies, the officer responsible for loading would have access to the most current data on the cargo carried: distribution and real weight. This, in turn, would allow fast relocation in case of errors and failure to meet stability requirements.

The practical application of the proposed model requires a detailed economic analysis and analysis of the technical possibilities of applying the proposed solutions. This is the subject of future research into the development of the proposed concept.

DISCUSSION

Container ships in service face a number of hazards related to the impact of weather conditions (parametric roll, sudden gusts), structural failures (material fatigue, structural defects) or human error (wrong stowage plan, inappropriate marking of containers with dangerous cargo, misdeclaration of container weight).

The above-mentioned risks were considered as the main causes of container ship accidents, including such specific factors as changes in hull structure, incorrect navigation in the area, improper loading conditions and previous damage, human factors, incorrect weathering, misdeclaration of container content, and insufficient familiarisation with the ship.

The authors' analyses indicated interrelations between these factors and identified elements that the individual factors consist of. It becomes clear that none of the elements can be indicated as dominant. It is their combination that leads to an accident and the consequential loss of containers. It can also be concluded that, although some of the factors arose independently (bad weather conditions), many of them were due to negligence and human error at the construction stage (improper steel used, discontinuity of girders) and in operation (fatigue, wrong weathering, incorrect loading and repairs).

Based on statistical research, it was found that the number of events related to the loss of containers due to random causes and in catastrophic accidents increased or remained at roughly the same level. This conclusion follows from the analyses of the World Shipping Council (2008–2016) and the authors (2015–2019). No sudden drop was noted in the surveyed period. Therefore, it follows that continuous improvement of container securing equipment is needed, referring to methods of lashing and interlocking, of the navigators' ability to assess the situation and conduct the ship safely in storms (weathering), or of the amount of data available and used in ship stability programmes. However, the risk of container loss cannot be completely eliminated. It can only be minimised by improving preventive measures.

Another conclusion from the cause analyses of container loss or damage at sea and in port is that these causes are recurrent. In the case of a ship underway, decisive causes include adverse weather conditions, fire, loss of stability and list. The first two of these causes are not entirely related to the human factor, but decisions made by the personnel may significantly reduce the risk of cargo loss (proper weathering, interpretation of weather forecast, container marking). The main causes of accidents during a ship's stay in port were found to be operator errors, failure during un/loading and loss of stability. It can be noted that in both areas human error was a significant causative factor. This may suggest the need to take actions aimed at reducing wrong decisions or human participation generally in the decision-making process.

One of the key elements affecting ship stability is the preparation of the stowage plan. This is dependent on several cooperating parties – ports on the ship's route, stevedoring companies in these ports and the ship's stability officer. The effectiveness of loading depends primarily on the order of loading and unloading; therefore it is essential to properly plan the location of container batches intended for different destinations. In addition, each of the parties should make sure that reefer containers, containers with dangerous goods are correctly placed (some companies do not allow them to be stacked below deck).

To reduce human errors at various stages, the proposed model of container ship loading includes these actions:

- draw up a loading/unloading plan for a given port, taking into account the order of operations to correctly distribute cargo in holds and the discharge yard;
- send the plan to the ship, to be verified by the stability officer;
- pass specific parts of the plan to crane operators;
- weigh the truck and container before it is lifted by a crane;
- load the container and confirm its location of loading or enter a new empty space (done by crane operator);
- close the holds and check hatch cover securing;
- secure containers (port workers) as per securing plan;
- check the securings (watch officer);
- complete data on container location and weight in the stability program (done by the stability officer); compare with data from location-confirming devices; check stability criteria;

• verify the new stowage plan of the ship (planner).

To implement the proposed model, modernisation would be required in ports (truck/container scales), containers (position-verifying devices) and the methods of communication between the parties concerned (smooth exchange of information). The above- mentioned solutions are an innovation requiring the commitment of ports, shipowners and stevedoring companies.

The authors, utilising various research tools, demonstrate that loading is the most important task related to the safety of container ships that those involved can modify and improve. The optimisation of this process is a key goal for maritime transport professionals in the years to come. The loading model presented in the article is linked to the checklist based on diversification of tasks and may contribute to minimising the risk of container ship accidents related to loading and stowage.

CONCLUSIONS

On the basis of the research carried out, it can be concluded that the causes of container ship accidents are interrelated. Identification of the elements that make up the individual risk factors does not allow any one element to be identified as dominant. It is their combination that can lead to the loss of containers.

The risk of losing a container can be minimised by improving preventive measures. It is therefore necessary to continuously improve container security devices with regard to lashing and locking methods, as well as the ability of navigators to assess the situation and the safe handling of the ship in bad weather conditions.

From analyses of the causes of loss or damage to containers at sea and in port, it can be concluded that these causes are recurrent.

It can also be concluded that loading is the most important container ship safety task that humans can modify and improve.

The authors aim to optimise this process in future research. The paper presents a loading model that is linked to a checklist based on task diversification. The practical application of the model can contribute to minimising the risk of accidents on container ships related to loading and stowage. At this stage of research, the practical application of the proposed model requires a detailed analysis of the economic and technical feasibility of the proposed solutions.

In order to implement the proposed model, financial investment would be required for upgrades in ports and improvements in communication methods between participants. Innovation requires the combined involvement of ports, shipowners and stevedoring companies.

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