Critical Analysis of Container Accidents in International Logistics

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ABSTRACT

Purpose: *Container accidents are a significant issue in international logistics, causing property damage, financial loss, environmental hazards, and even loss of life. These accidents can occur in various settings, such as ports, container yards, roads, rails, or seas. Efforts are being made to enhance container safety, but they remain a persistent challenge that requires ongoing attention to ensure the safe and efficient movement of goods across the globe. By understanding the specific aspects of container accidents that are human-controllable and addressing these issues, a more sustainable and efficient global logistics industry can be achieved.*

Methodology: *An exploratory research design is used in the research study. A comprehensive review of existing literature, including research papers, academic journals, books, reports, and reputable online sources was done. Literature that focuses on container accidents, maritime safety, human factors, and accident investigation reports was extensively studied to gain an understanding of the current state of knowledge on the topic. Data from relevant secondary sources that provide information on container accidents that are human-controllable were identified and collected.*

Results & Outcome: *Container accidents that are happening owing to natural calamities such as floods, cyclones, sea perils, etc are uncontrollable. There are other forms of container accidents viz cargo damage, container equipment damage, container vessel damage, loss of life owing to container fall, etc occurring due to container sliding while handling, tipping of container vessels while loading, skewing of container vessels in the transit voyage, etc. that are controllable by human interference. Unevenly loaded containers seem to be the prime reason for many container accidents that are apparently controllable by humans by following the International Convention for Safe Containers (CSC) guidelines of the International Maritime Organization. In an LCL (Less than Container Load) scenario, adhering to such guidelines may be challenging. There are many research articles discussing the load balancing of containers in an LCL scenario using various optimization techniques, and it appears that the literature is still evolving.*

Originality: *A exploratory study to understand the human controllable factors in container accidents, further study the regulatory guidelines, and analyse the research papers published.*

Type of the Paper: *Exploratory research.*

Keywords: container accidents, logistics, load balancing, sliding, tipping, skewing

1. INTRODUCTION :

International logistics is the core activity in international business. 80% of the shipments are done by sea in international logistics (UNCTAD. (2022). [1]), out of which 90% are containerized (Wikipedia. (2023). [2]). Containerization is the process of unitization of export cargo in international logistics for easy handling and cost-effectiveness (Harcourt, Keith. (2012). [3]). Containerized movement of cargo is periled by container accidents. Container accidents refer to incidents of containers during handling, loading unto container vessels, and transportation. These accidents can occur in various settings, including ports, container yards, roads, rails, or seas. The consequences of container accidents can range from property damage and financial loss to environmental hazards and even loss of life. Improper stacking (building of layers one above the other while stuffing) or overloading of containers can lead to stack collapses, where containers topple or fall. This can occur in container yards or on ships during loading or unloading operations or even in the middle of the seas. Stack collapses can cause significant damage to containers, cargo, and equipment, and pose risks to personnel in the vicinity (Smith et al. (2009). [4]). Efforts are continually being made to enhance container safety. However, container accidents remain a persistent challenge that requires ongoing attention to ensure the safe and efficient movement of goods across the globe (Bai. (2012). [5]).

2. PROBLEM STATEMENT :

Container accidents are posing an important issue in the international transportation of goods. Container accidents lead to cargo damage, container equipment damage, container vessel damage, and loss of life. If container accidents happen in the middle of the sea, then they may cause irreparable loss to the environment. Environmental hazards may impede the element of sustainability in international logistics. Certain container accidents are controllable and certain others are uncontrollable. Controllable container accidents can be mitigated by wise planning as those are controllable by human interference. Container accidents that are happening owing to natural calamities such as floods, cyclones, sea perils, etc are uncontrollable. A broad understanding of container accidents would nevertheless keep the chain of international logistics going without untoward incidents thereby contributing to international trade as a whole.

3. RESEARCH OBJECTIVES :

To study the overall impact of container accidents in international logistics. To evaluate the impact of container accidents in international logistics that occur owing to human error or the lethargic attitude of humans. To identify the indicators of container accidents. Further, the research objective is to determine what specific aspects of container accidents make an accident human controllable. Further, to study the prime reason for such container accidents which are human-controllable. Further, to analyze the literature that discusses the ways to weed out container accidents owing to human error or lackadaisical attitude of humans.

4. METHODOLOGY :

A comprehensive review of existing literature, including research papers, academic journals, books, reports, and reputable online sources was done. Studies that focus on container accidents, maritime safety, human factors, and accident investigation reports were studied to gain an understanding of the current state of knowledge on the topic. The relevant secondary sources that provide information on container accidents that are human-controllable were identified and collected. These sources include accident databases, safety organizations, regulatory bodies, industry reports, news articles, and case studies. Made sure that selected sources that are reliable, authoritative, and up-to-date. By extracting relevant data from secondary sources and analyzing the data to identify patterns, trends, and common factors associated with container accidents. Looked for information on the causes of accidents, such as human error, equipment failure, inadequate training, operational procedures, or maintenance issues. Different accidents to identify those that are potentially human-controllable were compared and contrasting factors were studied. The container accidents, which are based on controllability factors were identified. To determine whether an accident was caused primarily by human error or factors that could have been controlled or mitigated by human actions, the factors such as negligence, training deficiencies, lack of adherence to procedures, or poor decision-making were taken into consideration.

5. RELATED WORKS :

Container accidents can give rise to various problems, including safety hazards, environmental concerns, and economic impacts. Some common issues associated with container accidents are as below:

a). **Human injuries and fatalities:** Container accidents can result in severe injuries or even loss of life for workers involved in handling, loading, or unloading containers. Accidents may occur due to improper stacking, inadequate securing, or structural failures of containers (HSE. (2022). [6]);

b). **Property damages:** Damage to or complete loss of properties involved in international logistics are referred to as property damage**.** The following are the obvious properties that may be damaged owing to container accidents:

(i). **Cargo damage:** Cargo stuffed in the container may suffer damage thereby making them unsuitable for delivery at the overseas destination;

(ii). **Container damage or loss:** Containers may suffer damage or loss during accidents, leading to financial losses for shipping companies and potential legal disputes (ICS. (2014). [7]);

(iii). **Damage to container handling equipment:** At times, container accidents may lead to damage to container handling equipment;

(iv). **Damage to container vessel:** Breaking or drowning of container vessels when met with an accident in the middle of the sea may be an irreparable loss to liners;

c). **Environmental pollution:** Container accidents can result in spills of hazardous materials or pollutants, posing risks to ecosystems, water bodies, and public health (IMO. (2018). [8]);

d). **Port congestion and disruption:** A container accident can cause delays and disruptions in port operations, affecting the timely movement of goods and creating congestion issues (Yishu et al. (2016). [9]);

e). **Insurance claims and increased costs:** Container accidents may lead to insurance claims by affected parties, resulting in higher premiums for shipping companies and increased costs throughout the supply chain (Ann. (2011). [10]);

f). **Legal and regulatory consequences:** Accidents involving containers can lead to legal investigations, regulatory scrutiny, and potential fines or penalties for non-compliance with safety and security regulations (FMC. (2023). [11]).

5.1. Indicators of Container Accidents:

The indicators of container accidents are the factors that signal the occurrence of an event or the probable occurrence of an event.

(i) Container sliding while handling;
(ii) Tipping of container vessels while loading;
(iii) Skewing of container vessels in the transit voyage;

The results of these indicators, if not addressed properly are: cargo damages, making containers less fit (suitable) for multimodal transportation, specific pickup functions (e.g., uplifting jobs) may even become impossible completely, unbalanced loads may result in unacceptable, and imbalance spread of axle weights when the containers are moved on a truck (or in rail).

5.2. Sliding of Containers:

The stuffed containers are handled at various points of multimodal transportation. A poorly load-distributed container would skew one side (to the side where the cargo is overloaded in the container). This would apparently make container handling more cumbersome. A balanced (loaded) container (left image) and a skewed container (right image) are shown in Figure 1.

One of the devastating impacts of the sliding of cargo in the container owing to unequal weight distribution is the inherent and irreversible damage to the consignments. Australian Chamber of Shipping (2005) [12] notes that uneven weight distribution of cargo in stuffed containers would lead to cargo damage in transit. Due to the uneven weight distribution of cargo, damage to the cargo occurs due to falling or sliding around during the container’s movements on land or in the sea. Uneven weight distribution issues *viz*, container sliding while handling, tipping of container vessels while loading, and skewing of container vessels in the transit voyage account for cargo damages.

Due to the sliding of containers (while handling) and damage to the stuffed cargoes, the containers may become less fit for multimodal transportation. The multimodal transportation feature of the containers is the key element that attracts more and more exporters to turn out for the use of containers. The issues correlating to the uneven distribution of load in containers if not properly fixed may jeopardize the use of containers for cargo shipment in the future.

Though dunnage and cargo securement materials may contribute to securing the consignments in place within the container, it apparently would not completely set right the snags of a poorly loaded container (poorly loaded distributed container).

5.3. Tipping of Container Vessels:

Tipping of container vessels while loading the consignments onto them is yet another problem that may arise out of poor load-balanced containers. This tipping issue may arise either when the containers are loaded onto the sea or air cargo container vessels. There are two important considerations when determining the container loading sequence (and thus the positions the containers occupy on the vessel). First, if containers loaded in the sequence are too heavy, the vessel may actually tip over backward, an occurrence that clearly must be avoided (but which happens in practice). The second involves the location of the center of mass (cm) of the fully loaded vessel with respect to the "front to back" axis. Ideally, the cm is located such that the vessel is balanced in transit. If the cm is a bit away in either direction, the vessel can still proceed, but there would be greater fuel consumption to coup up with the imbalance. Thus, there is an increasing cost penalty associated with an increasing imbalance. The issue of packing containers in a cargo deck is basically a two-dimensional bin packing problem for which significant literature exists. But the issue of balance is not addressed in the two-dimensional bin packing literature (Robert et al. (1996) [13]). However, significant attempts were made by a number of scholars since 1982 to address the issue of container vessel balance, thereby avoiding the tipping issue in container vessels while loading.

Karrnarkar and Karp (1982) [14] used a problem space search heuristic approach with a differencing algorithm to address the tipping issue of cargo vessels. Karrnarkar and Karp's efforts apparently constitute the maiden literature to address the tipping issue of cargo vessels. In 1985, Martin-Vega (1985) [15] investigated dividing cargo into groups with one group being assigned to each vessel. However, he does not address how each vessel is to be loaded. Following Martin-Vega, Cochard, and Yost (1985) [16] developed heuristics within a decision support framework to aid load planners in cargo loading onto the vessels. They first address the two-dimensional bin packing problem with heuristics and then seek to balance the vessel by swapping groups of cargo which fall into separable regions. The most relevant works with respect to balancing are those of Arniouny et al (1992) [17], Mathur (1998) [18] and Robert and Joseph (2007) [19]. Amiouny et al (1992) [17] investigate loading items along a single dimension so as to meet a pre-specified target center of mass. They attempted loading containers of different widths (as well as different weights) along the front-to-rear axis. They first assume that the center of mass of each container is located at its center point, then later relax this assumption and consider orientation as well. They do not apparently address the issue of tipping during the loading process.

Mathur (1998) [18] provides an improvement to the balance algorithm of Amiouny et al. [17]. As in the case of Amiouny et al [17], Mathur [18] assumes a unimodal sequence of weights. That is, the sequence is such that there exists an algorithm for fixing up the positions of the containers. Given this assumption, the problem can be viewed as partitioning the containers into two sets, those to the left of the heaviest container, and those to the right of the heaviest container. Mathur shows how the resulting partitioning problem can be formulated as a subset sum problem which can be then solved heuristically.

Robert and Joseph (2007) [19] propose two approaches to solving the loading problem. First, they formulate the problem as a mixed integer programming problem and solve it using CPLEX (IBM ILOG CPLEX Optimization Studio often informally referred to as simply as CPLEX; CPLEX is an optimization software package developed by IBM). They show that CPLEX performs reasonably well for a small number of containers (N) and a small optimality gap. However, with increased N and/or a decreased optimality gap, the Mixed Integer Programming (referred to as MIP; MIP is a module in CPLEX optimization package of IBM) becomes difficult to solve in a reasonable amount of time, as the application requires the containers to be loaded as soon as possible after being weighed. Thus, they propose a heuristic that follows the procedure proposed by Mathur, with one notable exception; they solve the subset sum problem using a problem space search heuristic with the differencing algorithm of Karrnarkar and Karp (1982) [14] embedded.

All the above literature attempting to avoid tipping of container vessels while loading assume that the center of gravity of each container is located at the center of the container. Thus, container load balancing (addressing load balancing constraint) would circumvent the container vessel tipping in toto.

5.4. Skewing of Container Vessels:

The issue of skewing of container vessels in transit may arise if containers are not loaded in equilibrium while stuffing. A container ship must maintain its equilibrium in the water. Strong gusts and huge waves can occasionally strike and damage ships. The balance of a ship may alter if the cargo containers are not placed uniformly. In the event that the cargo is not adequately balanced, there are two main risks. When the ship is pounded by waves, there will be a lot of stress in the middle, if the huge cargo weight is at either end. This can cause a massive ship's centre to crack over time. A ship can easily tip over or lean to one side if the weight of the cargo is not distributed equally on both sides. A cargo plan is typically present for cargo ships, including container ships. The plan indicates every piece of goods in every container and it will be given to the port, where it will be unloaded. Since the plan is so intricate, it is typically developed using computer programmes. Ships carrying containers frequently exchange some but not all of their containers while in ports. New containers will be loaded while other containers are left behind. Again, the basic assumption in the cargo plan for avoiding skewing of cargo vessels in transit is equal distribution of load while stuffing containers (Australian Marine Environmental Protection Association. (2008). [20]).

Fig. 1: Balanced stuffed container (left) and sliding of a container while handling owing to improper load distribution (right)

Image courtesy: Pinterest.

Fig. 2: Container Vessel - Tipping while loading (left) and Skewing in the middle of the sea (right)

Sliding of containers while handling, tipping of container vessels while loading, and skewing of container vessels in transit are interwoven issues arising out of the load balance disequilibrium but differences do exist between them (refer to Figure 2 for tipping and skewing). Of course, both issues can be fixed by even distributing the weights of the stuffed consignments across the container while in the stuffing process and it is a controllable factor that can be controlled by human interference.

5.5. Reasons for and Human Factors in Container Accidents:

There are various factors that may lead to container accidents such as natural calamity, negligence in driving container trucks, derailing of container boogies, improper handling of container equipment, improperly stuffed containers that lack load balancing, etc. Container accidents that are happening owing to natural calamities such as floods, cyclones, sea perils, etc are uncontrollable. There are other forms of container accidents *viz* cargo damage, container damage, container equipment damage, container vessel damage, loss of life owing to container fall, etc occurring due to container sliding while handling, tipping of container vessels while loading, skewing of container vessels in the transit voyage, etc. that are controllable by human interference. Unevenly loaded containers seem to be the prime reason for many container accidents that are apparently controllable by humans. Container accidents are mostly due to improperly loaded containers that are short of proper load balancing. Container load balancing is a crucial function in the containerization of export cargo. The container load balancing is the process of even distribution of container load across the stuffed container. While in the process of stuffing, the stuffing workers have to ensure beforehand whether their proposed stuffing stratagem would lead to a balanced spread of container load across the whole container. Uneven distribution of load in a stuffed container can be efficiently addressed by human interference by following the international organization regulating container operation in international logistics.

5.6. Container Load Balancing:

Balanced loading of containers reduces the risk that the cargo shifts (from one place to another within the container) while the container is moved and there are various problems that may arise in an improperly load-balanced container.

Guidelines for even weight distribution and safe handling of cargo in containers are given in the International Convention for Safe Containers (CSC) (which was adopted on 2 December 1972 and came into force on 6 September 1977) by International Maritime Organization (International Maritime Organization. (1977). [21]).

Weight distribution constraint shall be addressed in two methods:

(1) Method I: The centre of gravity of the stuffed cargo should be nearer to the dimensional (geometrical) mid-point of the floor of the container;

(2) Method II: The centre of gravity of the stuffed cargo should not surpass a certain distance from the dimensional (geometrical) mid-point of the floor of the container.

Further, after fixing the method of addressing the weight distribution constraint, there are 4 means to achieve this (refer to Table 1):

(1) Longitudinal means: to attain weight spread along the length of the container;

(2) Lateral means: to attain weight spreading along the breadth of the container;

(3) Latitudinal: to attain weight spreading along the height of the container;

(4) Crosswise: to attain weight spreading along the diagonal of two corners.

The centre of gravity of the cargo should be as near to the centre of the container as feasible, especially when it will be handled by a spreader, forklift, or crane. In order to move and handle the container safely, it is necessary to exert more effort if the centre of gravity is too distant from the centre.

Table 1: IMO Guidelines for Container Load Balancing

Means	Position of Center of Gravity	20'	40'
Longitudinal	Length wise	maximum 0.60 metres from the container's centre.	maximum 0.90 metres from container's centre
Crosswise	Transversely	at the midpoint of the container	
Latitudinal	Height wise	beneath the container's geometric centre of gravity	
Lateral	Breadth wise	*- no guidelines –*	

Adapted from source literature: International Maritime Organization (1977) [21].

Adhering to the guidelines for longitudinal, crosswise, and latitudinal load balancing may not be simple and it is cumbersome in reality for the reason that the cargo dimensions (primarily, the shapes and sizes) may widely vary in one shipment in a container. In a Less-than-container-load scenario (where a single exporter is unable to use the whole container space and often referred to as an LCL scenario), the container load balancing poses a stiff challenge as the consignments are picked and consolidated from more than one consignor (usually from many consignors). In less-than-container-load stuffing, usually, the shape, size, weight, and handling parameters of cargo may vary significantly from one consignor to another.

Though there is much literature discussing the load balancing of containers in an LCL scenario and it appears that the literature is still evolving. Gehring, Menschner & Meyer (1990) [22], Davies & Bischoff (1999) [23], Techanitisawad & Tangwiwatwong (2004) [24], & Balakirsky et al (2010) [25] addressed the weight distribution constraint by Method I, whereas Gehring & Bortfeldt (1997). [26], Bortfeldt & Gehring (2001) [27], Liu, Tian & Sawaragi (2007) [28], Sciomachen & Tanfani (2007) [29], Liu et al (2011) [30] opted for Method II.

Eley (2002) [31] attempted the weight distribution by longitudinal (length-wise) means. A (linear) mixed integer optimisation approach is also introduced by Chen, Lee, and Shen (1995). [32] to solve weight distribution using longitudinal means. Davies & Bischoff (1999). [33] argue that length-wise balancing is more important than height-wise balancing and they observed that length-wise (longitudinal) balancing would avoid vessel tipping.

Sommerweib (1996) [34], Chan et al (2006) [35], Balakirsky et al (2010) [36], as well as Liu et al (2011) [37] paid close attention to how much weight should be on each side of the container's height. The authors demand that the centre of gravity be situated as low as practicable in every situation. Therefore, heavier goods should be stored close to the bottom of the container, while lighter items should be stacked higher.

Attempts were made on lateral balance too (though no importance was given in the guidelines) but crosswise balance was completely ignored in the literature.

6. CONCLUSION :

Container accidents that are happening owing to natural calamities such as floods, cyclones, sea perils, etc are uncontrollable. There are other forms of container accidents *viz* cargo damage, container equipment damage, container vessel damage, loss of life owing to container fall, container sliding while handling, tipping of container vessels while loading, skewing of container vessels in the transit voyage, etc. that are controllable by human interference. Unevenly loaded containers seem to be the prime reason for many container accidents that are apparently controllable by humans. In conclusion, improperly balanced container load distribution can lead to tipping and damage to cargo during multimodal transportation. Proper handling and balancing of containers can help prevent tipping and ensure the safe and efficient use of containers for cargo shipment. Skewing of container vessels in transit can occur if containers are not loaded in equilibrium while stuffing. Improperly balanced cargo can put tension on the midsection of the ship, causing it to collapse over or lean to one side. Container ships must maintain balance in the ocean. Every piece of cargo and every container on a cargo ship is identified on the cargo plan, and it is given to the ports where it will be unloaded. The basic assumption in the cargo plan is equal distribution of load while stuffing containers. Tipping of container vessels while loading and skewing of container vessels in transit are interwoven issues arising from load balance disequilibrium. Both issues can be fixed by evenly distributing the weights of stuffed consignments across the container during the stuffing process, which is a controllable factor that can be controlled by human interference. The International Convention for Safe Containers (CSC) provides guidelines for even weight distribution and safe handling of cargo in containers. Weight distribution constraints can be addressed through two methods: Method I, where the center of gravity is close to the geometrical mid-point of the container floor, and Method II, where the center of gravity does not exceed a certain distance from the container floor. There is much literature discussing the load balancing of containers, and it appears that the literature is still evolving. Research papers have attempted weight distribution by longitudinal means, linear mixed integer optimization models, and crosswise balance.

7. LIMITATIONS & FUTURE WORK :

The limitation of the research is the research methodology as it may be potentially biased owing to the factor that the research relied upon secondary sources. As vast secondary literature is found, the research study may be incomplete as the research results are based on the gathered literature alone. More in-depth research may throw further light on this research topic.

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