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Data Analytics for Safety and Security within Ports based using Open Sources

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Abstract

In the global trade, ports act as pivotal junctures bridging marine and terrestrial transportation networks. Ensuring smooth operations within these hubs is extremely important, as it guarantees the consistent transit of commodities and services. Consequently, maintaining safety within these complex environments has become a paramount concern for state entities, port overseers, and marine transport enterprises. This paper delves into a novel approach for gathering and dissecting data on prevalent accident causes and injuries within these hubs, further exploring variances in safety standards based on geographical locations, facility types, and other pertinent parameters. Such insights lay the foundation for sculpting safety-enhancing policies and operational practices. Additionally, the study showcases innovative technological solutions pioneered by the authors, harnessing the prowess of Modeling & Simulation (M&S) and eXtended Reality (XR) to augment safety measures.

Keywords: Port Facilities, Simulation, Training, Safety

1. Introduction

It is very common for Industrial operators to manage with dangerous goods or non-dangerous goods, but in a risky environment because of the storage system with the risk that entails. For instance, in many industrial plants there are various types of dangerous situations such as excessive temperature, high level of noise, dust or presence of chemical agents.

The evolution of supply chains has expanded the global movement of commodities, and even in the face of disruptions like the Covid pandemic, the global transportation of merchandise has surged. This rise in international trade presents novel competitiveness challenges, necessitating ports to elevate their operational efficiency and optimization. Indeed, maintaining streamlined port activities is pivotal for a consistent flow of goods and services, as emphasized.

However, this escalating goods movement poses inherent risks. Port operators are often exposed to hazardous

environments due to the continuous traffic and intricate handling tasks. Interestingly, many of these risks are mirrored across both maritime and on-land settings like harbors and industrial sectors. Kletz asserted that the recurrent accidents in process industries can often be attributed to information underutilization and the failure to assimilate lessons from past incidents. Ports, as primary hubs for accidents of this nature, play a crucial role in international trade, with 75% pertaining to global imports and exports and 36% (European Commission) dedicated to intra-EU exchanges. Notably, Europe boasts over 300 multifunctional ports with approximately 130 specifically designed for container handling (Hèrvas-Peralta et al., 2020).

The lack of robust protocols, coupled with insufficient education, training, and oversight, poses heightened risks to port operations. Instituting preventive strategies is imperative to forestall both catastrophic events and routine mishaps that could jeopardize the port industry's equilibrium. Yet, the intricate interplay of internal and external factors within the port makes this an intricate endeavor. This study delves into an assortment of qualitative and quantitative methodologies to discern the elements driving accidents in urban ports. Furthermore, it gauges the efficacy of preventive mechanisms across established and burgeoning regions. Our research amalgamates insights from pertinent literature and dissects recent accident case studies, underlining the pressing need to refine safety standards, training, and accident surveillance, particularly in emerging areas, emphasizing the crucial role of preemptive actions in sustaining port sector stability.

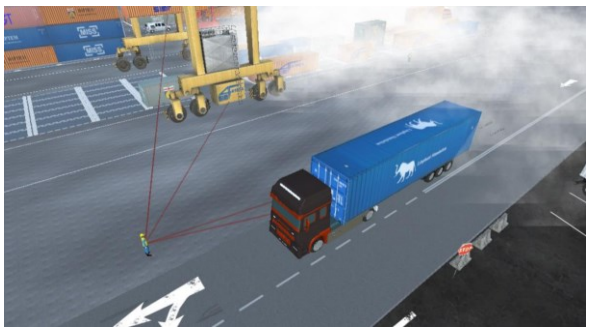

Figure 1 COYOTE Virtual Environment

2. State of the art

With escalating sea traffic and competition, ports face increasingly hazardous conditions, pivotal for a nation's progress. Iconic disasters like those in Bhopal (1984), Toulouse (2001), Texas City (2005), the Gulf of Mexico (2010), Tianjin Port (2015), and Beirut (2020) underscore the rising threats, with profound casualties, infrastructure damage, and strategic implications on surrounding ecosystems (Souaiby & El-Hussein, 2020). While the International Maritime Organization (IMO) diligently tracks maritime accidents, a conspicuous void exists concerning reliable data on port facility and terminal incidents, typically overseen by national entities. The critical need is evident for a comprehensive, global database to refine prevention and mitigation strategies.

Many research endeavors, including those by Kim et al. (2021), Rawson & Brito (2023), have delved into the application of machine learning and artificial intelligence within the maritime domain, particularly port operations. For instance, some studies have harnessed time series data from specific ports, considering variables like weather conditions, cargo type, and more, to calculate accident probabilities using algorithms like SVM, KNN, LightGBM, and XGBoost (Atak & Arslanoğlu, 2022). Conversely, research like that by Kretschmann (2020) crafts overarching conceptual structures rooted in machine learning, subsequently applying these to distinct port case studies for maritime-port risk evaluations. Others dealt with an analysis of the database they had through the use of decision trees and the probability of different accident scenarios. Using these decision trees and figures detailing the frequency of the events that gave rise to the accidents, the accident frequency was determined (Ronza et al., 2003).

However, despite the promising outcomes, the diverse and intricate nature of global port contexts hinders the seamless crafting of these algorithms. training these models on scant data can lead to overfitting, wherein the model becomes excessively tailored to the training data, rendering it ineffective on novel data. This issue of overfitting is also evident in models crafted for specific port case studies, potentially compromising their robustness (Roelofs et al., 2019). For these reasons this paper pioneers a framework to harmonize disparate data from diverse national standards. Through the Design of Experiment (DoE) approach, correlations between primary indicators and accident determinants were elucidated (Bruzzone et al., 2012). Furthermore, the paper delves into avant-garde methodologies, specifically Modeling and Simulation (M&S) and eXtended Reality (XR), championing them as tools to bolster terminal safety and curtail accident likelihood. In this sense, it's been many years that work has continued on augmented simulators that can serve as education and training tools (Bruzzone et al., 2021). The results seem to be promising, showing us how in the future this logic will be increasingly useful and effective.

3. Data Collection and Data Processing

In the scope of this extensive study, an initial step was the compilation of safety data from different national authorities, aiming to discern patterns and correlations. The endeavor of collecting incident data within ports proved daunting. Internal regulations and confidentiality constraints rendered many authorities reticent, indicating a probable paucity of available data. Compounding the challenge, discrepancies in data collection methodologies led to inconsistencies in the datasets. As an illustration, while certain countries release their statistical reports exclusively in their national languages, complicating the data extraction process, countries like Turkey offered partial data in English, whereas Japan's information was solely in Japanese. Direct data comparison was rendered infeasible due to these inconsistencies; for example, India's datasets recognized 10 accident types, while Japan detailed 21 categories for similar incidents.

To facilitate an effective comparison, supplementary information was necessary to craft a cohesive analysis. Beyond the safety-centric data, external metrics crucial for normalization and cross-national comparisons were also sourced. These encompassed annual port traffic metrics, economic indicators like GDP, and markers of digital advancement. The data was culled from reputable organizations such as the United Nations (UNdata, 2023) and CIA FactBook, in addition to national regulatory websites.

In our study, we compiled our data into a dynamic repository, enabling intricate analyses using queries and the design of

experiments (DOE). This structured approach facilitated the exploration of correlations between diverse variables and culminated in a comprehensive sensitivity analysis. Leveraging advanced statistical methodologies, we merged a multitude of data types, encompassing accident causes and types, along with macro-level parameters and commodity flow data from numerous nations. It's important to note that data granularity varies globally. The available data might encompass varied information such as demographics of the injured, specific occupational roles involved in the accident, nature of the injury, the severity and resultant absenteeism, the size of the employer, and even the timing of events.

Moreover, there are distinct cultural and procedural differences in how countries record and report accidents, potentially influencing the data's fidelity. Given this disparity, a pivotal challenge was data harmonization, ensuring different datasets were aligned and comparable. To resolve this, we developed an application capable of bridging inconsistencies across datasets, a step crucial in discerning accident causality patterns which differ across sources. For instance, our sophisticated algorithm can cluster varied job roles, port locations, and combine differing accident data, synchronizing it with pertinent macro-indicators. An excerpt of our harmonized dataset is displayed in the succeeding figure.

4. Results

In our study, we conducted a year-by-year comparison of accident occurrences, taking into account both fatal and non-fatal categories. This comparison was extracted from the available data sets pertaining to the ports of Hong Kong, Japan, Italy, and India. For Hong Kong and India, we were able to obtain comprehensive datasets that trace back to 1997. These datasets revealed a promising decline in the rate of accidents over the years, suggesting possible advancements in safety protocols or infrastructure improvements in these regions.

Conversely, the available data for Italy and Japan was somewhat limited, encompassing only recent years. From the data at hand, neither Italy nor Japan demonstrated a consistent decrease in accident rates during the covered period. This might raise questions about the effectiveness of recent safety measures or highlight the importance of considering longer data periods to identify genuine trends.

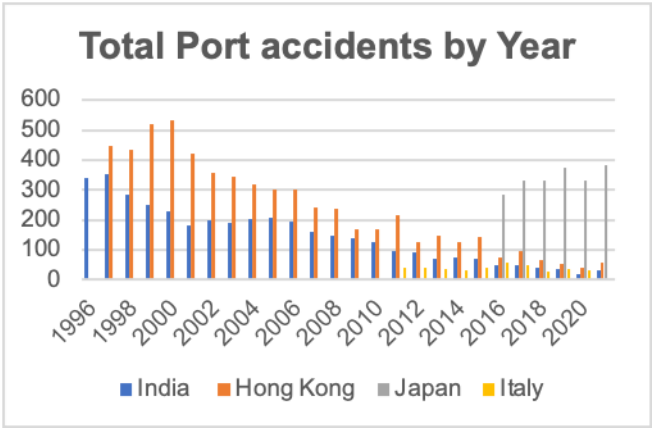

Figure 2 Accidents by Year

An additional layer of analysis was introduced by juxtaposing the number of fatalities against port traffic, quantified in terms of Twenty-Foot Equivalent Units (TEUs) annually. By deriving a ratio from this comparison, we achieved a more nuanced perspective on safety: it essentially represented the average number of TEUs handled between each fatal accident.

This approach offers a more refined insight because it accounts for the actual volume of port traffic rather than just absolute numbers of fatalities. It's crucial to emphasize the significance of this normalization process. By solely focusing on raw fatality numbers, discrepancies might arise due to the sheer volume differences in port activities across countries. When we account for the actual traffic (measured in TEUs), we level the playing field and ensure that comparisons between countries are based on the proportionality of fatalities to port activity, rather than merely on absolute fatality numbers. This method provides a more contextually accurate representation, especially when comparing countries with vastly differing port capacities and activities.

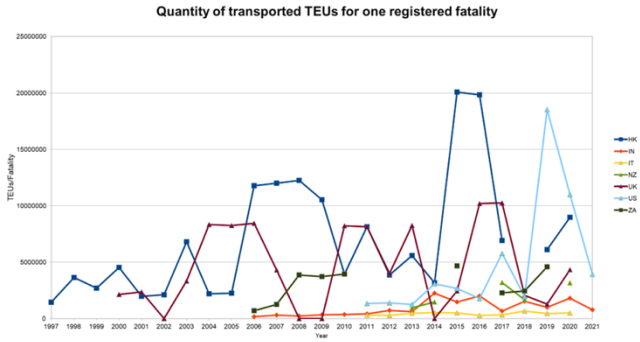

Figure 3 Quantity of TEU

The study ventured into deciphering the intricate interrelationships between the variables associated with "Port Safety" through a comprehensive multifactorial analysis. The primary focus of these analyses was to probe and identify parameters that exhibited sensitivity.

As illustrated in Figure 5, the sensitivity analysis zeroes in on India and Hong Kong, shedding light on the interplay between the key variables in question. It's imperative to note that the values presented in the figure have undergone normalization and are subsequently displayed using a logarithmic scale to ensure clarity and facilitate interpretation.

One of the standout insights from this examination was the discernible influence exerted by certain categories, such as specific types of incidents or their consequential impacts. Furthermore, a noteworthy finding was the interrelation of these factors. For instance, simultaneously considering the nature of an incident and its resultant impact proved to be vital. While the factor of the country (India or Hong Kong) was indeed present in the analysis, its influence appeared somewhat subdued when juxtaposed against other factors, especially when assessed in isolation.

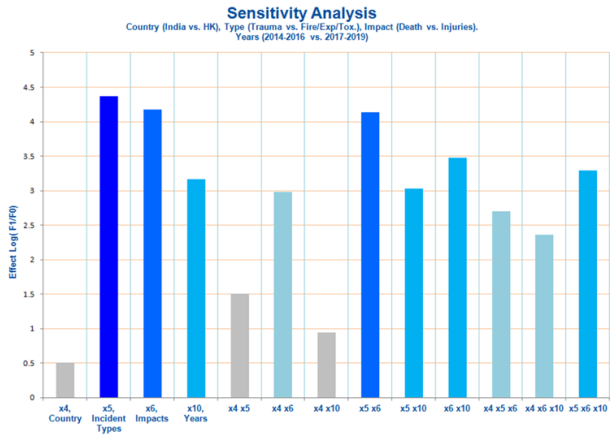

Figure 4 Sensitivity Analysis

From Fig.5 it is clear that the country factor is not the most sensitive variable, while the type of impact incident turns out to be a variable present everywhere, an indication that types of incidents like this are among the most common in all global port

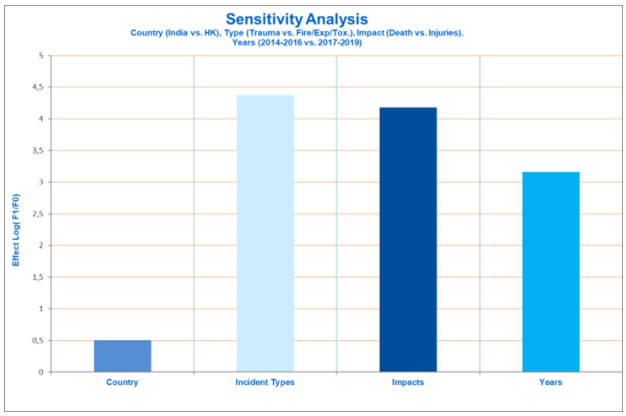

Figure 5 Sensitivity Analysis C.T.I.Y.

It is evident from the available datasets that there have been improvements in terms of injury reduction. This can be observed from historical data from India or Hong Kong, where many decades of data were available. Although the data analysis is not complete due to the difficulties of the limited datasets available, it is evident from this study that many different correlations and causes can impact port accidents. This is due to the nature of port operations, which ultimately forms a Complex System. In particular, analyses conducted on the correlation between literacy and wealth suggest that operator awareness is also as important as ensuring a safe workplace.

5. M&S and XR for improving Port Safety

Training and strategic planning are increasingly recognized as pivotal elements in ensuring port safety and operational efficiency. While strategic planning predominantly targets the decision-makers at the helm, training has a broader reach, extending its benefits to on-ground operators as well.

Over recent years, the realm of modeling and simulation has risen to prominence, acting as a linchpin in pioneering innovative solutions and introducing transformative paradigms. Simulation, with its ability to replicate synthetic environments, offers a unique avenue for recreating real-world systems and scenarios, albeit in a controlled and safe environment. For instance, through advanced computer technologies, it's possible to simulate high-risk situations, like explosions within ports, which are naturally untenable and impossible to reproduce in real-world settings.

The integration of Modeling, Simulation, and Serious Games (MSSG) marries the capabilities of modeling and simulation with the engaging nature of Serious Games. This synergy, further bolstered by advancements in Extended Reality, offers a comprehensive platform for both training and planning. The authors have been at the forefront of this integration, spearheading two pivotal projects.

COYOTE is the maiden venture aimed at enhancing training paradigms. Conceived as a Serious Game, its primary objective is to arm port operators with a dynamic training system tailored to foster accident prevention. The immersive three-dimensional world of COYOTE mimics a bustling port yard, complete with vehicles, containers, and agents, all meticulously simulated to mirror real-world dynamics. Players are transported into this world, handed missions, and navigate through the port's intricate layout. The game environment is enriched with challenges, like reduced visibility and auditory distractions, to test and hone the player's skills. The ultimate goal is to nurture heightened situational awareness. Leveraging the prowess of Virtual Reality, COYOTE, when paired with the OCULUS hardware, ensures an immersive experience, replicating the sensation of being physically present within a port.

ALACRES is the second project tailored for decision-makers, serving as a robust tool for contingency planning. This simulator replicates a lifelike three-dimensional seaport, bustling with routine port operations. Players are presented with a gamut of potential crisis situations, ranging from toxic gas leaks and ship collisions to full-blown explosions. Much like strategy-centric video games, players must strategize and mobilize virtual assets, including recovery vehicles and helicopters, to navigate and mitigate these crises. This tool is especially invaluable for high-ranking decision-makers, enabling them to trial and assess various strategic responses within simulated crises. Notably, the incorporation of the Monte Carlo approach introduces a layer of unpredictability. While every simulated scenario springs from consistent initial conditions, outcomes can vary widely. This variability ensures that contingency plans crafted within the simulator are not only effective but also resilient and adaptable. The ultimate objective is to empower players to craft robust emergency response blueprints and cultivate the acumen to pivot

effectively in the wake of unforeseen challenges.

6. Conclusions

Port terminals stand as the linchpins of international commerce, acting as vital nodes in the vast web of global trade. Their operational efficiency and stringent security protocols directly influence the ebb and flow of international trade dynamics. Over time, advancements in technology, bolstered security, and optimized operational efficiencies in these terminals have garnered significant attention worldwide. Yet, it's evident that the strategies countries adopt to address these facets vary considerably.

This study delves deep into the archives of various nations, shining a spotlight on their respective efforts and capital injections aimed at fortifying their port terminal's technological backbone, security frameworks, and operational efficiencies. While the amassed data presents certain challenges in terms of homogeneity, it unveils intriguing patterns, offering insights into the unique trajectories chosen by individual nations. Such findings are instrumental, serving as a roadmap for sculpting bespoke awareness initiatives, training modules, and even for crafting novel technological interventions. A unique advantage of this study is its suggestion to employ virtual realms to pilot these innovations, fine-tuning them based on real-world accident analysis to ensure optimal effectiveness.

This research offers a holistic statistical overview, encapsulating global trends and intricacies related to port and harbor plant operations. The results spotlight both clear correlations and apparent discrepancies, sketching a predictive graph of impending trends. Undoubtedly, a recurring theme is the unwavering commitment and hefty investments countries are channeling to amplify safety in these often high-risk zones. This data underscores a predominant emphasis on integrating advanced technological solutions and bolstered security to enhance operational fluidity, all while minimizing accident probabilities.

A significant takeaway from this research is the value it adds to the realm of awareness campaigns and targeted training. Recognizing the pivotal role of personnel in ensuring port safety, numerous nations have doubled down on their training and awareness outreach. In this ever-evolving landscape, virtual environments have emerged as powerful allies. These digital spaces serve as testing grounds, allowing for the trial and optimization of innovative procedures and tech-driven solutions. The synergy between Modeling & Simulation (M&S) and Extended Reality (XR) stands out as particularly potent in this context. The latest scalable solutions, compatible across diverse platforms, further amplify this potential, making these tools more accessible and user-friendly. Such innovations, especially when adapted for mobile use, can seamlessly integrate into the community's routine, maximizing their reach and efficacy in fortifying port safety.

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