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Operations in Ports supported by Simulation, XR and AI

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Abstract

This paper proposes and experimentation related to operations in Port Terminals carried out on a MS2P (Modeling, interoperable Simulation and Serious Game) solution using stochastic Simulation and XR (eXtended Reality). The subject is pretty important considering the critical topic of Safety within Ports, especially on Yard Operations, that is crucial to protect human life and that it affects heavily many other issues including Port Attractiveness, Competitiveness, Efficiency, Reliability, etc. The research used an innovative Simulator, developed by the Authors, on different groups of Port Operators allowing to finalize a research to improve the effectiveness in Education & Training (E&T) for Safety thank to the capabilities of new generation MS2G.

Keywords: Safety, Operations, Ports, Terminals, Modeling & Simulation, Extended Reality

1. Introduction

Port and Industrial operators often have to deal with possibly hazardous materials, not only because these may be flammable and explosive, but because they have to be handled in an environment such as the warehouse that we can say is a "living environment," full of other entities moving along with us, autonomous systems, machinery, etc. Research in the field of safety measures to preserve the health of operators is steadily increasing, although the overall number of accidents remains high. A trial aimed at investigating whether the use of combined technologies such as Modeling & Simulation and Virtual Reality can increase the safety level of operators in hazardous environments was initiated in this research. The field of application is related to the ongoing activities and operations at a container terminal yard and other port activities. The experimentation is designed to measure key parameters such as improvement between background and foreground performance, understanding of port hazards in the terminal Yard, reduction of risk exposure, reduction of vulnerabilities, and efficiency and effectiveness of activities. The simulation is conducted on a specific version of the Coyote simulator (Container terminal & Yard Operator simulator for Training & Education) for the scenario under consideration with the studied indicators. The improvement goal in Coyote is measured by a MoM (Measures of Merit). MoMs represent goals to be achieved and play an important role in safety in an operational context. Each operator is assigned a mission, each time different, randomly generated by the scenario generation system managed by the Computer in the Simulation, but consistent with the level of difficulty and complexity chosen; the level of difficulty is related to the type of boundary conditions and in particular to the number of other vehicles and operations going on in the assigned work area along with weather conditions that may reduce visibility and other boundary factors; conversely, the complexity is related to the number of tasks assigned.

Figure 1 COYOTE Virtual Environment

2. State of the art

The continued growth of maritime traffic and high levels of competition have created potentially dangerous conditions for port activities, which could have a major impact on a country's development. Indeed, maritime transport is the backbone of international trade and the global economy. More than 80 percent of the volume of international trade in goods is transported by sea, and the percentage is even higher for most developing countries (United Nations Conference on Trade and Development (UNCTAD), 2021). Examples of this problem are provided by tragedies that occurred in specific instances of maritime trade, such as the ammonium nitrate incident that occurred in the port of Texas City in 1947. Explosions from this incident involved 2,300 tons of NH4NO3 causing 468 deaths, making it the largest industrial disaster in U.S. history. (Prugh, 2010). There are many other examples that confirm the enormous impact of accidents in the port environment near cities: Tianjin Port (2015, NH4NO3 800 tons, explosion, 173 casualties, equal to 0.256 ktons, 304 buildings compromised, destruction of 12'428 cars and 7'533 containers), Beirut (2020, NH4NO3 2'750 tons, explosion, 218 casualties, equal to 1. 1 ktons, 300,000 homeless) with a dramatic effect not only in terms of casualties and destruction, but also at the strategic level on the evolution of the city (Souaiby & El-Hussein, 2020; Nemer, 2021; Yu, et al, 2022). However, it is important to note that unlike port accidents, traditionally all disasters at sea and on ships are fairly well monitored in terms of history, details, and statistics by the IMO (International Maritime Organization) to ensure continuous updates on regulations and procedures for protecting human life and traffic (Knudsen & Hassler , 2011). Despite the efforts of the International Maritime Organization to monitor accidents at sea and on ships, there is a lack of reliable quantitative archives for accidents at port facilities and terminals, which are often subject to national authorities and agencies. The high density of simultaneous operations in ports requires high quality standards and procedures to maintain competitiveness, safety, and productivity. Usually these analyses focus on specific countries or major ports (Yip, 2008; Lecue & Darbra, 2019; Chen, et al., 2020). Often even in ports, these analyses focus on ship accidents due to collisions and other shipboard events (Pedersen, 2010; Mou, et al., 2019; Park, Yip, & Park, 2019; Pawel & Katarzyna, 2021). Harsh weather conditions are also a key safety issue and also entail the need for very high quality standards and procedures in order to maintain high competitiveness, safety, and productivity (Othman, Elgazzar, and Knez, 2022). Collecting data from the field, processing it by creating a globally structured database is absolutely crucial for the development of more reliable and accurate prevention and mitigation countermeasures against maritime and port accidents (Dominguez-Péry, Vuddaraju, Corbett-Etchevers, & Tassabehji; Kulkami, Goerlandt , Li, Banda, & Kujala, 2020). Through the acquisition of large volumes of data, it is now possible to create sophisticated predictive models. Several studies have examined the use of machine learning and artificial intelligence in the maritime industry, including port operations (Kim, Kim, Lee and Park, 2021; Rawson and Brito, 2023; Merrick, Dorsey, Wang, Grabowski and Harald, 2022). Some of these studies, for example, by taking the time series of specific ports and different input variables such as time, weather, cargo carried, temperature, humidity, wind, and current provide an accident probability through the use of different algorithms such as SVM, KNN, LightGBM, or XGBoost (Atak & Arslanoğlu, 2022). Other studies, however, create general conceptual frameworks based on machine learning and apply them to some case studies in specific ports to carry out risk assessment in the maritime-port environment (Kretschmann, 2020).

Although the results seem comforting, the complexity and diversity of port scenarios around the world poses great limitations to the development of such algorithms. These techniques require large amounts of data to accurately train the models Neural networks and other similar techniques, for example, do not work well in the case of large and noisy datasets (Osisanwo, et al., 2017; Ray, 2019, Feb.). models on small datasets can lead to overfitting, in which the model becomes too specialized for the training data and performs poorly with new data. The problem of overfitting may also arise in the case of small case studies in specific ports, and the model may then lose robustness (Roelofs, et al., 2019). For these reasons, this study aims to develop a Framework to serve as a guide for the collection and structuring of aggregate data from different countries (thus with different standards) and to conduct a more accurate analysis through the use of DoE (Design of Experiment) of what the correlations are between the main indicators and factors of accident risk (Kang, Doerr, & Sanchez, 2006; Kadir, Mohammad, Othman, Chelliapan, & Amrin, 2017). The authors adopted in this paper the innovative paradigm defined MS2G (Modeling, interoperable Simulation and Serious Game) that allows to create intuitive and immersive solutions by using Modeling and Simulation (M&S) in combination with Serious Game engagement logic (i.e. competition) and eXtended Reality (Bruzzone et al.,2014).

Thus, the analysis produced highlighted some crucial factors in managing port terminal-related risks. For this reason, the paper used extensively MS2G innovative paradigm combining M&S and XR (eXtended Reality) to improve safety and optimize efficiency of processes in terminals while minimizing the risk of accidents (Bruzzone et al., 2022). M&S is a powerful tool that can simulate real-world systems, processes and events at the operational or strategic decision-making level (Bruzzone, et al., 2014, 2016). In port security, M&S can be used to model the behavior of ships, cranes, and other equipment, as well as the interactions between them (Ouyang, 2014). Through the use of a digital twin of the port and all its resources, it becomes possible to identify potential hazards and assess the impact of security measures on operations and evaluate different possible courses of action (CoA) (Hanna, Reaper, Cox and Walter , 2005). In addition, through the combined use of M&S and XR, workers can be trained on safety procedures and emergency response in virtual environments that simulate port operations (Bruzzone, et al., 2021). XR can also provide real-time monitoring of equipment and workers, which can help prevent accidents and optimize operations (Alizadehsalehi & Yitmen, 2023).

3. MoM and Performance Indicators

Each mission is composed of multiple tasks that usually involve checks on the yard and the condition of the containers therein, checking for leaks, and checking on positioning and seals. Mission tasks include multiple accomplishments that must be successfully completed and correspond to the objectives achieved; these can be multiple for a single task and/or also have different weights. Specifically, in this case, MoMs were identified to be used to evaluate the performance of port operators, which are thus defined in relation to the tasks assigned within a mission:

- Accuracy: represents a measure of the quality of the work done by the operator and how much of the assigned work was completed correctly;
- Readiness: represents a measure of how quickly the operator completed the assigned work;
- Correctness: represents the ability to comply with rules and procedures and not make mistakes in performing the assigned task;
- Accuracy: represents the operator's prudence and attitude not to expose himself to risk, or his ability to reduce his exposure to risk while performing the task;
- Awareness: represents a measure of the operator's awareness of the risks around him and his ability to limit them by taking appropriate actions in carrying out the assigned task.

The Performance measures used to measure the different MoMs were updated from the first assumptions as defined below:

- Duration: Mission Completion time; time limit now equal to 20 minutes
- Pts: Correctness of the Controls Performed on the different Containers Incidents Number of User Incidents and Collisions and their severity; even a single Incident represents a criticality for not passing the mission;
- TotRE: Total Risk Exposure, provides an indication about the risk exposure recorded during the mission by the individual User;
- AvgRE: Average Exposure to Risk, provides an indication about the average exposure to risk recorded during the mission by the individual User and represents a measure of quality of the performance performed; in this scenario, 30 points is considered to be the threshold above which the mission is not virtuous;
- MaxRE: Maximum Exposure to Risk, provides an indication about the average exposure to risk recorded during the mission by the individual User and represents a measure of quality of performance performed; in this scenario 120 points is considered to be the threshold beyond which the mission is not virtuous;
- PTotRE: Total Exposure to Risk Perceived by User, provides an indication about the exposure to risk recorded during the mission by the individual User relative to his ability to perceive it and thus how much he has unconsciously exposed himself to risk;
- PAvgRE: Perceived Average Exposure to Risk by User, provides an indication about the average exposure to risk recorded over the course of the mission by the individual User and thus how much he or she was unconsciously exposed to risk. This represents a measure of quality of performance performed; in this scenario, 120 points is considered to be the threshold above which the mission is not virtuous;
- PMaxRE: Maximum Perceived Exposure to Risk by User, provides an indication about the average exposure to risk recorded during the mission by the individual User and thus how much he or she was unconsciously exposed to risk. This represents a measure of quality of performance performed; in this scenario, 120 points is considered to be the threshold for the mission to be virtuous.

These variables were important to describe for the tables to come later.

4. Materials and Methods

A total of 27 Port Operators were involved in this Experimentation conducted within the Port of Genoa and Gioia Tauro for a total of 355 trials using the simulator with different input and boundary conditions. Twenty-one engineers from universities were also involved to conduct further comparisons, out of a total of 170 trials. For each trial, user data and respective performance indicators were recorded so as to compare any performance improvements between players, between simulation "runs" per player, and between groups of players. For these experimental trials, the platform used was the PC.

The tasks to be performed by the user are as follows: Each Simulator User will have to perform a Mission that involves inspecting three containers, called Containers, placed on the Port Container Terminal yard (Container Terminal), technically called the Yard. The name of the Containers and their place on the Yard are identified in the upper left corner of the interface. The Container is defined by an ID, Identifier code (e.g., SFFU 123001) followed by the location defined as follows: BKA-X-Y-Z which corresponds to Block BKA, Row X, Slot Y (column), Shot Z (shot is the level of the individual container in a stack of containers and 1 represents the fact that it is resting on the ground); so an example is BK23-3-2-1 which means Block 23, 3 Row, 2 Slot and resting on the ground (Shot 1).

The Mission consists of three tasks i.e., a given check to be performed on three containers: the User has to find the three containers by searching the area for them based on the data received; each time he finds a container he will have to indicate whether it has a small slick, medium slick, or is intact. Similarly, he should check whether the seal protecting the container door is present or not. Its absence could represent a possible malicious action that could have caused the spillage of hazardous material or simply undermined the integrity of the goods.

Figure 2 Big leakage under the container

Figure 3 Few visibility due to the fog

Having completed the mission of checking the status of the three containers, it is possible to close the simulation, automatically saving the results to a file; the summary of the experience will also be presented on the final screen that proposes only a few indicators among the many measured, explained later. The test can be repeated or you can exit and do another simulation later, re-launching the Simulator and entering the same name. Higher levels of difficulty correspond to more means, worse visibility conditions, and the location of the Container is not provided, simulating that it has not been positioned correctly and the information system has the wrong location. Under poor visibility conditions, audible and flashing alerts are activated. During the Simulation, there are trucks/trailers/tires, cranes, and other vehicles moving in the yard and care will need to be taken both to avoid being run over and to maintain an adequate distance. The User must conduct the mission quickly, completely and correctly, without incurring any accidents; in addition, the Simulator calculates various performance indicators related to how much risk one has been exposed to in order to estimate caution in performing the virtual experience. If during the course of the Simulation test, the User is run over by a vehicle or crane, the mission will be considered failed and the test data will be automatically saved. At the end of each Simulation trial, the summary of the main indicators obtained will be visible, which will also be automatically saved both in final summary form and throughout the duration of the test. During the experiments it is possible to activate the Augmented Mode On mode that allows to visualize via red lines all the main hazards, their distance and direction; this mode, when activated, allows the User to understand what the sources of risk are and thus educates him to understand the hazards and keep a proper distance from them.

5. Results and Discussion

The following graph shows the average improvement obtained by (port) users in terms of correctness expressed in points achieved out of the total of 6 (3 correct identifications of the state of integrity of the container and three of its seal).

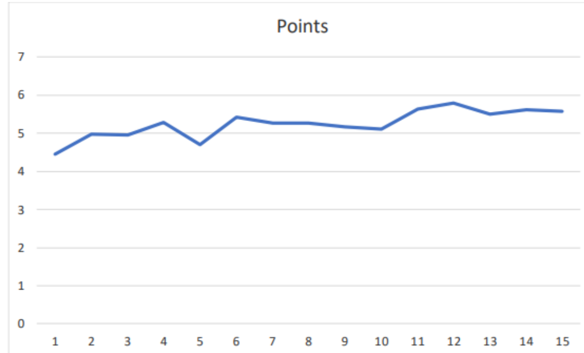

Figure 4 increase in the number of points in relation to runs

In a similar way, a comparison is proposed on the first part of the tests (first 25%) and on the final one (last 25%) for the group of PSA Port Operators of Genoa, noting an increase in speed or productivity

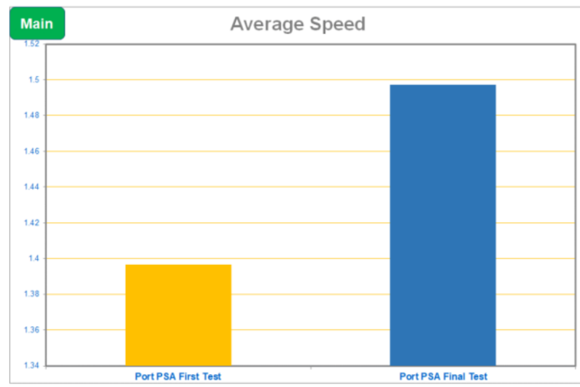

Figure 5 speed difference between the first and last runs

Already these two results show us a marked improvement in performance in terms of accuracy and speed of execution. The user gradually becomes familiar with a tool that he does not know at first glance, but with experience he is able to understand and interpret it better and better, similar to what already happens with a standard education method.

Another interesting analysis was made by comparing the results obtained between port operators and engineers. In fig.6 and fig.7 the average speed and average exposure to risk of the two groups have been compared. Both in speed and exposure to risk, the engineering group notes a slight improvement over the port operators group. This result is not trivial, as many members of the engineering group had no experience in the port sector, and certainly knew very little about the container yard world. The motivation may lie in the younger age of the academic group, but above all in a predisposition given by the experience of tools such as virtual simulators on laptops.

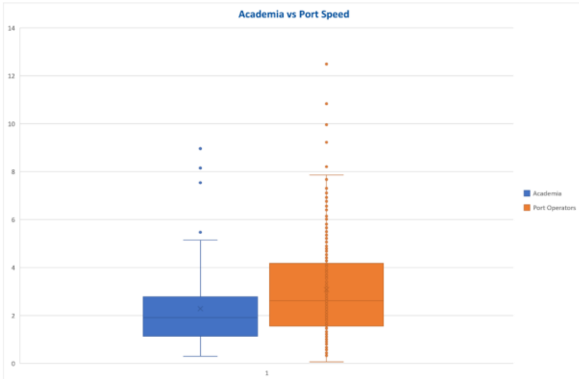

Figure 6 Avg Speed between Academia and Port Operator

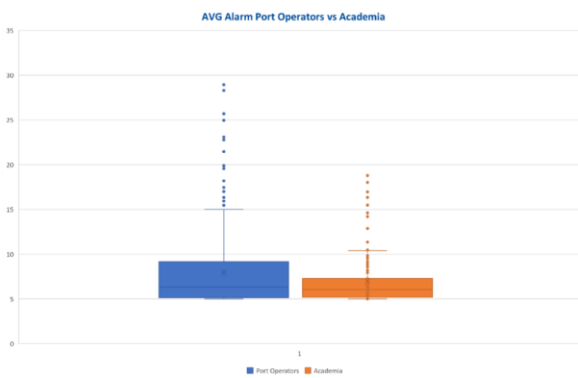

Figure 7 Avg Risk Exposure between Academia and Port Operator

This result should not make us doubt the correct investments in this area, but give the certainty that modeling and simulation will be an increasingly effective tool in the field of education and training.

6. Conclusions

The research outline the benefits provided by innovative MS2G Solutions in improving Safety within Ports; indeed, the Experimental Analysis outlines significant results, reporting improvements in operator performance by using the simulator. Specifically, we observed a significant increase in task execution speed, indicating an increase in efficiency and productivity. More importantly, we noted an improvement in operators' perception of risk, suggesting that training through the Serious Game enhanced their awareness and understanding of potential hazards in the work environment. An additional noteworthy aspect is that operators' performance was found to be affected by visibility conditions in the terminal. This allows us to better understand the challenges faced by operators in different environmental conditions and adapt the Serious Game to more effectively prepare operators to handle these situations.

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