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Evaluation of Risk Awareness by Simulation & Extended Reality in Industrial Plants

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Abstract

Accidents within high-risk environments such as industrial plants or port terminal yards are commonplace. This occurs due to various factors, such as the presence of hazardous materials, unstable chemical reagents, high temperatures, etc. which vary the extent of the danger of the possible accident. To accentuate this risk there is the inefficient use of information and the lack of learning from the lessons that are available from accident data which results in an absence or incorrect training for operators. In this study the authors aim to address the safety problem by creating an interactive synthetic environment that represents dangerous areas, such as the yard of a port terminal, in order to improve the preparation of operators. In particular, it is studied how operator training through simulation can improve not only the efficiency of work activities, but also the real and perceived risk by the user during the performance of the assigned task.

Keywords: Safety in Operation, Extended reality, Serious Games, Dangerous Areas, Container Terminal

1. Introduction

Often Yard Terminal workers handle dangerous goods or they use to operate in a risky environment due to the storage system or critical environmental conditions. For instance, in many ports there are various types of dangerous situations such as excessive temperature, high level of noise, dust or presence of chemical agents. A lot of endogenous and exogenous factors can affect accident frequency such as job design, environmental conditions and human factors (Fabiano et al., 2010).

Many of these accidents occur due to the inexperience of port operators or paradoxically from the overconfidence of more experienced workers. Therefore, it is fundamental to train operators according to precise regulations. In this sense, in order to improve efficiency and safety in carrying out work tasks, it is essential not only to train the operators on the correct procedures to follow but also to increase the

perception of risk. The authors use innovative M&S (Modeling and Simulation) e. XR (eXtended reality) technologies in order to increase safety in industrial & port environments through the creation of virtual worlds.

In these Environments it is possible to create effective virtual experiences as well as to develop new education & training programs for risk prevention, impact reduction and operational performance improvements.

Indeed, the scenario identified for the experimentation is a major port, with particular attention to human activities during the loading and unloading operations on the terminal yard and on the dangerous goods area. During these operations, the user's multisensory experience becomes of fundamental importance to have a perception and complete control of the surrounding situation and risks. In relation to the proposed case study, an immersive three-dimensional simulation environment was developed in which the components related to visual and auditory perception where modeled. Thanks to this model it was possible to evaluate the efficiency of the task operation related to the risk perception.

2. State of the Art

The increase of container ship traffic led to a consequential increasing request of workforce, resulting also in high number of low experience workers. For instance, in EU, seaborne traffic represents 20% of the total transport (Hervàs-Peralta et al., 2020) It is very common for industrial and logistics operators to handle dangerous goods or work in a risky environment. For example, in some industrial plants, as well as in ports and related terminals, there are areas intended for dangerous goods and/or confined spaces where storage constitutes a dangerous context for the safety of operators as well as the risk of serious accidents. Although research in the field of safety is constantly growing, the dizzying expansion of flows, operations and the complexity of procedures leads to an increase in the number of accidents. Despite the numerous frameworks for port risk analysis and management (Pallis, 2017; Alyami et al., 2014; Nguyen, 2021), the number of accidents still remains high (Häkkinen & Posti, 2015). There are several different factors which occurs in ports accidents. One of the most common factors for the accidents is related to Human mistake. There are a lot of human factors involved in yard accidents: Human omissions, worker's experience, communication misunderstandings, execution of the job safety rules and regulations, workload and stress (Kadir et al., 2017). Another common and very dangerous factor associated to big accidents is the temporary storage of dangerous substances waiting for further transport (Christou, 1999). Other common mistakes are improper storage modes and weak safety awareness of employees (Xie et al., 2021). Accidents due to transport vehicle (Fabiano et al., 2010). In this scenario it turns necessary not only to create new and more strictly regulations but also to train constantly decision makers and operators in order to guarantee the execution of certain procedures. The training process in critical scenarios, due to costs and risks, is obviously limited if only real simulations are used. To overcome this problem and create virtual training laboratories, simulations and serious games are becoming increasingly significant (Bruzzone et al., 2013; Checa & Bustillo, 2020). This not only leads to the training of the selected task during the reproduction of a given scenario, but allows to redesign the operating procedures and carry out capability assessment of multiple KPIs as well as to make assessments.

Thanks to the developments in software and hardware in recent years, it is possible to recreate immersive and interactive experiences capable of training users with innovative technological solutions at low costs (Hale & Stanney, 2014; Bruzzone et al., 2016; Berg & Vance , 2017). Among these solutions we can re-produce for example Hololens for AR ($ 4,000), Oculus Rift ($ 400) up to less than 40 euros for a headset support for smartphones capable of supporting stereoscopic vision and VR (Papachristos et al. , 2017; Bruzzone et al. 2019a; Elor et al. 2020).

For these reasons this paper presents an innovative solution in order to improve efficiency and safety of yard operations. The simulator presented in the paper allow to conduct immersive and interactive experiences designed to improve the ability to prevent risks and to increase the perception of the risk itself, for those who work in the yard or who may find themselves passing through it (e.g. maintenance, supplies, checks, visits, etc.).

3. Case Study

The scenario analysis was based on the need to identify a context of interest to demonstrate the potential of XR and M&S technologies, already providing valuable support to reduce risks, increase safety and efficiency. it was decided to focus attention on the Container Terminal yard and on the Dangerous Goods area and the Personnel that can be found operating in that area, however the virtual world built for this research is suitable for further applications and is close to people. The following paper reports in particular the case study of the PSA Pra Terminal which represents the first Terminal Container of Genoa and of Import in Italy and belongs to the PSA Pte Ltd group. the traffic of containers, in over 60 terminals in the world and is the second Port Company in the World after Hutchison Port Holdings (which controls the Port of Hong Kong in China). The paper presents the development of Models and the virtual world through the reproduction of the operations in the port terminal and in particular in the yard, then reproduces the movement and actions of the forecourt vehicles thanks to the control given by the AI. The AIs also monitor ground personnel and the

operations they conduct, both standard (e.g. customs inspections, service to refrigerated containers, vehicle and yard maintenance, handling support, refueling checks, shift changes, periodic inspections) and those related to particular cases (e.g. investigating a problem or a suspicious situation).

The container blocks with their characteristics and any risk elements of different nature (e.g. spillage of liquids, spills of toxic material, fires, explosions, loads, etc.) are also represented and dynamically simulated. The scenario involves people, cranes, vehicles, containers on the yard and docks in respect of safety problems and takes into consideration realities corresponding to the port observers involved, easily extensible to others. The simulator was developed to create a highly immersive solution thanks to multisensory. Users were then asked to perform different tasks within the synthetic environment and thanks to the developed real and perceived risk assessment algorithms, it was possible to study the variation in terms of efficiency, risk exposure and perceived risk exposure to recurrence. evidence. In this way, the simulator can be part of a broader training program that supports the usual communication channels with an innovative training platform based on Extended Reality and Modeling & Simulation.

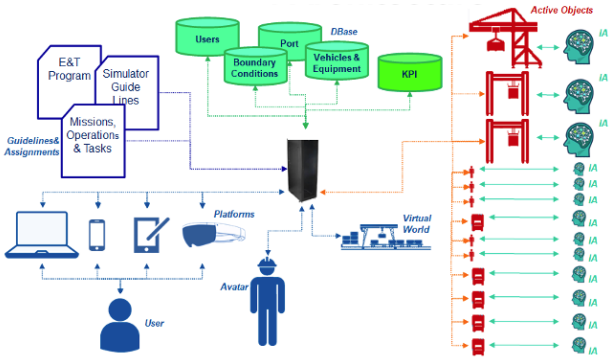

Fig.1 Simulator Architecture

4. Conceptual Models

First of all, it must be said that the simulator is based on a discrete event stochastic computer simulation that adopts the MS2G paradigm (Modeling, interoperable Simulation and Serious Games), Agent Driven. The 3D scenario, including the associated 3D sound produced by virtual objects based on their dynamic actions and status, allows you to create Immersive characteristics that ensure user involvement and maximize training effectiveness. The Interoperability of the presented simulator is based on the ability to connect the different models that represent different Entities and/or Units that make up the Scenario, including different cranes, vehicles, equipment operating on the same Virtual World. The architecture is proposed in Figure 1 and the simulation used for this research is Coyote (Container terminal & Yard Operator simulator for Training & Education) developed by Simulation Team as extension of previous Container Simulation Systems within a new Virtual Framework (Bruzzone et al., 2013, 2016, 2019).

The simulator introduces various elements of difficulty into the game to which the user must react.

Some of these are pre-established events, which are based on specific tasks and dangers that we want the user to face and avoid, such as keeping away from pre-established areas where some vehicles move containers in marked spaces and which are always the same.

The Simulator reproduces the movements and actions of vehicles in the apron of the port terminal thanks to the use of Intelligent Agents. During the simulation, these vehicles move independently, carrying out typical activities within the terminal. The straddle carriers move in such a way as to position themselves in correspondence with some containers chosen for handling, picking them up and placing them in points designated for storage. The trucks move within the yard between the rows of containers, respecting the road signs below. To search for the optimal path that the means must follow, the algorithm called "A *" is used. This graph-based algorithm identifies the best path given the starting node and the target node by examining step by step the nodes with the best score. Once it arrives at the target node, the vehicle can perform a task, such as lifting the container and carrying it to another node or starting the search for another target. To make the simulation more immersive for user training, it was necessary to create a list of target nodes in order to randomly choose different paths that the vehicles can travel. In this way, even by repeating the simulation several times, the user will not be able to identify a unique pattern of the handling vehicles and the simulation will be more realistic. Thanks to the diversification of the scenario, it is possible to observe the actual improvement in the completion of the tasks by the user. The user within the simulation will have to impersonate the figure of a worker, whose task is to check the status of the containers that are arranged in the map.

The user must perform tasks within the port terminal avoiding excessive exposure to the risks associated with the movement of vehicles. The user must therefore move around the virtual environment in search of containers with the same code shown in the list presented to him. Once one of the containers has been found, the second task to perform is to check its status. In facts, each container has different states:

-ok: the container shows no signs of damage and appears intact

-small leakage: the container has a small leak of chemical material

-big leakage: the container has a large loss of chemical material.

The execution of these tasks, however, is conditioned by disturbing and dangerous elements within the

synthetic environment. At each simulation launch, the paths followed by the vehicles are different so as not to allow the user to learn a predetermined path. The performance improvement objectives, in terms of productivity and safety, are defined as MoM (Measures of Merit).

Fig.2 Extended Reality by Simulation Team

MoMs represent the objectives to be achieved and play an important role for safety in an operational context:

- -Precision: It represents a measure of the quality of the work performed by the operator and how much of the assigned work has been completed correctly
  - readiness: It represents a measure of the speed with which the operator has completed the assigned work
  - correctness: It represents the ability to respect rules and procedures and not make mistakes in carrying out the assigned task
  - awareness: It represents a measure of the operator's awareness of the risks surrounding him and his ability to limit them by adopting appropriate actions in carrying out the assigned mission

Therefore different KPIs were defined to measure the different MoMs:

- -Duration: mission completion time
- -Points: Correctness of the checks carried out on the various containers
- -Incidents: Number of User Accidents and Collisions and their severity; even a single Incident represents a critical issue for not exceeding the mission
- -TotRE: Total Risk Exposure, provides an indication of the risk exposure recorded during the mission by the individual User. This parameter takes into account both all the AvgRE values over the entire duration of the mission & maximum risk exposure.
- -pTotRE: Total Risk Exposure perceived by the User, provides an indication of the exposure to risk recorded during the mission by the individual User with respect to his ability to perceive it and therefore how much he is unconsciously exposed to the risk. This parameter takes into account both all pAvgRE values over the entire duration of the missionand the perceived exposure to maximum risk.

5. Implementation

The objects within the virtual world were modeled through the open source *Blender* software and subsequently imported into Unity 3D. Unity is an open source graphics engine capable of running on MacOS, Windows and Linux based. The software is based on C#.

6. Verification & Validation

The verification and validation (V&V) of the simulator has been planned and conducted extensively throughout the entire life cycle of this research, involving port expertsand is based on: review of the objects and detailed analysis of the definition of the objects, Flowcharts and Variable Controls for Concept Models, Face Validation & Dynamic Implementation Tests, ANOVA & Sensitivity Analysis on Simulator Execution & Experimental Data Analysis tests were conducted on a large population of engineering students of Genoa University and some port experts to identify bugs, gaps and improvements to models, game logic and the simulation environment

7. Material and Methods

The A total of 18 participants were involved by the Department of Mechanical Energy and Transport Engineering (DIME) of the University of Genoa and the University of Calabria, while a control group of 4 participants was used by the Simulation Team of the University of Genoa. The experiment was conducted on the two samples on different days. Both samples repeated the experience following the same procedure.

- 6 normal level 2 tests (with medium traffic intensity)
- 2 tests at level 2 with Augmented Reality On (Visual danger signals)
- 2 normal level 2 tests

The last three tests are aimed at verifying whether the user has improved his understanding of the scenario. In this way we try to understand if there are improvements in the execution of the tasks assigned to users, in the perception of risk and in exposure to risk. Through tests 7 and 8, on the other hand, it is investigated whether through the use of augmented reality the user derives benefits in terms of optimization of performance and safety. eraFor each test, user data and their respective performance indicators were recorded in order to compare any performance improvements between players, between simulation runs per player and between groups of players. For these experimental tests the platform used is the PC.

8. Results and Discussion

The following table shows the results relating to the most important indicators for the purpose of verifying the improvement of a test, i.e. duration, duration in relation to distance, exposure to total risk, exposure to

total perceived risk, exposure to maximum risk, exposure to risk maximum perceived, exposure to average risk, exposure to average perceived risk

Table on Output		*Dur*	*Dur/Dist*	*TotRE*	*pTotRE*
Users Improvements	[%]	85	100	100	85
Average Improvements	[%]	51	57	56	63

9. Conclusions

This research allowed to further tailor a simulator capable of immerse the user into a virtual experience inside the yard of a container terminal, carrying out tasks that are dangerous due to the present risks and the interactions during operations. In this sense, a training program is being developed to exploit the potential of this simulation to create a training platform to support those operators who carry out high-risk work within ports. The results achieved in this development phase have shown how users could improve their performance and perception of risk through a precise education and training process based on the use of solutions adopting the innovative paradigm of MS2G (Modeling, Simulation and Serious Games). These results will be used to calibrate not only the next version of the Coyote simulator, but also to develop new educational & training programs best suited to different users and tasks, including University Courses on Safety and Logistics.

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