# LEARNING EFFECTS IN PROFESSIONAL TRAINING FOR EMERGENCIES MANAGEMENT IN INDUSTRIAL PLANTS WITH SERIOUS GAMES

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**ABSTRACT**

The complexity of situations and potential error connected to maxi-emergencies and disasters management are increasing in the last years. The analysis of natural disasters and related possible dysfunctions of the "emergency chain" leads to well-encoded rescue plans. The simulation has allowed in recent years to improve and optimize the management of these events. This study presents results of a new serious game that simulates activities, procedures and processes that have been implemented to train figures entitled in the management and aid activities during the maxi-emergencies that may occur in industrial plants.

In particular, the serious game presented is based on a discrete event simulator and it is able to reproduce emergency situations in which the players can assess their own abilities. The results presented show how the use of such training simulator significantly improves the initial score, increasing the awareness of coordination and decision-making abilities in emergency situations.

Keywords: simulation, serious games, maxi-emergency, health

## 1. INTRODUCTION AND MOTIVATION

Virtual training offers a huge potential to reduce the time and effort of traditional hardware training (Ordaz et al., 2015). However, before being deployed in an industrial environment, virtual training systems need to prove their reliability and user acceptance: with this purpose Ordaz et al. (2015) determined the impact of gaming experience on the learning process of a manufacturing operation using a serious game that simulates manufacturing environments in order to train operators to perform manual tasks; ten operators participated in the study, which found that gaming experience influences positively on training completion time. Boyle et al. (2016) developed a systematic literature review where most frequently occurring outcomes related to games for learning was knowledge acquisition, while entertainment games addressed to broader range of affective, behaviour change, perceptual and cognitive and physiological outcomes. Games for learning were found across varied topics with Science, Technology, Engineering and Maths (STEM) subjects and health the most popular. Smith (2010) underlined how military field used games for training, tactics analysis, and mission preparation for Centuries: the challenge in that field is computer gaming, that offers a dynamic representations of the physical world and proposes interesting and useful tools for operating training where real-life simulations are not possible or not convenient (i.e. considering economic or logistic aspects). Wiemeyer and Kliem (2012) discussed the impact of serious games (SG) on prevention and rehabilitation, applying different criteria: effectivity and efficiency, as well as additional benefits of serious games that can be described and explained by different models including social, psychological, physiological and sensory–motor factors. The main aim of the study proposed by Knight et al. (2010) was to evaluate the effectiveness of such a serious game in the teaching of major incident triage by comparing it with traditional training methods. As a main result of the work they conclude that serious game technologies offer the potential to enhance learning and improve subsequent performance when compared to traditional educational methods. Concerning the role of serious games to facilitate sustainable change in aviation industry, Zon et al. (2012) presented A Learning, Training & Mentoring Framework (LTM) that supports change initiatives involving training and competence development for change management skills, in order to facilitate the implementation of these skills in practice. Finally, next to the world of training, Longo et al. (2014) applied serious games and simulation to develop a mobile device application for tourists that can enjoy digital contents through interactive and virtual experiences. In the same work the authors also presented another mobile app, based on augmented reality and on an intelligent personal assistant, aimed at creating new patterns of interaction with real contents and historical findings during a real tour in a museum or in an archaeological site.

A particular area for the development of serious game is the “health sector”, with particular emphasis on the games for professional training, e.g. simulations for medical staff training, emergency management, .... In these areas the decision-making process is very dynamic and complex. Strohschneider et al., (1999) analysed the complex decision-making processes and the human tendency to make certain kinds of mistakes. Danielsson et al. (1997), focusing their study on the analysis of emergency management, concluded that in these areas it is essential to have high information and training: in such situations, an error in the decision-making process can become very dangerous and have a possible disastrous impact on the entire system. Emergency management is based on "staff work" that focuses on the design, coordination and monitoring of the operational procedures (Orasanu et al., 1996). A list of serious games developed for emergencies management is shown in Table 1: no simulator appears compliant with the Italian Regulation and might be suitable for training Italian's emergency staff.

The serious game presented in this work aims at proposing a model of reality that allows the evaluation and prediction of dynamic and interactive execution of a series of events and processes, enabling operators (the player assumes the role of Medical Disaster Manager - MDM) to experience countless situations, and to define best practices to be adopted in all possible scenarios and variants, thus increasing their experience and preparation. In particular, the actions that the player can choose are designed in compliance with the Italian Regulation.

Main aim of this research is to investigate how the usage of this new developed serious game by different skilled operators may help their learning process.

The remainder of the paper is organized as follows: Section 2 describes the assumption and the logic of the simulator, Section 3 presents the structure and the functionalities of the simulator. The main findings on learning effects while using the tool are discussed in Section 4. Finally, conclusions and future research developments are summarized.

Table 1: Characteristics of serious games for emergencies management

| Name | Developer | Description | Regulation area |
|---|---|---|---|
| CERRTS – Civil Emergency Reaction and Responder Training System | Raytheon | Training Emergency Operation Centres (EOC) Operators | USA |
| A-TEAM, Advanced Training System for Emergency Management | Environmental Software and Services GmbH | Real-time training experience in the field of emergency management | USA |
| Emergency Preparedness Incident Command Simulation (EPiCS) | U.S. Army Training and Doctrine Command Analysis Center (TRAC) | Set of tools that allow to simulate, visualize and record the activities carried out during the management of an emergency | USA |
| NCBR - Nuclear, Chemical, Biological, And Radiological Environment Ser- ver | ITT Industries, US Army Soldier and Chemical Biological Com- mand, Defense Threat Reduction Agency | The NCBR is a set of simulation and modeling tools that allow you to analyze and manage nuclear disasters, chemical, biological and radiological | USA |
| VERTS - Virtual Emergency Response Training Simulation | U.S. Army STRICOM | VERTS is a powerful simulation software used by the US National Guards | USA |

## 2. ASSUMPTION AND SIMULATION LOGIC

In this section the main structure of the simulator is provided, by explaining the key objects and parameters. In particular, the simulator is divided in two main sections: a scenario configuration section, where it's possible to set the scenario for the game, and a game section where the scenario is played. Below are listed the different scenario configuration areas; the game section is presented in Section 3.

In figure 1 the entities of the simulator and their relationship are presented. In the specific, it's possible to set up:

- Scenario description
- Victims
- Emergency vehicles
- Accidental event
- Activities and human resources.

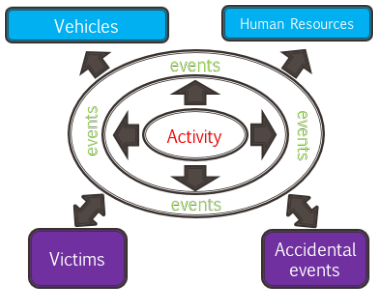


Figure 1: Entities of the simulator

*Scenario description setting*

The first section to configure is the discursive scenario description which has to include the text that describes the initial situation of the scenario and all initially information. This text will be shown to the player in a special dialog box before the game start. This permits to communicate to the player the appropriate information about the game.

*Victims setting*

This section contains a list of all persons involved in the event that has caused the unexpected emergency, precisely named "Victims". In particular, it should be decided ex-ante how many victims to consider and their characteristics. It's no limitation on the number of victims, however, the scenario appears likely if the number of victims is comparable with the number of resources (emergency vehicles and human resources) that the player has available (to be configured in separate sections). Of course a large number of victims, ceteris paribus, increases the difficulty of the scenario. Each victim, besides being uniquely identified, is characterized by the following configurable parameters:

*Gravity*

Allowed values: W (White), G (Green), Y (Yellow), R (Red), B (Black).
Description: Specifies the starting severity code of the victim: from slightly injured (White) to the deceased (Black).

*Victim Awareness*
Allowed values: Yes (the victim is known and the player can act on it), No (the victim is not known).
Description: Indicates whether the victim is initially known to the player. Likely only a low percentage of victims will be known at the initial time. The other victims will be discovered only if and when the player decides to make a reconnaissance of the event place.

*Location*
Allowed values: INT (Trapped), LOC (Localized).
Description: This field identifies the position of the victim in the rescue process.
Initially, the victim can be (1) trapped (INT), so that before being taken from rescuers, he/she has to be vacated (e.g. extracted from the rubble), or (2) localized (LOC) that he/she may be treated immediately and then recovered (transported to Collection point). During the simulation, it is expected that the victims position can take on different states: once completed the first medical treatment (preparation of the victim to the recovery phase) he/she reaches the state of treated (TRT), once recovered, he/she has the recovered status (REC), and then completed the phase of medication, he/she gets the status of medicate (MED) and finally, once identified the transport vehicle to the hospital, he/she reaches the final state of evacuated (EVA), that represents the completion of the rescue process of the victim.
Once the victim is sent to a hospital, the simulator considers the rescue process for the specific victim as completed; downstream stages are not covered.
It must also consider that the severity of the victim is modified over time according to a stochastic law set in this section. In particular, this law generates a parameter indicating after how long the victim's status is changed from the current one to the next with a consequent increase of severity.
During the rescue phase the main objective is to ensure the safety of victims and to stabilize their condition, not to cure (in the strict sense) victims. Therefore, it is not possible that a victim in Green code can change its code in White and so, recursively, for all other colour codes.

*Emergency vehicles setting*
This section contains a list of all the emergency vehicles. In a similar manner to the victims setting, in the scenario definition phase it's possible to decide ex-ante the number, type and other characteristics of all the resources that the player may request for the intervention. Also in this case there is a limit to the maximum number of vehicles that it's possible to make available. However, the number of available vehicles must be related to the victims involved as mentioned above. Of course, the lower the available vehicles the more difficult will be the emergency management. Per every vehicles it's possible to specify the type; you can choose from five different varieties: ambulance (MSB), equipped ambulance (MSA), helicopter (ELI), firefighters vehicles (APM) and finally police vehicles (VOL). In the scenario setting, it's possible to set up the time that the vehicles need in order to arrive at the event place.
Having the opportunity to decide the time of arrival of each vehicle, it allows to simulate different starting points for each type of vehicles and between vehicles of the same type. In this way, for example, by configuring appropriate times of arrival, one can establish that a number of ambulances can leave from a certain place and some other from a different site.
The last parameter that must be defined is the time required for a vehicle to transport a victim to the hospital, starting from the event place (this parameter should only be considered for those types of vehicles able to transport the victims: ambulance and helicopter).
Who configures the scenario cannot characterize the single resource, or the specific rescuer, doctor, policeman etc. In reality, however, during the simulation it will be also possible to act on the individual resources. In fact, any type of rescue vehicle, upon arrival at the event place, makes available a predetermined amount and type of resources. These, unlike the emergency vehicles and victims, are not uniquely identified but are managed "at group" (it is managed only the type and relative amount). All other parameters, such as the time required to perform a given activity, will be differential between only one type of resource and another. The following table shows for each type of emergency vehicle, type and quantity of contained resources.

Table 2: Composition Vehicles / Resources

| Vehicles / Resources | Emergency medical technicians (EMT) | Medical Doctors (MD) | Firefighters | Policeman |
|---|---|---|---|---|
| MSB | 3 | 0 | 0 | 0 |
| MSA | 1 | 2 | 0 | 0 |
| ELI | 2 | 2 | 0 | 0 |
| APM | 0 | 0 | 5 | 0 |
| VOL | 0 | 0 | 0 | 2 |

*Accidental Event Setting*
In this section, all the accidental events can be entered, such as fires or gas spills. Who set up the scenario must decide ex ante all the accidental events that may occur. There is no maximum number of accidental events; however, the number of events must be related to emergency vehicles that the player may request. Each accidental event is characterized by a textual description, a severity indicator and some parameters that determine its temporal evolution. Of course, increasing the number of scheduled events, their severity and speed of development, it will increase the overall difficulty of the scenario. In detail, the fields to be defined are the following.

*Gravity*

Description: Defines the initial severity code for each accidental event. Gravity is measured on a scale of three numeric values: 1 (minor), 2 (bad enough), 3 (very severe) and 4 (hopelessly severe)

*Start*
Description: Indicates at what point in time, from the beginning of the simulation, the specific accidental event will take place. It's possible then configure one or more accidental events both at the initial instant, or after a certain time since the start of the simulation. Hypothetical maxi-emergency due to an explosion may for example provide a set of fires already at the start of the simulation and a leakage of harmful fluids after a certain period of time.

*Description phenomenon*
Description: This field (optional), which describes the type of accidental event, will be shown to the player when the event occurs and at each deterioration stage of the event. Whereas it is not possible to define different types of events, this field has the objective to provide the player a concise description to facilitate the management of resources to be used for resolution of the event.
The evolution of the state of severity of each event partially follows the one of the victims. When an accidental event occurs, it takes on the severity code set in the field and it continues to deteriorate until it reaches its last possible value, or 4. The intervention of one or more resources to deal the accidental event, after the time required to perform the treatment, causes a reset of the event itself, or its severity code is reset and its temporal evolution is cancelled.
When an accidental event occurs or when it undergoes a worsening of its severity code, it will have negative repercussions on the victims. This special feature is designed to assure that the player quickly manages the accidental events, in order to minimize the worsening of the condition of the victims. The following table describes the effects on the victims for each severity code.

Table 3: Description severity code

| Severity | Victim's effects |
|---|---|
| 1 | No effects |
| 2 | Increasing of the worsening speed (default 10%) |
| 3 | Increasing of the colour code Gravity for victims in the state (LOC, INT and TRT) |
| 4 | All victims in the state LOC, INT and TRT become Black (B) |

*Activities setting*
This section contains all the tasks that the player may decide to implement during the simulation session. During the scenario simulation each activity is represented by a command button in a dialog box. In this way the player can decide which activities to perform and their sequence. Each task can be configured by editing the appropriate parameters. Each activity is represented by the following parameters:

- The first field contains the description of the activity.
- The second set of parameters has the aim to define which types of resources can be assigned to an activity and the time needed to complete the action. It's possible to sort the various types depending on the efficiency in performing a task.
- The third set of parameters is represented by the minimum and maximum number of resources that the player may decide to assign to the specific activity. The number of resources that the player assigns to each activity is reflected on the related execution time: for each additional resource, the previously defined execution time is reduced by 25%. This methodology prevents that the execution time of any activity becomes zero due to the high number of allocated resources.
- The fourth and final set of parameters describes the effect that each activity will have on other variables (emergency vehicles, accidental events and victims). For some effects, it's possible to change the value of the parameter that determines the amount (weight) of the effect described. In the following section the activities and the related effects are reported.

## 3. THE SIMULATOR

The developed simulator models the rescue management in a maxi-emergencies that may occur in an industrial plant. The overall objective is to evacuate the maximum number of victims in the shortest possible time with the rational use of the available resources. The model predicts the existence of certain classes of variables, which are characterized by specific attributes, as described in the previous paragraph.
Time passing, the victims and accidental events worsen their status. To contrast this development, the player will trigger the activities that will allow him/her to use resources and vehicles in order to accomplish the actions on the victims and on the accidental events. Noting that, as explained above, the objective of the game is the rescue of the victims, in order to avoid that the player is brought to ignore accidental events, the model predicts that any worsening of the severity of an accidental event produces a health worsening of the victims. In this way the player will be brought to dedicate part of the resources available to treat even accidental events.
The most critical aspect in emergency situations is certainly the time. For this reason, the simulator is equipped with a virtual time line, connected to the game timer, inside which are placed all events that entail a change of the attributes of the classes listed above. At the beginning of the game, some events based on information imported from the scenario setting are automatically loaded. Subsequently, each time the player decides to start a specific activity, the simulator will generate other events that will place on the virtual time line as a function of the durations and delays computed

by the probability distributions. In general, the game timer runs constantly throughout the simulation session. However, in the event that, due to the temporary unavailability of resources due to the actions undertaken by the player, it is not possible to do any activities, the simulator will implement an instantaneous temporal advancement to the next event on this virtual time line. This prevents the player to spend time without being able to take any action.
The model has been coded in MS® Excel® with Visual Basic® for Applications routines. The choice of this simple environment was to guarantee the portability and the easy development of the prototype. The next step will be to implement the model in a Web-based environment.

*Starting the game simulator.*
At the start time, once the scenario is chosen, it is shown to the player a dialog box containing a text description of the scenario that will be simulated. The text has the purpose of presenting the scenario, describing in a generic way the main features, such as the type of plant, the type of incident, the logistic characteristics of the area and other information that distinguish the situation of departure.

*Allowed gaming action.*
After starting the phase of real simulation, a graphical interface is shown containing some dialog boxes. In figure 2 it is shown the simulator dashboard.

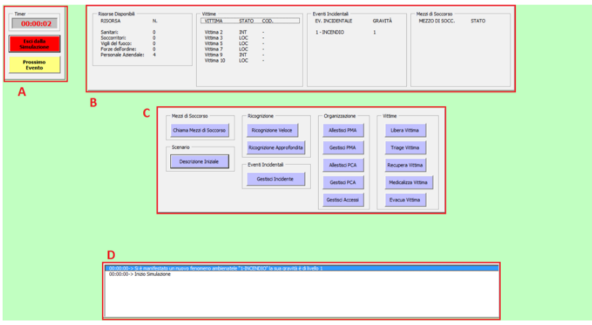

Figure 2: Simulator's dashboard

At the top of the screen there is a window, named "Status Bar" [B], where on-time conditions of the known victims are shown, together with emergency vehicles, available resources and the state of accidental events. in this way it's possible to check at any time the overall state of all the elements involved. In the central part of the screen it's possible to see another window, i.e. "Dashboard Activity" [C] dialog box where the player can see all the activities that he/she can undertake during the simulation, in order to arrange the logistics of the emergency area and manage resources at its disposal. The activities mentioned above are contained in "Activities" section. In the upper left part of the dashboard there is another window, named "Timer" box [A], that keeps track of time throughout the simulation session. Finally, it is provided a space dedicated for alerts [D] that informs the player on the duration of the simulation, as well as on the events and changes in the status of the variables involved.
The dashboard of the activity is organized in sections that group activities according to their characteristics. In the following all the activities that the player can undertake during the simulation are described.

*Call emergency vehicles.*
This is the only activity that does not require the use of resources or emergency vehicles to be activated. For this reason, even if the player is not formally forced to follow a predefined sequence during the simulation, this appears to be the first action to be performed. In fact, if the player decides to activate another activity, the simulator, verified the unavailability of resources, would return an error message and prevent the player to move on. After pressing the call button, the player can select user-emergency vehicles appropriate. In this phase it is important that the player considers that each rescue vehicle contains a given number and type of resources. Completed the selection of the vehicles, the simulator will calculate the instant when each vehicle will arrive on the place of the event. This is a fundamental activity for the success of the game: an inadequate sizing of the emergency services available on the place of the event will result in a bad final performance. In case additional vehicles and resources are required during simulation, the player-user is still able to do another (or more) call.

*Fast reconnaissance and Deep reconnaissance.*
Both reconnaissance can be used only once during the game. Furthermore, the start of deep reconnaissance automatically inhibits the fast: this is because the deep reconnaissance is nothing more than an extension of that fast. When you start a survey, the simulator will ask the player to select the type and amount of resources to be allocated to this activity. As explained earlier, each resource type can have a different execution time. So, it is necessary to carefully choose the most suitable type of resource for each activity. Also, the greater the number of resources allocated to the activity, briefer will be the running time. What distinguishes fast respect to deep reconnaissance are the completion times (the deep one will take longer) and the effects they generate on other variables. In fact, if the player will choose to perform a fast reconnaissance the unknown victims, who are inside the event place but which are not trapped, will be revealed. Using the deep reconnaissance instead, it will be revealed to the player also the trapped victims.

*Accidental event control.*
This activity allows the management of an Accidental event. The player can start this business a certain number of times, until there is at least one active Accidental event. When the button is pressed, the player has to specify on which of Accidental events he/she intends to act and then he/she selects the type and amount of resources to be allocated. Once the activity is set and confirmed, the simulator, on the basis of type and number of allocated resources and seriousness, will calculate the

actual duration of the action. At the end of this operations, the player can see an alert information and the treaty event is solved.

*Build AMP (Advanced Medical Place).*
This activity can be undertaken only once during the simulation and it allows the user to prepare an Advanced Medical Place. When the button is pressed, the player will have to specify the type and amount of resources to be allocated. The construction of an AMP has no direct effect on the variables involved (victims, resources, etc.); however, it allows the user to be able to undertake the activity entitled "Activate AMP".

*Activate AMP (Advanced Medical Place).*
This activity allows to allocate resources for the management of the AMP. The activation of the AMP will have the effect of reducing the percentage of the treatment time.

*Build ACP (Advanced Command Place).*
This activity can be undertaken only once during the simulation and allows the player to put on an Advanced Command Place. When the button is pressed, the player will have to specify the type and amount of resources to be allocated. The construction of an ACP has no direct effect on the variables involved (victims, resources, etc.); however it allows the user to be able to undertake the activity entitled "Enable ACP".

*Activate ACP.*
This activity allows to allocate resources for the management of the ACP. The activation of the ACP will have the effect of reducing the percentage of the execution time of all the operations carried out by resources.

*Access management.*
This activity allows to allocate some resources to the management of the input and output of emergency vehicles passages. When the button is pressed, the player will have to specify the type and amount of resources to be allocated. This type of activity does not provide a time duration, so the allocated resources will not be available for other activities throughout the duration of the simulation. Access management will have the effect of reducing the percentage of the time of arrival and evacuation of emergency vehicles.

*Free victims.*
This activity allows to free any trapped victim. The user-player can select this activity every times that there is at least one known victim in "INT" position, or trapped. When the button is pressed, the player will have to specify which victim of "INT" he/she intends to free and later he/she will have to select the type and amount of resources. The simulator, on the basis of type and number of allocated resources, will calculate the actual duration of the action. At the end, it's possible to see an alert information, the victim will be released (their status will become "LOC") and the previously committed resources will be available for other activities.

*Victim's Triage.*
This activity allows to treat any non-trapped victim who is on the place of the event. The player can start this activity if there is at least one known victim in "LOC" position, or localized. The player will have to specify which victim of "LOC type", he/she intends to treat and later will have to select the type and amount of resources to be allocated. The simulator, on the basis of type and number of resources allocated and the severity of the victim, will calculate the actual duration of the action. So, the status of the victim will pass from "LOC" to "TRT" (treated) and previously dedicated resources will be available for other activities.

*Victim's recovers.*
This activity allows to carry a victim from the localization place to the collection point, or AMP. The player can start this activity if there is at least one known victim in "TRT" position or treated. The player will have to specify which victim, type "TRT", intends to recover and later will have to select the type and amount of resources to be allocated. The simulator, on the basis of type and number of allocated resources, will calculate the actual duration of the action. So, the status of the victim will change from "TRT" to "REC" (recovered) and the previously dedicated resources they will be available for other activities.

*Medicalizes Victim.*
This activity allows to medicalize any victim who is at the point of collection. The player can start this activity if there is at least one known victim in the "REC" position, which is recovered. The player will have to specify which victim of "REC type", he/she intends to medicalize and later will have to select the type and amount of resources to be allocated. The simulator, on the basis of type and number of resources allocated and the severity of the victim, will calculate the actual duration of the action. So, the victim's status will change from "REC" to "MED" (medicalized) and previously dedicated resources they will be available for other activities.

*Evacuates Victim.*
This activity allows to evacuate any victim previously medicalized. The player can start this activity if there is at least one known victim in the "MED" or medicalized, and at least one rescue vehicle for the transport of the victims. The player will have to specify which victim of "MED type", he/she intends to evacuate and later will have to select the type and amount of resources to be allocated and the rescue vehicle to use. So, the status of the victim will change from "MED" to "EVA" (evacuated) and consequence will end the rescue process of the specific victim. The simulator, according to the type and number of assigned resources and to the vehicles chosen, will calculate the actual duration of the

action. At the end of this activity, previously dedicated resources and vehicles will be available for other activities.

*Simulation term.*

When all the victims have been evacuated or died, the simulation finishes. A report of the simulation session is shown, listing all the actions taken by the player and the situation of all victims, resources, transport and accidental events. In addition, it is computed an overall score that will allow the user to compare any other simulation sessions and evaluate improvement (or deterioration) over time. It's important to consider that the simulator presents two game mode: easy and hard mode. In the easy mode the player can see the list of the choices made during the game. In the hard mode, no information is supplied during the game. The hard mode tries to simulate the real situation during a maxi-emergency when it's hard to have updated information.

## 4. GAME'S RESULTS ANALYSIS

The goal of the presented serious game is to increase learning and the preparation of emergency managers. Particular attention is then placed to the analysis of simulation results, thus two macro-investigations are carried out.

The considered topic does not allow the validation of the simulator with field-tests (Experimental validity). So we have validate the simulator with test validity; the simulator would in general be a valid measure of emergency management skill if performance on the simulation was a good indicator of emergency management performance on real context in a real emergency. In particular, the simulator contains content that relates to the knowledge that is required in the area of emergency management. In fact, the simulator is based on the skill of a group of experts. They agree that the simulator allowed for the evaluation of critical technical and non-technical skills in emergency management area (Content validity).

The first is aimed at understanding the influence of various actions that can be taken by the player on the overall result of the simulation. The second is aimed at understanding the learning effect induced by the serious game.

*Analysis of the effects of the player action on the final result*

Table 4 shows in detail the results of the game sessions performed.

Table 4: Table of scores achieved on 15 analysis sessions 1

| Game session | Initial score | Game mode | Victims gravity | Undiscovered victims | Vehicles | Accidental event | Final score | Time [min] |
|---|---|---|---|---|---|---|---|---|
| 1 | 1000 | 200 | 192 | 120 | 180 | 60 | ***248*** | ***33*** |
| 2 | 1000 | 200 | 192 | 0 | 180 | 80 | ***348*** | ***49.2*** |
| 3 | 1000 | 200 | 192 | 0 | 180 | 60 | ***368*** | ***37.3*** |
| 4 | 1000 | 200 | 192 | 120 | 0 | 60 | ***428*** | ***34.2*** |
| 5 | 1000 | 200 | 136 | 0 | 120 | 0 | ***544*** | ***33.4*** |
| 6 | 1000 | 200 | 120 | 0 | 70 | 0 | ***610*** | ***38*** |
| 7 | 1000 | 200 | 104 | 0 | 80 | 0 | ***616*** | ***41.4*** |
| 8 | 1000 | 200 | 104 | 0 | 70 | 0 | ***626*** | ***41.3*** |
| 9 | 1000 | 200 | 112 | 0 | 60 | 0 | ***628*** | ***39.3*** |
| 10 | 1000 | 200 | 104 | 0 | 60 | 0 | ***636*** | ***41.3*** |
| 11 | 1000 | 200 | 96 | 0 | 60 | 0 | ***644*** | ***38.4*** |
| 12 | 1000 | 200 | 96 | 0 | 60 | 0 | ***644*** | ***41*** |
| 13 | 1000 | 200 | 96 | 0 | 60 | 0 | ***644*** | ***38*** |
| 14 | 1000 | 200 | 112 | 0 | 40 | 0 | ***648*** | ***39.7*** |
| 15 | 1000 | 200 | 88 | 0 | 50 | 0 | ***662*** | ***39*** |
| ***MIN*** | ***1000*** | ***200*** | ***88*** | ***0*** | ***0*** | ***0*** | ***248*** | ***33*** |
| ***AVG*** | ***1000*** | ***200*** | ***129*** | ***16*** | ***84.7*** | ***17.3*** | ***553*** | ***38.9*** |
| ***MAX*** | ***1000*** | ***200*** | ***192*** | ***120*** | ***180*** | ***80*** | ***662*** | ***49.2*** |

In particular, the simulation sessions carried out for the first analysis have the following features:

- all game sessions are performed by a single player;
- all game sessions are performed on the same computer;
- all game sessions are performed on the same scenario;
- the player who uses the simulator knows the general rules of the emergency management.

The game sessions are sorted in ascending order according to the final score. Each row of the table shows, in detail, the components that produce the final score of the simulation sessions performed and the execution time. Moreover, in the lower part of the table three parameters are shown indicating the minimum, maximum, and average values of each score component. In particular, the fields in the table are:

*Initial Score*: constant value in all game sessions: it indicates the starting point from which the penalties are then subtracted. Theoretically it represents the maximum score, although in practice is unachievable.

*Penalties for game mode*: in this analysis the player performs all game sessions in "Easy" mode, therefore, at each simulation session is applied a penalty of 200 points. In the "Hard" mode no penalties are applied.

*Increase Penalties for victim's gravity*: adopting very different task sequences with each other the value of this penalty has a fairly broad range of variability; it can vary from 320 to 88 points, with an average value of 146 points. The reason why the first four games recorded the highest penalty values is due to the activities undertaken by the player. In fact, in the first case the user does not perform any action that will improve the health of the victims. Consequently, victims worsen their health up to code "N" (deceased) and this determines the maximum achievable penalty value on this scenario. Another aspect to note is the correlation between the penalties linked to the worsening of the victims and the final score. Higher penalties are found in the game session with a worse final score and, conversely, the lowest penalty value on the deterioration of the victims is manifested in the game sessions with the best overall score. As shown in the graph in Figure 3, the trend of the deterioration of the victim's penalty is mirrored in the final score. This shows how this type of penalty is of fundamental importance for the determination of the final score. Consequently, during a simulation, if the player's objective is to maximize the final score, it is essential that he/she focuses on those activities which directly or indirectly allow the victim's rescue.

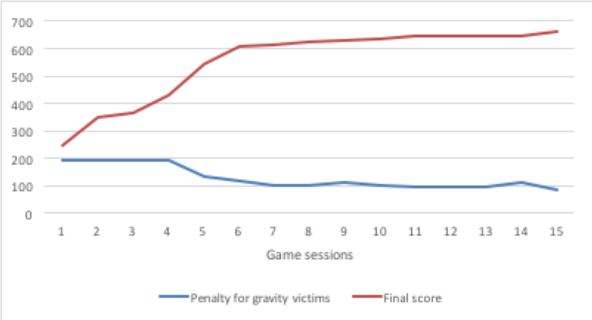


Figure 3: Comparison between the final score and the penalty for victim's gravity

*Penalties for undiscovered victims*: this type of penalty is closely linked to the activity of reconnaissance. In all simulation sessions the player makes the deep reconnaissance (which ensures the discovery of all victims which are not yet known) with the exception of the first and fourth case where the user is limited to observe the spontaneous worsening of the victims without taking any action. Note that there is no case where the player decides to exclusively undertake the fast reconnaissance, so this series cannot be analysed. Therefore, it is possible to observe a single evidence: if reconnaissance is not performed, the final score undergoes a curtailment of 120 points (depending on the number of not discovered victims). Then the player has to evaluate whether to employ operators for reconnaissance or reassignment to other activities in order to maximize the scoring.

*Penalties related to vehicles*: for each emergency vehicle requested during the simulation are subtracted 10 points to the final score. As explained above, this penalty is intended to prevent that the player asks for the intervention of an excessive number of vehicles and resources than the real needs. As reported in the table in Table 3.1 the value of this penalty varies from a maximum of 180 points, corresponding to the case where the player requests all vehicles available, up to a minimum of 40 points, that is the case where the player only selects 4 vehicles. The graph in Figure 4 shows the trends of the final score and the penalty related to the request for emergency vehicles. As it can be seen, the highest final scores are obtained in the game session where the number of emergency vehicles employed is reduced. This phenomenon is due to two factors: the first is the minor penalty, inflicted by the simulator, for the requested vehicles; the second is due to the choices made by the player. In fact, in the last simulation sessions the player has increasingly adequate and weighted better the chosen actions and this allowed him/her to handle the emergency by rationalizing the number of necessary resources.


Figure 4: Comparison between the final score and the penalty for vehicles

*Penalties for accidental events*: the scenario considered in this analysis predicts the existence of only one accidental event. As it can be seen in Table 4, in most cases this penalty assumes a null value: this is due to the choice of solving the accidental event player. Only in the first four games, the event is not managed, and hence the penalty is not null. In three of the four cases just cited the magnitude of the penalty is 60 points, corresponding to a final severity level equal to 3. While in only one case (the third played) the penalty assumes the maximum value, equal to 80 points. This peculiarity is due to the overall time. As it can be noted, in the second piece of skill, the latter is greater than the other three cases. This peculiarity is due to the overall simulation time and it is allowed an incidental event to reach the last level of gravity predicted by the model which consequently generated a penalty of 80 points.

*Final Score:* this field is no more than the sum of the initial score and all penalties just commented. Being a combination of all the other components, this field has the maximum variability, it changes from the minimum value of 248 points up to the maximum value of 662 points, with an average value of 553 points. In the graph in Figure 5, for each game it shows the final score and the amount of all penalties.

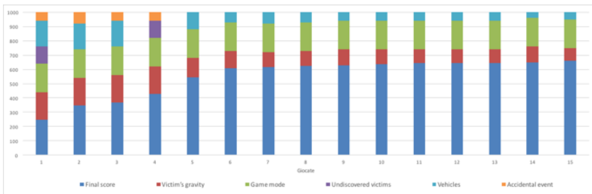

Figure 5: Summary of the score

*Overall time:* as the last parameter is provided the total time taken for the entire simulation. The total duration of each simulation mainly depends on two factors. The first is the speed of the player in performing the activity, or the ability to make decisions rapidly. The second factor, not controllable by the player, is represented by time values that the simulator assigns to each operation as a function of the probability distributions defined during the initialization of the scenario: this is the reason why a number of game sessions, carried out by the same player considering only one scenario, determines different values of total time of simulation. In particular, in these

game sessions the average time spent by the player is equal to about 39 minutes. Moreover, the minimum recorded value is of 33 minutes, while the maximum is equal to about 49 minutes.
In summary, in the first analysis it is discussed and deepened the meaning of the components that make up the total score of each simulation. in the following, a second analysis is discussed: by this second analysis two players are compared, with the goal of verifying the simulator training function.

*Analysis about the simulator training capacity.*
The second analysis is characterized by a series of game sessions carried out on different scenarios. In this case, the simulation sessions have the following features:

- the game sessions are held on 10 scenarios;
- the game sessions are performed by two different players who are identified as PLAYER 1 and PLAYER 2;
- the game sessions are performed on the same computer;
- each player plays two game sessions for each scenario, one game session in "Easy" and one in "Hard" mode;
- players using the simulator know the general rules for the management of emergencies.

In this analysis, each player faces both game modes available in the simulator. In the "Easy" mode the status of the simulation in real time throughout the game is shown, while, in the "Hard" mode the status of the default simulation is not known by the player.
The objective of this second analysis is to verify that the simulator is a training tool. More precisely, the expected result is a continuous learning of the player during the execution of the various game sessions due to the learning of new knowledge for the resolution of emergencies. In this way, during the game sessions, applying the new knowledge obtained, the player should be able to better manage the emergency and then get a higher score. The scenarios available to the player are sorted in ascending order according to the difficulty. More precisely, scenario A is characterized by a lower difficulty compared to scenario B, which in turn presents a lower difficulty respect to the scenario C, and so on up to the scenario L. For both players, scenarios are played in the same order and with the same game modes: the experiment begins from the scenario A, first in "Easy" mode and then in "Hard", and ends with the scenario L.

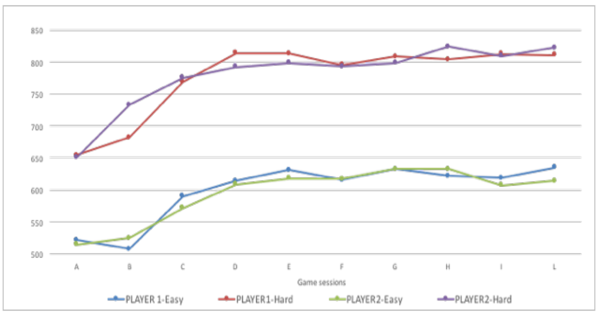

Figure 6: Simulation sessions for the two players

Figure 6 shows the scores of the various simulations carried out. The x-axis identifies the scenarios, while on the y-axis the final score of the simulation is shown. The results of the two players, despite the increased difficulty of the scenario, show a continuous improvement in final scores of the various game sessions. In particular, observing the tables of results, it can be seen on the scenarios A and B that the two players have not performed an initial deep reconnaissance. Due to this, undiscovered victims died (black code "N") and consequently the simulator has applied a strong penalty. Moreover, the first game sessions are characterized by a request of emergency vehicles quite high, which has further decreased the score. Considering subsequent game sessions, it can be seen that both players improve their skills in emergency management. Already from the simulations performed on the scenario C, the players properly perform the initial recognition and improve their performance. In later game sessions the victim's management is rather stable and the management of the emergency resources is optimized. Therefore, the results obtained are in line with initial forecasts and show the training feature of the simulator.
In a maxi-emergency, the main objective is to save as many victims as possible. For this reason, it is interesting to look at the factors that influence the management of the victims during the simulation. In the present case, according to the results obtained from simulations, it is carried out an analysis that compares the simulation time employed in the various game sessions with the relative situation of the life management of the victims, represented by the sum of the penalties relating to the increase in the victim's severity and victim's undiscovered. This analysis allows to understand whether the time taken by the player to carry out rescue operations significantly affects vital status of the victims. Times of the various activities have been extracted from statistical distributions and are therefore subject to variability during the game session.

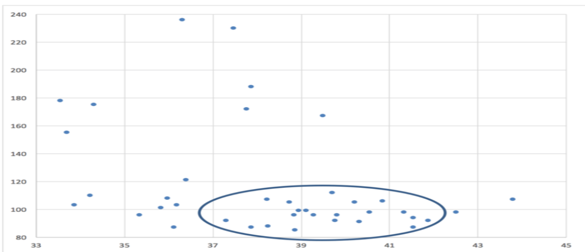

Figure 7: Simulation time - Worsening of the victims"

In Figure 7 horizontal axis represents the simulation times in minutes of the various game sessions while the vertical axis represents the penalty points achieved. As it can be noted, in general the time does not affect particularly on the victim's health during simulations. In fact, comparing the game session with quite similar simulation time, it's possible to see that some of the records have a high penalty on the deterioration of the victims while others report the opposite results. So, the victim's management depends mainly on the method by which the emergency management activities are carried out, and only secondarily from the simulation execution time. Simulation time lies between 37 and 42 minutes. As shown in the Table 5 and 6, these cases are linked to simulations carried out on the latest scenarios, where the player is more "expert".

Another aspect to consider is the importance of the reconnaissance: the graph shows how the lack of initial reconnaissance penalizes the score. The player is still "inexpert": he prefers to manage the discovered victims, and forgets to use the resources for reconnaissance. In this way the discovered victims are treated faster but in the meantime, the undiscovered victims die and produce a strong penalty on the final score. The results obtained from the analyses suggest that the simulator can be used as support for the training of maxi-emergency managers. In particular, over the different scenarios tested, it allows to investigate the behaviour of the different players and their related learning effect while reiterating the simulation.

## 5. CONCLUSIONS

The main objective of the proposed research is to create a serious game dedicated to the management of emergencies in industrial plants. The aim of the simulator is to provide support for the training process of the operators called to manage and coordinate complex emergencies. In particular, in order to investigate the learning effect of the operators, different players are selected to carry out several simulation sessions on specific scenarios. These simulations allowed to test the validity of the game and subsequently to analyse such results with the aim of verifying the effective training capability of the tool. The use of a simulator can substitute real practice in the development of the management skills. Moreover, one option to further test the validity of the simulation game is to check the behaviour of the operators with different level of practice in a physical simulation of emergency. However, it should be considered that using a simulation game for training may have the effect of mainly improving the capability in the tool itself (Owen et al., 2010).

One aspect that can be the subjected to a possible future development is the addition of instruction errors in the rescue chain. The next step will be the development of an integrated simulation environment capable of integrating different role in the management of the industrial emergencies: this will be the central point of the ongoing project named DIEM-SSP (Disasters and Emergencies Management for Safety and Security in industrial Plants), which details can be found in Bruzzone et al. (2014).

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## REFERENCES

Boyle E.A., Hainey T., Connolly T.M., Gray G., Earp J., Ott M., Lim T., Ninaus M., Ribeiro C., Pereira J., 2016. An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. Computers & Education, 94, 178-192.

Bruzzone A.G., Frascio M., Longo F., Chiurco A., Zanoni S., Zavanella L., Fadda P., Fancello G., Falcone D., De Felice F., Petrillo A., Carotenuto P. Disaster and emergency management simulation in industrial plants. 2014, 26th European Modeling and Simulation Symposium, EMSS 2014, 649-65.

Danielsson M., Ohlsson K., 1997. Models of decision making in emergency management. Engineering psychology and cognitive ergonomics. ed. Don Harris. Vol. 2: Job design and product design Aldershot : Ashgate Publishing, 1997. pp. 39-45.

Knight, J.F., Carley, S., Tregunna, B., Jarvis, S., Smithies, R., de Freitas, S., Dunwell, I., Mackway-Jones, K., 2010. Serious gaming technology in major incident triage training: A pragmatic controlled trial. Resuscitation, 81, 1175-1179.

Longo, F., Nicoletti, L., Vena, S., Padovano, A., 2014. Serious games at increased impact on culture and tourism. 26th European Modeling and Simulation Symposium, EMSS 2014, 641-648.

Orasanu J. M., and Backer P., 1996. Performance under stress in military operations. In : J. Driskell & E. Salas (Eds.) Performance under stress, pp. 89-125. Hillsdale, NJ: Lawrence Erlbaum Associates.

Ordaz, N., Romero, D., Gorecky, D., Siller, H.R., 2015. Serious Games and Virtual Simulator for Automotive Manufacturing Education & Training. 3rd International Conference on Virtual and Augmented Reality in Education, VARE 2015; Monterrey (Mexico), 75, 267-274.

Owen A.M., Hampshire A., Grahn J.A., Stenton R., Dajani S., Burns A.S., Howard R.J., Ballard C.G., 2010. Putting brain training to the test. Nature, 465 (7299), 775-778.

Smith, R., 2010. The long history of gaming in military training. Simulation and Gaming, 41, 6-19.

Strohschneider S. and Guss D., 1999. The fate of the Moros: A cross-cultural exploration of strategies in complex and dynamic decision making. Int. Journal of Psychology, 34 (4), 235-252.

Wiemeyer, J., Kliem, A., 2012. Serious games in prevention and rehabilitation-a new panacea for elderly people? European Review of Aging and Physical Activity, 9, 41-50.

Zon, R., Corrigan, S., McDonald, N., Maij, A., 2012. A Learning, training & mentoring framework (LTM) & the role of serious games to facilitate sustainable change in the aviation industry. 11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012, Helsinki, 6, 5044-5051.