DISASTER AND EMERGENCY MANAGEMENT SIMULATION IN INDUSTRIAL PLANTS

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ABSTRACT
This paper presents an approach to model and simulate industrial plant accidents as well as the related emergency management; interoperable simulation is proposed as approach for applying High Level Architecture in this context. The authors are focusing their attention on the disaster simulation and its interaction with the emergency management. Modern simulation, by using technology enables such as mobile solution, enhance its support to first responders, the dynamic reaction to crisis evolution as well as the improvement in training and management of safe routing and handling of injured people. This paper introduces these elements as part of new research track devoted to get benefits from interoperable simulation in federating multidisciplinary models for industrial plant emergency management.

Keywords**:** *Interoperable Simulation, High level Architecture, Industrial Plants, Emergency Management, Safety and Security*

1. INTRODUCTION

Emergency Management is a problem where simulation represents a crucial element since many years; hence specific organizations and events are consolidating in this area to address the phenomena complexity (Wybo et al. 1996; Bruzzone and Kerckhoff 1996); indeed the complexity of accidents due to physical aspects and interactions among many elements are usually promoting simulation as the main investigation approach.
Therefore it becomes evident today the opportunity to get additional benefits from current advances in this area for enhancing the potential of modeling and simulation (M&S). Indeed M&S has been extensively applied in Industry both for supporting decision making on for training purposes (example of M&S applications in industrial plants can be found in Latorre-Biel and Jiménez, 2013; Longo, 2013, Bruzzone and Longo, 2013, Pereira et al. 2013). From this point of view there are different elements to be considered, from one side the technology enablers, such as Internet of Things (IoT), allows today to distribute easily simulation; this concept is even more stressed by introducing the Simulation as a Service (SaaS) paradigm that could allow to transform any mobile device (Amram 2009; Bruzzone et al. 1999).
From other point of view, disasters in Industrial Plants are critical issues not only for the internal complexity of phenomena by their selves, but also for the necessity to combine them together; for instance it is growing the interest in further develop existing models in order to be able to address combined cases such as dust explosion and fire or interaction among seismic activities and firefighting (Dastidar et. al. 2005; Hinrichs et al. 2011; CSB Reports 2005 and 2008). From this point of view the use of interoperable simulation allows to federate different models and to let them to interact dynamically (Kuhl et al.

1999); this approach enables also to combine models reproducing the people reaction as well as the actions carried out by the different responders (Mujica and Piera 2012); in this sense it could be possible to obtain interesting results by applying intelligent agents (Shi 2008; Taboada et al. 2011); in the proposed approach it is expected to federate in the interoperable simulatior the IA-CGF (Intelligent Agent Computer Generated Forces) developed by Simulation Team and already tested over earthquake scenarios and in health care sector (Bruzzone Massei 2010; Bruzzone, Novak, Madeo 2012).

Due to these reasons the authors are currently developing an innovative research line for applying interoperable simulation to disaster and emergency management within industrial plants and in this paper it is proposed the general approach as well as the federation architecture. Indeed this research is currently supported within the DIEM-SSP Project (Disasters and Emergencies Management for Safety and Security in industrial Plants) co-sponsored by the Italian Department for Research (MIUR) and carried out by several Universities and Institutions (i.e. DICAAR University of Calabria, DII University of Cassino, Simulation Team, DIME University of Genoa, DIMI University of Brescia, DISC University of Genoa, IAC CNR, MSC LES University of Calabria); indeed the main goal of DIEM-SSP is to carry out research and developments activities to deal with the complexity resulting from emergency management in industrial plants and critical infrastructures.

Currently the authors are working on this research track in strong international collaborations (both in medicine and engineering area); for instance, the following institutions have already expressed their interest in taking part in the DIEM-SSP project: the Harvard Medical School (MA, USA), the Dartmouth University (NH, USA), the Old Dominium University, Virginian Modeling, Analysis and Simulation Center, VMASC (VA, USA), in addition to several Firefighters Departments.

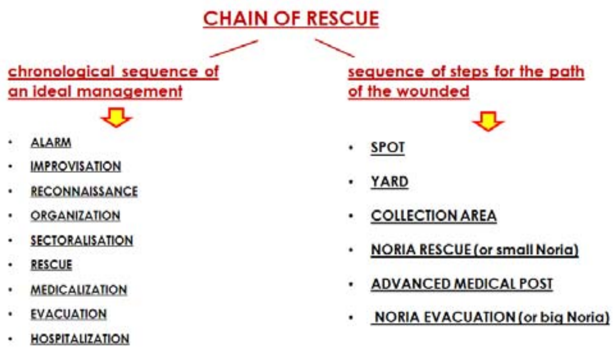

Figure 1- Chain of Rescue during a Disaster

2. INDUSTRIAL PLANTS, SAFETY & SECURITY

Many industrial plants represent Critical Infrastructures (CI), and it is evident the complexity of these CIs exponentially increases when emergency occurs, both for safety or security issues. In this sense there are, among others, different crucial aspects to be addressed in emergency management within this context:

- Disaster dynamics related to the specific plant and disaster on going as well as to interactions among the different elements: e.g. domino effect in fires and explosions within a chemical plant (Babrauskas 2003; Crowl 2003)
- Medical issues intended as the need to have emergency procedures allowing medical staff to operate efficiently in stressing and complex environments.
- Emergency management issues intended as capabilities to reduce human errors as much as possible (during emergency management) and properly route any patients with severe trauma to the proper First Aid Facility.

The proper and effective management of an emergency scenario is usually based on work scheme in which specific roles held by doctors nurses and rescue workers (with adequate training) are identified.

This management approach requires to combine technical and medical aids provided by the different actors (e.g. firefighters, police, health care systems, etc.) so it becomes evident the importance to have multiple models addressing these different elements. In addition and based on this assumption, it is important to define the chain of rescue that support the process as proposed in figure 1.

Hence the disaster could emerge as accident or as a manmade event, due to these reason it could be pretty interesting to model not only the safety systems and to use the proposed simulation as support for safety engineering and procedure design, but also the security systems; it is evident that malicious behaviour represents a threat for industrial plants that could be pretty challenging to be mitigated. Simulation supports the vulnerability reduction in this context by allowing evaluation of the effectiveness of introducing innovative technologies, new solutions as well as new security procedures.

In addition to these problems the accidents represent another very important element to be introduced, even in this case sometime the human factor affect the relevance of the event as well as its evolution; so it is evident the necessity to model these elements.

Due to these reason it is evident the importance to develop a new generation of interoperable simulators addressing these problems; indeed it become necessary to create simulators able to combine different models addressing these different elements.

In addition it is evident the necessity to develop decision support systems able to face simultaneous all these crucial aspects: efficient procedures are needed both on the emergency site and in hospitals as well along the entire supply chain (Merkuryeva et al. 2011); these procedures should be combined with a proper critical patients routing toward the most suitable First-Aid Facilities should be designed and prepared in order to improve effectiveness and to reduce the human errors during the crisis. Furthermore, new procedures or methodologies for emergency management must be carefully tested before used: the need to assess their validity before their application in a real emergency situation strongly depends on the capability to have a clear picture of the procedures effectiveness based on simulation (Sell, Braun 2009).

Due to these reasons it emerged the opportunity to develop interoperable simulators, based on the IEEE 1516 High Level Architecture (HLA) and to test tem on specific case studies for validating the approach.

In order to complete successfully these aspect it is necessary to address several specific elements:

- Modelling of the disaster evolution in dynamic interaction with humans
- Modelling Human Behaviour Modifiers in order to evaluate their impact on the crisis evolution; in particular to evaluate the possibility to reduce the number of patients with severe trauma as well as the damages to critical infrastructures by adopting using emergency procedures which take into account the human factor/error
- Modelling new emergency procedures to be used in hospitals for critical patients management (the patients with severe trauma coming from the emergency site)
- Modelling new technological aid able to support emergency management (i.e. RFID and/or face recognition to track and manage patients)
- Development of algorithms to guarantee the proper routing of critical patients from the emergency site to the most suitable First Aid Facilities through the optimal location of proper infrastructures (including hospitals) and logistic network redesign (Lin et al. 2009)
- Development of Training Solution based on Simulation to support education and training of first responders, emergency management planner, civil protection, firefighters and other actors (Raybourn 2011).
- Development of Decision Support Systerms based on Simulation to support emergency management on the field adopting edge maturity level (Bruzzone et al. 2009).

This research obviously strongly focuses on the necessity to model the complex issues related to emergencies management in industrial plants and CIs; to achieve this goals it is necessary to be able to create models that rely on the capability to acquire knowledge and collect data related on this context; for instance it is crucial to be able to properly model emergency procedures to be carried out in healthcare facilities or directly in the emergency site, as well as to assess their impact on the performance of such structures; another critical element is provided by the necessity to model the handling of injured people, the optimal healthcare facilities identification selection, as well as the human behaviour modifiers that could affect the crisis and potential solutions to mitigate their effects.

For instance a critical aspect in emergency management is related to the efficiency of first aid facilities. It is critical to have accurate symptoms assessment and quick decision-making to match critical patient needs. Real-time points-of-care (based on new approaches/methodologies, i.e. ultrasound) are the real added value for the assessment of critical patients both in pre-hospital and in-hospital situations. Although recommendations in terms of education and decision making have been proposed by a variety of specialties, today there are still scattered and limited examples of standards for critical and intensive care professionals (Raybourn 2012). The potential of simulation is very high in this sector providing the capability to visualize the situation and the emergency evolution in clear way (Jezek et al. 2012).

From an engineering point of view, in case of emergency in a critical infrastructure, evacuation and routing of injured people to first aid facilities (that should have as a consequence optimal capabilities as well as convenient location) must be properly addressed, since many experiences have shown that inefficiencies at this stage lead to seriously problems both on people and infrastructures (CSB 2005). In addition, the “human factor” significantly contributes in creating the emergency as well as in the emergency management; many studies have been carried out in this area and they usually consider separately human factor and systems reliability, without considering any interactions among themselves as in the conventional reliability allocation methods (Bruzzone et al. 2008). Considering high risk industrial areas, it is clear the need of combining risk analysis with human factor evaluation methodologies, known under the name of Human Reliability Analysis (Vuorio et al. 1987; Bieder et al. 1998; Reer et al. 2004).

It is worth saying that in such a context, any new emergency procedure or methodology need to be extensively tested and validated before use. To this end, simulation has been widely recognized as the most suitable approach for investigating, analyzing and solving complex problems in real systems such as industrial plants and critical infrastructures. The authors acquired experience confirming that simulation is very effective in emergency management even if much more can be done by using interoperable and distributed simulation and the author are currently working on using architecture for distributed simulation such as HLA (High Level Architecture) to further empower this approach (Bruzzone and Massei 2010). In this case different interoperable simulation models recreating the behaviour of different entities acting in the same scenario could be used to recreate the crisis framework and to test the interactions among all the actors involved; by this approach it becomes possible to evaluate the effectiveness of the simulated procedures and methodologies as well as their efficiency; for instance it is possible to use a simulation model to reproduce the evacuation processes and the critical patients routing to first aid facilities during an accident in a chemical plant, in this case the simulation model could reproduce the disaster evolution as well as the application of emergency procedures on site and in the first aid facilities (Vonolfen et al. 2011).

3. HEALTH SUPPORT AS CRUCIAL ELEMENT IN INDUSTRIAL PLANT DISASTERS

The health support is one of the most complex aspects in emergency management in industrial plants, because the structures must be able to ensure, in the early hours, a rapid response in order to give aid to as many people as possible.

In response to these complex requirements in Italy was created a macro system able to address of the integrated management of Emergency Care; this organization is supported by National Health System (DPR 27/3/1992), which can be accessed for free through the 118 telephone number unique on the whole national Italian territory (Cossiga 1992). The core of this system is the Operational Territorial Centre able to immediately activate locally the first public health response to an emergency situation. In this way it is possible to achieve seamless integration between community care and hospital care in its various forms. In addition to the Operational Territorial Centres the macro system for medical emergency management is composed by mobile rescue units (road transportation vehicles, special emergency vehicles for fast response), fixed and mobile points for first responders located on decentralized areas, emergency assets as we (Chen 2010); as multilevel Departments (i.e. I and II level). In the event of a disaster, the integration of all the actors (Police, Fire Brigade, Health Personnel) is crucial for guarantee successful management of the emergency. The specific activities of each actor include among the others area demarcation, police services, radio link activation, rescue operations, rescue, health care. The goal of all these phases is the collection of the victims and their subsequent treatment. The first triage (triage sweeping), corresponding to the first quick immediate action, is performed within the area of the disaster, if accessible, with the aim of selecting the victims at the end of their evacuation and of their initial treatment on site if possible (basic actions necessary to ensure survival). The method adopted for the first triage system is called START (simple rapid triage and treatment); it should be noted that next to the START method it is applied also CESIRA (which don't include black code) intended for first responder teams that don't include medical component and that is unable to address deaths on the field (Higgins 1987; Benson et al.1996; Bateman 2014). the Advanced Medical Post (AMP), the seat of second triage, health treatment, including procedures for stabilization and subsequent evacuation to the most suitable hospital centres is located at the outer edge of the safety area, or in a central area respect to the front of the event, protected from any risk of evolution and near roads, is compiled and managed by the staff of the 118.

Hence the main objective of the proposed simulators is to be able to carry out experimentation to address the complexity that comes from emergency management in industrial plants and in critical infrastructures; indeed this elements becomes even more critical when the emergencies are resulting from voluntary manmade disasters; it is evident that one of the first objectives to be pursued is creating a simulator supporting planning from a multi-disciplinary point of view (Rauner 2012). In this case it becomes fundamental to promote new "points of care" in order to maximize the basic and advanced skills in the evaluation and management of critical patients; from this point of view the simulator could support evaluation of new methods proposed for covering diagnosis over crisis site as well as in (e.g. ECO FAST); in addition the simulator could allow to estimate effectiveness and efficiency provided by the introduction of new telemedicine technologies and procedures focused on improving early diagnosis (Lagi et al. 2009). The diagnostic and therapeutic paths followed by patients with multiple trauma within the hospital will be evaluated by considering the different existing protocols for multidisciplinary management.

Therefore the definition of new emergency procedures is not the only aspect to be considered to improve the management of emergencies in case of accidents or disasters in critical infrastructures; in fact, it is necessary to improve the activities carry out outside of emergency rooms, in order to properly route the critical patients to the appropriate facility (including both optimal location of first aid facilities that critical infrastructure and efficient logistics network design) and to reduce human errors during the emergency phase; to this end, all patients will be evaluated with specific diagnostic score, a score correlated to treatment outcome.

The proposed simulator could serve as a tool to investigate the problem by identifying bottlenecks and most sensitive parameters in addressing the emergency management respect a specific scenario becoming an useful decision support system as well as an effective planning aid and training equipment.

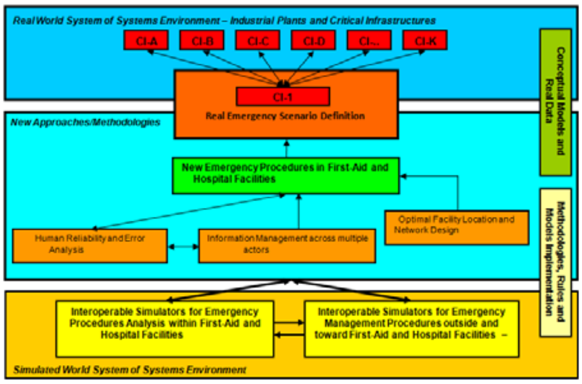

Figure 2- Disaster Modelling Multi Layer Approach

4. GENERAL APPROACH

In order to succeed in modeling disasters in this complex environment as well the related emergency management it is proposed an approach based on a 3-layer approach (see the following figure); indeed the approach is based on approaching the real world as a system of systems; usually it includes multiple interconnected Critical Infrastructures (CIs) that represent the first layer; the approach move toward to the definition of new emergency procedures to be used in case of disasters/accidents in CIs both within First-Aid and Hospital Facilities (with the aim of improving the critical patients pathway) and outside to support the optimal location of most effective First-Aid and Hospital Facilities; the routing of critical patients and the reduction of human errors in the emergency management represent the second layer in the proposed approach. Finally, the third layer is a simulated system of systems environment that includes different simulators to be used for testing the new emerging procedures.

The three layers are interconnected at two different levels that also represent the main research effort of the research:

- innovative emergency procedures will be defined (in the second layer) by strictly considering real CIs (first layer) and they will be tested and validated by using the interoperable simulators provided in the third layer
- test and validation of the emergency procedures will require the implementation of interoperable simulators (third layer); such implementation will require the definition of conceptual models and data collection from the real system (first layer) and the correct translation of the approaches and methodologies (defined in layer 2) in a form able to be executed through interoperable simulators.

As clearly shown in the modeling approach, these activities require joint engineering-medicine research efforts and knowledge. Accurate assessment, rapid decision-making and ad-hoc procedures are essential to save lives and improve performances in emergency situations and it is necessary to proper identify the critical issues to model working side by side with subject matter experts. It is evident that creating a virtual simulation reproducing these dynamics represents a very interesting support for education and training people operating in First-Aid and Hospital Facilities: these people receive critical patients coming from an accident area, so an high level of quality is necessary and it should be guaranteed by appropriate education, experience, credentialing, quality control, continuing education, and professional development. Although educational recommendations have been proposed over the time, to date they are still scattered and limited examples of standards and emergency procedures for critical and intensive care professionals; improvements in these areas could be guaranteed by the proposed simulators. In particular, the challenge of providing adequate decision-making, as encouraged by major medical societies, is made even more difficult by the diversity of critical care methods utilization and by the lack of well-defined guidelines in the advanced trauma life support. Therefore the first goal to be pursued within First-Aid and Hospital Facilities is to plan a multidisciplinary "Critical Care Pathway" for the management of a critical ill patient (arriving from a disaster scenario) and promote specific points-of-care program with the aim of maximize basic and advanced competences in assessing and managing the critical patients.

However, while new points-of care programs are the correct way to define new emergency procedures to be used within first-aid and hospital facilities and tremendously contribute to save human lives, it is also important to understand the effect in terms First-Aid and Hospital performances when these new emergency procedures are applied. The definition of new emergency procedures within First-Aid and Hospitals facilities (and their impact on facilities performances when applied) is not the only aspect to be considered for improving emergency management in case of emergency in CIs. Indeed, much more should be done outside the First-Aid and Hospital facilities for supporting the routing of the critical patients toward the First-Aid and Hospital Facilities (optimal facilities localization and logistic network design) and also for reducing the human errors during the emergency management. In fact, there are many examples of accidents/disasters in CIs where many lives have not been saved for human errors (above all at leadership level). Also in this case it is critical not only to define, but also to understand "a-priori" the effect that new methodologies for routing optimization and optimal facilities location as well as for human errors reduction may have on the emergency scenario management. Therefore while a research effort will be devoted to define new emergency procedures within First-Aid and Hospital Facilities, to investigate the effects of human errors in case of emergencies management in CIs and to study routing problems and optimal facilities localization, an additional research effort will be carried out to implement two interoperable simulators that will be used as test-bed and released as demonstrators based on specific case studies. This will give the possibility to simulate different scenarios including medical and para-medical units or other operators both outside and within the First-Aid and Hospital facilities; the correct definition of the human behaviours will require extensive information in terms of human reliability assessment and error analysis and a great contribution from medical experts is also expected to implement correctly the new emergency procedures.

From this point of view the simulator should be able to model the different phases of the disaster including:

- Simulation of the Cause of the Disaster
- Simulation of the Disaster
- Simulation of the Effects related to the Disaster
- Simulation of the behaviour of systems of intervention

The methodological approach that will be used for implementing the new interoperable simulators will be based on the standards for interoperable simulation projects IEEE HLA 1516 (High Level Architecture). Initially the authors plan to develop two families of interoperable simulators will be released : the first one devoted to investigate the effects of the new procedures within the First-Aid and Hospital facilities, while second one focusing on simulating what happens in a CI (therefore before the arrival of patients to the hospital); in this second case the simulators will investigate the effects of human errors and for testing new methodologies for optimal hospital facilities location and for optimal patients routing toward hospital facilities.

Furthermore in order to increase the success of this research the authors are creating a Simulation Quality Assurance (SQA) group devoted to act as responsible – during the whole research– for the Verification, Validation and Accreditation (VV&A) of the new simulators (Frydman et al. 2009). To prevent developers' bias, the SQA group will involve people and subject matter experts (both engineers and doctors) that are not directly involved in the definition of the new emergency procedures as well as in the implementation. The proposed simulators are expected to improve reaction capabilities of industrial plants and critical infrastructure respect man-made and/or natural disasters also from a social and economic perspective; these aspects aim at increasing security and response capabilities of industrial plants (and generally speaking, of critical infrastructures) in emergency situations through advanced technologies based on M&S.

5. MODEL DEVELOPMENT PLAN

The proposed research is currently articulated in different main activities devoted to achieve, step by step, the main objectives including new simulator experimentation

5.1 Data Collection and Knowledge Acquisition on major disasters in critical infrastructures and Industrial Plants

This activity will survey the major disaster in critical infrastructures during the last 20 years, including disasters in industrial plants and critical infrastructures.

5.2 Simulators Requirements Definition

The goal of this task is to define the requirements of the new simulators.

5.3 Definition of Case studies and Scenarios for Experimentation

With the support of subject matter experts involved in the research the most interesting case studies for demonstration and experimentation will be defined. These case studies will constitute the main scenarios to be experimented on the new simulators

5.4 Human Reliability Assessment and Error Analysis: Methodologies for human reliability assessment and error analysis

Starting from both state of art and data input analysis, the approach to address the human factors in the different danger situations will be defined.

5.5 HRA: Methodologies for machines reliability assessment and fault analysis

For this task the same approach will be applied to machines: Starting from both state of art and machines data, safety allocation techniques which study the machines in different possible danger situations will be defined. The reliability methods will be based on different techniques on reliability analysis.

5.6 Characterization of cognitive model-based human error analysis and reliability assessment

After the identification of evaluation methods, cognitive models will be created to address human error analysis and reliability assessment.

5.7 Interactions for procedure definition

Once defined the application methods and cognitive models, the interactions will be model in order to support the identification process of best procedures able to ensure minimization of injuries and victims in accidents.

5.8 Development of global human behaviour models for human reliability assessment and error analysis in critical infrastructures

Creation of global human behaviour models allowing errors reduction and reliability improvement.

5.9 Analysis of the Optimal Facility Location and Network Design respect industrial Disasters

Special attention will be paid to examining the most recent industrial disasters respect the methods for facility location and network design. During this activity important aspects will be investigated regarding risk management, medical care management, analysis of the critical issues affecting traffic and supply logistics.

5.10 Identification of most significant parameters and new methodologies definition

The Preparation of the protocols to be implemented in case of disaster requires identification of key parameters; this achievement leads toward development of the methodologies for transport management in case of emergencies within critical infrastructures and industrial plants.

5.11 Testing and validation of Logistics in Disaster Management

This phase will be devoted to testing and setting up the related methodologies. The tests will consider both people directly involved in the event and those mobilised for managing the emergency as well as those who indirectly hinder emergency services. The protocols will refer to the specific building or site where the emergency has occurred, to exit flows and evacuation network towards safe places and health care facilities as well as within those facilities themselves. Special attention will also be paid to internal pedestrian mobility.

5.12 Definition of New Emergency Procedures in First Aid Facilities and Hospitals

During this activity the research team will be in charge of identifying and defining emergency medical scenarios as well as all the situations and consequences of an emergency scenario. Such medical scenarios will be the base for the simulators conceptual models

5.13 Analysis and study of the actual hospital pathway

This activity will focus on the study and analysis of the actual standard hospital pathway followed by critical ill patients in order to indentify critical issues and possible improvements. Interacting with referent professionals involved in critical scenarios management (e.g. surgeons, emergency doctors, anaesthetists), model will developed on the diagnostic resources habitually used by the emergency clinicians.

5.14 Information management in emergency situations

The aim of this activity is to develop models for information and communication management among professionals, operators and victims involved in an emergency situation.

5.15 Identification and Definition of clinical outcomes for procedures evaluation

This activity aims at defining clinical performance indicators and outcomes to be used for evaluating the performance of new procedures. Note that the evaluation of the impact of the procedures used on the technical efficiency of the hospital will be evaluated by using the simulators.

5.16 New Emergency Procedures and points-of-care programs

The main idea behind this activity is to define new emergency procedures and points-of-care programs to be used for critical ill patients. This will be a challenging opportunity to create a multitasking Emergency Team made by different professionals involved in the critical ill patient management.

5.17 Federation Architecture

This activity aims at defining and implementing the interoperable simulators conceived. Therefore the main goal of this activity is to implement the architecture of the federation of the interoperable simulators that will be based on the standard for distributed simulation IEEE 1516 HLA (High Level Architecture).

5.18 Interoperable Simulators for emergency procedures analysis within First-Aid and Hospital Facilities & for Emergency Management Procedures outside First-Aid and Hospital Facilities

Both the simulation engines and the interface will be developed as part of this activity based on previously defined conceptual models.

5.19 Federation Verification, Validation and Accreditation

The Verification, Validation and Accreditation (VV&A) of the federation will be done according to the guidelines proposed by the IEEE 1516 HLA standard. In order to assure high quality for the simulators this phase will be on going along the entire development lifecycle.

5.20 Federation Development and Integration

The Federation Development and Integration will be made according to the procedures available in the IEEE standard 1516,3 FEDEP (Federation Development and Execution Process)

5.21 Federation Experimentation and Demonstrator

The Federation will be used to carried out specific experimentations to assess the potentials and validity of the proposed emergency procedures and methodologies on the defined simulation scenarios.

6. CONCLUSIONS

The paper proses an approach for modelling industrial plant disasters taking into account the human factors as well as the complexity related to the emergency management; special attention is attributed to how to handle and route the injured people along the health care facilities.

This research results from a common effort of multiple Institutions operating in different areas and this paper represents just a preliminary description of the modelling approach and of the technologies under investigation.

Currently the authors are developing the conceptual models while they are also defining the scenario to be studies.

The research is moving forward in development of the new simulators able to create the interoperable federation combining all the different models**.**

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