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Design of a Semi-Virtual Training Environment (Serious Game) for Decision-Makers Facing up a Major Crisis

Florian Tena-Chollet*, Noémie Frealle, Aurélia Bony-Dandrieux, Jérôme Tixier

Institute of Risk Science (ISR), Ecole des mines d'Alès, Alès, France
Florian.Tena-Chollet@mines-ales.fr

When major crises occur, organizations face critical concerns, such as stress, uncertainties, need of quick anticipation and better communication. The need of experience implies a regular training of those involved. Serious games and environmental computer-based simulations are useful training tools for people who have to manage a crisis. They are relevant for educational purposes, for the acquisition of technical and non-technical skills, of automatic reflexes, and of ways of thinking. The suitability of the teaching strategy in link with the profile of participants and the moderation by the trainers are difficult. The present work aims at solving these difficulties by the development of a distributed multitier architecture, computer-assisted training, a multiagent system, and requirements for a relevant physical infrastructure. Our methodology integrates four steps: exercise modeling, scenario modeling, scenario simulation with a multiagent system, debriefing approach and learning objectives assessment. Our methodological recommendations have been applied in order to define a real semi-virtual training environment. Limits and prospects are already identified for further improvements.

1. Introduction

Disasters of the last decades illustrate how most societies are increasingly faced to highly disruptive events (e.g. Fukushima in 2011). According to Morin, the concept of emergency has spread to all areas but remains the sudden and intense appearance of a rupture event, which usually requires a human response [Morin et al., 2004]. In a crisis cell, stakeholders have to make decisions under stress and in critical conditions, for example in order to mitigate consequences or avoid negative impacts on high-stake elements, with the obligation of issuing a public report to the media. The human factor, rather than existing plans, the management of resources, or the uncertainty of the situation, is often a major source of vulnerability in the decision-making process [Smith and Dowell, 2000; Morin et al., 2004]. Conversely, decision-making, communication, mental model sharing, leadership and coordination are useful skills [Lagadec, 2012]. Theoretically, the processes of decision-making can be creative, analytical, procedural or naturalistic. In practice, a crisis involves critical stakes, significant effects and limited reaction times, and the decision-making process is thus mainly naturalistic. This raises the following paradox: although a crisis is exceptional, decisions during its management depend on previously experienced situations. Training in crisis management aims at facilitating the transposition of learned skills from theory to practice: learners can share their experiences, knowledge and points of view in order to experience new ways of thinking. The training session requires the following steps: planning, preparation, exercise, and reflexive analysis [Morin et al., 2004].
We have noticed that there is no typology of skills in the field of crisis management in major risks. Then there are no links between pedagogical needs and events of a realistic crisis scenario. We thus propose to study all the skills necessary for emergency management through the decision-makers' experience. The study of the different types of training environment is required in order to check whether the required stakeholder skills are integrated into the existing training sessions. Some difficulties can be noticed and structured around three types: the limits of existing learning strategies, the insufficient definition of essential skills for emergency management, the unsuitability of existing training environments.

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1.1 Limits of existing learning strategies

Usually, a training session can be based on “exchanging roles” (1), “managing events” (2), or “acting under degraded conditions” (3). Approach (3) is also called “critical thinking training” and covers some key concepts of crisis management, for example, to cope with large amounts of information [Fowlkes et al., 1998]. We can notice that the approach (2), also called “event-based approach” uses naturalistic decision making and is thus directly in the scope of our research question. Table 1 summarizes the main pros and cons of each training approach. We can see that the first one (based on the exchange of roles) is not adapted to our research (do not train on skills usually assumed by stakeholders).

Table 1: Pros and cons of the three main training approaches

Exchanging roles (1)	Pros: train to anticipation and pooling skills. Cons: do not allow the emergence of expert profiles.
Managing events (2)	Pros: global educational structure and dynamics of a crisis. Cons: difficult to prepare, simulate and debrief.
Acting under degraded conditions (3)	Pros: realistic context (emergency, stress). Cons: mainly focused on stress and emergency.

Different types of exercises can be implemented: “tabletop”, “real-life”, or “functional”. Real-life exercises usually focus on specific tasks and mobilize many actors (e.g. stakeholders, emergency services, residents). They are then difficult to organize and are often one shot exercises. Tabletop exercises help to test the capability of an organization to respond to a simulated event in terms of planning, preparation, and coordination, in a stress-free environment: equipment is not used, resources are not deployed, and time pressure is not introduced. Generally, tabletop exercises are focusing on specific parts of a crisis only. Functional exercises confer the advantage of working on the roles and interactions of everyone involved in the crisis and they are based on a simulated scenario, easily reproducible without having to mobilize all the stakeholders usually involved [Trnka and Jenvald, 2006]. They are also more faithful to the dynamics of crises. They facilitate the management of events and their evolution in fast time, real time or slow time simulation, and reduce their development costs. Table 2 summarizes the main pros and cons of each type of exercise.

Table 2: Pros and cons of the three main types of exercise

Real-life exercises	Pros: immersive, reproduce the real constraints. Cons: some aspects cannot be reproduced. Expensive. Mobilize many participants.
Tabletop exercises	Pros: strong freedom of action (theoretical). Solicit cooperation skills. Cons: Temporal bias. Maintain control of the scenario is difficult.
Functional exercises	Pros: extend pedagogical possibilities. Reproducibility and flexibility. Cons: a modeling of the system must be carried out beforehand.

Then we propose to reinforce the importance of the decision-making within a crisis cell: the use of functional exercises with an event-based approach and degraded conditions.

1.2 Unsuitability of existing training environments

Finally, it can be noted that most of the training environments for crisis management are intended for tactical or operational levels (emergency services, firemen, etc.), and not for strategic ones (e.g. stakeholders). The study of existing training environments using functional exercises in crisis management has contributed to the identification of several limits [Tena-Chollet, 2012]. One can distinguish those related to the unsuitability of the teaching strategy in link with the profile of participants, and those relative to the complexity of moderation for the trainers. On one hand, it is necessary to facilitate a proactive and participating immersion of the learners in a realistic crisis situation. On the other hand, the experience of trainers face to expert learners is essential for creating immersive situation but it is not always sufficient. They must promote success and explain the failures by factual reasons (particularly during the debriefing), to maintain the training pedagogy.

Some of these difficulties (moderation, immersion, and factual indicators) seem to be solved by the use of computer-assisted training [Kebritchi and Hirumi, 2008]. The use of real or credible data in interaction with a geographical information system is also a good way to ensure the realism of simulations. Flexibility is usually viewed as an important factor in learning environments [Sun et al., 2006]. Learning difficulties (profiles of participants, pedagogy, debriefing) seem to be solved by the use of a social constructivist approach extended by a continuum of organizational learning structured around three profiles (beginner, intermediate, and expert). This approach, in line with Pasin and Giroux, highlights the need to develop specific educational objectives and different assessment levels of the learners [Pasin and Giroux, 2010].

2. Methodology

We propose to solve existing difficulties by the development of a distributed multitier architecture, computer-assisted training, agents as a modeling paradigm for the crisis simulation, and requirements for a relevant physical infrastructure. The design of a multiagent system (MAS) requires the definition of the global system, expected behaviors of the agents, and the agents themselves. The environment in the MAS is assumed to be observable, dynamic, discrete, and non-deterministic. Our methodology integrates 5 steps: skills definition, scenario design, scenario modeling, scenario simulation with a MAS, and a first debriefing approach.

2.1 Skills involved in training sessions

Usually, the skills necessary for emergency management through the decision-makers' experience are not clearly specified, are not factually assessed, and then the debriefing step is poor [Lagadec, 2012].

In order to achieve a common goal, each member of a crisis cell must perform tasks involving teamwork and must mobilize the following non-specific technical skills: anticipation, communication, teamwork, stress management, decision-making, and leadership [Rasmussen, 1983; Endsley, 2003; Crichton, 2009]. Decisions cannot be taken in full knowledge, but they require the cooperation of emergency management actors who are not always accustomed working together [Smith and Dowell, 2000]. These difficulties can lead to a lack of shared mental models between actors, and of internal/external communications of the crisis cell.

Then, we consider that general, intermediate and specific skills must be structured. We propose 6 general skills: anticipation (1), communication (2), cooperation (3), stress management (4), decision-making (5), and strategic steering (6). These skills are used to achieve 5 intermediate sets of tasks: management of the crisis consequences (1), tactical and operational response (2), crisis cell management (3), crisis communication (4), and overall view in the short, medium, and long-term (5). In addition, we have identified 16 groups of "expected actions": human management (1), resource management (2), hazard assessment (3), identification of issues involved (4), strategies for returning to normal state (5), protection of threatened high-stake elements (6), reinforcement management (7), analysis of the situation (8), management (9) and arbitration (10) of strategic options, four types of communication – within the crisis cell (11), with media (12), authorities (13), or the public (14), monitoring and forecasting (15), and identifying the possible scenario changes (16). These 16 skills have to be improved through events and interactions induced by the crisis scenario.

2.2 Scenario design

The 16 skills identified have to be improved through events and interactions induced by the crisis scenario. In order to design it, we used a pattern that integrates two approaches: real past crisis scenarios (1), and fictional crisis scenarios (2). The result includes three steps: expression and analysis of the learning objectives, construction of a set of realistic events, implementation of the crisis scenario created, and evaluation of possibilities for managing it. For (1), it is necessary to use a specific framework (e.g. a real past crisis) based on experience feedback analysis about the disaster to be simulated. Then, we reconstitute operational resources deployed and tactical actions performed (simulation parameters). Finally, global events must be identified in order to keep realistic the future scenario. For (2), we recommend creating a global context, including the definition of strategic, tactical and operational actors possibly involved. Then, it is possible to model the overall system, its subsystems and interactions between each of them. Finally, an experience feedback study in the current field can lead identifying credible events to link with pedagogical objectives. The last step consists in making the scenario animation easy with the help of training and assessment aids, in developing needed agents, in calibrating the speed simulation, and in validating with test cases.

2.3 Scenario modeling

The model we propose distinguishes between three subsystems in the overall crisis environment: dangerous phenomena (fires, explosions, atmospheric and aquatic dispersion, earthquakes, floods, tsunamis), sensitive issues (human, infrastructural, and environmental ones), and crisis management responses (the tactical/operational resources). Static links between each subsystem can be organized in a tree structure. For modeling dynamics of a crisis scenario, we propose to use an organized and systemic risk analysis method known as MOSAR [Perilhon, 2007]. MOSAR aims at:

- Identifying technical and operating failures with system and subsystems definitions;
- Characterizing interactions between hazard sources, hazard propagation, and sensitive targets;
- Highlighting the undesired events that can be produced by their sequencing.

2.4 Scenario simulation with a multiagent system

The following hierarchy is proposed: abstract agents (with general simulation methods), georeferenced agents (instantiated with a coordinate system), and archetypical agents (including stereotypes of human behaviors). Figure 1 shows the main triggers and specialization links for fires agents (georeferenced ones). For instance, a pool fire agent can be added in the simulation (with puddle fire properties). When specific conditions are reached, the pool fire agent may trigger a boil-over phenomenon, and will evolve into a fireball agent (it is killed and a new agent is created instead). The fireball agent will also inherit all the thermal properties of fires.

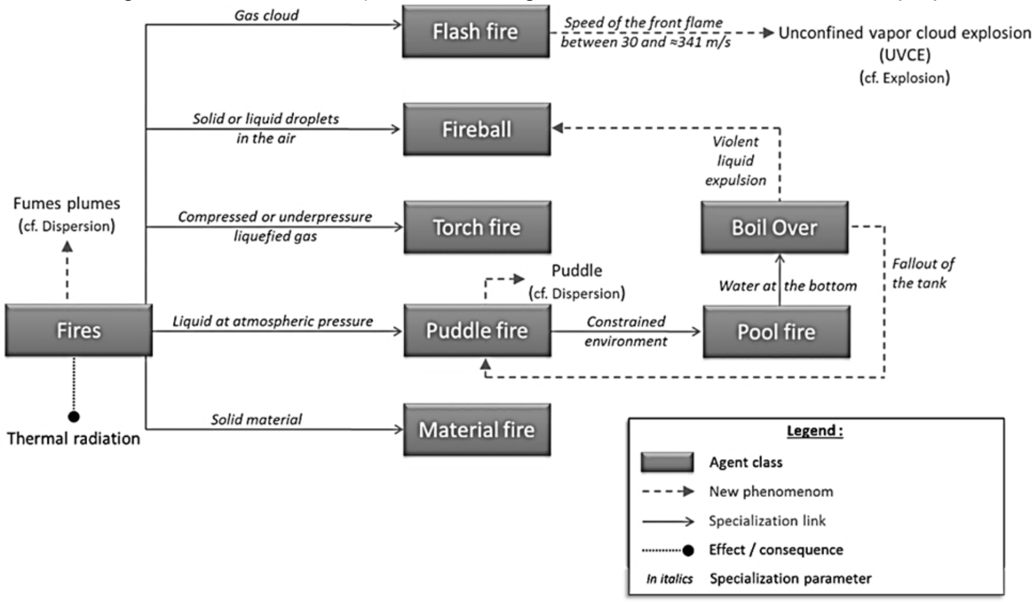

Figure 1: Focus on fire inheritance of agents.

We assume that an organizational system taking account of key human (H), infrastructural (I), and environmental (E) issues, is sufficiently relevant for characterizing critical or sensitive targets in the case of major crises. Our typology specifies archetypical agents for (H) (e.g. private dwelling, people in public assembly building, users of communication networks). Then, georeferenced agents are defined for (I) (communication/energy/water networks, health infrastructures…) and (E) (natural areas…).

Tactical and operational responses depend on the context and type of crisis simulated (fire departments, police services, and emergency medical services). Each one needs to instantiate the archetypical type. We propose the following steps for archetypical agent behavior: goal definition, response planning, execution of actions, and assessment of the effectiveness of the response (with inferences). Each action is linked with an archetypical skill depending on the behavior required. In order to determine the success or failure of actions attempted, four characteristics are proposed to define archetypical agents: observation, cognition, precision, and constitution (health). If the attempted action score exceeds the difficulty action threshold, then it is a success, otherwise it is a failure. In a first MAS version, all characteristics are initialized to 12.

2.5 Debriefing approach and learning objectives assessment

Trainers must ensure real-time learners monitoring to make a performance diagnosis. If necessary, trainers must influence the scenario (simulation speed, the number of events, and complexity) with data input devices. On the one hand, we propose to realize this monitoring through sound and video recordings, telephone conversations and email archiving. The objective is to study the verbal and non-verbal factors contributing to skills activation. On the other hand, we propose to use a role-playing aid for trainers. The idea is to temporarily track each skill mobilized, to transform it into a stimulus for the multiagent system so that the crisis scenario integrates learner strategies. Of the 16 groups of expected actions, 5 (a) can only be assessed by observers and 7 (b) can only be assessed by trainers. The other 5 groups of expected actions (c) can be independently or jointly assessed by observers and / or trainers.

a: management of decision making, arbitration of strategic options, communication within the crisis cell, human management, identifying the possible scenario changes.

b: protection of threatened high-stake elements, strategies for returning to the normal state, reinforcement management, resource management, communication with medias, authorities, and public.

c: hazard assessment, identification of issues involved, analysis of the situation, monitoring and forecasting.

3. Results

This research was performed and materialized at the Institute of Risk Science (Ecole des mines d'Alès, France), which now has a training simulator for crisis management. Our methodological recommendations have been applied in order to define a semi-virtual training environment. Two training areas enable to animate two simultaneous exercises. The trainers' room allows the global and non-intrusive supervision of two groups of learners by way of a one-way mirror and a video camera. Five immersion devices (global, visual, soundscape, participative, and kinesthetic) have been set up taking account of building constraints. Finally, a technical area includes all the elements needed in order to provide a dynamic training session (software, multimedia hardware, simulation servers). A distributed multitier architecture, as proposed in the design phase, was deployed in the physical platform. The CRISIS-SIM suite (Figure 2) has been developed (in Delphi© language) to support the project in terms of training, pedagogical monitoring, and learner assessment. A dedicated multiagent system named ASYMUT (Agents and Synopsis Management UTility), has been developed with the help of an existing open source framework (Jade, Java language).

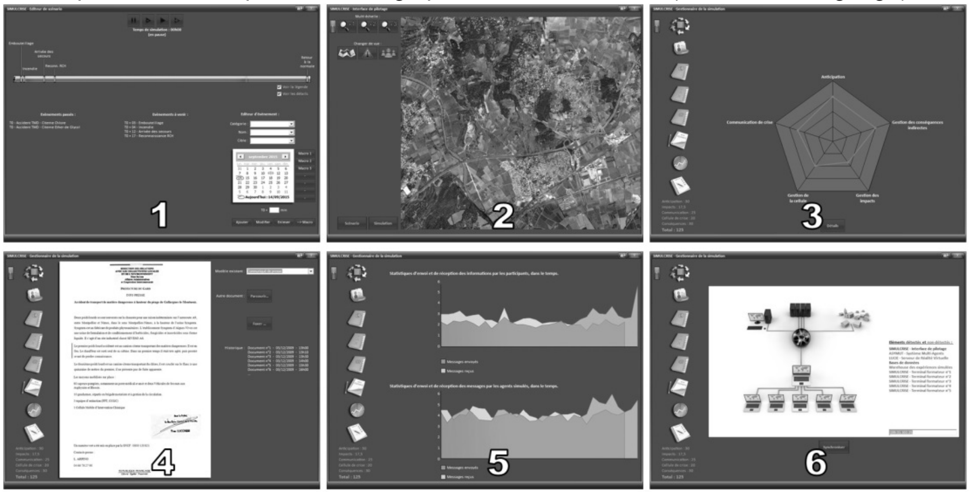

Figure 2: CRISIS-SIM suite – focus on the scenario manager.

As shown in figure 2, a summary timeline (1) aims at viewing the past and upcoming events. New events can also be added and can be linked to a set of agents in ASYMUT (creation/destruction commands, behavior activation, and parameter changes). Georeferenced agents (including archetypical ones) are automatically located on a map (2) in order to help trainers to understand the current state of the crisis simulation. A database of documents is available (4) and aims at sending information by email or fax. Indicators (3) and statistics (5) are calculated in real time and feed the debriefing step. Screenshot (6) shows the scenario manager which is an overview of the distributed multitier architecture. The combination of a monitoring tool with ASYMUT contributes to making the management of complex scenarios easier. Unlike other approaches which consider the entire training environment as a multiagent system, ASYMUT is seen a part of our environment. A software layer including a 3D virtual simulation server helps to immerse learners in a scenario close to reality. Each of these components is associated with man-machine interfaces providing access to the key features needed of a training session exercise (adding major events, setting simulation speed).

4. Improvements

There are several limitations of our distributed multitier architecture. The first one comes from the 3D virtual simulation component because the use of this kind of software interface can lead to differences between the planned uses and the results obtained. This constraint stems from the differences between the cognitive models of designers and users, and between learners and trainers.

From a modeling point of view, two main difficulties have been identified for using MOSAR. The first one concerns the display of all possible changes in the simulation, which are difficult to interpret because of a large number of events linking all the sub-systems of a crisis scenario. This method takes into account all the scenario paths from the point of view of hazard and it should be interesting to take more into account sequences of actions. Providing the scenario with such a design will give the possibility to imagine all the possible contingencies and to have scripts to make an interactive drama [Si et al., 2005]. The second one is due to the physical impossibility to provide both an overview of all sub-systems (to anticipate next events) and a local view (to provide a clear and precise readability). We should note that MOSAR fully performs the functions of modeling a system to be simulated, but does not seem to be appropriate when different levels of dynamic visualization are simultaneously required. It may be interesting to simulate interaction with potentials users and keep the story paths for well-motivated users [Si et al., 2005]. This kind of tools should reduce the authoring work and get the system more efficient.

From the author point of view, it could be easier to design a scenario if data about stakes, hazard, human and material means and emergency organization were available and organized in databases for instance. Such a data management could make simpler to purvey harmonized contents for training moderation. It would be necessary to determine which input data is needed and how it has to be supplied to the system.

5. Conclusion

In a crisis cell, decision-makers have to mobilize various technical and non-technical skills through teamwork. However, we have highlighted that the need for experience implies regular training of the stakeholders involved. Our research is situated at the confluence of the pedagogical and technological difficulties typically encountered. The use of functional training exercises may reinforce the importance of the decision-making within a closed group. The basis of this event-based approach to training is the simulation of events that can occur in order to make learners aware of the key concepts put at stake. During a virtual exercise, the learners must be faced with dilemmas requiring naturalistic decision-making, and thus be able more easily to share existing or new mental models. We also recommend integrating the emergency dimension by using a critical-thinking training approach. It enables the raising of learners' awareness of optimizing the ratio of reaction time versus the amount of available information. A typology of educational objectives was identified, with six general skills, five intermediate sets of tasks, and sixteen groups of expected actions. We have proposed a new approach to emergency management training and suggest a set of specifications in order to design a semi-virtual environment. Serious games need to define models, scenarios, unexpected events, timed processes, role guides, procedures, decisions, consequences, indicators, symbols and a specific infrastructure. Thus, a scale of the scenario difficulty is proposed, taking into account three possible learner profiles (beginners, intermediate levels, or experts). From educational and technical points of view, scenarios linked with virtual simulations seem to be a good way to simulate and represent a real or a fictitious situation. This approach entails a simulation kernel for which we suggest a multiagent system. Our methodological recommendations have been applied in order to define a real semi-virtual training environment which integrates five immersion devices, two layouts of the learners, a software suite named CRISIS-SIM, 3D virtual simulation server, and a dedicated multiagent system named ASYMUT. Our experimental approach has been validated by several training exercises, with institutional stakeholders, industrialists, and students.

Reference

Crichton M. T., 2009, "Improving team effectiveness using tactical decision games", Safety Science 47(3): 330, 0925-7535.

Endsley M., 2003, "Designing for situation awareness in complex systems", Conference on Human factors in decision making in complex systems, Dunblane, Scotland.

Fowlkes J.E., Dwyer D.J., Oser R.L., Salas E., 1998, "Event-based approach to training.", The International Journal of Aviation Psychology, num 8, pp. 209-221.

Kebritchi M., Hirumi A.C., 2008, "Examining the pedagogical foundations of modern educational computer games", Computers & Education 51(4): 1729.

Lagadec, P., 2012, Du risque majeur aux mégachocs, Editions Préventique, 224 p (in French).

Morin M., Jenvald J., Thorstensson M., 2004, "Training first responders for public safety using modeling, simulation, and visualization", SIMSafe, Karlskoga, Suède, 15-17 June.

Pasin F., Giroux H., 2010, "The impact of a simulation game on operations management education", Journal of Computers & Education.

Perilhon, P., 2007, La gestion des risques - Méthode MADS-MOSAR II - Manuel de mise en œuvre, Editions Démos, (in French).

Rasmussen J., 1983, "Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models," Systems, Man and Cybernetics, IEEE Transactions on, vol.SMC-13, no.3, pp.257,266, May-June 1983, doi: 10.1109/TSMC.1983.6313160.

Smith W., Dowell J., 2000, "A case study of co-ordinative decision-making in disaster management", Ergonomics, volume 43, numéro 8, pp. 1153-1166.

Si M., Marsella S.C., Pynadath D. V., 2005, "Thespian: Using Multi-Agent Fitting to Craft Interactive Drama", Proc. Fourth Int. Jt. Conf. Auton. Agents Multiagent Syst., pp 21–28.

Sun P.-C., Tsai R.J., Finger G., Chen Y.-Y., Yeh D., 2006, "What drives a successful e-Learning? An empirical investigation of the critical factors influencing learner satisfaction".

Tena-Chollet F., 2012, "Development of a semi-virtual environment training in strategic crisis management, based on multi-agent simulation", Doctoral Thesis, ENSM St-Etienne, France (in French).

Trnka J., Jenvald J., 2006, "Role-Playing Exercise – A Real-Time Approach to Study Collaborative Command and Control", International Journal of Intelligent Control and Systems, volume 11, num 4, pp. 218-228