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Towards A Serious Game Within the Frame of Major Crisis Simulations for Decision-makers: How Do We Connect the DOTs?

2.1. Introduction

Serious games and simulation-based learning exercises are useful training approaches in crisis management. When major crises occur, organizations face critical concerns, such as stress, uncertainties, and the need for quick anticipation and better communication in order to mitigate consequences or avoid negative impacts on high-stake elements. Many factors are critical in a training environment to ensure that effective learning occurs, mainly experience improvement, engagement and immersion, and realism. In a previous piece of work, a set of recommendations was proposed to specify the main components of an improved training environment (Tena-Chollet *et al.* 2016b). More specifically, we proposed to consider 10 DOTs (Degrees of Training). These DOTs are structured in general, intermediate and specific skills that must be involved in each crisis scenario. In this chapter, we show how to connect the DOTs. To do so, we transpose our previous specifications to the technical requirements of a real semi-virtual training environment (SVTE),

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which is presented here. We also demonstrate the advantages of two developed software programs: a dynamic crisis simulation kernel based on a multi-agent system (called “Asymut” for Agent and SYnopsys Management UTility) and a crisis scenario manager (called “SimulCrise”).

In the field of major risks, a crisis is characterized by a loss of control and thus a high level of stress for the stakeholders involved due to a “spark event” (i.e. an unexpected trigger) causing a disruption of the balance of a system (e.g. an organization, an infrastructure, a territory). When major crises occur, stakeholders are organized through a crisis unit. The human factor, the management of resources or the uncertainty of the situation are often major sources of vulnerability in the decision-making process of a crisis unit (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 (Tena-Chollet 2012). This raises the following paradox: while crises are exceptional, decision-making during crisis often depends on previously experienced situations.

We can note that most training environments for crisis management present shortcomings or limits. They are intended for tactical or operational levels (emergency services, firemen, etc.), and not for strategic ones (stakeholders, for example). The study of other existing environments using functional exercises in crisis management has identified several limits (Tena-Chollet *et al.* 2016b). It is possible to distinguish those related to the unsuitability of the teaching strategy for the profile of learners and those relating to the complexity of moderation for trainers.

On the one hand, it is necessary to facilitate a proactive and participating immersion of learners in a realistic environment and in a group that is as homogeneous as possible in terms of knowledge and experience. On the other hand, the role of trainers is difficult as their

authority may not be granted in a group of experts in crisis management. Nevertheless, they must promote success and explain the failures with factual reasons (particularly during the debriefing), while maintaining a certain distance from learners. Some of these difficulties seem to be solved by the use of computer-assisted training (Kebritchi and Hirumi 2008). Training in crisis management through crisis simulation aims to facilitate 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.

Our research studies how to create an immersive environment for learners who have different profiles of experience, and how to simulate pedagogical crisis scenarios in a playful and realistic manner. Recent works demonstrate that simulation games, like serious games, are effective tools in the teaching of management techniques and engineering, and have been widely used in experiential learning (Mawdesley *et al.* 2011). We have therefore chosen to target the following three domains of improvements (Tena-Chollet *et al.* 2016b):

- the teaching strategy, in order to help trainers to create educational scenarios, to observe learners and to prepare the debriefing phase;
- the simulation system, which must help to make real-time, slow-time or fast-time simulations in order to simplify or highlight the studied phenomena and to immerse learners in a credible scenario;
- the training environment, with the aim of deploying immersion devices and simulation kernels.

Then, we present our methodology, and more specifically:

- the definition of “Degrees of Training” (the DOTs);
- the way to connect the DOTs, with a definition of the required skills in crisis management;
- the activation of the skills by a crisis scenario;

- the scenario execution through a semi-virtual training environment (SVTE);
- the first elements of serious gaming in a real infrastructure for crisis management training.

2.2. State of the art

2.2.1. Teaching strategy

Learning processes are part of the “perception-data-information-knowledge-wisdom-vision” cycle, ensuring that decision-making does not affect the environment in which the group is situated (Le Bas 1993; Guéraud 2005; Tena-Chollet 2012). The sequence of these steps entails two prerequisites. The first is that any educational event must be perceptible in order to be picked up by the learner. The second highlights the need to integrate the heterogeneity of learner profiles in the same group. Four classical approaches, namely behaviorism, cognitivism, constructivism and social constructivism, differ in this respect (Werhane *et al.* 2011; Ertmer and Newby 2013).

Social constructivism deals with the problems of collective learning better, but does not focus on the definition of a pedagogical framework suited to the learner profiles (Morin *et al.* 2004; Guéraud 2005). We therefore propose to extend the social constructivist approach through a continuum of organizational learning that is structured around three steps, depending on whether the group is neophyte, intermediate or expert in crisis management. We will call these three steps the “beginner mode”, “intermediate mode” and “expert mode”. In line with Pasin and Giroux, our approach highlights the need to develop specific educational objectives and different assessment levels of learners (Pasin and Giroux 2011). Finally, the learning speed may be higher during the first two modes (Tena-Chollet 2012). An uninitiated audience increases its skills faster than a group of experts. Although our initial topic of research comes from the need to train stakeholders (i.e. experts in crisis management), we also chose to retain the other two learner profiles

(neophyte and intermediate people), which are of considerable teaching interest.

2.2.2. Simulation strategy

Business intelligence (BI) facilitates the anticipation and understanding of a situation and decision-making. Interactive environments have several advantages: motivating the user, they help him/her to better understand complex or dangerous situations, studying them with a different scale of view (Joab *et al.* 2005; Mendonça *et al.* 2006; Crichton 2009).

The study of the typology of interactive environments for human learning distinguishes simulation games, microworlds and role-playing games. Simulation games are considered suitable for training decision-makers because they integrate models, scenarios, unexpected events, timed processes, roles, procedures, decisions, consequences, indicators, symbols and helpful hardware (Crichton 2009). This type of serious game may consist of simulators for educational purposes, for the acquisition of technical and non-technical skills, of automatic reflexes and of ways of thinking (Connolly *et al.* 2012). These are used for demonstration purposes, self-training, self-assessment or collaborative work. In every case, it relates to a way of learning through discovery and action (Joab *et al.* 2005; Labat *et al.* 2006).

Three modes determine what the dominance of the simulation will be: the position of independence, the position of competition and the position of cooperation (Tena-Chollet 2012). More importantly, the third one has the advantage that learners work together in order to develop their ability to achieve consensual decision-making. It is possible to make real-time, slow-time or fast-time simulations in order to simplify or highlight the studied phenomena but these settings must be justified from a pedagogical point of view (Joab *et al.* 2005). The propensity of people to attach great importance to the visual aspect should encourage developers to allow the use of maps, data, and 2D or 3D representations in order to assess the impact of the crisis unit's planning during the exercise (Morin *et al.* 2004).

2.2.3. Training environment

Typically, virtual environments are destined for either technological or educational uses (Mellet D'Huart 2001; Burkhardt 2003). From a pedagogical perspective, they are used to generate didactic interactions and as a form of exercise management (Burkhardt 2003). In practice, the stress of crisis management can be recreated, and so this can lead learners to carry out tasks under conditions close to reality (Lourdeaux 2001). This approach improves the following types of learning: being, knowledge, know-how and social skills.

These objectives can be better achieved through multimedia interfaces, time constraints, information overload (Critical Thinking Training) and visual representations (Sniezek *et al.* 2001; Kebritchi and Hirumi 2008). The use of real data in interaction with a geographical information system is also a good way to ensure the realism of simulations. Several techniques already exist to facilitate integrations into various environments. Nevertheless, the use of virtual representations to produce new information questions its consequences in an environment which aims to reproduce the real conditions of a crisis management situation. For Buche, virtual representations are defined by three elements: immersion, imagination and interaction (Buche *et al.* 2007). We should note that all the three elements theoretically fit the immersive dimension needed in a crisis simulator, the participating and proactive behaviors expected from learners in a serious game.

Two methods of representation are distinguished: virtual reality and virtual simulation (Pernin 1996). A comparison of these two methods highlighted that virtual simulation is more suited to our approach (Tena-Chollet 2012). Like virtual reality, the use of virtual simulations also makes it possible to replay educational sequences, record data of the exercise or take a break. However, virtual simulations allow for greater reversibility actions (Burkhardt 2003), thus giving the environment a strong didactic aspect. Through any user involvement, the virtual simulation makes it possible to repeat a scenario as many times as necessary, to intervene on the kinetics of the event, the occurrence of particular events, adding constraints,

resources or concerning the evolution of the scenario. Therefore, the disconnection from existing reality (implied with virtual reality) allows the learner's decisions to be better taken into account, using temporal distortions if necessary, and replaying all the sequences to give the opportunity for retroactive corrections in cases bad choices were made.

The main disadvantage of the virtual simulation comes from the need to constantly feed it with calculated data, simulation models, computational behaviors and more particularly a dynamic generation of crisis scenarios. Flexibility is usually viewed as an important factor in learning environments (Sun *et al.* 2008). We propose using intelligent agents as the modeling paradigm for the crisis simulation.

2.3. Methodology

Our methodology aims to define the concept of “Degrees of Training” (DOT) for the main human factors involved in crisis management and then to connect them with other parts of a training system.

2.3.1. Definition of “Degrees of Training”

The expected reactions of learners seem to be spelled out before the training exercise. We propose that the learning strategy and the content of each exercise depend on the profiles of the learners. For example, a raw novice must learn to identify viable strategies based on the crisis phases, while an expert, by contrast, needs to work on interpersonal relationships within the crisis unit. Three teaching strategies will be established. These are associated with various objectives, are all assessed differently, and take into account the type of learner (neophyte, intermediate or expert).

Stress, resources and time management are the three main constraints that can hinder the process of decision-making. Assuming that a crisis imputable to human causes is more difficult to manage due to emotional involvement, the determination of a scenario should therefore both integrate the identified learning objectives and

contribute to a motivating context for the crisis unit. More accurately, the instinct of cooperation within a group is activated and strengthened when problems or common difficulties are clearly seen and if there is at least one solution identified by a significant number of members of the group. So, we propose that no event should be induced that cannot be associated with a possible solution. We also note that the cohesion of a training crisis unit must be maintained by a set of events (either recurrent or triggered on demand).

At the same time, learners do not need to know each other or to have previously cooperated in order to be placed in a learning situation. However, automatic reflexes are only learned and reproduced if the context is the same as that for which the exercise is being conducted. It is important to reproduce the environment in which a learner will be during a real crisis. Four positive factors must be taken into account (instinct, learning, intelligence and adaptability) and six psychosocial weaknesses identified (alterability, subjectivity, ignorance, credulity, disaffection or asociality) (Tena-Chollet 2012). We propose to consider these 10 elements as “Degrees of Training” (DOT) in order to define each crisis scenario and lead to an instructive debriefing. Now, the question is: how to connect the DOTs?

2.3.2. Connecting the DOTs with a definition of the skills required

Usually, the skills necessary for emergency management through the decision-makers’ experience are not clearly specified, nor factually assessed, and thus, the debriefing step is poor (Lagadec 2012).

Through the prism of our DOTs, it is possible to characterize general goals in terms of skills needed (Tena-Chollet 2012).

In order to achieve a common goal, each member of a crisis unit 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 2001; Crichton 2009). Decisions cannot be taken in full knowledge, but they require the cooperation of

emergency management actors who are not always accustomed to working together (Smith and Dowell 2000). These difficulties can lead to a lack of shared mental models between actors and a lack of internal/external communications of the crisis unit.

Therefore, we consider that general, intermediate and specific skills must be specified. We propose six general skills: (1) anticipation, (2) communication, (3) cooperation, (4) stress management, (5) decision-making and (6) strategic steering. These skills are used to achieve five intermediate sets of tasks: (1) management of the crisis consequences, (2) tactical and operational response, (3) crisis unit management, (4) crisis communication and (5) overall view in the short, medium and long terms. In addition, we have identified 16 groups of “expected actions”: (1) human management, (2) resource management, (3) hazard assessment, (4) identification of issues involved, (5) strategies for returning to the normal state, (6) protection of threatened high-stake elements, (7) reinforcement management, (8) analysis of the situation, (9) management and (10) arbitration of strategic options, four types of communication – (11) within the crisis unit, with (12) media, (13) authorities or (14) the public, (15) monitoring and forecasting and (16) identifying the possible scenario changes. These 16 skills have to be improved through events and interactions induced by the crisis scenario (Tena-Chollet 2012).

Conventionally, the main phases of a training session are planning, preparation, the exercise itself and debriefing. This last step is very important because it leads to the acquisition of knowledge by a reflexive analysis of the decision-making. The debriefing must follow specific rules. Indeed, the errors made by learners should not lead to a value judgment. The aim of this step is to reveal the origin of these errors and to understand why they occurred (cognitive process of reconstruction). Therefore, we propose the following evaluation categories for all phases of the continuum of organizational learning: anticipation, communication, teamwork, stress management, decision-making and leadership. These elements are thus identified as the main objectives which should be specified. These objectives can be completed in real time by observers with checklists in order to

identify how the group organizes itself to deal with the crisis, the leadership involved, the sharing of information, coordination and the way decisions are made. The checklists can give the results of the training room observations to inform facilitators about the trainees' reactions during the exercise.

When a situation begins with incomplete information, and moves forward in time, new information is known and may show that the initial decisions are no longer adequate. Other methods can therefore be investigated in order to identify the profile of the group (from a teamwork point of view) and to focus on the recognition and the management of these potential errors.

Finally, the use of DOTs implies the intervention of one or more trainers. They are essential as they guide learners to the predefined didactic situations. Role-play guides should thus be created in order to help trainers. Nevertheless, it is not recommended that trainers should intervene during an exercise. The way learners will be led to the didactic situations must be defined, insofar as these aspects must be performed implicitly.

2.3.3. Skills activation by a crisis scenario

Two main types of scenario can be embedded in a simulator (Tena-Chollet 2012):

- canvas scenarios, setting a number of rules before the beginning and then allowing free interactions to take place;
- programmed scenarios with a set of actions planned in advance; these actions can be optional or not.

We consider that canvas scenarios increase imagination and satisfy all the elements that should be integrated in simulations while enabling the integration of experience feedback.

The 16 skills previously identified have to be activated through events and interactions induced by the crisis scenario. In order to design it, we used a pattern that integrates two approaches: (1) real past crisis scenarios and (2) fictional crisis scenarios. 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 realistically maintain 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 to the identification of credible events to link with pedagogical objectives. The last step consists of making the scenario animation easy with the help of training and assessment aids, developing needed agents, calibrating the speed simulation and validating with test cases.

2.3.4. Scenario execution through a simulation

In order to dynamically simulate a real or fictitious crisis scenario, the multi-agent approach seems to be appropriated, particularly to model canvas-rules (e.g. physical effects or human behaviors), and then to allow the system to self-organize and schedule all the crisis events. The study of the main MAS indicates the BDI approach, which is based on Stimulus-Organization-Reaction models, as a coherent work perspective in order to simulate agents' behaviors during a virtual crisis (Tena-Chollet 2012).

The model we propose distinguishes between three subsystems in the overall crisis environment: dangerous phenomena (fires, explosions, atmospheric and aquatic dispersion, earthquakes, floods, and tsunamis), sensitive issues (human, infrastructural and environmental) and crisis management responses (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 (Périlhon 2007). MOSAR aims to:

- identify technical and operating failures with system and subsystem definitions;
- characterize interactions between hazard sources, hazard propagation and sensitive targets;
- highlight the undesired events that can be produced by their sequencing.

2.3.5. Simulation execution through a semi-virtual training environment (SVTE)

Our previous research on the technical and organizational requirements has suggested the idea of a distributed multitier architecture for freely sharing the expected features (Tena-Chollet *et al.* 2016a, 2016b). Therefore, seven features of our serious game are identified (Figure 2.1): (1) a simulation kernel based on an MAS (multi-agent system), (2) exercise management under the responsibility of a supervisor, (3) exercise management, thanks to trainers, (4) virtual simulation, databases, (5) data warehouse about experience feedbacks and (6 and 7) the two crisis units. We propose the new concept of semi-virtual training environment (SVTE) for this kind of system. Our SVTE model is said to be semi-virtual because a virtual simulation component is used instead of a virtual reality one.

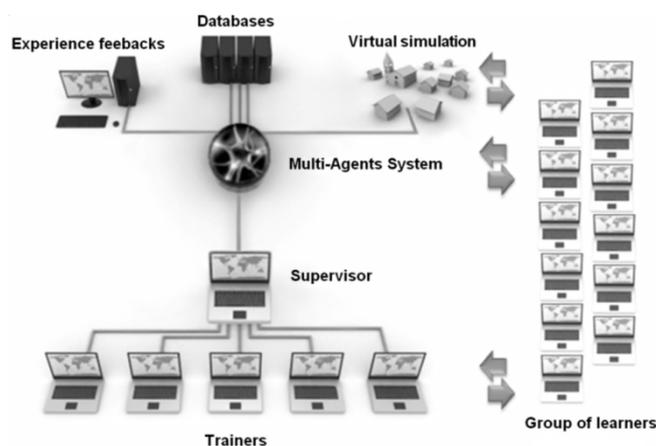


Figure 2.1. A multitier architecture

The design of an MAS requires the definition of the global system, expected behaviors of the agents and the agents themselves (Tahir *et al.* 2008). More particularly, the BDI software model (Belief-Desire-Intention) seems to constitute an initial basis in order to simulate human behaviors and accident phenomena (Wooldridge and Jennings 1995). The MAS depends on trainers and their pedagogical objectives as well as the virtual simulation display. This module receives specific input data (physicochemical effects, behavioral models, etc.), which depend on events in a simulated crisis, and involves learner decisions.

The SimulCrisse software suite has been developed (in Delphi© language) to support the project in terms of training, pedagogical monitoring and learner assessment. A dedicated multi-agent system named Asymut (Agents and Synopsis Management UTility) has been developed with the help of an existing open source framework called Jade (Java language). The multitier distributed architecture designed during this research led to the identification of seven layers for our SVTE (Figure 2.2).

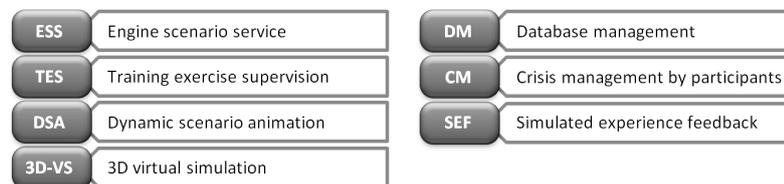


Figure 2.2. *Components of the multitier distributed architecture*

Except for SEF, all the layers have been developed and integrated into the SimulCrisse software suite. ESS is an MAS (Asymut), specially designed and calibrated in order to simulate crisis dynamics. Unlike other approaches which consider the entire training environment as an MAS, Asymut is an SVTE component. This difference stems from the fact that the ESS is considered to be a module used for scenario animation and not as a prerequisite in our engineering system. Learner decisions and trainer guidance are taken into account by the DSA layer. Tracking sheets are used to monitor the scenario events simulated by ESS and to link them to associated

learner skills. We should note that these sheets can be preconfigured and/or modified during an exercise in order to integrate new interactions depending on learners' 10 DOTs. However, the main difficulty involved in this process is the association of each new event with a set of skills to be tracked. Finally, centralization in the events log (in the SEF layer) enables tracking sheet enrichment (in the DSA layer).

As shown in Figure 2.3, a summary timeline (1) aims to view 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 to send 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 multi-agent system, Asymut is seen as 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 required for a training session exercise (adding major events, setting simulation speed).

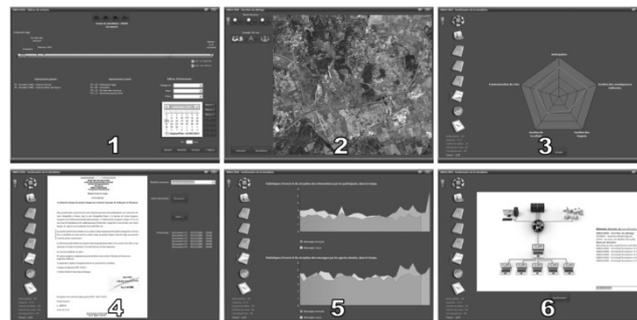


Figure 2.3. *SimulCrisis suite – a focus on the scenario manager*

2.3.6. Towards serious gaming in a real infrastructure for crisis management training

This research was performed within the framework of a new risk science institute (IMT Mines Alès, France) with the aim of including a crisis management simulator for training decision-makers. Our methodological recommendations have been applied in order to create a physical SVTE (semi-virtual training environment).

Four adjacent rooms have been located so as to carry out two simultaneous exercises (Figure 2.4). The trainers' room allows for the global and non-intrusive supervision of two groups of learners by way of a one-way mirror. Finally, a technical area includes all the elements needed to provide a dynamic training session (software, multimedia hardware and simulation servers).

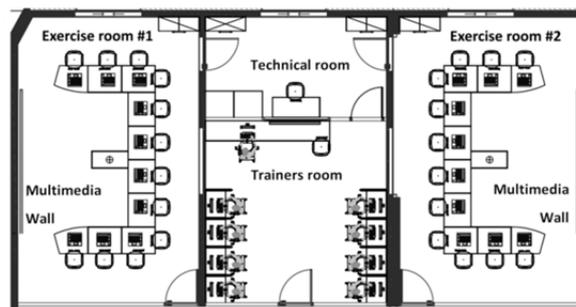


Figure 2.4. A physical infrastructure design

The key step in the debriefing led us to consider a particular organizational approach to encourage learners to share the same mental models. To foster both individual and collective reflexive discussion, we propose to have the same crisis scenario managed by two different crisis units at the same time. During the debriefing phase, the sharing of strategies chosen separately by the two groups is intended to foster learning from peers and not from trainers.

As shown in Figure 2.5, five typical layouts of learners are relevant for the training (Noyé and Jacques 2015). (1) The classroom layout fosters a one-way communication and passivity. This slows and

fragments the exchange of perceptible information between learners. (2) The meeting room layout helps foster discussion, but the proximity of learners with different skill levels limits the conditions of cooperation. (3) The roundtable layout enables face-to-face contact, but one person is usually the center of attention. (4) The semicircular layout draws attention to a point of interest, while facilitating communication within the group. (5) The working group layout creates “think tanks” without having to move. This layout fosters new ideas for action when there are many learners. The need to facilitate intergroup communication, participation in decision-making and equal access to available information, led us to choose a semicircular layout for learners (fourth layout in Figure 2.5).

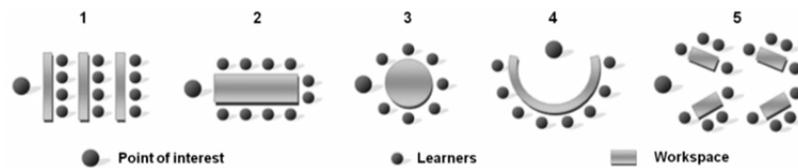


Figure 2.5. *Typical layouts of learners*

Furthermore, five sets of devices are proposed in order to immerse learners in a realistic context. (1) Global immersion devices consist of insulation shutters creating confined rooms in order to remove any external factors (time of day, season, weather), which may interfere with the simulated crisis scenario (we should note that this is usually done in most crisis simulators). (2) Visual immersion devices include a multimedia wall with touch boards. These devices aim to achieve the real-time display of the required information through a customizable and collaborative workspace. (3) Soundscape immersion devices are necessary to transpose some crisis events to perceptible elements (media information, rain, explosion sounds, etc.). (4) Participative immersion devices are intended to reconstruct a crisis unit while guaranteeing the non-intrusive management of trainers. We suggest the use of one-way mirrors between the trainers’ room and the two exercise rooms so that trainers can see without being seen. We also propose to deploy monitoring cameras and audio feedback systems in order to more easily follow oral interactions between learners.

(5) Kinesthetic immersion devices mainly include thermal management equipment in learners' rooms. The purpose is to degrade crisis management conditions (heating or air-conditioning failures) and to simulate a context that corresponds to each scenario. It is worth noting that part of these devices must be anticipated before the construction of a new training environment. Finally, learners must interact with trainers, thanks to communication devices commonly used during real crisis management (phones, fax and email).

This crisis simulator can be therefore used as a training platform and as an experimental framework for calibrating, testing and validating new approaches and tools.

2.4. Discussion

We have proposed a methodology of design which implements **seven steps** in order to model a semi-virtual training environment (SVTE) connecting DOTs in the field of crisis management (Figure 2.6). **Step 1** concerns the specification of the environment and integrates the training chronology, the structuration of the subsystems involved and the expected features (what are the immersion devices and software involved? How many people are required for the training session? etc.). Then, a physical infrastructure and information technology architecture can be defined. **Step 2** includes the specification of the users (learners and trainers) and the modalities of interactions (phones? emails? fax? etc.). **Step 3** concerns the kernel design (in the form of a hierarchy of dangerous phenomena), high-stake elements (typology of possible human, material and environmental issues), and tactical and operational actors that have to also be simulated. **Steps 4** and **5** concern the creation and the simulation of a crisis scenario. These steps integrate the educational objectives and imply the specification of activation rules for the events of the scenario. **Step 6** involves the design of man-machine interfaces in order to help trainers to moderate the exercises. Finally, **Step 7** assembles all the techniques and tools required for debriefing. We should note that **Step 3** is in the form of a multi-agent system (MAS).

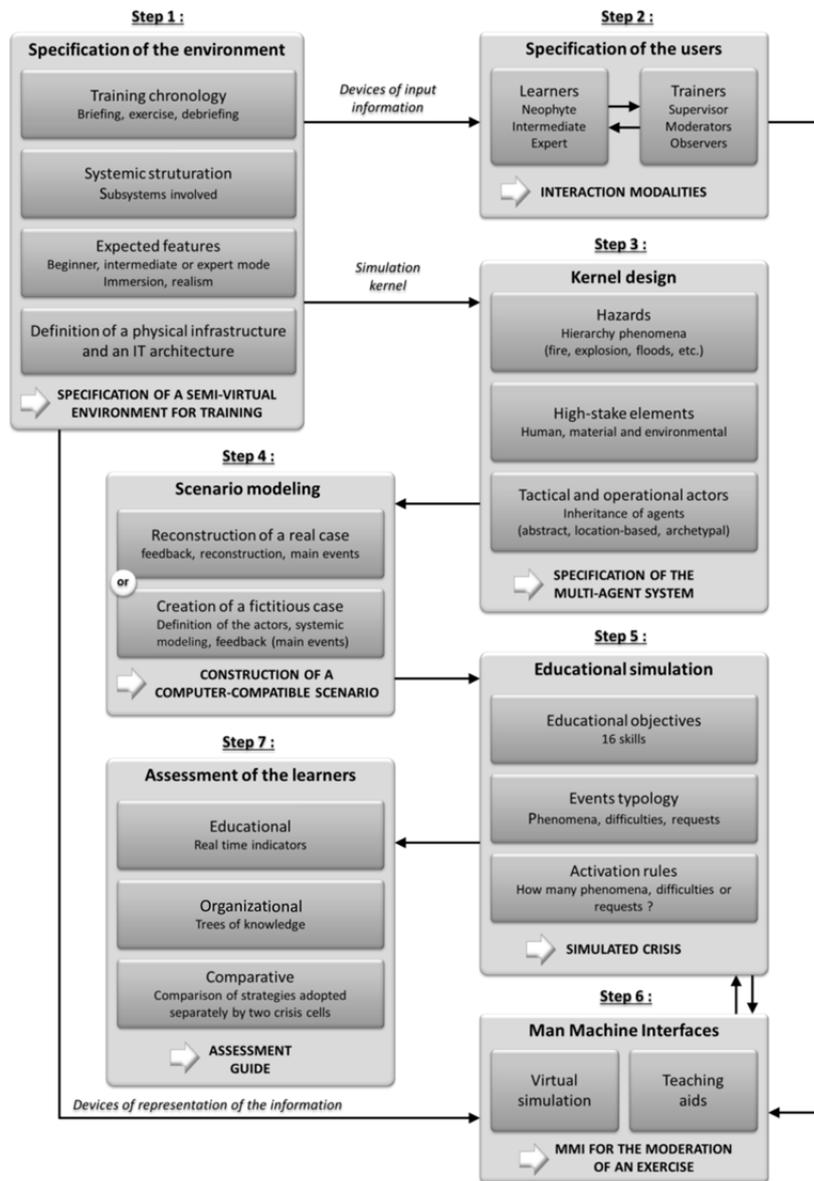


Figure 2.6. A model proposed for the design of a crisis management simulator

The proposed simulator allows our DOTs to connect with any part of this system (learners, expected skills, pedagogical objectives, debriefing step, etc.).

However, 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 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 subsystems of a crisis scenario. This method takes into account all the scenario paths from the point of view of hazard, and it would be interesting to take sequences of actions into account more. 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 difficulty is due to the physical impossibility of providing both an overview of all subsystems (to anticipate next events) and a local view (to provide 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 potential users and keep the story paths for well-motivated users (Si *et al.* 2005). This kind of tool should reduce the design work of a crisis scenario and make the system more efficient.

From the point of view of the scenario designer, it would 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 data management could make it simpler to enter harmonized data into the system. It would be necessary to determine which input data is needed and how it has to be supplied to the system.

2.5. Conclusion

In a crisis unit, 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 at stake. During a virtual exercise, learners must be faced with dilemmas requiring naturalistic decision-making and thus be able to more easily share existing or new mental models. We also recommend integrating the emergency dimension by using a critical-thinking training approach. This makes it possible to raise 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 16 groups of expected actions. All these expected forms of behavior fit our concept of DOTs (Degrees of Training) and must be connected and stimulated by events in a crisis scenario.

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. Therefore, our simulator does not actually fully fit the concept of a serious game because formal criteria of the expected playful characteristics are not yet defined. These criteria constitute the main means of improvement in our methodological approach.

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 fictitious situation. This approach entails a

simulation kernel for which we suggest a multi-agent 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 learners, a software suite named SimulCrise, a 3D virtual simulation server and a dedicated multi-agent system named Asymut. Since 2011, our experimental approach has been validated by several training exercises with institutional stakeholders, industrialists and students.

Finally, we should note that a specific debriefing methodology is needed to assess learners in order to take into account the 10 DOTs (Degrees of Training) chosen, the performance of the crisis units, the profiles of learners and the skills involved during each exercise. These points will be developed, described and analyzed in our semi-virtual training environment for crisis management.

2.6. References

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