



Original paper

Crisis simulation scenario building methodology that considers cascading effects

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Abstract Crisis management is based on knowledge and reflexes that replace the normal functioning of an organization. This implies the need for managers of crisis situations to have gained some experience in a practical or theoretical way. Crisis simulations appear to be a pedagogical solution for this experience gaining. A simulation is supposed to recreate as accurately as possible a realistic situation. To do so, the crisis simulation should be based on the psychological reality illustrated by the characteristics of the situation as well as the characteristics of the crisis managers' reaction who cope with it. The scenario is an essential part of the simulation, it contributes to enhance some of the previously cited characteristics such as the evolving nature of the problem, the important consequences, the surprise, etc. The scenario is chosen and elaborated as a function of the objectives of the simulation. This study has been undertaken within the framework of the European project CascEff which aimed to better understand cascading effects. Its objective was to develop a methodology that enables the modelling of cascading effects. The validation of such methodology in a context of a crisis situation was an intrinsic part of the development process. The iCrisis simulation approach enables to simulate crisis situations at a strategical level. The scenario is a key element of this approach. Based on classic scenario building methodologies and cascading effects assessment methodologies, this communication proposes a scenario building methodology for the iCrisis simulation approach that considers cascading effects, in order to study this concept and the added value of the developed CascEff methodology for crisis managers.

Key words Crisis management; Crisis simulation; iCrisis; Scenario building; Cascading effects.

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1. INTRODUCTION

Simulation is a process that is widely used in a large variety of domains. A simulation is supposed to recreate as accurately as possible a realistic situation (Borodzicz 2004) to let the user imagine any type of situations. Simulations are mainly used for two types of purposes: scientific for prediction, in climatology or finance for example; and pedagogical for preparation in surgery or emergency management for instance.

As a disruptive and unknown situation affecting an organization or a given system as a whole, a crisis situation often requires urgent and novel decisions and actions (Pauchant and Douville 1993). Crisis management is based on knowledge and reflexes that replace the normal functioning of an organization which implies the need for managers of crisis situations to have gained some experience in a practical or theoretical way. Crisis simulations appear to be a pedagogical solution for this experience gaining issue (Moats *et al.* 2008). However, due to the complex nature of the situation, important processes induced by the situation must be understood and well known in order to improve the steering process of the crisis situation. In this context, crisis simulations could be used to fulfil scientific objectives that focus on improving the understanding of what happens during a crisis situation such as the consideration of cascading effects among others.

Cascading effects modelling is an emerging field of scientific research. Recent worldwide events such as the eruption of Eyjafjallajökull volcano (2010) or the Tohoku earthquake and tsunami (2011) have significantly raised the attention on cascading effects. This encouraged the development of several cascading effects modelling methodologies or tools. For instance, the European project CascEff developed a methodology to help risk and emergency managers to take into account the cascading effects in the whole phases of the risk cycle (Carré *et al.* 2017). Among all, the crisis situation was targeted as being a very persistent phase to study the consideration and the perception of the cascading effects by crisis managers at a strategical level (Edjossan-Sossou *et al.* 2017). To enable such investigation, crisis simulation was the chosen solution. However, cascading effects being implemented in the simulation through the scenario, a specific improvement of the scenario building methodology was needed. In this paper, we propose to apprehend the process of improving the scenario building methodology in order to make it consider cascading effects. This work has been conducted with the iCrisis simulation approach.

In the first part, a presentation of the concepts of crisis simulation as well as scenario is made. Then, a focus is made on the chosen crisis simulation approach called iCrisis, its scenario building methodology and on the CascEff methodology to model cascading effects. A third part presents the scenario building methodology that considers cascading effects and its implementation in one scenario, the “Alpine area” scenario. Eventually, this communication finishes with conclusions.

2. STATE OF THE ART

2.1 Crisis simulation

Today, simulations are widely used in the domain of crisis management and exist under different forms such as in full scale, table top or computer based.

Simulation is the closest experience one can get except from real situations. However, for some situations such as disasters, it is not desirable to only rely on human experience because they are either rare or not even happened yet. Moreover, to consider these type of events and study theories to cope with them, experts cannot only work on the basis of technical studies about the hazard but also on the involved crisis management systems. Crisis simulations are then a solution to understand, develop models, teach and train managers for improving crisis management (Walker *et al.* 2011). Eventually, if one takes into account the costs of making mistakes in real-life crisis situations, then crisis simulations are cost-efficient in comparison with real events.

Crisis simulations are a common practice for incident management preparedness. They can be performed as table-top, discussion-based exercises, operation-based, full scale field exercises or virtual training in serious gaming. When focusing on crisis management at a strategic level, simulations rely a lot on human operations to consider the unique and complex nature of the situation. Therefore, all operations are generated by human players or animators. Starting from a baseline scenario, simulations enable to confront players with a sequence of events. These decision-making opportunities for players are supplied by the animators of the simulation through a more or less fixed-script. As a group coping with the crisis situation, each participant is given an individual role to reach to collective decisions.

There are different types of crisis simulations in order to adapt to the conditions of simulating but also to fit with the objective and thus the purpose of it. Kleiboer (1997) discusses six purposes of use of crisis simulations:

- as a **research tool**, crisis simulations enable scientists to study the mechanisms of crisis behaviours such as the decision making process or the leadership etc.;
- as a **teaching approach**, crisis simulations offer to trainees a setting that resembles real-life experiences with the objective of learning how to apply theories and procedures while coping with a crisis situation;
- as a **training tool**, crisis simulations allow to mimic the characteristics of the crisis, such as stress and the occurrence of critical events. This allows the participants to raise their awareness regarding the pitfalls induced by the crisis and to confront themselves with the complexity of its management;
- crisis simulation may be used during the preparedness phase as a **tool to assess plans and procedures** to reveal weaknesses and gaps in actual emergency systems;
- as a **design decision support** tool, crisis simulations contribute to develop models to be implemented in decision support system like done by Kraus *et al.* (1992) to develop a hostage negotiator model;

- crisis simulations can also serve as **a tool to assess individual's competencies** such as technical and non-technical skills because they create an environment in which an individual can be evaluated in action.

Although Kleiboer made an exhaustive list of crisis simulation purposes, most of which focuses on teaching and training purposes with the aim of improving managers' skills. Less common is the awareness as these activities provide opportunities for testing, validation and demonstration of new knowledge, procedures, tools or technologies (for example in the eNOTICE EU H2020 project).

The crisis scenario is the basis of a crisis simulation and its design must respect specific criteria of the simulation, then an improvement of the crisis scenario is needed to take into account cascading effects.

2.2 Crisis simulation scenario

2.2.1 The concept of scenario

The first use of the term "scenario" as an analytical tool has been made in the early 1960s by researchers of the RAND Corporation to define states of the world within which military strategies would have to perform (Walker *et al.* 2011). From this period, the use of this term has increased rapidly leading to different meanings with consequences such as misunderstandings while dealing with scenario.

In the literature, most definitions about the concept of scenario either focus on what a scenario is in terms of content, or define scenario by its purpose, i.e. its intended use.

Scenarios can be used for many different purposes, such as: to illustrate alternative solutions and identify potential problems (Bødker 2000), to prevent certain effects, to reduce uncertainty (Hansmann 1983), to question existing assumptions (Vartia 1994), to indicate thinkable futures (Scholz and Tietje 1996) or desirable futures (Godet 2000). They can also be used as a management tool to improve the quality of strategic decisions (Wilson 2000). A scenario is also a situation simulated during an exercise that must allow participants to develop their crisis management skills and abilities. Thus the scenario is the mechanism that provides to participants a realistic method to validate their exercise objectives using their own decision making (Fagel 2013). Since the crisis simulation mimics a real crisis situation, the scenario must consider crisis characteristics (Limousin *et al.* 2016) to be well recreated. The complexity of the scenario is that it must respond to all these requirements.

A scenario can be described as a story of possible future events, with some degree of uncertainty. As a story telling, a scenario must correspond to a sequence of facts organized in a specific space-time framework (Bouget *et al.* 2009) which is initiated by an event (Rankin *et al.* 2010). Other authors see the scenario as being a concept more complex, Walker (1995) defines a crisis management scenario (based on a more general definition suggested by Quade and Carter (1989)) as: *"a description of the conditions under which the crisis management system or crisis management policy to be designed, tested or evaluated is assumed to perform"* (Walker 1995).

Walker (1995, 2011) proposes to split a crisis management scenario into two parts known as the context and the crisis. The context is *"the overall background or environment within which the specific crisis is to be considered. It is the state of the affected area at the time of the crisis"* (Walker 1995). This includes a specific timeframe, demographics of a local population, geographical location, organisational relationships, availability of data etc. The context determines the framework which a crisis is taking place in, or where others might be embedded (for the purpose of the study). Walker then describes the crisis, as *"It includes the chain of (hypothetical) events that lead up to the crisis"* or *"the sequence of events to which the crisis management system must respond"* (Walker 1995). One context can thus embed different types of crises and within the crisis script, the chain of events can be altered, both leading to different scenarios (see further, multiple timeline development). The association of both the context and the crisis provides the necessary information for the player.

2.2.2 Scenario building

The scenario design is the process in which the elements and events are defined, which are the basis of the simulation content (Kleiboer 1997). The purpose of the crisis simulation must be taken into consideration to build an adequate scenario. Walker (1995) identifies four criteria for scenarios to be adequate and qualitative:

- **Consistency** which refers to the script not being self-contradictory.
- **Plausibility** which means that the scenario needs to be likely to occur, i.e. it *might* happen (without necessarily being predictable). Extreme or worst case scenarios are not excluded, since some large scale historical incidents, such as the gas leak incident in Bophal, India in 1984 and the Chernobyl nuclear accident in 1986, were considered unthinkable before they happened.
- **Credibility** which is closely linked to plausibility. It includes circumstances, consecutive steps and any changes in them should be logical, and it is important to understand why they occur.
- **Relevance** which relates to the purpose of the scenario and is reflected in predefined selection criteria.

Building a scenario is a long process that can bring a lot of elements and ideas. In order not to go beyond the scope of the scenario design objectives, these four pre-cited criteria must remain as questions to be asked to the designer of the scenario during all the process.

Whether the scenario is considered as an input to a crisis simulation, the purpose and structure of the simulation will impose many elements of the scenario and therefore, the boundaries of the simulation will dictate the boundaries of the scenario. These inputs will give about the environment (geography), the players (who are they?) and other information that are necessary to build the scenario.

Within the process of building the scenario, four requirements proposed by DeLeon (1975) may be considered since they are able to set the boundary of the scenario:

- **Time setting:** the time to be chosen is the present because the objective is to observe how does the crisis response system work
- **Environment setting:** it should be as close as possible from the reality with all the needed data / information to make a decision
- **Level of details:** the geographical area where the crisis takes place should be well documented but without too many details that could not be taken into account by the participants
- **Knowledge, experience and sophistication of players:** the profile of the players should be well known in order to choose the adequate type of elements to be implemented within the scenario

Based on these requirements, the scenario designer is able to create an adequate and qualitative scenario. However, for a more detailed process for developing and also using scenarios, Wilson and Ralston (2006) provided eighteen steps. Each step in this process is a critical point of adding value and exposing mental models and assumptions during the scenario project. These 18 steps are divided in four general phases of scenario planning, namely, “(a) *getting started*, (b) *laying the environmental analysis foundation*, (c) *creating the scenarios*, and (d) *moving from scenarios to a decision*”.

3. MATERIAL AND METHOD

3.1 iCrisis simulation approach

3.1.1 General description

iCrisis (Verdel *et al.* 2010) is an organizational and technical system developed from crisis simulation experimentations that have been carried out with students and professionals since 2003. As an system enabling message exchange, iCrisis is a web application that supports the conduction of full-scale virtual simulations. The information that is transferred though the web-application remains virtual, but each participant in the simulation is a real person playing under conditions that are supposed to resemble crisis-like.

The iCrisis approach is being scientifically validated as an approach that recreates the characteristics of the crisis situation as well as of the reaction it provokes among crisis managers (**Error! Reference source not found.**).

Table 1. Characteristics of the crisis identified based on literature review

Crisis situation	Reaction to a crisis
Chaos	Astonishment
Unexpectedness	Time pressure
Important consequences	Anxiety
Uncertainty	Changes in relationship
Evolving nature of the problem	Relative nature of the crisis
Irregular rhythm	
Numerous stakeholders	
Information management issues	
Media involvement	

An iCrisis simulation implicates one to several physically kept apart crisis units (**Error! Reference source not found.**), an animation team and a media office. As an example, the crisis units generally consist of a Regional command post, a Municipality command post and a Company command post, which are connected by internet messaging through the iCrisis app. However, any configuration at a strategic level can be applied. Groups can exchange messages (see full line arrows in **Error! Reference source not found.**); the animation team can exchange messages with all groups and also receives copies of all messages exchanged (see dashed arrows in **Error! Reference source not found.**) through the iCrisis application, to know exactly what is occurring for the participants. Journalists take part as free agents and can come by the different crisis units to collect information. Their role is essential since their interactions with the participants and their interpretation of the information they gather can originate disturbances. These interconnections and the presence of observers (see solid blue arrows in **Error! Reference source not found.**) enable the animation team to adjust the storyline based on the participants' reactions.

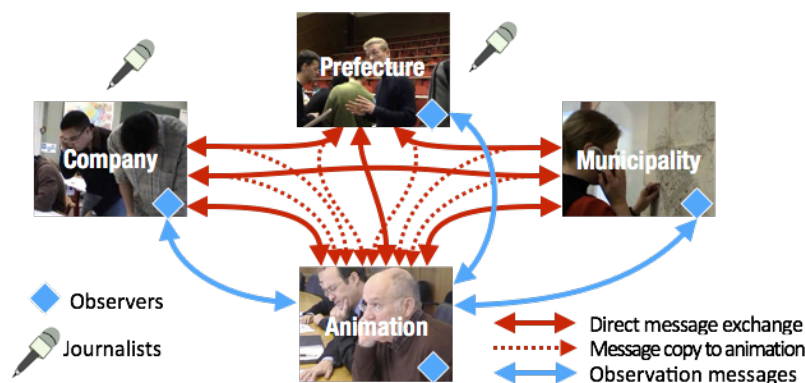


Figure 1. iCrisis simulation general overview of the organization

The simulations carried out with iCrisis run an open scenario; that is, only the context of the scenario remains set. The story of the scenario is willingly left flexible in order to be congruent

with the behaviour of the participants, which is not predictable. A debriefing that lasts for approximately two hours comes after each simulation. During the debriefing, participants from each crisis unit relate their experiences which gives to the facilitators the opportunity to talk about the pitfalls that can be encountered in dealing with the crisis situation and increase participants' awareness.

3.1.2 Objectives of an iCrisis simulation

The majority of crisis simulation objectives tend to focus on technical (capability to apply a procedure) and non-technical skills (decision making process, leadership etc.) and so as other crisis simulation approaches the objectives of iCrisis are mainly pedagogical. However, the simulations conducted with iCrisis rather aim at raising awareness of trainees about the crisis situation and the pitfalls that it carries. More precisely, the objectives are as follows, enabling participants:

- to cope with crisis characteristics;
- to perceive the state in which the manager is immersed;
- to not play own role, which enables to not feel judged and helps realize how it feels to be placed in someone else's position;
- to cope with crisis communication issues (high flow, misunderstandings etc.);
- to deal with media involvement management;
- to manage the situation at the strategic level and become conscious of the difficulty to manager the situation away from the field.

3.1.3 Crisis simulation scenario building methodology used with iCrisis

A crisis situation is by definition unique, therefore regarding one situation, one group could feel as being living a crisis whereas another not, due to previous experience. For this reason, the iCrisis approach plays an open scenario that allows adaptation of the story depending on how the participants chose to cope with the situation. That is, only the main storyline with precise information about the events is fixed but the way this information is communicated in terms of manner (*e.g.* direct message or through an involved stakeholder) and nature (*e.g.* severity of the event) is left adjustable. This adaptation must be natural and relies on facilitators and experts (*e.g.* of the event's nature or the territory) expertise.

While each crisis is specific in terms of variables and outcomes, they all reflect similar characteristics. The crisis simulation must reproduce these characteristics (Limousin *et al.* 2016) through the scenario but also through the way of playing. More precisely, the scenario enables the creation of certain characteristics of the crisis:

- **Unexpectedness:** induced by the occurrence of an extraordinary event during daily routine management situations.

- **Important consequences:** structural or organizational aftermaths induced by the occurring events.
- **Evolving nature of the problem:** starting from a warning and continuing with the occurrence of the event.
- **Irregular rhythm:** by alternating slow periods and rapid sequence of events.
- **Numerous stakeholders:** induced by the number and the diversity of events affecting many systems.

Furthermore, other characteristics are created through the way of playing:

- **Uncertainty:** by conveying unclear information about the nature, the extent and the duration of the event.
- **Information management issues:** by conveying ambiguity and by creating a high flow of information.
- **Media involvement:** created by journalists playing their role as free electrons with the right to interview the participants.
- **Chaos:** induced by the accumulation of all the above features leading to impulsive choices.

The scenario building methodology specifies the whole set of elements which form the basis of the simulation content. To model a scenario, the iCrisis approach relies on several steps (**Error! Reference source not found.**) that have been proposed by the literature and clearly sum-up by (Limousin *et al.* 2016).

The creation of scenarios is based on a multidisciplinary expertise and on documentation that must be as complete as possible, this collaborative work environment promotes realism through the expertise of professionals in the domains of the selected events. This expertise support is essential to complete each step of the methodology in order to develop a credible and plausible scenario. A very last step (n°9) comes as a “security” in the end of scenario building process to make sure that the built scenario is compatible with the objectives of the simulation that have been pre-set.

3.2 CascEff knowledge on cascading effects

Within the framework of the CascEff project, reflexions have been carried out to develop a methodology to model the cascading effects and the so-called Incident Evolution Methodology (Carré *et al.* 2017). In this part, a global overview is presented with the purpose of understanding how to consider the cascading effects in order take them into account within a crisis situation scenario.

The literature provides several definitions of cascading effects. The one underlying this paper is the definition provided by Reniers and Cozzani (2013) and adopted by the CascEff project. According to them, cascading effects are “*the result of an initiating event where*

- *system dependencies lead to impacts propagating from one system to another system, and*
- *the combined impacts of the propagated event are of greater consequences than the root impacts, and*
- *multiple stakeholders and/or responders are involved”.*

Table 2. Crisis simulation scenario building methodology used in iCrisis approach

Scenario building steps	
1	Write a synopsis to set the context (<i>e.g.</i> scale, location, nature of the problem).
2	Collect information on the territory: assets and hazards.
3	Collect information about the involved organisations (<i>e.g.</i> missions and functioning).
4	Make a list of potential events (put all your ideas on the paper).
5	Select and put the events in order.
6	Add side events of the regular life.
7	Link events with a script and adjust if needed.
8	Check consistency with the chronology.
9	Verify compatibility with established objectives of the simulation.

Table 3. Description of asset categories (Carré *et al.* 2017)

Asset categories	
Power supply	Sea transportation
Telecommunication	Agriculture
Water supply	Business and industry
Sewage supply	Media
Oil and Gas	Financial asset
District heating	Governmental asset
Healthcare	Emergency response
Education	The public
Road transportation	Environmental
Rail transportation	Political asset
Air transportation	Food supply

Several steps are needed to identify the potential cascades. The first consists in identifying the assets⁴ within the area, then characterizing these assets with regard to the category of assets (**Error! Reference source not found.**) to which they belong to, the geographical location,

⁴ in this study the terminology “asset” is chosen and refers to the word “system” previously used in the definition of cascading effects

the surface, the components, the services or products provided to other assets and the services or products needed from other assets for their proper functioning. The next step is the definition of the assets vulnerabilities (or effects that they are sensitive to) as well as their potential outgoing effects they can generate. **Error! Reference source not found.** summarizes the different categories of effects.

With reference to the retained definition of cascading effects, it is clear that there will not be cascading effects without dependencies between assets. **Error! Reference source not found.** shows a sample of dependencies between a set of assets. The purpose of this step is the identification of these dependencies as they will allow to predict which assets can be affected by the disruption of other assets and to which extent.

Eventually, the last step consists in setting the initiating event that can be described as the first event in a sequence of several events that may affect one or more of the assets within the study area. Once the initiating event is set, one can identify the assets impacted by the outgoing effects of this event then assess the outgoing effects of these impacted assets in order to identify the assets which would be affected by the assessed outgoing effects.

Table 4. Effect categories (Carré *et al.* 2017)

Effect categories	Effects sub-categories	Code
Natural	Flood / Water	(WA)
	Epidemics	(EP)
	Wild Fire	(FI)
	Ground Movement	(GM)
	Storm	(WS)
	Tsunami	(TS)
Accidental	Blast	(PRI)
	Projectile	(MI)
	Toxic effect	(TO)
	Thermal Radiation	(TH)
	Fire	(FI)
Functional	Service degradation	(SD)
	Communication service degradation	(CS)
	Water service degradation	(WSD)
	Workforce service degradation	(WFS)
	Energy service degradation	(ES)
	Food supply degradation	(FS)
Intentional	Transport service degradation	(TSD)
	Bombing	(PRI)
	Social effect	(SO)
	Hostage taking	(HO)
	Shooting	(SH)
	Fire	(FI)

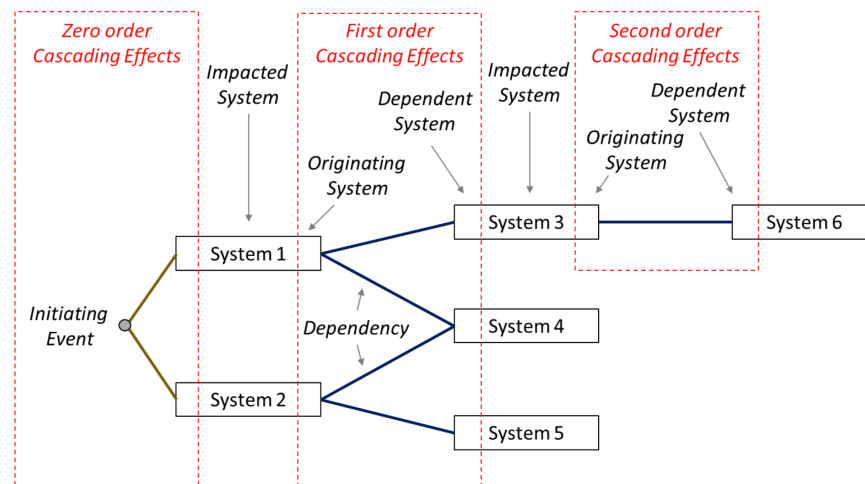


Figure 2. Sample of dependencies between systems (or assets) (extracted from Hassel *et al.* 2014)

4. RESULTS AND DISCUSSION

4.1 Presentation of the improved methodology

The scenario building methodology used in the iCrisis approach originally aims to recreate crisis situations. To run a crisis simulation that considers cascading effects, the design of the scenario has been adapted. Because the principal objective of the simulation remains unchanged, the regular scenario design methodology was kept. However, the CascEff approach to model cascading effects brings elements that had been selected to identify interdependencies between assets and thus to draw potential cascades that can be taken into account in the scenario. The main steps of the cascading effects modelling approach that have been chosen to be integrated in the iCrisis scenario building methodology is presented hereafter:

- **Identify assets:** on the chosen territory, relevant assets are identified;
- **characterize assets:** a certain number of parameters are fulfilled for each asset such as the categorization, its location, its surface, its own services, its connected services with other assets, its number, the number of people, economic information etc. This list must be adapted by the scenario designer in regards with the relevant needed information;
- **definition of incoming effects:** based on a list of effects, the scenario designer has to determine to which effect an asset is vulnerable. At this stage, values about effects and threshold can be implemented if needed;
- **definition of outgoing effects:** same as previous (3.) but for the effects an asset can generate;
- **identification of dependencies:** based on previous information about assets, physical and functional interdependencies between assets;
- **set of initiating event:** it generates an effect whose aftermaths trigger the cascade.

These six steps resume the process to draw potential cascades on a territory and with regards to chosen events that must be considered. The adaptation of the regular crisis scenario building methodology consists in precisising some steps to obtain the relevant information in order to draw cascades. This adaptation is presented in the **Error! Reference source not found.** where the majority of the original steps remains unchanged or adjusted (1-3 and 9-12). Former steps 4-5 (**Error! Reference source not found.**) dealing with the created events and their order of occurrence defined based on reflexion have been removed and replaced by steps to frame the determination of the potential cascade of events (in bold in table 5).

This methodology can be implemented on any type of crisis simulation scenario (natural, industrial or intentional disasters). It is adjustable in terms of asset categories, effect types as well as in terms of data level of precision which enables to apply it with simulation participants of different backgrounds (*e.g.* students, professionals).

4.2 Implementation of the methodology: The Alpine area scenario

The Alpine area scenario is a fictitious scenario that belongs to low probability with high consequences type of scenario. The established database for this scenario has been created with information found in public publications and discussions with experts. However, for

confidentiality reasons, the assets and locations remain unnamed in this article. The situation takes place in an alpine valley where assets characterized by cities, chemical industries and main roads are mostly gathered in the bottom of the valley surrounding a mountain stream. This fictitious scenario takes place nearby the city of Grenoble in France. One particularity of this alpine valley is that there is a mountain slope characterized by constant rockslides that threatens to collapse entirely which would create a natural rock-dam in the valley causing retention upstream and potentially a flood wave downstream once the natural rock-dam collapses. Basically, the scenario consists in a double cascade of events induced by an earthquake:

- the rockslide of the entire mountain slope that creates a natural rock-dam in the valley which interrupts the stream of the river generating a flooding upstream and finally, the pressure of the water retention provokes the collapse of the natural rock-dam creating a flooding wave downstream;
- a disruption in a chemical process of a plant generating a blast affecting a train carrying hydrocarbon that fires causing multiple disturbances in the industrial area causing aftermaths at a wider scale.

The identification of the assets on the territory is presented on a map (**Error! Reference source not found.**). The list of assets has been thoroughly made in regards to the objectives of the simulation to focus on buildings open to the public. The characterization of the assets enables to categorize them and to be represented with different colours as shown on the map. The geolocation of assets brings out an insight on the configuration of the territory and the spatial distribution of the assets. It reveals that the assets are mainly concentrated in the valley which accentuate the proximity between them. The other characteristic of an alpine valley is that there is only one main road and potentially one rail way which enables the entirety of the local travels.

Table 5. Crisis simulation scenario building methodology considering cascading effects

Scenario building steps	
1	Write a synopsis to set the context (<i>e.g.</i> scale, location, nature of the problem).
2	Collect information on the territory to identify assets and hazards.
3	Collect information to characterize assets .
4	Determine asset vulnerability in regard to incoming effects.
5	Determine the asset potential generated effects.
6	Draw the assets interdependencies.
7	Set the initiating event.
8	Choose a potential cascade based on the initiating event and a possible propagation.
9	Add side events of the regular life.
10	Link events with a script and adjust if needed.
11	Check consistency with the chronology.
12	Check consistency with the established objectives of the simulation.



Figure 3. Alpine area scenario assets location (zoom view)

Table 6. Examples of assets incoming and outgoing effects analysis and dependencies

ID of asset	Asset cat.	Asset vulnerability effect	Pot. gener. effects	Potential impacted assets
S3	B. & I.*	WA, EP, FI, GM, WS, TS, PRI, MI, TO, TH, SD, CS, WSD, WFS, ES, FS, TSD, PRI, SO, HO, SH	TH	Nd* S1 S4 S7 S13 S56 S57 S59 S58 S60
			PRI	Nd S1 S4 S7 S13 S56 S58 S60
			FI	Nd S1 S4 S6 S7 S13 S41 S56 S57 S58 S59 S60 S63
			TO	Nd S1 S4 S6 S7 S13 S14 S15 S16 S30 S37 S38 S39 S41 S42 S43 S44 S56 S58 S60
			MI	Nd S1 S4 S6 S7 S13 S41 S56 S57 S58 S59 S60 S63
S4	B. & I.	WA, EP, FI, GM, WS, TS, PRI, MI, TO, TH, SD, CS, WSD, WFS, ES, FS, TSD, PRI, SO, HO, SH	TE	Nd S3 S7 S59 S60
			PRI	Nd S3 S7 S58 S60
			FI	Nd S3 S7 S57 S58 S59 S60
			TO	Nd S3 S6 S7 S57 S58 S59 S60 S63
			MI	Nd S3 S6 S7 S57 S58 S59 S60 S63

* B. & I. = Business and Industry; Nd = neighbourhood

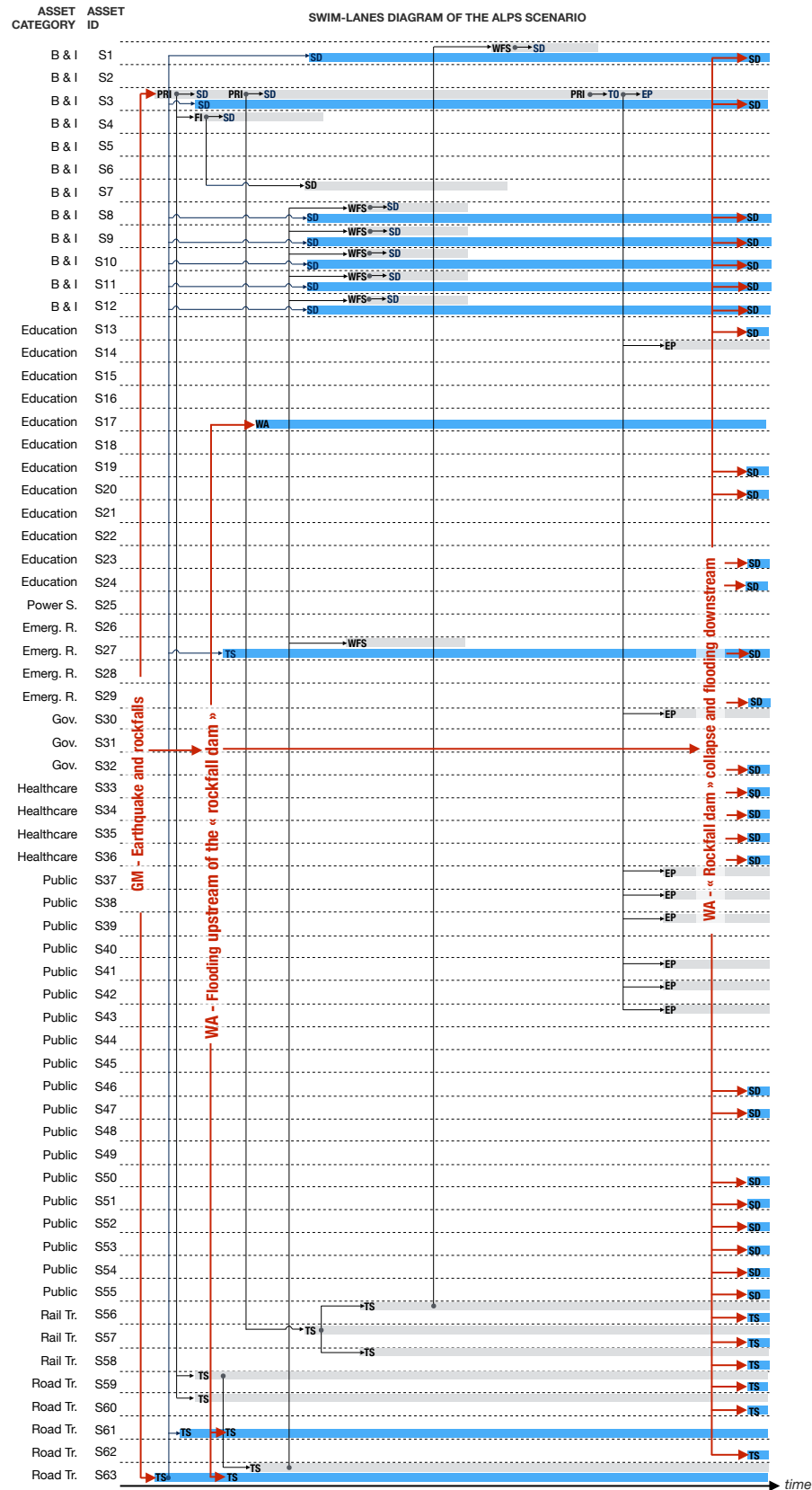


Figure 3. Alpine area scenario assets location (zoom view)

For each asset, its vulnerability, its potential generated effects and dependent assets are defined and highlighted (here for two examples) in a table (**Error! Reference source not found.**). For this scenario the analysis has been conducted under the expertise of relevant experts such as a local inhabitant; an industrial-risk expert; a local natural-risks manager; an officer from Fire and Rescue services; and a regional authority representative). By doing so, for each asset on the territory its potential dependent asset is identified showing for instance that if “S3” is impacted by a fire (FI) which causes the generation of a toxic effect (TO) then nineteen assets and the surrounding neighbourhood would be impacted. The power of this methodology is its capability to improve the level of details. Indeed, whether one would want to develop a scenario at a higher level of description, values of effects and vulnerability threshold for example could be added (Carré *et al.* 2017).

Eventually, based on the dependency analysis, the scenario designer makes choices to come upon with potential cascades and the scenario under the shape of a swim-lanes diagram (**Error! Reference source not found.**). The swim-lanes diagram appears to be a relevant manner to present the crisis situation scenario that considers cascading effects for two reasons: firstly, it illustrates the dependencies between the involved assets very easily with enough information about the time (impact time, resistance time etc.) and the nature of effects (incoming and outgoing) for instance; secondly, the fact that there are no pre-defined messages, gives to the simulation animators a certain freedom regarding how to inject the information in order to adapt the story to the players reactions. For the Alpine area scenario, as mentioned above, two main events are occurring. They are illustrated in the diagram by two colours: blue for the cascade of events in relation with the rockslide whereas grey is used for the cascade induced by the industrial accident. The red represents the initiating event which is the earthquake and the problems that deal with the natural rock dam which is not an identified asset even though it plays an important role behaving as an asset (vulnerable to incoming effects and generator of potential outgoing effects). This synthetic way of representation shows easily the cascade(s) of events with the possibility to quickly focus on a part of the chain where or when the consequences could be very critical. In our case, one example is the clear representation of the high consequences that would be if the collapse of the “rockfall dam” occurs with thirty-three on the sixty-three systems would be affected.

This methodology highlights that, starting from the regular crisis scenario methodology to which elements of the cascading effects analysis methodology are added, a crisis scenario considering cascading effects can be created. However, the characterization of the environment, here the systems needs to be a dedicated work in order to develop a chain of events that responds to the most important condition of scenario which is : plausible and credible. To do so, a very good knowledge of the territory is required, inducing the support of experts (technical, local *etc.*).

5. CONCLUSION

In the risk management community, there is a growing concern on better understanding

cascading effects, its representation and its consideration in the risk cycle and also during a crisis situation. To respond to this need, crisis simulation approaches which originally focus on the basic objective to recreate a crisis situation, thus had to consider the implementation of cascading effects within the methodology. Regarding the notion of cascading effects, since it deals with the simulated story, it was decided that its consideration should be done through the scenario.

Based on the knowledge produced by the CascEff project about the concept of cascading effect, it was studied how the original crisis simulation scenario building methodology should be adapted to consider them. The choice of adapting the original methodology relies on the fact that the main objective remains the creation of a crisis situation. Based on that fact, it was clear that the nature of the story to be played through the scenario could take into account cascading effects whose modelling relies on improving and precising original steps about the characterisation of the environment.

The methodology has been presented for the iCrisis crisis simulation approach because it was implemented in this tool. However, it is characterized by its flexibility that enables its implementation in other crisis simulation approach and at different levels of precision.

The Alpine area scenario highlights, through its representation, that the methodology is suitable. Moreover, it was utilised and enabled to fulfil the CascEff project objectives (Edjossan-Sossou *et al.* 2017) without altering at any point the pedagogical capacities of the iCrisis approach about experiencing the characteristics of a crisis situation.

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