Three Units of Analysis for Crisis Management and Critical Infrastructure Protection

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ABSTRACT

Society's welfare is very dependent on the effective performance of Critical Infrastructure (CI). Nowadays, CI constitutes a network of interconnected and interdependent entities. This means that a serious event in one CI can originate cascading events in the rest, leading to a serious crisis. As a consequence, Crisis Management (CM) and Critical Infrastructure Protection (CIP) should converge and integrate their findings, providing a more unified approach.

One relevant issue when developing integrated CM/CIP research is what type of unit of analysis should be used, as it conditions the research objectives and questions. This paper presents an analysis of three different units of analysis used in CM research, focusing on the research objectives and questions used in them. These three different units of analysis have been used in a European CIP research project where three simulation models have been developed based on these three units of analysis.

Keywords

Crisis management, critical infrastructure protection, modeling and simulation, crisis peak, crisis lifecycle, multicrises scenario, system dynamics.

INTRODUCTION

The welfare of society has exponentially grown in recent decades in almost every country throughout the world. Advances in health, education, energy, communication, etc. have supposed significant benefits for our quality of life. But, at the same time, this has also increased our dependency on the infrastructures that support these services which have become critical for us. Consequently, the concept of Critical Infrastructure (CI) has been created to define assets which are essential for the functioning of our society. Although there is not a unique list of CI, some infrastructures such as Power or Health are unanimously accepted as critical. Nobody could imagine our world without power or hospitals.

One characteristic of current CI is their interconnectivity. This means that a problem which takes place in one particular CI can expand through the CI's network, causing cascading effects in other CI. This is quite easy to imagine. For instance, a serious problem in the power supply would have consequences in many other CI, as some of them can only have autonomous power generation capacity for a limited time slot. Analogously, a pandemic which initially would only impact the health sector could also expand its consequences to any other sector, when the availability of skilled operators reaches a critical point.

According to Rinaldi (2004) there are four different types of CI interdependencies:

1. Physical: If the state of each CI depends upon the material output(s) of other CI.
2. Cyber: If the state of a CI depends on information transmitted through the ICT infrastructure.
3. Geographic: If local environmental changes affect the CIs in that region, e.g., when the flooding of a reservoir knocks out a generator, this implies close spatial proximity.

Reviewing Statement: This full paper has been fully double-blind peer reviewed for clarity, relevance, significance, validity and originality.

4. Logical: If the state of each CI depends upon the state of another via policy, legal, regulatory or some other type of governmental mechanism.

Thus when we think of CIs, we can not think of them as isolated entities, but as a network of interconnected and interdependent elements. But knowing that interdependent CIs are essential for our welfare is not enough; we also have to design and implement measures which allow their efficient performance. This is the reason for having created a new knowledge area known as Critical Infrastructure Protection (CIP). This is a recent concept which was consolidated in the USA under the Presidential Directive in 1998 and in Europe through the European Programme for Critical Infrastructure Protection (2006)[1].

This means that CIP is still an incipient area of knowledge. Recent reports have confirmed the lack of development in this area of research (Bologna et al., 2006), with very fuzzy and confused boundaries. Initially, CIP was more focused on technical aspects, but when the concept developed and matured, more organizational, economic, legal and social aspects have also come into play.

Moreover, humans have suffered crises throughout history due to pandemics and natural disasters. Consequently, there has always been some academic interest on how to reduce the probability of a crisis occurring and mitigating their impact. The Crisis Management (CM) area of knowledge has evolved from observing crises as almost random events to perceive them as dynamic evolving processes. As Coombs (2007) states, a crisis does not happen, it evolves. This perspective about crisis as evolutionary processes still has to be transferred from CM to CIP.

Two are the main objectives of this paper. The first one is to identify and explain the three units of analysis that can be used when analyzing a crisis. Here, explaining the scope and the main indicators must be taken into account. The second one is to show three models created for crisis management based on the three units of analysis.

To achieve these two objectives the paper is structured as follows; the second part explains the three units of analysis that can be used in CM, in the third point how those units of analysis have been applied in the SEMPOC Project is commented with the help of a diagram for each model. In the last part the general conclusions are presented.

THREE UNITS OF ANALYSIS IN CRISIS MANAGEMENT

The "unit of analysis" concept is used in social sciences to define the major entity that is being analyzed in the study (Babbie, 2007). Once the unit of analysis is defined, the relevant research questions and objectives can be established.

During this bibliographical review, we have identified three different and complementary units of analysis which have been used to identify the research question and objectives that a research project in CIP/CM should deal with.

ANALYSIS UNIT 1: THE CRISIS PEAK

The peak of the crisis is the phase which receives more attention from Society. Crises are perceived as rare "events", which happen with a very low frequency (Pearson and Clair, 1998). This means that decision makers, mass media, and society tend to ignore their occurrence probability. As a consequence, the crisis peak episode surprises them, being very visible especially when the crisis directly affects population and the mass media echoes the event.

Crises are usually caused by a triggering event, which is usually considered the origin of the crisis. This event and its immediate temporal surroundings are usually analysed in detail by official and unofficial reports. This approach tends to present a crisis as the consequence of an exceptional event. Thus, this type of research tends to focus on the technical aspects of the event which triggers the crisis, and on the details of the immediate response.

Many reports that analyze crises concentrate on the peak of the crisis. The analyzed time scope is quite narrow since they only concentrate on studying the system's evolution some hours before the triggering event and the resolution of the problem during the following days or weeks.

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[1] http://europa.eu/legislation_summaries/justice_freedom_security/fight_against_terrorism/l33260_en.htm

For instance, in the report that analyzes the Italian Outage occurred on 28th September 2003 (UCTE, 2004), authors analyze the details of what took place during the few hours before and after the triggering event. The root cause of this power outage was that a single line was overloaded and the weather conditions were extreme, due to strong wind and high humidity. As a consequence, the protection system was activated disconnecting the line from the power system. This provoked a cascading effect overloading the remainder connected lines. This overload, in turn, crashed the grid.

Another similar example can be found in Canada in 2003 (US-Canada Power System Outage Task Force, 2004). Deficiencies in specific practices, equipment and human decisions were the main causes of the outage. The workers of the company were not proficient in the use of the system, they failed to assess and understand the inadequacies of the system and they did not know which the critical points of the system were. Maintenance work was being done on some generators during this period. Due to the hot weather, many air conditioners were being used and electricity demand increased considerably achieving peaks in electricity supply. However, the one responsible of overseeing the power grid and administrating the electricity market, MISO, was not aware of the unavailability of those generators due to previously mentioned maintenance tasks. Additionally, the information about what was happening was not well interpreted by the managers which meant they were not aware of the critical state of the power grid. In addition, the workers failed to adequately handle the repair tasks creating some technical problems. The communication systems did not work as expected either and MISO did not receive the information about what was happening in real-time. As explained before, the interconnectivity that exists among different Critical Infrastructures provoked a cascading effect disturbing a number of nuclear power plants. Nine nuclear power plants tripped within about one minute as a result of the grid disturbance.

The American Society of Civil Engineers developed an in-depth analysis of the causes as to why the levees protecting the area of New Orleans collapsed (2007) during Katrina hurricane. This report is an excellent example of a profound and detailed study about the immediate causes of a big disaster. The report goes directly to identify which were the design, construction and maintenance vulnerabilities which led to a risky situation, but does not analyze the evolution of the crisis preparation activities or the hurricanes' long term impacts.

Having analysed reports which use this unit of analysis, we can conclude the following about the objectives and research questions of this type of analysis:

<u>Objectives of the research using the Crisis Peak unit of analysis</u>

- *Reduce the crisis occurrence probability*. Avoiding the occurrence of the crisis is, of course, the best alternative. These studies try to identify the root causes of the crisis to define countermeasures which could have enabled the system to prevent the crisis.
- *Reduce the crisis impact*. These studies also analyze which were the mechanisms that amplified the crisis impact and made possible the cascading affects that ended up disturbing different critical infrastructures. The objective is to define efficient measures that can isolate a problem and avoid its impact on other CI.

<u>Research questions</u>

- *Which are the conditions that allow the occurrence of a crisis peak?* There is a strong interest in the root cause(s) of the crises. Any study using this unit of analysis emphasizes this, providing details about the crisis triggering event(s).
- *Which are the (exploitable) vulnerabilities?* In some cases the system can be vulnerable due to the existence of weaknesses. Indications about these vulnerabilities and the knowledge that exists about them at the time of the crisis are frequently mentioned.
- *How can the impact of a crisis be mitigated?* These studies also analyse the effectiveness of the measures put in place for reducing the crisis impact.
- *Which are the stakeholders' coordination mechanisms?* Usually the first response to a crisis is not the responsibility of a single agent. In these stressful environments the proper performance of coordination mechanisms can be a key success factor for the crisis response.
- *How do CIs' interdependencies affect the crisis evolution?* Once a CI is affected, this can create cascading effects within other CI. An excellent example of this type of phenomena is a power grid. Some papers also deal with the affects of problems in one CI on the rest of them (US-Canada Power System Outage Task Force, 2004).

ANALYSIS UNIT 2: THE CRISIS LIFECYCLE

Reports and papers using this unit of analysis observe the crisis from a more long term perspective. In addition to some details on the crisis peak, they also analyse the long term consequences, taking into account the whole lifecycle of a crisis and evaluating its behaviour on the pre, peak and post-crisis, providing a more holistic evaluation. This unit of analysis also allows crisis managers to assess the success of the applied prevention and preparedness activities. This unit of analysis is the one most commonly used when dealing with the economic impacts of a crisis.

For instance, Kahan et al. (2009) analysed the potential evolution of crises based on the type of crisis preparation. They identified three potential strategies for increasing the resilience of a system against a potential crisis by increasing each of the three types of resilience components: resistance, restoration and absorption. As a consequence, they related what happens during the post-crisis phase to what had been done in the pre-crisis phase without paying significant attention to the crisis peak details.

There are many modeling methods to analyze and evaluate the whole lifecycle of a crisis (Cochrane H., 2004; Rose and Lim, 2002): Input-Output models (I-O), Computable General Equilibrium models (CGE), Linear Programming models and Econometric models. Most models represent the evolution of the economy in a region and, adapting some features of these models, they can be used to determine both the short and long term effects.

Although crises always generate negative impacts, sometimes some sectors may increase their economic activity due to the reconstruction phase. Guimaraes et al. (1993) presented an econometric analysis of Hurricane Hugo in which the economic benefits in some sectors, such as construction, agriculture, transportation and public utilities, can be seen. Based on econometric models, they quantified the economic effects generated by the hurricane focusing on *with and without* a crisis. First, they forecasted how the economy of the region would have evolved if the hurricane had not happened and, for that, they took the data from the state previous to the disaster. Then, they measured the real value of the economic variables after the occurrence of the crisis and the gap between both variables gave the real impact.

Linear programming can also be used to evaluate direct and indirect impacts of a crisis. Rose et al. (1997) used this method to evaluate the impacts caused by a disruption of an electricity lifeline due to an earthquake. The data needed to define the factors of the model's equations are taken from historical data. The paper shows different simulations based on the system's level of resilience. The first simulation supposes that the level of system resilience is 0. The second one assumes that the level of resilience is higher, but not the optimum, since they optimize the way in which the resources are reallocated. Finally, the last one represents the maximum resilience level where not only is the reallocation of resources optimized but also the restoration process.

Gordon et al. (1998) evaluated the transport-related impacts due to the Northridge earthquake in 1994. In order to get the information about the problems that firms and individuals had related to transport, they carried out some surveys. Once they had obtained data about the amount of people and companies affected, they estimated the decline in final demand in the economic sector. Input-Output models facilitate evaluating the effects in one sector when certain effects in another related sector occur. The authors used this methodology to estimate the effects in sectors related to final demand.

The CGE models are actually the most used ones in order to evaluate the economic impacts and policy analysis of a crisis and they solve many weaknesses that other models represent. Rose and Guha (2004) used this type of model to evaluate the impacts on electric utilities due to an earthquake in Shelby Country (Memphis, Tennessee). Different simulations based on different crisis phases and with different resilience levels were carried out to see how the total economic impact changed in different situations.

Having analysed reports which use this unit of analysis, we can conclude the following about the objectives and research questions of this type of analysis:

Objectives of the research using this unit of analysis

- *Connect the efforts of the pre-crisis phase to the behaviour of the crisis peak and post-crisis phase*. The best result of an effective crisis mitigation strategy is that nothing happens. This means that the return of investment of such a strategy is not easy to perceive. These studies work on making the cause-effect relations of mitigation policies and crises impact values explicit.
- *Develop holistic methodologies that allow determining the impact of a crisis*. Crises may have a long series of consequences which are not immediately observable. Evaluating these impacts is also a highly interesting area for researchers. These studies focus on identifying and evaluating crises' direct and indirect impacts, emphasizing in the latter, which are less visible at first sight.

Research questions

- *Which type of efforts can we develop during crisis preparation?* Crisis preparedness can be seen as a resilience building process. Understanding in depth how resilience can be built will allow a more efficient use of resources for this purpose. These studies research the resilience components and their dynamics.

- *Which is the pre-crisis effort's outcome on crisis impact reduction?* As mentioned before, the crisis preparedness pay-off is not easy to recognize. Studies which relate what has been done before the crisis triggering event to its consequences are of special interest for the researcher community.
- *Which types of methodologies can we use to determine crisis impact, including long term effects?* Gathering detailed information about all the possible consequences of a crisis occurrence is a necessity for a better estimation of the crisis impacts and the preparedness policies' effectiveness. The usefulness of different available methodologies is analysed in this studies.

ANALYSIS UNIT 3: THE CONTINUOUS MULTICRISIS SCENARIO

This unit of analysis researches how Crisis Management evolves over time, focusing on the learning process derived from the crises occurrence. This type of research adopts a long term perspective, where different crisis peaks can take place (and some others might be avoided due to effective prevention policies).

Crichton et al (2009) analyzed in depth the different types of learning that can be obtained from previous events. For this purpose, they analyzed seven different crises that happened in different systems and identify the obtained "lessons learned". They discovered 47 distinct lessons learnt from these crises, and although they analyze different systems and crises originated by diverse triggering events (fires, power outages, floods, rail crashes and others), they catalogued them in eight categories. Their main message is that it is not enough to learn from just the sector one organisation belongs to, but that it is much more effective to take advantage of the learning that can be obtained from the crises that occurred in other sectors, as recurring problems can be extrapolated or translated from one sector to others.

Elliot (2009) identifies and documents four barriers which impede an efficient organizational learning from crises:

- The persistent failure to translate acquired knowledge into new behaviours.
- The difficulties to effectively implement and comply the regulatory regimes (when they are updated).
- The institutional field forces that may block or diffuse changed norms and behaviours on institutions that are usually overloaded and under resourced.
- The little attention given to the development of a culture of information sharing.

Deverell and Olsson (2009) compared learning which takes place in two organizations similar in scope, mission, size and operations. While the first organization had a centralized managerial crisis management style, the second one had a more decentralized one. Analysing the type of learning that took place in both cases, they concluded that the "centralized" organization developed a cognitive type of learning, that is, a learning inferred from experience residing in the minds of the top managers, while the "decentralized" one resulted in a behavioural learning, which results in the creation of new organizational structures and standard operative procedures.

Having analysed the mentioned papers and some others that use the same unit of analysis, we can conclude this about the objectives and research questions of these type of analysis:

<u>Objectives of the research using this unit of analysis</u>

- *Improve the learning process.* Organizational learning has been a traditional research field, but learning specifically about crisis management has some connotations; as their occurrence rate is usually very low and many agents are involved in their management. This makes exploring this type of learning process a challenge for researchers.
- *Identify learning barriers.* What impedes efficient learning? Answering this question through the analysis of unsuccessful cases can shed light to improve this process.
- *Characterize different learning types.* Learning activities do not constitute a homogeneous process. Researchers can find particularities that condition the learning of different agents.

<u>Research questions</u>

- *What and how can we learn from one crisis to another?* The analysis of different cases can illustrate how learning takes place. Crises have different natures and circumstances; but they also have some higher level characteristics that can be extrapolated from case to case, and from sector to sector.
- *Which are the elements conditioning this learning process?* Learning does not occur in the same way in different cases. It is relevant to investigate which are the learner's characteristics that condition this process. There are studies that have identified some clues that can explain differences among learners' learning processes

- *Are there also forgetting mechanisms?* The final step of any successful learning process is using what has been learnt. Researchers have also shown interest in determining why some lessons that should have been learnt are apparently forgotten and not put into place.

APPLYING THE THREE UNITS OF ANALYSIS TO THE SEMPOC PROJECT

The SEMPOC (Simulation Exercise to Manage POwer cut Crises) project does research into the combination of CIP and CM. The SEMPOC project analyzes a crisis originated in one CI (Power sector) and its consequences, not only within this sector, but also on all other CIs and society as a whole.

The SEMPOC project takes advantage of the knowledge already developed in the crisis management field to export and integrate it within the CIP field. Thus, the SEMPOC project uses the three units of analysis identified in the crisis management literature review and adapts them to the case under study. This project uses modeling and simulation techniques, and consequently some decisions about the scope, boundaries and time horizon of these simulation models had to be made. Using these three different units of analysis leads to the development of three different simulation models, which will be explained in next section. Each model captures the elements needed to shed light on the objectives and research questions defined for each unit of analysis in the previous section.

To elicit knowledge from experts, three workshops were organized and in each of them, one different unit of crisis analysis was worked out. During these workshops a collaborative methodology called Group Model Building (GMB) (Andersen et al., 2007; Andersen et al., 1997; Rich et al., 2009) has been used to elicit fragmented domain expert knowledge. After that, using System Dynamics (SD) (Forrester, 1961; Sterman, 2000) the modelers developed simulation models which reproduce the behaviours identified by experts.

The First Model

The first workshop and the corresponding model were focused on the peak of the crisis; the experts analyzed the triggering event and the immediate response without evaluating the pre-crisis and the post-crisis periods. The scope of the developed model was sixteen days; two previous to the outage and fourteen after the event.

The power sector, government, clients and socio-political effects were identified as the most influential sectors during the peak of the crisis. Figure 1 shows the relationship among different sectors.

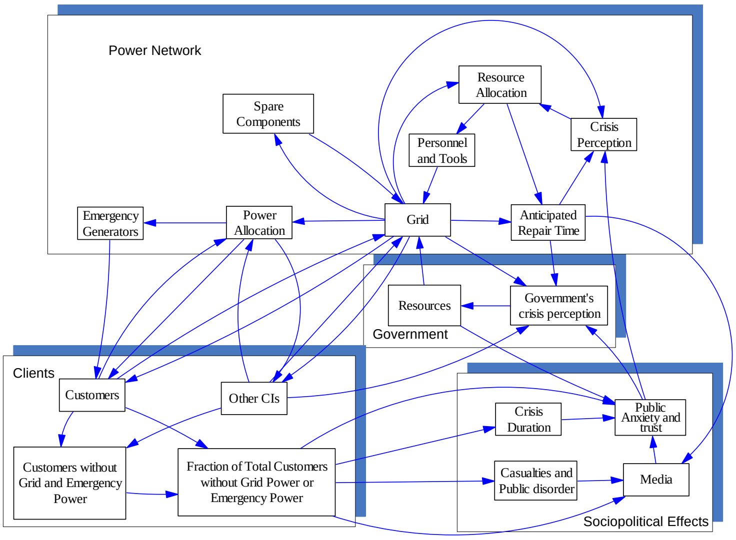

Figure 1: Diagram of the crisis peak model

The Power Network sector refers to the availability of the Power Network to respond to the clients' needs. When a blackout occurs, a certain percentage of the grid is out of work. An adequate maintenance of the line provides a more robust power system and allows reducing the number of components that can be damaged. The availability of spare components and well trained workers reduces the response time which decreases the impact.

The Clients sector corresponds to the amount of customers that have access to the energy. If the availability of the Power Network is reduced, some clients will be affected. However, some customers, such as Critical

Infrastructures, have emergency generators that allow them to maintain their normal activities in case of a blackout.

The unavailability of energy generates socio-political effects, such as, public anxiety. This variable is very sensitive to the media's reaction and the duration of the crisis. The level of distortion in the news can increase the rejection of the public to the crisis managers increasing the public anxiety. The longer the duration of the crisis, the greater society's anxiety will be.

The last sector corresponds to Government, which can help in the resolution of the problem. Its contribution will be influenced by the socio-political effects and the extent of the outage. In addition, if Government presents a weak commitment towards the crisis resolution public anxiety will increase.

The Second Model

The second workshop and the corresponding model focus on the second unit of analysis identified in the literature: the entire crisis lifecycle. This time, the scope of the crisis is longer, ten years in order to analyze not only the peak of the crisis, but also the pre- and post-crisis phases.

Figure 2 summarizes the relationships among the main variables of the entire lifecycle model.

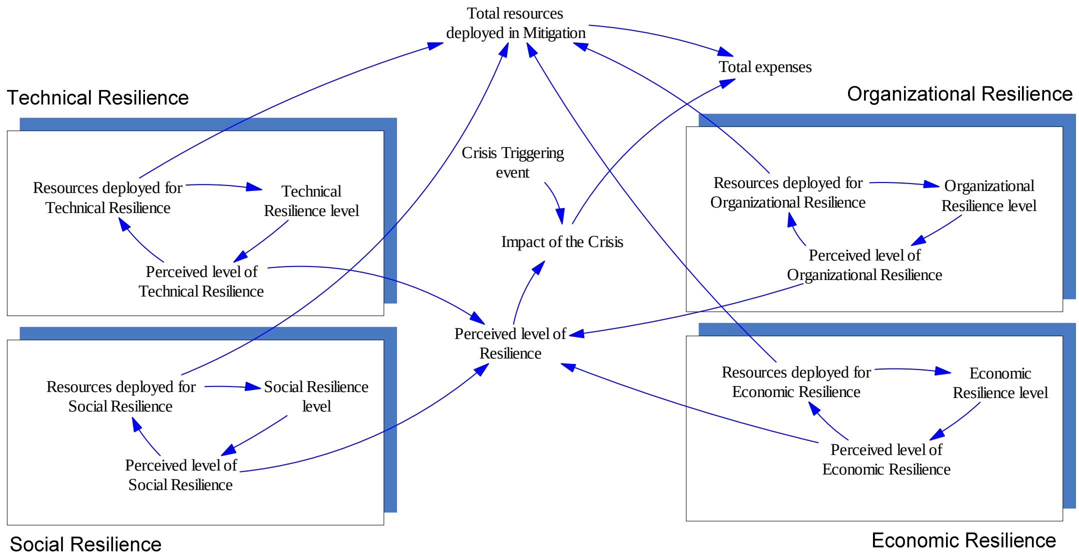

Figure 2: Diagram of the crisis lifecycle model

Different measures taken in the pre-crisis period can help to reduce or even avoid the occurrence of a crisis. Resilience is defined as the ability of the system to reduce the failure probability, reduce the consequences from failures (abrupt reduction of performance) and reduce the time to cover actions that reduce losses from crises (Bruneau et al., 2003). Resilience can be desegregated in four different dimensions (Bruneau et al., 2003; MCEER, 2008): Technical Resilience, Organizational Resilience, Social Resilience and Economic Resilience. During the workshop, experts identified several policies which crisis managers can work on to improve the resilience level of the system. Each policy affects one or more dimensions of resilience as can be seen in Figure 3.

RESILIENCE DIMENSIONS	Technical Resilience			Organizational Resilience		Economic Resilience	Social Resilience			
VARIABLES IN OUR MODEL	System Design	Maintenance	Data Acquisition and Transmission system	Detection Communication and Analysis	Organizational Training	Power Company Budget	Government and First Responders Training	External Training	Legal and Regulatory issues	Public Budget

Figure 3: Relations between the policies and Resilience's dimensions

A high resilience level allows reducing or even avoiding the impact of a crisis and, consequently, the impacts generated. However, achieving a good level of resilience is a difficult task because mitigation activities are very costly and resources are usually scarce. Therefore, in order to optimize the resources applied to crisis management, crisis managers should evaluate the cost-effectiveness of mitigation measures to minimize the total expenses.

The Third Model

The last workshop was focused on a larger time scope where several crises happen. The model analyzes how the lessons learned from one crisis to another are applied. The time horizon of this last model is twenty years in order to be able to represent more than one crisis, and the subsequent learning process.

Figure 4 shows the diagram of the third model continuous multicrisis scenario where various crises are simulated. Traditionally, models used to represent learning and improvement processes are constituted by one loop or cycle (Kim, 1994). Analogously, this diagram captures the learning process which happens from crisis to crisis.

The learning cycle is constituted by three main elements: events and outages, indicators and experience and learning.

The occurred events and outages have to be investigated. Once they have been investigated they can be translated to leading indicators, that is, to indicators which are able to represent the system's current status. These indicators become the explicit information about the system behaviour.

The continuous use of these indicators allows the development of experience within the agents responsible for mitigating and responding to crises. The more experience these agents have, the more efficient they are at developing mitigation and impact reducing policies.

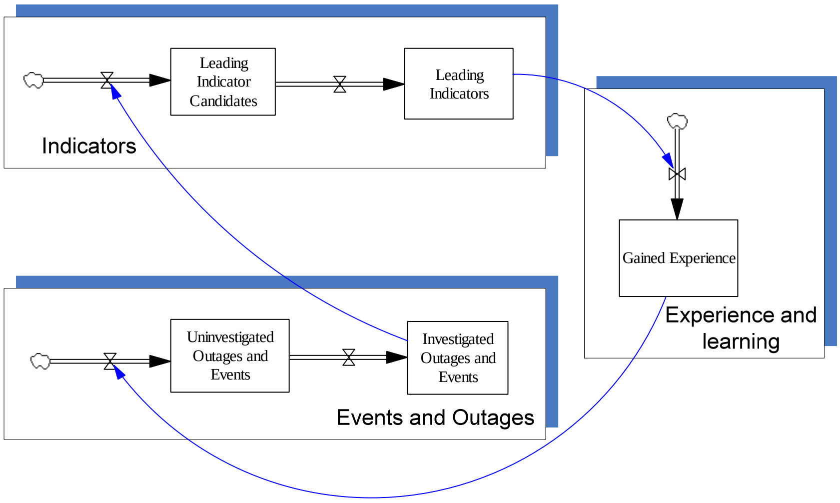

Figure 4: Diagram of the continuous multicrisis model

CONCLUSIONS

The existence of infrastructures critical for society's welfare adds some challenges to traditional Crisis Management. At the same time, Critical Infrastructure Protection should take into account advances in the Crisis Management field. So we can conclude that both fields need to go on taking steps forward in their convergence process.

A relevant question for researchers in the Critical Infrastructure Protection field is what type of unit of analysis should be used. Crises affecting CIs can be observed as low probability events that have to be responded to, so in this case, the details that refer to the crisis triggering event become very relevant and an in depth case specific analysis is carried out. But crises can also be seen as cumulative processes where system vulnerabilities and system resilience evolve over time. It is the evolution of these two aspects that conditions crisis occurrence probability and impact size.

The third approach focuses on crisis to crisis relations. A crisis event can weaken the system and make it more vulnerable to subsequent episodes. But crisis managers can also learn from previous crises and improve their preparedness based on learnt lessons. This multicrisis perspective adds new insights to the problem analysis.

Obviously, the unit of analysis used conditions the objectives and research questions that can be posed. Using these three units of analysis allowed the development of three different simulation models within the SEMPOC project, which analyses the overall evolution of a severe crisis originated due to problems in the Power sector in Europe. The use of the three units of analysis has lead to the development of three perspectives that complement each other, allowing the generation of different elements of knowledge which can satisfy the diverse needs of the various agents involved in managing crises that affect CIs.

The developed models have been useful to make explicit which are the elements and variables that have to be more precisely defined and calibrated to build the answers for the research questions posted for each unit of analysis.

ACKNOWLEDGMENTS

The SEMPOC project is supported by European Commission – Directorate-General Justice, Freedom and Security in the framework of the European CIPS strategic objective.

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