Supporting Course of Actions Development in Emergency Preparedness through Cross-Impact Analysis

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ABSTRACT

Emergency plans are developed to serve as a basis for response actions required in real situations. However, plan development is not an easy task and usually relies on complex processes. Due to the uncertainty of emergencies, one of the most challenging tasks is the development of possible courses of action. To deal with this uncertainty, we propose the use of scenario techniques for the definition of courses of action. Specifically, we adopt the use of CIA-ISM scenario technique for structuring the chain of events that can occur in a crisis that would support planning teams to develop courses of action. A practical application of the methodology has been successfully conducted by an emergency planning team in Brazil. The practical application of the CIA-ISM process was supported by a software artifact called CAEPlan. Lessons learned about the empirical application of both the methodology and the software artifact are presented.

Keywords

Planning. Emergency Plan. Scenarios. Course of Action. CIA-ISM. Emergency Support Systems.

INTRODUCTION

Emergency events can be derived from the dynamic effects of nature like rain, earthquakes, tsunamis, among others, or actions conducted directly or indirectly by man. The emergency events are capable of generating losses of material and natural goods, and most importantly human lives. Preparing for such events or similar events is critical to minimize these risks by requiring that every risk event should be observed and studied so that preventive measures can be taken. In this sense, the highest frequency in the 21st century of extreme natural events responsible for many disasters, and increasing emergency situations caused by humans accidentally and intentionally, such as fires, explosions and terrorist attacks reinforce the need of tools for supporting the emergency management with special attention to the actions of disaster prevention and preparedness for emergencies and disasters (Castro, 1999, Aldunate et al., 2006; IPCC, 2007).

One way of improving the management of emergency situations is by the definition of suitable Emergency Plans as well as by the training of participants in the application of such plans. An Emergency Plan is defined as a document that compiles both the prevention rules and the procedures to be applied in an emergency situation, as well as existing laws, by detailing all potential incidences that might occur and influence its management. In order to design a good Emergency Plan, experts from different areas need to work collaboratively to identify all the events and the relationships among such events (FEMA, 2010). Scenarios are frequently used during this collaborative process based on significant events that have occurred in the past, and need to be updated to take into account the current conditions (Bañuls and Turoff, 2010). Scenarios are stories about people and their activities, and are characterized by well-defined attributes, usually indicating the nature of the happening (e.g., an accident), the product involved (if applicable), the site where something occurred, and the environmental conditions under which it took place. They can also be abstracted and categorized, facilitating designers recognize, capture, and reuse generalizations. Besides, they provide the backdrop and storyline to drive exercises for emergency situations (the first step when designing a scenario is determining the type of threat, hazard or situation it is addressing) and promote work-oriented communication among stakeholders, making design activities more accessible to the great variety of expertise that can contribute to design (Lage et al., 2010).

Despite the important role of scenarios in emergency response management, there is a lack of academic research on how to generate and analyze this set of scenarios and how to integrate them in the development of Emergency Plans (Aedo et al., 2011). In recent years, some studies have contributed to bridge this research gap with the application the CIA-ISM scenario technique (Bañuls and Turoff, 2011) for supporting collaborative scenario development in emergency preparedness (Lage et al., 2011; Turoff and Bañuls, 2011; Bañuls, Turoff and Hiltz, 2013). With this scenario technique, managerial and technical actions as well structures with possible response systems could be explored in order to prevent or improve response to emergencies.

In this paper we go one step further applying the CIA-ISM scenario technique for structuring the chain of events that can occur in a crisis and, based on this information, helping to develop courses of action by the planning teams. A proper actions' planning in response to any emergency situation and appropriate personnel training are required to help in its resolution and to reduce its effect. As indicated in (Waugh and Streib, 2006), the emergency response capability is built from the bottom up, that is, it must arise from the all those who put in practice the plans and do not depend on the experience of managers. This requires making periodic training to enable employees understand their responsibilities and know what actions to perform, when they should be performed and how to perform them. This includes learning the procedures to be carried out to fulfill a particular task or mission, such as how they should coordinate their efforts with the rest of the staff involved in resolving the emergency. Maintaining discipline and following the plan also help to reduce the possibility of producing another series of side events, derived from an inappropriate response to the original event.

We demonstrate a practical application of the CIA-ISM methodology in a team exercise conducted by the staff of the Secretariat for Civil Protection of São João de Meriti (Brazil) who showed great enthusiasm for the support in matching the information and the visualization from the generated scenario. This scenario was developed with the aim of providing the basis for an operational plan, whose triggering event would be a landslide mass (sliding slope) on a residential street with housing after a heavy rain. This process was technically supported by the artifact CAEPlan "Course of Action for Emergency Planning". Its operation is to receive data from planners (events and estimations), guide them in the inter-relationship of their estimation, structure the results in graph form through CIA-ISM methodology (scenario/course of action) and finally allow choose the one that best adapted to their understanding.

In this paper, we first briefly review the methodological background of CIA-ISM technique that can inter-relate events and structure them as a directed graph representing an outline of a course of action. This is followed by the introduction of CAEPlan artifact, its architecture, and its process for generating a course of action. After this, a case study applying the artifact is presented mentioning the assumptions (we make), the set of events generated, the results reached, and the feedback from users. Finally, we present the final conclusion.

METHODOLOGICAL BACKGROUND: CIA-ISM

Cross-Impact Analysis (CIA) is a methodology developed to help determine how relationships between events may impact resulting events and reduce uncertainty in the future. Due to this ability of CIA to analyze complex contexts with various interactions, CIA is one of the most commonly used techniques for generating and analyzing scenarios, both historically (Turoff, 1972) and currently (Bañuls and Turoff, 2011). The main goal of CIA is to forecast events based on the principle that the occurrence of events is not independent. An individual or a group must come up with a set of interrelated events that might occur in the future. This requires users to be able to modify or iterate their estimates until they feel the conclusions inferred from their estimates are consistent with their views. Following Turoff (Turoff, 1972), for this type of event there is usually no statistically significant history of occurrence, which would allow the inference of the probability of occurrence. So, the cross-impact problem is to infer causal relationships from some relationships among the different worldviews of participating experts (knowledgeable participants in the planning process). This is established by perturbing the participant's initial view with assumed certain knowledge as the outcome of individual events. This approach deals with subjective probabilities that translate into causal relationships, notated as C_{ij} and G_i, with C_{ij} being the linear impact factor of event E_j upon E_i, and G_i being the linear impact factor of the events that are not specified in the event set upon the *i*-th event. By taking each event in turn and asking the user to assume it definitely will or will not occur and having them estimate the probability of the other events, we are asking for estimates for *n* different event sets. These resulting event sets do not follow a Bayesian relationship. Instead we are assuming they follow the Fermi Dirac Distribution in Quantum Mechanics. This and the other assumptions (Turoff, 1972) allow us to transform a non-linear probability scale (0 to 1) to the linear C_{ij} scale factors (– to + infinity) for influence factors providing linear relationships among events.

Given the linear influence factors we can show estimators the consistent relative relationships between any event and those that influence it by plotting these relationships on a linear scale. We can then use a different modeling method, Interpretative Structural Modeling (ISM), to analyze the complexity of the resulting weighted influence graph (Warfield, 1976). The following extension would allow individuals to receive a graphical visualization of their judgments and increase their ability to make improvements. The extension will also allow a group to receive a linear visualization of their collective results. In Figure 1 the methodological merger between CIA and ISM is shown. In this approach, the structural matrix model is obtained from processing the C_{ij} and G_i factors of the transposed cross-impact matrix. That is, the output of the CIA is the input to the ISM

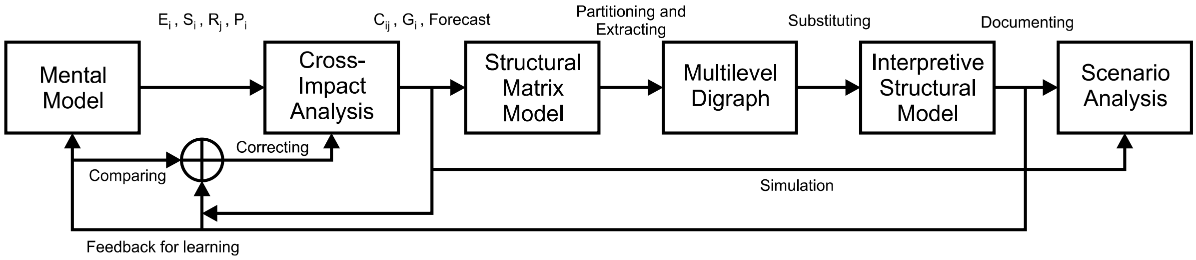

Figure 1. CIA-ISM process (Bañuls and Turoff, 2011)

These are the fundamentals of the CIA-ISM approach. Nevertheless, it is important to remark that the theory behind the CIA-ISM process requires additional reading (Bañuls and Turoff, 2011). In summary, an individual or a group constructing a model can take the final visualization of the impacts and recognize which events are the most critical and if there are any cyclic clusters of events that could be collapsed into a mini scenario to reduce the size of the event set into a more manageable model. The transformation from the cross impact model and the ISM model is a perturbation process where one takes the largest absolute value impacts between any two events and converts them to 1 and the rest 0 to form a standard binary network of 0 or 1 relationships. One examines the results and keeps adding more of the C_{ij} values converted to 1 to see how the graph gradually changes and to determine what might be a good point to use as a final conceptual model of the overall scenario.

One of the major limitations to the use of this methodology is the difficulty that the supporting both calculations and process manually (Bañuls, Turoff and Hiltz, 2013). That is why one of the major technological contributions of this research is the development of a software artifact to support the process in the field of Emergency Management (CAEPlan). Keys issues of the artifact are introduced in next section.

CAEPLAN ARTIFACT

As stated earlier CAEPlan is a tool to support the definition of courses of action in emergency plans. This tool is based on CIA-ISM principles and aims at supporting the scenario generation process in a planning context. This section discusses issues related to the architecture, the generation process, and user interface.

Architecture

CAEPlan was built to be a desktop application rather than a web one to experiment a group interaction in the same place at the same time during the planning process (Ellis, Gibbs and Rein, 1991). The architecture of CAEPlan is divided into three layers, shown in Figure 2.

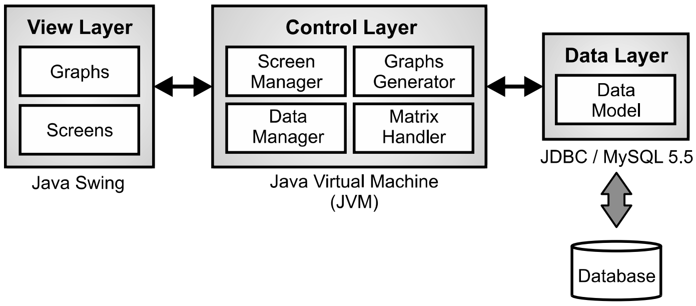

Figure 2. CAEPlan Architecture

The control layer uses the structure of the Java Virtual Machine (JVM) environment to manage the screens of the view layer passing on the information of the data structure. Furthermore, the control layer is responsible for handling information that comes from the data layer and to direct it to the appropriate destination. This layer also has four mechanisms:

- Matrix Handler: responsible for handling the CIA-ISM matrix calculations.
- Graph Generator: receives data from the matrix handler and generates the graphs using the tool Graphviz (Graphviz, 2011) based on DOT language (Dot, 2011).
- Screens Manager: responsible for controlling the transition between windows and the other mechanisms of control layer. Uses the resources of JVM.
- Data Manager: responsible for controlling the data coming from the data layer. Uses the resources of JMV.

The data layer uses a set of classes and interfaces (API) present in the MySQL JDBC (MySQL, 2012). It is responsible for sending and receiving data from the data manager layer control. The base was implemented using the MySQL 5.5 database from Oracle.

The view layer uses the API, or the widget toolkit, Java Swing to draw on its own all the components rather than delegating this task to the operating system (Swing, 2012). It is responsible for receiving information from the control layer and to turn them into visual elements: the screens of CAEPlan tool and the images in binary format created by the graph generator. Another assignment of this layer is to capture users' data and send them to the data manager of the control layer.

The screens show an interactive menu consisting of icons (toolbar) that are enabled or disabled depending on the context used. When you open a project three tabs are shown: Project, Events, and Course of Action. Project tab is responsible for displaying the details of the project and the scenario. The details of the events can be seen in the Events tab.

Course of Action Generation Process

CAEPlan is aimed at facilitating the different stages of the CIA-ISM process (Figure 1) in order to obtain the most probable course of action for an emergency plan. In figure 3 are exposed the main steps of the course of action generation process.

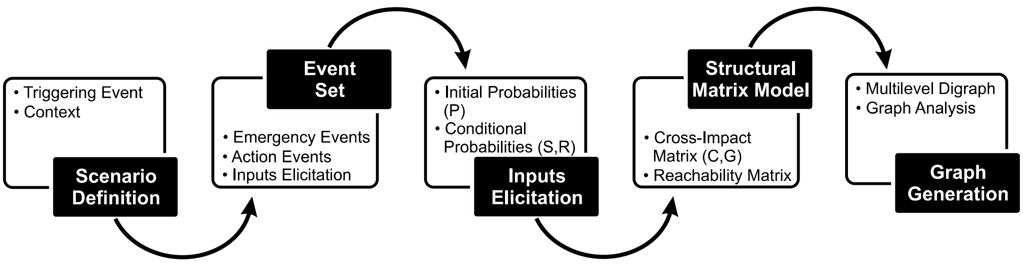

Figure 3. Course of action generation process

The scenario definition is based on the selection of triggering event (natural or man-made) that causes the emergency. The scenario should include also the context definitions as well as other relevant data (through variables) for the exercise such as number of people involved, time and location. These variables are often used to determine quantities or some qualities (that defines some kind of degree) within a scenario. These variables may express some sensible or limiting factors of the scenario being studied and can modify the way it should be treated or even how it is seen, namely scenario variables have the ability to change the characteristics of a scenario.

In the event set definition stage, the user should create an event set that include both emergency and action events. The potential occurrences of emergency events (i.e. explosions, flood, fire, etc.) are not under emergency managers' control and are the cause of the crisis situation. The action events (i.e. search and rescue, fire response, communication, etc.) are decisions that could be carried out to respond to the emergency events. Each emergency event list is associated to a taxonomy based on a literature review (ANPC, 2011; CIVES, 2011; FEMA, 1993; HEPG, 2011; Meningitis, 2005; PNDC, 2007). This taxonomy is not a restrictive and allows the inclusion of new emergencies. Action events are based on the emergency support functions from FEMA (FEMA, 2010). New actions could be added by the users. Figure 4 shows how events are captured and structured for planners' quick view.

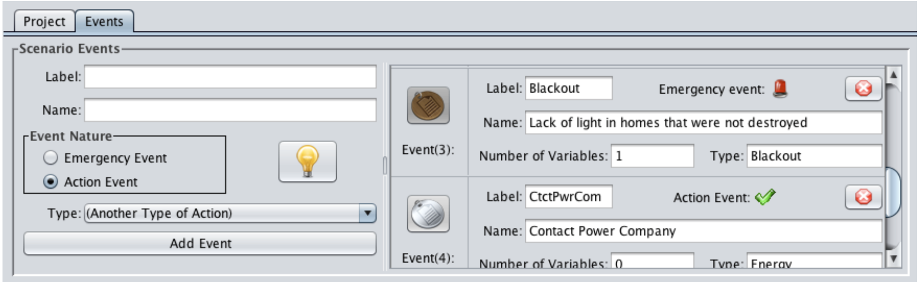

Figure 4. CAEPlan event capture screen

Once we have defined the whole set of events the graph generation process starts with the estimations of the probabilities of the events. Emergency managers must now define the likelihood of occurrence for every event. This exercise has to be done several times until they conclude their estimates are consistent with their views. If the team perceives that there is uncertainty about the occurrence of an event, they should set the probability of 0.5 for it (neutral). Thereafter, with all the probabilities already set up (P_i), we need to obtain subjective probabilities. This is done perturbing members' mind by asking that if the *i*-th event is certain to occur or not, what would be their estimates of changes in the probabilities of occurrence for the other events. That is, if we assume event *n* is certain to occur, it is necessary to estimate how it would change the probabilities of the others and then give final probabilities as shown in Figure 5. Subjective probabilities should be provided for both occurring and non-occurring events in the same way as previously explained.

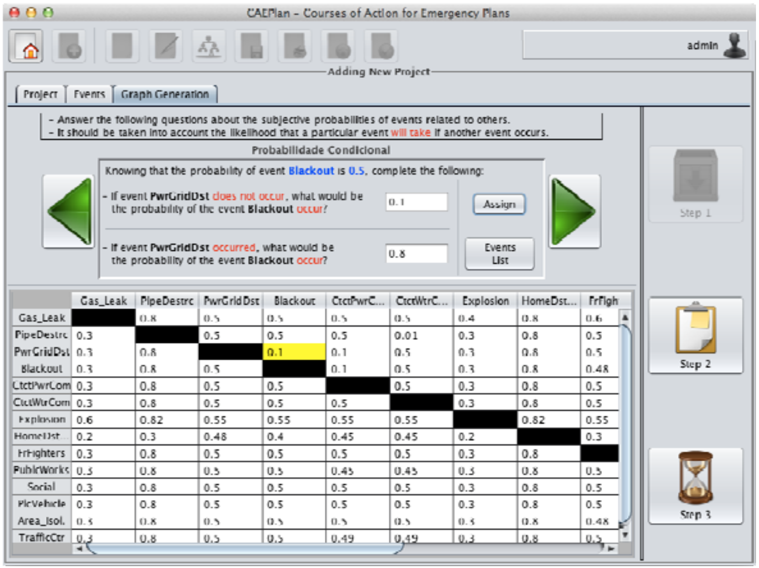

Figure 5. CAEPlan subjective probabilities capture screen

With this information we can reach the calculated subjective estimates of correlation coefficients that measure casual impact, that is, give the association between events and so the structural matrix model. These associations will give us the calculations of the cross-impact matrix, the matrix that contains all C_{ij} for each event as well as the reachability matrix (second Section).

Once we have the structural matrix model, we have to hierarchically reconstruct the digraph represented by the reachability matrix following the CIA-ISM process. As a result, you have a graphical map of the impacts of events upon the others. This map indicates that an event is likely to occur and that the occurrence of an event can carry to the occurrence of another event.

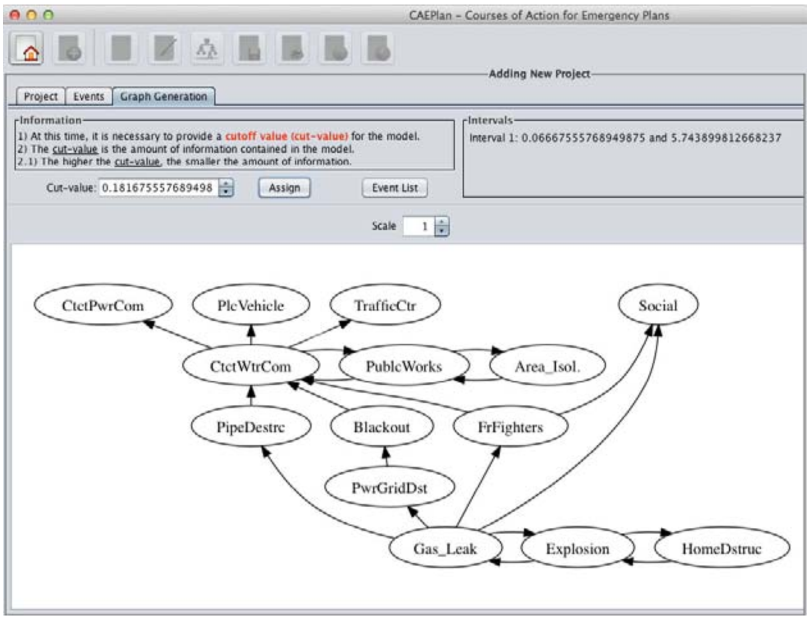

Figure 6. CAEPlan graph generation screen

This graph represent a chain of interrelated events and supply every event with a set of variables that may help increase the capability of representation (than with just events), making it closer to hypothetical real situations. To reach this aim it is necessary to determine a lower limit (cut value) to C_{ij} that the group feels relevant for the optimal course of action. This cut value is the quantity of information that will be included in the model and it can be varied within an interval defined mathematically that prevents inconsistencies in the results. This builds another graph using the same data previously provided. Figure 6 shows the screen that allows cut value to be changed and the resulting digraph.

CASE STUDY

The CAEPlan artifact has been applied experimentally to real case conducted by the staff of the Secretariat for Civil Protection of São João de Meriti (Rio de Janeiro, Brazil). Specifically a mudslide scenario in an urban area was developed by a team of an emergency manager and a responder leader, both responsible for the preparedness of that area. The task was building a mobilization strategy through various municipal agencies to restore the situation of normality.

Assumptions

There was a planar-type mudslide on a cut-slope densely populated on a rainy day (100mm/24 hours). The cut-slope has a slope/inclination between 70 and 90 degrees. There were houses in bad state of conservation and with various precarious pipes and open sewage. The surface composited of a large amount of embankment uncompressed was favoring the landslide. There was also a large amount of trash and debris. Houses were built of wood, with no technical pattern/standard construction. There were poles and trees inclined indicating a slow land moving. The slope has some places without vegetation and plantation of banana trees. There were affected approximately 200 inhabitants, and 50 residences. The mudslide caused 3 deaths, 10 people injured, 50 displaced people and 150 homeless people.

Event Set

The responsible for the planning created a set of 14 events: 6 emergency events and 8 action events (Table 1). There was included some relevant information for the response to each event. At this point is important to remark that he has total freedom to define the event set. Due the nature of the exercise — generating a course of action for building a mobilization strategy — all action events are dynamic events aimed at responding the effects of the emergency events.

Label	Short description	Relevant specifications	Event Type
Gas_Leak	Natural Gas Leakage or Loss of Gas Network	Gas leaking from a canister-type LPG	Emergency
PipeDestrc	Destruction of water pipes and sewage	The continuous release of water and sewage might generate a new landslide.	Emergency
PwrGridDst	Destruction of the power grid	Loss of the power grid	Emergency
Blackout	Lack of light in homes that were not destroyed	It is affected an area of about 1 square kilometer	Emergency
Explosion	Canister-type LPG explosion	-	Emergency
HomeDstruc	Home destruction	The majority of homes are destroyed.	Emergency
CtctPwrCom	Contact Power Company	-	Action
CtctWtrCom	Contact Water Company	-	Action
FrFighters	Rescue of victims from the adverse event by firefighters	Two ambulances and two rescue teams should be designated.	Action
PublcWorks	Support the from Secretariat of Public Works for debris removal	It will be needed a backhoe loader and a truck.	Action
Social Contact	Social Assistance Secretariat to assist the affected population	The Municipal School is determined to receive the homeless. Direct food/alimentation should be supplied for. Clothing and hygiene should be supplied for victims	Action
PlcVehicle	Placing emergency vehicles on site	2 Civil Protection vehicles and 1 Police patrol to support and assure safety to the disaster site should be positioned nearby the area.	Action
Area_Isol	Isolate Area	Itacaré St. should be isolated to traffic.	Action
TrafficCtr	Municipal Guard support to control traffic	4 teams from Municipal Guard should be placed to control the traffic in the surroundings of the Itacaré St.	Action

Table 1. Case study generated events

On the contrary other CIA-ISM exercises (Bañuls, Turoff and Hiltz, 2013) included sources events (such as emergency teams resources and training skills or population confidence with the local authorities) aimed at evaluating the preparedness level for responding the emergency as well as outcome events (such as economic costs) aimed at measuring the level of success of the response. These differences in the definition of the set of events are an indicator of the flexibility of CIA-ISM. That is, the set of events might be adapted according to the requirements and needs of the emergency planning team.

Results

Once the set of events is established, the estimations were carried the inputs elicitation process. Based on these estimations the cross-impact matrix was built (Table 2). The rows (*i*) and the columns (*j*) of the matrix are the events; the cells are the influence factors C_{ij}, the diagonal being the overall probabilities (OPV).

	Gas_Leak	PipeDestrc	PwrGridDst	Blackout	CtctPwrCom	CtctWtrCom	Explosion	HomeDstruc	FrFighters	PublcWorks	Social	PlcVehicle	Area_Isol	TrafficCtr
Gas_Leak	OVP	0.00	0.00	0.00	0.00	0.00	1.79	0.67	0.00	0.00	0.00	0.00	0.00	0.00
PipeDestrc	0.00	OVP	0.00	0.00	0.00	0.00	0.19	2.79	0.00	0.00	0.00	0.00	0.00	0.00
PwrGridDst	0.00	0.00	OVP	0.00	0.00	0.00	0.29	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Blackout	0.00	0.00	4.39	OVP	0.00	0.00	0.29	0.51	0.00	0.00	0.00	0.00	0.00	0.00
CtctPwrCom	0.00	0.00	4.39	4.39	OVP	0.00	0.29	0.25	0.00	0.40	0.00	0.00	0.00	0.07
CtctWtrCom	0.00	5.74	0.00	0.00	0.00	OVP	0.29	0.25	0.00	0.40	0.00	0.00	0.00	0.07
Explosion	0.63	0.00	0.00	0.00	0.00	0.00	OVP	0.67	0.00	0.00	0.00	0.00	0.00	0.00
HomeDstruc	0.00	0.00	0.00	0.00	0.00	0.00	0.19	OVP	0.00	0.00	0.00	0.00	0.00	0.00
FrFighters	0.58	0.00	0.00	0.16	0.00	0.00	0.29	1.06	OVP	0.00	0.00	0.00	0.11	0.00
PublcWorks	0.00	0.00	0.00	0.08	0.00	0.00	0.11	0.51	0.00	OVP	0.00	0.00	0.29	0.00
Social	0.00	0.00	0.00	0.08	0.00	0.00	0.11	1.73	0.40	0.00	OVP	0.00	0.00	0.00
PlcVehicle	0.00	0.00	0.00	0.46	0.00	0.00	0.14	0.29	0.19	0.46	0.00	OVP	0.00	0.00
Area_Isol	0.07	0.00	0.00	0.46	0.00	0.19	0.36	1.06	0.19	0.88	0.00	0.13	OVP	0.16
TrafficCtr	0.12	0.00	0.00	0.81	0.17	0.17	0.63	0.26	0.81	0.81	0.00	0.00	2.56	OVP

Table 2. Case study generated events

As we mentioned in the second Section, C_{ij} represents the impact of the *j*-th event on the *i*-th event. Positive C_{ij} means it enhances the occurrence of the event and negative detracts from the occurrence. The effect of reducing the coefficients is the inclusion of more information in the model (Bañuls and Turoff, 2011) the users could add information to the diagraph. Finally the cut value that better met the planning team view was c_{ij} = 0.316 (Figure 7).

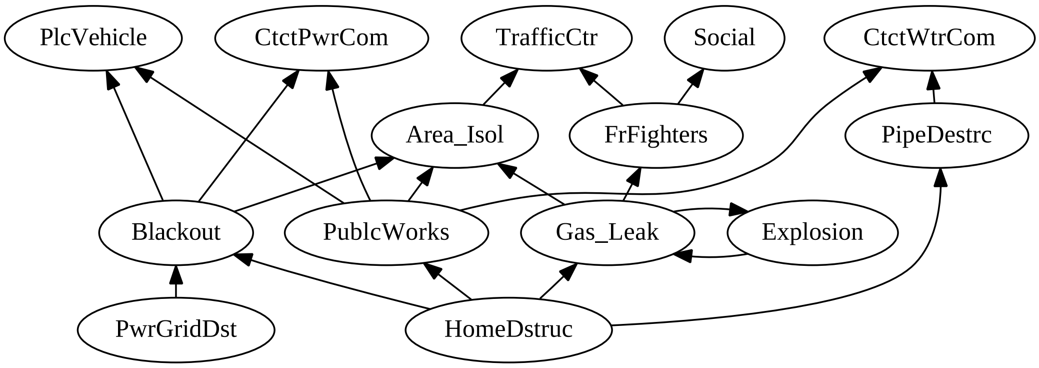

Figure 7. Graph that best met the vision of the planning team during the case study

The above shown Figure 7 represents the most probable scenario in the case of the mudslide along with the necessary response. This is a scenario in with all the emergency event occurs in a certain sequence and activates different action events.

Users' Feedback

A questionnaire was sent to the participants. The experimental application of CAEPlan gave us some feedback:

- The method was considered effective in supporting the construction and visualization of the scene.
- It is helpful for supporting the preparation of the course of action plan.
- Scenario variables as elements of contextualization were seen as good.
- The categories defined by the taxonomy and support functions (FAE) are adequate.
- The inputs elicitation process requires an adjustment to not become repetitive when the user introduces information.
- It partially meets the need of planners for developing a course of action.
- It could be combined with other techniques such as narrative scenarios to improve its effectiveness.
- It consumes approximately the same time of a traditional course of action development process.
- The restrictions of the artifact were not considered impediments for adoption.

Taking into account the method applied by the tool and the one currently used by the emergency group, some points were stressed as better when using CAEPlan:

- Graph Generation – As they are planning a possible situation and the events that might be involved, the ability to turn these loose events into a graph of influence was said as the most interesting. The emergency team usually writes in a sheet of paper the description of events and then tries to depict a scenario manually. With CAEPlan they could actually see a visual result of their input and choose the one that best fits according to their opinion.
- Mutual Event Influence – During the planning process and the scenario development, some events' influence in other events tends to be forgotten or underutilized. CAEPlan was able to overcome this issue by asking the emergency planning team to set new probabilities of occurrence for all events if a specific event occurs or not. That was said that trough this way they could better envision the impact of a certain event in the scenario as a whole. That makes also possible to include (think about) new events not designed originally to the scenario.
- Reuse of Past Scenarios – CAEPlan suggests events that occurred in past scenarios similar to the one being developed. That was noticed as a great help during the scenario design. Besides managers' knowledge and expertise (that is part of the usual development), the tool offers suggestions of events by reusing previous knowledge embedded in past projects (scenarios).

CONCLUSIONS

In Emergency Management, the processes adopted by organizations don't end up being followed or are totally underutilized, largely because of their complexity and difficulty. Within this context, in this area many scientific contributions are aimed at identifying problems and proposing feasible solutions. This research goes in this direction and follows structuring the development of course of action in emergency plans. Emergency plans are essential to the resolution of cases in which the procedures of everyday life are not only able to control as well as for large-scale events. They are constructed from historical data and experiences of planners who typically use long processes that ultimately inhibit its construction more regularly and make tend to be generic to accommodate as many situations as possible and reduce the need to build plans for specific situations.

The course of actions is the main structure of the emergency plan generation, because it defines the actions and possible situations that may arise during the emergency. The courses of action are generated from scenarios prepared by the group of planners. In this sense the aim of this research effort is to reduce the time and effort required to perform the aforementioned process by adopting a method for constructing scenarios that reuses past knowledge, which helps planners' cognition and allows visualization of the scenario. But it is not only speed up the process, but motivating work providing correct information at the right time and in an appropriate manner.

The CIA-ISM methodology aims at helping emergency mangers to deal and measure cascading effects and contributes to address this research question, allowing experts to work with a broad range of events. In this context CIA-ISM aims at creating new plans by helping to support foresight and understanding, and to structure complex emergency situations. The feedback received was positive regarding CIA-ISM process that directs managers to think about the impact of an event on the other, and allows the detection of other events not listed in the scenario development that underlies the emergency plan itself. It's well known that emergency events/situations are most often unpredictable, but managers' expertise and past experiences contribute to a continuous development of emergency planning. CIA-ISM approach is one that tries to do so.

CAEPlan is the artifact that technically supported the construction of the courses of action. This artifact was based on CIA-ISM methodology and it was tested by staff of the Secretariat for Civil Defense of São João de Meriti. They considered that structuring the information by events and variables, and the ability to turn them into a scenario is relevant and useful to their daily work. The main benefits of this tool is directing the attention of planners to find elements that characterize the scenario; mapping the influence of all events in relation to others, which is often overlooked because it is arduous, but necessary for the preparation; and the scenario structured as a graph that improves and makes compact visualization of the scenario. At this moment CAEPlan is not focused on supporting the entire process of creating an emergency plan, concentrating only on the construction of the courses of action. So extension to its functionalities could be addressed by future research.

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