XVIII ICIEOM 2012
International Conference on Industrial Engineering and Operations Management
Guimarães - Portugal
July 9 - 11, 2012

Emergency Management Concepts: a network approach

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Abstract

The socio-technical systems that make part of our lives are subject to disturbances through disasters that can have serious consequences (at the limit, completely destabilizing the basis system). To deal with this situation modern societies have developed structures, tools and mechanisms that aim to reduce the probability of occurrence of these negative situations.

Good decision making is critical and information is needed when analyzing the environment for risks, when defining emergency plans, when training agents and society to deal with the foreseen accidents. All elements and people involved in the emergency cycle phases need to have a common mental structure to deal with information issues.

The present work is an exploratory study that aims to identify a semantic base underlying the mental model from the field of emergency management, using a collaborative approach to build it. Mental models, underlie how people structure concepts; how they relate them; what concepts they recall first and which concepts they associate with them. We use a group Civil protection graduates to verify the suitability of the proposed methodology.

This approach merges both the power of collaborative techniques and the use of social sciences methods to obtain the data that will allow to build a network of concepts that represents the participants' mental models.

The data obtained, by aggregating all the answers, allow us to deepen the analysis of the resulting network, to understand connections and main group concepts in this domain. Some of the questions we want to answer are: (1) type and intensity of the relations defined; (2) network coherence, by searching missing key nodes or relations.

Keywords: Conceptual maps; mental models; emergency management; networks

1 Introduction

The disturbances that socio-technical systems are subject to through accidents and emergencies can have serious consequences. To deal with this situation modern societies have developed structures, tools and mechanisms that aim to reduce the probability of occurrence of accidents, their consequences when accidents cannot be avoided, a rapid response to the parts of the system that are under threat and a rapid recovery afterwards.

One issue that is crucial to the good functioning of all the above mentioned moments is decision making and, to be effective at this task, information is needed. The challenges of information production, usage and communication are critical to the success of this process. Information is present when analysing the environment for risks, when defining emergency plans, when training agents and society to deal with the foreseen accidents. When an accident happens information is needed to access the situation, to coordinate the response teams and later on the recovery phase.

Decision-makers need a permanent and updated information supply that is frequently distributed over multiple documents, information systems and even, organizations (Kai, Qingquan, & Lili, 2008), given that poor decisions, ineffective communication and lack of information can result in disaster expansion. Conversely, the rapid dissemination and exploitation of usable information can be of great benefit in the first few hours after disaster strikes (Scott & G. L. Rogova, 2000:1).

Gaining insight into those aspects of human cognition that underpin preferences, action, and behaviour is of great value to the field emergency management. It is widely accepted in the cognitive science and

psychology literature that people develop and use internal representations, i.e., 'mental models', of external reality that allow them to interact with the world. (Jones, Ross, Lynam, Perez, & Leitch, 2011)

Mental models are conceived of as a cognitive structure that forms the basis of reasoning and decision making. They are built by individuals based on their personal life experiences, perceptions, and understandings of the world. Mental models provide the mechanism through which new information is filtered and stored. However, people's ability to represent the world accurately is always limited and unique to each individual. (Jones et al., 2011)

A variety of techniques exist for eliciting mental models, ranging from brainstorming, to interviews or text analysis. They can be applied both individually or to a group of people. (Carley & Palmquist, 1992; Langan-Fox, 2001) The majority of procedures used are based on the assumption that an individual's mental model can be represented as a network of concepts and relations. Some procedures are designed to elicit a network representation of a mental model directly from the interviewee through a diagrammatic interview. Other procedures require the researcher to re-create, or infer, the network from oral interview data or questionnaire data. (Jones et al., 2011)

When working together people must share a part of the mental model to deal effectively with each other. Team mental models promote understanding among team members regarding information requirements and the need for communication and coordination. (Sayama, Farrell, & Dionne, 2010)

In the case of emergency management cycle all elements and people involved need to have a common mental structure to deal with information issues. This is a common problem referred in emergency management literature (Alexander, 2002; Griffin, 2009; Kai et al., 2008). This common structure can be referred to as an ontology (Noy & Mcguinness, 2000).

The present work aims to develop a semantic base underlying the mental model of a group of civil protection graduates by using a collaborative tool to build and define it. The use of this group of study is justified by the ease of reach for the authors and because civil protection, in the Portuguese context is the societal branch related to emergency management.

The emergent network of concepts will be studied through complex network analysis tools to understand connections and main group of concepts in this domain.

2 Network approach

The study of networks has become very important even outside their traditional areas of application, such as mathematics, computer science, and the social sciences. This use resulted from the development of mechanisms for representation, measurement, and modelling (Butts, 2009).

In order to represent a network a group of entities is needed. Each element of the group is usually called a node and it represents a single entity that may take part in the relation under study. Relationships are represented via edges, that can be either unordered pairs of nodes (i.e. the relation is said to be undirected) or ordered pairs of nodes (i.e. the relation is said to be directed). The network is represented by a graph, which is defined as a set of nodes together with a set of relationships among them.

The main result of the study of complex networks has been the identification of a series of unifying principles and statistical properties common to most of the real networks considered. It is possible to identify different kinds of networks (Newman, 2003):

- social networks if the entities are people and the edges are their relationships;
- technological networks if we are analysing the connection between resources, commodities or man-made facilities;
- information or knowledge networks when the relation is between entities that fall in this category (books, citations, films) and

- biological networks, representing biological systems.

As mentioned above, an ontology is a description of concepts and the relations among them formally describing a field of knowledge which results in a shared conceptualization. If we take the concepts as nodes and relationships between them as edges it is possible to represent the ontology as a network (or graph).

Therefore (following the above classification), the network representation of an ontology falls in the information network category.

However, in this work it is proposed a fifth category, named "concept network", given the special nature of the entities under study. These entities are abstract yet powerful, and have a great impact in the daily lives of individuals and institutions, therefore they have the potential to become an autonomous branch of study.

It is important to note that the representation of an empirical phenomenon such as a network is a theoretical act, that is based on assumptions about what is interacting, the nature of that interaction, and the time scale on which that interaction occurs (Butts, 2009). In this case we are considering the concepts and the way respondents relate them.

2.1 Network measures

A relevant property in networks is the degree of a node, which is, the number of its direct connections to other nodes. In real networks, the degree distribution, P(k), defined as the probability that a randomly chosen node has degree k (or, equivalently, as the fraction of nodes in a graph having a k degree), significantly deviates from the Poisson distribution expected for a random graph and, in many cases, exhibits a power law (scale-free) tail.

Scale-free networks are also indicated by low clustering and average path length as we will verify later in the present work.

A first approach, as we follow the network perspective, is to rely on mainstream measures suitable to its analysis (node degree, average path length, clustering, centrality). As referred earlier, the node degree, usually denoted $<k>$, is the number of connections to other nodes. It's possible to isolate the incoming links to the node, the in-degree or the outgoing links to other nodes, the out-degree.

The average path length is the average number of connections joining two randomly chosen nodes (denoted l). The clustering coefficient of the network reflects the transitivity of the mean closest neighborhood of a network vertex, that is, the extent to which the nearest neighbors of a vertex are the nearest neighbors of each other. (Borge-Holthoefer & Arenas, 2010)

Centrality coefficient measures to which extent a node i is near to all the other nodes along the shortest path, thus given an indication of its importance in the network.

In the table below are summarized some common measures suitable to network analysis (Johnson, 2006).

Number of branches	Network complexity
Variety	Number of dimensions
Size, size of grammar, size of matrix	Number of internal relations
Connectivity	Number of variables

Table 1 - Measures of network complexity

In some of the ontologies about emergency management (e.g. Kai et al., 2008; X. Li et al., 2008; Little & G. Rogova, 2006; D. Maio & P. D. Maio, 2008) a repetition of groups of elements can be observed since they are related to several concepts. This fact may suggest that, also in the case of "concept networks", it is possible to identify the existence of modules (modularity), that can be or are reused (reuse) and have a hierarchy (Hornby, 2007). This proposal was originally intended to be applied on software complexity

analysis, but it seems to us that, given the nature of elements we are dealing with, we could extend the application to this case, fostering and testing other possible applications.

Modularity takes into account the number of modules, i.e., an encapsulated group of elements that can be manipulated as a unit. Reuse is a measure of the average number of times modules are used to create the resulting design. Finally, hierarchy tries to capture the number of nested layers of modules.

3 Methodology

Although some ontologies for emergency management have been proposed (Kai et al., 2008; X. Li et al., 2008; Little & Rogova, 2006; D. Maio & Maio, 2008) they are mostly developed to be applied in contexts such as decision support systems or artificial intelligence applications. In this work we will start from the concepts from experts and analyse it.

The approach we propose merges both the power of collaborative web-based techniques and the use of social sciences methods (since it asks real people about their knowledge about an issue) (Carley & Lee, 2002) to obtain the data that will allow to build the network.

To accomplish this we ask group of graduate students to identify, organize and relate the concepts they recognize in the emergency management field.

For each of the concepts initially identified they were asked to indicate a new level of concepts related to them. By iterating on the mentioned steps, identification of a concept, related sub-concepts and again with this ones, put together a new sub-level of concepts, it is possible to build several levels of inter-related concepts (as represented in Figure 1). An individual structure is obtained representing the mental model of concepts of the respondents. The mental model of concepts and relations among them is representable as a network.

Figure 1 exemplifies the expected structure.

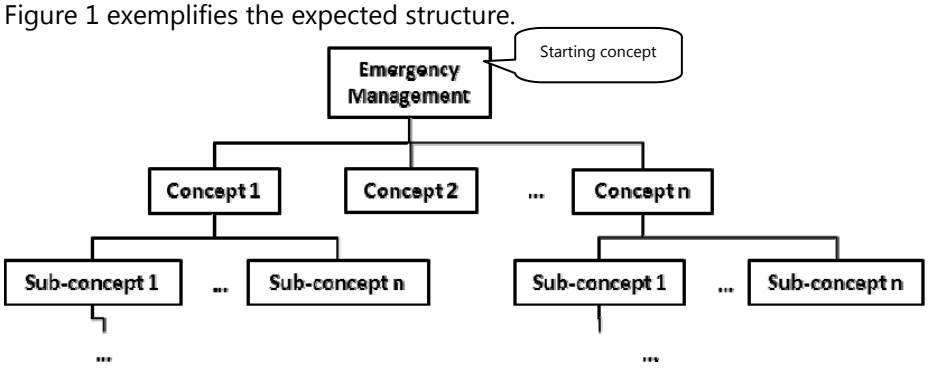

Figure 1 – Model of data gathering

3.1 The study

To implement the structure of data gathering presented in figure 1 above, a questionnaire was implemented, allowing to capture answers in a multilevel and relational format. The questionnaire was sent, by email, to 60 graduates in Civil Protection. Fourteen answers were received (23% of the sample).

As the concepts are words, the several responses were verified for major spelling errors and typos. This is an important step to ensure that the same concept indicated by two different respondents was not coded as different because of an error. Finally, the individual networks were grouped and processed to create a unique network with all the contributions.

In this network, we take into account the number of times a pair of concepts was mentioned by the respondents, because this stresses the importance of that relation among the group. That total amount was taken as a weight of the edge between concepts. In later extensions of this work we intended to introduce the weight of the nodes, i.e. the number of different times a individual concept was mentioned.

The data was processed to transform the concepts identified in a network structure, where a node represents a concept and an edge represents a connection between two concepts. Additionally, for each pair of nodes the respective weight was indicated.

A file was created in the native format of *Pajek* software and this package used to perform the analysis.

4 Results

In table 2 are presented some basic measures about the aggregate network of concepts. The difference between the two columns is the consideration of the starting concept or not. As mentioned above, when collecting the data for the construction of the network, the starting question was: "What are the main concepts you relate with civil protection?". "Civil protection" becomes the starting concept and therefore all other concepts propagate from this first one. It is important to analyse how the structures holds if we withdraw this ("Civil protection") concept.

	With the starting concept	**Without the starting concept**
Nodes	262	261
Links	357	315
<k>	2,7251	2,4138
L	3,7275	4,2401
C	0,11828	0,08461

Table 2 - Summary of network measures

If the initial concept ("Civil protection") is taken into account we have 262 different concepts and 357 links between them. The average degree (number of average links per node) is 2,7. Although the number of nodes (concepts) is high the average degree indicates that each was related with few other concepts. This can be due to the small sample of individual responses. The average path length (*l*) is 3,7 referring to average number of connections joining two randomly chosen nodes. The small value reflects the proximity between concepts but may be justified with the dimension of the network.

If we remove the initial concept ("Civil protection"), only one node is loosed but some changes occur in the network. The more notorious is a strong decrease in the number of links, meaning that the concept is strongly connected. It is also significant the increase in the average path length and the fact that some nodes became orphans (unconnected to the main core of the network). This can by observed in the following image representing the network.

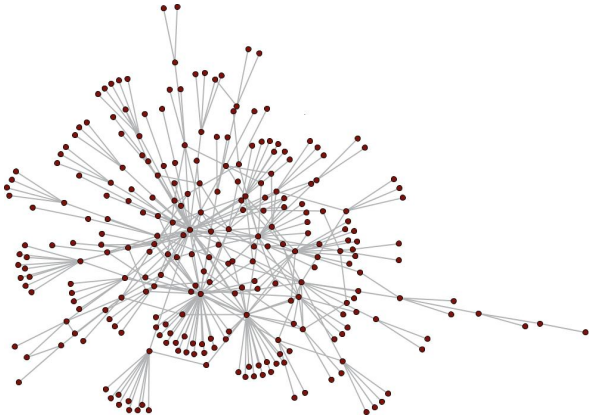

Image 1 - Representation of the concept network with initial concept

Image 2 -Representation of the concept network without initial concept

The values suggest that the network is a small-world type of network, because of low clustering and average path length.

Since the number of times individual answers indicated that a pair of concepts were related we can spot the main pairs on the network. In Table 3, we present the highest weights between concepts in the network, signalizing the respective importance.

As expected the more important ones are related with the main functions of emergency management in Portugal (Prevention, Rescue and Planning). We must note the absence of references to mitigation and recovery as key concept in the emergency management cycle and referred to in the Portuguese civil protection law. This can be due to lower emphasis given to these activities in common activities and decisions.

With starting concept		Without starting concept	
Start/End Nodes	**Weight**	**Start/End Nodes**	**Weight**
Civil protection-Prevention	6	Planning -Responsabilities	3
Civil protection - Rescue	6	Planning – Emergency Planning	2
Civil protection - Planning	5	Anticipation- Internal Emergency Planning	2
Civil protection – Protection	4	Prevention-Antecipation	2
Civil protection - Emergency	3	Emergency Planning -Action	2
Civil protection -Safety	3	Prevention-Scenaries	2
Planning-Responsabilities	3	Planning-Risks	2
Planning -Risks	2		

Table 3 - Weights of links between nodes

Once more, if the starting concept is removed the weights of the linked nodes strongly decrease. This is due to reduction in connectivity. As referred earlier, removing the starting node strongly reduces the clustering in the network,

In Table 4 we present the nodes with higher centrality index for both the networks (with and without starting concept). In the first case "civil protection" is the concept with higher centrality (and this help to justify the need to analyse the network without this concept). The more central nodes are the ones that represent basic functions in the field (planning, prevention, assistance and protection).

With starting concept		Without starting concept	
Civil protection	0,49	Planning	0,34
Planning	0,41	Prevention	0,32
Prevention	0,40	Assistance	0,32
Assistance	0,39	Protection	0,28
Protection	0,37	Plans	0,28

Table 4- Centrality coefficient

5 Conclusions

Network analysis seems to be a valid tool to study the mental maps of concepts that were elicited. It was possible to identify the most important pairs of concepts using the aggregated network built from individual answers. These pairs of concepts reflect the key concepts used in the field as defined in the legal basis of Portuguese civil protection and in the literature. The use of the links weights and centrality coefficients corroborate this claim.

Despite these findings, we must note that some other key concepts are not indicated, thus not receiving importance. This may , point the need for further information and training to the studied group.

Since this is an exploratory study that used a sample of graduates as the source of concepts, future work will replicate this approach with key professional in the civil protection field, in order for us to depict the mental models of the emergency managers.

To improve the analysis, using this technique, we think there is a need for a measure to compare different networks. This measure will enable to identify similarities and dissimilarities between mental models of individual and groups of people. The understanding resulting from that is helpful to take decisions

regarding the improvement of training and information sharing between individual or groups in key organizations in the field.

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