Decision Making in Disaster Management: From Crisis Modeling to Effective Support

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Abstract. Crisis management is a challenging domain to model because of its multiple stakeholders, its complex resource management, its rich communication and control mechanisms, etc. It consists in sets of interdependent activities occurring in an evolving environment under stressful conditions and high pressures. It becomes difficult to support given that any decision includes multiple actors, multiple emergency services, etc. [1]. Therefore, we believe that a systemic modeling of such complex sociotechnical system (including the decisions makers, stakeholders, coordination processes, etc.) would improve the potential to support effectively the crisis management. We focus in this paper on the effective use of modeling to manage crisis. In this paper, we present firstly most relevant existing metamodels of crisis management. Secondly, we describe the criteria we defined to classify these metamodels. Thirdly, we present the results of this classification and finally, we conclude by suggesting first requirements needed for an effective metamodel useful to support decision processes in crisis management.

Keywords: Decision making · Crisis management · Systemic modeling/metamodeling

1 Introduction

Crisis management is a challenging domain to model [1] because of a large number of activities, dynamic decision support requirements, changing environmental situations and multi-data sources [2]. To avoid human and material losses in disaster situations, high quality decisions are required.

Decision-making is an important task in disaster management because it appears in all management activities before, during and after a catastrophic event [3]. In disaster situations, ineffective decisions can lead to great losses (infrastructure destruction, human losses, etc.). Therefore, decision-making represents an activity that aims to reduce the aftermath of a disaster.

Decision-making process presents a big challenge for disaster stakeholders. Indeed, there are many reasons that make decision making difficult in complex systems such as: interconnected systems, multiple decision makers, multiple

I.M. Dokas et al. (Eds.): ISCRAM-med 2017, LNBIP 301, pp. 122–128, 2017.
DOI: 10.1007/978-3-319-67633-3_10

objectives and constraints, system dynamics and uncertainties in the environment [4].

Crisis management includes various concepts representing different knowledge. To exploit this knowledge in crisis planning and responding, we need to formalize it by using metamodels. The crisis management process, as a collaborative situation, concerns multiple partners [5]. That is why the first step to enhance coordination and collaboration of the crisis stakeholders is representing these partners and the relationships between them in different levels (operational, tactical and strategic) using metamodeling. In addition, we need to model this domain to understand its complexity.

To build a metamodel, we need to identify all generic concepts that appear in crisis management domain [1] then experts in the field should validated it. In our context, a useful metamodel is a metamodel which can:

- Provide a knowledge needed to build a management process in crisis situation, which contains the description of the activities sequence, the involved actors, their roles and the coordination between them.
- Support the decision makers by presenting the information needed to make a decisions.

Consequently, the objective of the present study is to assess whether the existing crisis management metamodels contribute effectively to support decision support processes in Crisis Management. To answer this question, we begin by a deep study of existing metamodels and classify them with regards to the objectives of the current paper.

This article is structured according to the following sections: Sect. 2 presents description of existing crisis management metamodels; Sect. 3 describes a comparative study of the metamodels; finally, Sect. 4 concludes and gives some requirements for an effective metamodel useful to support decision processes in crisis management.

2 Overview of the Metamodels for Crisis Management

Among our objectives in this paper is the study of the existing metamodels that cover the largest number of concepts in the crisis management domain and that present elements in relation to decision-making. Therefore, based on these criteria, we select the most relevant works.

We cannot consider these metamodels as a complete representation of the crisis management domain because each metamodel describes this domain from a specific point of view. Moreover, some metamodels are built to present a specific context or a particular type of crisis.

In this section, we present a brief description of the selected metamodels (Table 1). To describe these metamodels we focused on:

- The aim of the metamodel
- The concepts described by the metamodel
- The formalism description

Table 1. Crisis management metamodels description.

Metamodel	Aims	What does it describe?	How is it described?
[1]	– Lead to better knowledge sharing – Facilitate combining and matching different disaster management activities to best manage the crisis on hand	It contains the relationships among concepts, which can represent the semantic of disaster management domain. It represents the four phases of disaster management (prevention, preparation, response and recovery)	UML diagram based on the four-layer metamodelling framework of the Meta Object Facility (MOF)
[5]	Gather data and generate information usable to design collaborative schema for crisis management (preparation and response)	It describes different crisis management concepts and the relationships among them: – Crisis concepts – Behavior or collaboration process concepts (activities and events to manage the crisis situation) – Context concepts (elements impacted by the crisis) – Collaborative situation concepts (core) – Objectives (actual facts and risks)	Designed as a UML diagram
[6]	– Model for capturing human behavior during flood emergency evacuation – To assess the effectiveness of different flood emergency management procedures	– Human behavior during evacuation in response to a disaster warning – The human decision making process for evacuation – The factors that play an important role in the evacuation decision-making process	– Using system dynamics approach – Causal diagram
[7]	– Present a conceptual model of disasters affecting critical Infrastructures – Deal with communication and coordination among Humans or intelligent agents of the various critical infrastructures	– Concepts to describe a region and the people that occupy it and their well-being – Concepts to describe the various infrastructures that serve this region – Concepts to describe events such as a disaster and its impact on people, directly or indirectly through the infrastructures – Concepts to describe communication and coordination between infrastructures, the regions and people	UML diagram
[8]	Present an organization model for particular crisis (snowstorm)	It represents 3 models: – Snowstorm environmental model: describe the crisis environment – Snowstorm emergency role model: the roles involved in the considered crisis management system – Snowstorm emergency organizational structure and interactions model: the organizational structure of the crisis management system and interactions among actors	– UML diagram – Interaction model

3 Comparative Study

In order to understand the decision processes, their functions, their characteristics, their components and their actors in crisis management and to improve them, we compare the studied metamodels based on different criteria in relation with our objectives. We aim to identify which among these metamodels provides a holistic vision to the studied domain and which among them presents the decision-making elements such as the decision makers and their roles.

3.1 Criteria Definition

Based on the systemic approach [9], we identified some criteria to compare the studied metamodels. The systemic approach, based on the system theory, is often translated, as "The whole is more than the sum of the parts" [9]. It considers the system as a set of interrelated sub-systems. We use this approach because it allows us to understand the complexity of a system. In our context, the crisis and its management are qualified as a complex system [10]. Moreover, to study decision-making in crisis management effectively we should consider the decisional process in the different levels (strategic, tactic and operational) and the multiple actors involved in this process. Therefore, to classify the metamodels presented in Sect. 2, we consider the following questions:

- What aspect(s) presents the metamodel: structural, functional, genetic or teleological?
- What level(s) concerns the metamodel: strategic, tactic and operational?
- Does the metamodel presents the different stakeholders, their roles and the relationships between them or not?
- Does the metamodel concerns particular crisis types or not?

In addition, to model a system from a global view, we need to present it according to these four aspects [9]:

- **Structural aspect:** How the system is composed? We focuses on the relationships between the elements of the system more than the separated subsystems.
- **Functional aspect:** we try to answer the questions: what does the system do in its environment? What is it used for?
- **Genetic aspect:** How the system evolves?
- **Teleological aspect:** What is the purpose and motivation of the system?

3.2 Similarities and Differences

All the metamodels studied in this paper are structural because they contain relationships among concepts (components) which refer to parts of the crisis management domain. Each metamodel shows a particular part of the domain that is why they do not have the same elements. Moreover, they are all functional and teleological because they are built to provide solutions for different

crisis activities. For example, the metamodel in [5] is developed to deal with the collaboration problems by modeling the concepts dedicated to describe the collaborative behavior.

The metamodel presented in [6] is dynamic (genetic), it models the human behavior during flood emergency evacuation using causal loop diagram. The metamodel in [8] is the only one that presents the different actors and the relationships among them in the different decisional levels. It proposes a snowstorm emergency organizational structure and describes the communication between actors using an interaction model. These two metamodels [6,8] are focused on some particular types of crisis (the flood and the snowstorm).

The research works in [1,5] are the most relevant and mature until now. In fact, the metamodel presented in [1] is composed of four packages (prevention, preparation, response and recovery). It shows a unified view of common concepts and actions that apply in different crisis. It could be considered as a dynamic metamodel because it models the four phases of crisis management, so, its users can follow the process from the first phase (prevention) to the final phase (recovery).

The metamodel in [5] based on [10,11] is composed of five packages (core, context, partners, objectives and behavior). The main issue treated in this work concerns the coordination and collaboration of the crisis stakeholders. The package "partners" expresses the actors involved in the crisis management without presenting the different actors types (crisis managers, local and state government, crisis service teams) and the relationships between them.

In Table 2, we summarize these metamodels according to the criteria presented in Sect. 3.1:

Table 2. Crisis management metamodels classification.

Metamodel	Aspect				Decision level			Multi-actor?	Particular to some types of crisis?
	Structural	Functional	Genetic	Teleological	Operational	Tactic	Strategic		
[1]	✓	✓	✓	✓	✓			No	No
[5]	✓	✓		✓	✓			No	No
[6]	✓	✓	✓	✓	✓			No	Yes
[7]	✓	✓		✓	✓			No	No
[8]	✓	✓		✓	✓	✓	✓	Yes	Yes

3.3 Discussion: Strengths and Limitations

The studied metamodels are relevant and important. In fact, they all present some advantages. For example, the work in [1] offers the possibility to generate several models specific to crisis prevention, risks management, crisis response, etc. and, based on information stored in a "Disaster Management knowledge Repository" [1], the users of this metamodel could make better decisions. So, it can be used to support decision. Furthermore, the metamodel in [5] is dedicated

to support the use of data in crisis management, it can help to insert an "information layer" (interpretation layer) between "data layer" (data gathering) and "knowledge layer" (exploitation layer) [5].

However, all these metamodels have some drawbacks:

- They are dedicated to some precise type of crisis management.
- They do not represent the different types of stakeholders, their roles and the interactions between them.
- They are specifically dedicated to the operational level. They do not represent the other levels (tactic and strategic).
- They present the information needed for making decisions but they do not show the decision making process in crisis management.

4 Conclusion

In this paper, we present the description and the classification of existing crisis management metamodels according to different criteria (structural aspect, functional aspect, etc.). We aim to identify which of these metamodels present a global view of crisis management domain and describe concepts with relations to decision-making. We find that all of them focus on specific point of view and they all dedicated to support decision by providing information that can be needed to make decisions. Some metamodels could be the basis to build a holistic crisis management metamodel (such as the works in [1,5]) because they present a large number of domain concepts, but we believe that they do not offer a sufficient elements concerning the decision making process like presenting the actors, their roles and the interactions among them.

Consequently, they do not support effectively the crisis management process by eliminating the part of the decision-making. So, we can identify some requirements for an effective model useful to support decision processes in crisis management:

- The metamodel should present different aspects (structural, functional, genetic and teleological) to give a holistic vision to the studied domain.
- It should present the concepts related to the decision making process.
- It should show the different actors structures in different decision levels (operational, tactic and strategic).
- It should be generic and not particular to some types of crisis.
- To enhance the decision making process in crisis management, we, preferably, start by the representation of the stakeholders (decision makers), their roles and their relationships.
- The metamodel should be instantiable, useable and practical.

In the future work, we will try, based on the existing metamodels, the crisis reports and others sources, to:

- Identify the different crisis stakeholders, their roles and the relationships among them (For example: identifying the command chain between actors).

- Generate first model representing the crisis actor's structure and the data flow between them. Based on this model, we can generate BPMN (Business Process Management Notation) processes (scenarios) to manage the crisis situation.
- Conceptualize the decision types in crisis management and associate them to the corresponding decision makers.

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