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A Framework for Interoperability Assessment in Crisis Management

Daniel da Silva AVANZI [a,b1], Anderson FOGGIATTO [a], Eduardo de Freitas Rocha LOURES [a] and Fernando DESCHAMPS [a]
[a] *Industrial and Systems Engineering Graduate Program, Pontifical Catholic University of Parana – Curitiba, Brazil*
[b] *Instituto das Cidades Inteligentes, Curitiba, Brazil*

Abstract. It is noticeable the growing of the various types of concerns in large centers, whether by citizens or public officials. In that sense, an important dimension is the crises management such as in cases of natural disasters. This scenario calls for a task force in an attempt to predict or solve emergencies, especially in managing and integrating public and private spheres, which in turn are centered on public authorities, service providers, citizens, volunteers and systems. In order to allow the exchange of information and joint actions of those involved entities, the fulfillment of interoperability requirements become a critical factor promoting improved performance of the actions taken in situations of crisis. Based on the literature and related worldwide initiatives, the main concerns and attributes of crisis management are identified from the perspective of interoperability. Founded on this knowledge a framework that supports a Disaster Response Management System (DRMS) development cycle is proposed. In this paper, a focus is done on a diagnostic step based on a Multi-criteria decision analysis (MCDA) in order to assess potential interoperability of a public entity or locality. The proposed MCDA method facilitates the specification of integrated solutions for the public sector to meet interoperability requirements in disaster management scenarios.

Keywords. Disaster management system, interoperability assessment, disaster response, multi-criteria decision analysis.

Introduction

A crisis situation can occur in different ways, such as political, military, economic, humanitarian, social, technological, environmental or health. Lately is notable that the authorities are increasingly seeking solutions to improve the management of crises. Part of this growth is due to increased citizen participation, both in collaboration in crisis moments and in monitoring the measures taken by the responsible [1].

Regardless of its nature, it is possible to consider that the crisis is an abnormal situation, usually resulting from an instability that brings impact to a particular segment with unacceptable consequences. This implies the need for crisis management, which involves the participation of various entities working together in a life cycle based on four main phases: mitigation, preparedness, response and recovery [2]. The response dimensions represent the most relevant stage in order to meet performance requirement

[1] Corresponding Author, E-Mail: davanzi@gmail.com

in crisis management. The related efficiency is determined by the speed and precision with which information can be managed and exchanged between the partners (i.e., organizations, people, and devices involved in the collaboration). Thus, a successful crisis management requires the full integration of all involved, especially in response actions [1].

It is possible analyze a crisis management scenario considering two important entities directly involved in this kind of unexpected situation - firefighters and police. In the case of a notification, for instance, of a large crash on a highway, information simultaneously arrives at more than one police or fire departments without proper control and information sharing. This disaster event thus results more than one rescuer team sent to the scene and a impair mobility due to concentration of rescue vehicles. The resulting no-interoperable scenario highlights the importance of information exchange and integration of the different services involved in an incident.

Interoperability can be defined as a broad concept encompassing the ability of organizations to work together in pursuit of common goals and mutually beneficial. Thus, if two or more systems do not have the ability to collaborate, exchange information and coordinate actions, they cannot be considered interoperable in its domains [3]. For entities become interoperable, they must meet certain common goals and requirements, which in turn must be set according to each area or domain. To identify their capabilities, the entities should be subject to an assessment, which allows stressing out how a particular organization is interoperable in its domain to face disaster scenario.

This paper presents a DRMS development cycle framework with a focus on a diagnosis step devoted to potential interoperability assessment of a public/private entity or locality. The proposed approach is based on a multi-criteria decision analysis structure based on AHP (Analytic Hierarchy Process) and helps the organizations to perceive their strengths and weaknesses, encompassing actions to increase performance and maturity, closely related to their ICT capabilities. The diagnosis results support the specification of a DRMS in order to fulfill interoperability requirements coherent to entity capabilities on disaster management.

1. Scientific scenario and related works

1.1. Disaster Management

There are three main aspects of disaster management - life protection, property and the environment. Most often disasters are classified mainly into natural and man-caused categories. The former is related to events such as earthquakes, floods, storms, hurricanes, tornadoes, cyclones and forest fires. The latter, called man-caused, covers events such as fire and collapse of buildings and airplane accidents. Regardless of the type of disaster mitigation, an effective and coordinated action is a difficult task to the first responders [4].

The various rescue organizations such as police, fire, health, civil defense and other organizations need to be efficient when working in a collaborative way, considering the inter and intra organizational aspects, in addition to the different hierarchical levels of each involved team [5]. Thus the exchange of information becomes an essential prerequisite for dealing with the various types of disaster in a rapid and coordinated manner. To allow the exchange of information aiming the

prevention or mitigation of crisis situations a proper management and integration of its participants is needed [1]. Thus the whole operation requires that the information is up to date as possible, requiring real-time communication between participants.

This real-time exchange calls for the need to characterize information and communication technology system (ICT) integrated in disaster management, making the exchange and processing efficiently and safely [5]. Most collaboration issues and communication of a company are supported by Information System (IS) without capabilities to face process coordination and information flow between heterogeneous entities and systems. The implementation of a Mediation Information System (MIS) supported by Service Oriented Architecture (SOA), represents an interesting solution allowing an evolutionary monitoring of the crisis scenario and the management of information between involved entities [6].

Thus, in the field of emergency and disaster, the Crisis Information Management Systems (CIMS) or Disaster Management Interoperability System (DMIS) has been part of the prevailing concept in use in real cases as proposed in [7] [8]. Its main objective is to provide a complete set of ICT functions to address many needs of the actors in crisis management. CIMS has been highlighted as a preferred system of entities to meet the main needs of a crisis, especially in the exchange of information, enabling a joint and coordinated actions of those involved efficiently [7]. Some actions performed by these types of systems [9]: conduct an assessment throughout the period of crisis; start, maintain and control communications; identifies the incident management strategy; makes decisions according to the found resources; request additional resources; develop an organizational command structure; continually review action plans; provide continuation, transfer and termination of a call.

Therefore it is noticeable that the crisis management occurs efficiently when the information is exchanged and updated in real time between the involved organizations. These requirements suggest the use of technological tools to control and manage the data according to each occurrence [5]. Most often the speed and precision with which information can be managed and exchanged between the partners (organizations, people, and devices involved in cooperation) contributes with the results in the efficiency level of response [1].

But this is not the only important part to allow the operation of entities. It is necessary for organizations to adopt some established norms and standards for its domain, contributing to the interoperation of activities. It is essential that the business aspects of the organization, such as processes and business are aligned with the established standard, given syntactic and semantic requirements. The rules for the sector already consider cultural, legislative, different practices and various other factors that may contribute to loss of organizational interoperation [11].

With the necessity for better integration and management, organizations are also concerned about the quality of their participation in the acting domain. The entities are seeking to evaluate their interoperation capacity, aiming to better performance of the organization and also contributing to a more efficient environment [10]. The assessment of interoperability of a company is crucial to identify its weaknesses. When it comes to activities related to crisis management, each improvement can be even more important, since the domain is directly linked to emergencies involving risk to citizens. With the weaknesses identified, the activities can be improved and risks reduced, contributing to the efficiency of the process. Evaluations can be performed in comparison with another entity (a posteriori) or a generic domain (a priori) [13].

Among the phases of crisis management, the response step is the most important one because this phase does not allow errors. It requires coordinated and efficient actions, which is even more difficult with the participation of several entities. The interoperability aspects and their assessments contribute to the success of these activities [10].

1.2. Interoperability

The interoperability is considered progressive when organizations start to communicate and share information, and together create performance conditions that would be hard to achieve individually [14]. Going beyond people, machines and systems, interoperability is becoming a key success factor in all areas. The concept of interoperable systems therefore requires considerable attention to be evaluated and continuously improved [11]. A broad concept, encompassing the ability of organizations to work together in pursuit of common and mutually beneficial goals, represents one of the definitions involving interoperability [12]. This ability to interoperate can be affected by conceptual, technological and organizational barriers, which are classified [13]: Conceptual concerning different ways to represent and communicate concepts; Technological relating incompatibility of data and systems; Organizational regarding different methods of work.

The Enterprise Interoperability Assessment (EIA) allows the measurement of the degree of interoperation between entities, which in turn helps the specification of integrated solutions in the domain as well as the adjustment and adaption to improve the activities of those involved [11]. This type of evaluation identifies strengths and weaknesses imposed by interoperability barriers, enabling the prioritization of actions in order to enhance interoperability performance and maturity.

The literature presents several methods and models of assessment [15]. Evaluations can be based on Interoperability Maturity Models (IMMs) in order to infer about the potential degree of interoperation [16]. Each assessment approach should be conducted according to the domain to be assessed and may require a brief survey to identify the attributes and criteria that best characterizes the domain through interoperability perspectives [17]. In the context of this paper the assessment approach relies on the use of interoperability concepts in order to evaluate the entity coverage level within the crisis management domain, thereby allowing the identification of possible adjustments in order to improve disaster response performance.

The need to interoperate in crisis management activities determines the way that operations and service occur. The responsibilities involved in this scenario can be divided into state, national or even international spheres, represented by different teams from different public or private entities as civil defense, firefighters, police, etc. According to [10], entities mainly involved in crisis management should work through a life cycle consisting of phases: prevention, preparation, response and recovery. The authors seek to identify relationships through each stage of the crisis process, allowing the improvement of inefficient points and improved performance of Disaster Management Organizations (DMOs). In [18] the authors advocate that the analysis and search for interoperability requirements are focused on integrating lifecycle approach using the Enterprise Architecture approach (EA).

The new advent of Internet-of-Things (IoT) brings increasing complexity and diversification in information systems, making interoperability a key requirement for its scalability and sustainable development. In crisis management context [19] the

situation is different because the process involves most of the time a very heterogeneous group of entities that must work together in providing services and responses. In this case, ontology is used to identify and relate the various types of agreements between organizations, thus helping to create a unique environment that can be communicated through the same pattern, leading to the concept of Interoperability-of-Everything (IOE).

1.3. Worldwide Initiatives

The survey of the initiatives within the crisis management domain collaborates with the identification of best practices and technical requirements that can support a Disaster Response Management System (DRMS) development cycle. These systems are characterized as DMS (Disaster Management System) and mainly focused on the response to a particular occurrence. Some successful worldwide initiatives are presented next. They collaborated with the identification of relevant attributes concerning disaster management scenario assessment, as well as to support a relational study between these attributes and ICT interoperable requirements.

SAFETRIP [20] - Satellite application for emergency handling, traffic alerts, road safety and incident prevention (France)

Currently it has been noticed an increase in research and development of systems to assist the driver. Such systems are based on automated technologies and sensors capable of detecting the traffic situation around the vehicle warning the driver or performing some mechanical action automatically. In addition to vehicles, roads have also received significant improvements. Intelligent communications systems that interact with many devices and vehicles are being deployed with good results [20]. In this way, the SAFETRIP is one of these intelligent systems designed to improve the use of the road transport infrastructure generating alerts with many degrees of importance: informative, preventive, promoting actions, etc. This system helps to reduce the number of accidents and deaths because it increases the mobility of the involved entities and the information distribution. Vehicles can be interconnected via different media (called ICT) such as telephone channels, satellite and WiFi, radio, etc. To improve the exchange of information, new satellite technologies are being implemented to improve the communication in extreme environments and other problematic situation [20].

DECIDE [21] - Decision Support System for Disaster Emergency Management (Greece)

This project aims to provide assistance during emergencies caused by natural agents or by human action. It aims to improve the capacity of involved resources and also preventing future occurrences. Its development was motivated by the high complexity of the actions necessary to during disaster situations. A quick response and the prevention plans development are difficult because of this complexity. To minimize such difficulties, DECIDE proposes an Intelligent Decision Support System (IDSS) to promote greater efficiency and management capacity of local responsible and stakeholders to respond effectively to all types of disasters. The system proposes some goals, encouraging the use of innovative solutions and technology base to increase the

capacity of local authorities to achieve effective and efficient coordination in the prevention and response procedures. These procedures should consider the risks and enhance the capacity of society and volunteers to support a local disaster control, thus avoiding further losses. The main ways of achieving the goals is through IDDS where you can see its main features below:

- allocation of civil protection units;
- routing and guidance in emergency situations;
- network based on geographic information system (GIS) and risk mapping;
- viewer roles and responsibilities;
- alerts and warnings;
- management scenarios and users;
- multiple end user interfaces support (web, phone etc.).

SAVE ME [22] - System and Actions for Vehicles and transportation hubs to support Disaster Mitigation and Evacuation (United Kingdom)

In recent years, a large number of people have died due to natural disasters, fires in tunnels and public transport terminals. In addition, governments still have the difficult task of dealing with the threat of terrorist attacks. Synthetic or natural disasters always require rapid and coordinated response taking often mass evacuation scenarios. SAVE ME project aims to prevent these disasters by developing systems that detect both types of events. The system must support mass evacuation policies in a very short time protecting the lives of all involved. The system also provides features to handle all kinds of people, including people with some disability [22]. To achieve its objectives, the project presents an ontological framework able to recognize the different types of threats, classify them and propose possible solutions for their reduction. The approach is founded on a complex and innovative algorithm based on human behavior (under stress, panic and strong emotions, etc.). These behaviors can indicate an abnormality working as trigger alerts to be send to the respective responsibles.

2. DRMS development cycle framework

The proposed DRMS development cycle framework shown in Figure 1 aims to provide the organization the opportunity to discover and evaluate its strengths and weaknesses, facilitating the prioritization of actions to improve its performance and maturity. The idea of the proposal is to use the concepts found along with the aspects that directly reflect the domain interoperability issues to achieve disaster response management (DRM) objectives.

The proposed framework is centered on Disaster Response Interoperability Assessment Model (DRIAM), which aims to evaluate a reference DRMS architecture according to aspects of interoperability. The diagnosis promoted by DRIAM allows a granular assessment of capabilities of a public or private entity involved in DRM. As a result of this capabilities analysis, a deeper relational review of the functional and technical requirements of the reference architecture with DRM attributes could be conducted. The main steps and components of the framework are shown in Figure 1.

The process begins by creating the knowledge base in disaster management domain represented by a set of attributes. The knowledge could be obtained from

various sources, such succeeded initiatives, literature review and consultations with experts. The attributes are divided into two forms: (i) the so-called domain attributes (DA), which its main source is focused on the extraction of literature and disaster management specialists; (ii) technical and functional requirements, or simply system requirements (SR), identified from existing DMRS initiatives and also expert knowledge.

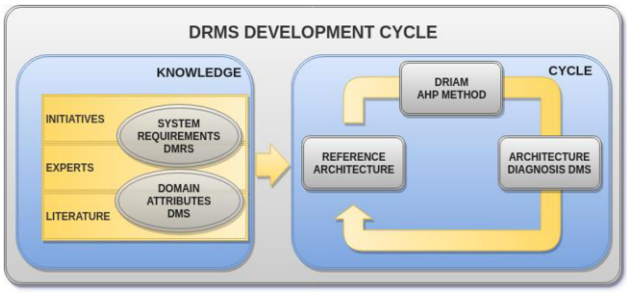

Figure 1. DRMS development cycle framework.

The first data set (domain attributes - DA) consists primarily of needs found within the crisis management domain, such as connectivity, safety, flexibility, among others. The second set of information (system requirements - SR) allow to identify the necessary means to ensure that the domain attributes (DA) are supported, for example the band speed, proxy settings and tools for system adaptation. Use cases could also be included in the system analysis and are normally presented directly by the involved stakeholders. Both the DA domain attributes as the system requirements must meet the interoperability requirements (I).

The scheme presented in Figure 2 illustrates, through a tridimensional view (cube), the relationship between the mentioned perspectives (DA, SR and I). The relational analysis that emerges from which perspective (cube surface) is conducted by DRIM (Disaster Response Interoperability Matrix) inspired in QFD (Quality Function Deployment) [23] and Axiomatic Design [24] methods. The DRIM will support the design of the DRIAM assessment structure based on AHP method. A similar approach is proposed in [25] concerning e-gov attributes and interoperability perspectives.

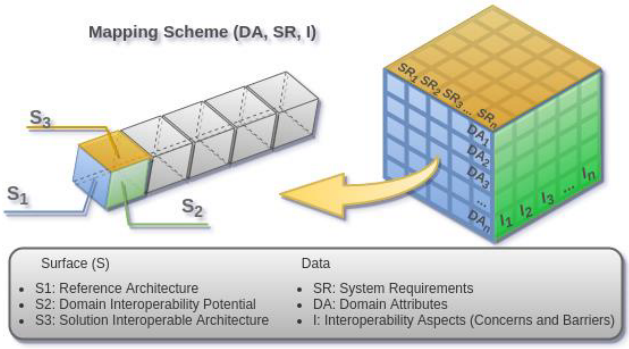

Figure 2. Mapping through the cube components.

Related to S1 surface (Figure 2), the purpose of the DRIM construction is to identify how the DRM needs are covered by the technical requirements. With this

matrix is possible to calculate how the technical requirements (SR) should be improved to meet the DRM requirements (DA). These importance levels could be applied by specialists, through brainstorms, use cases study, DEMATEL method [26], etc. The crossing of data conducted by DRIM is illustrated in Table 1, showing the degree of importance of each domain attribute (DA) to the system requirement (SR).

Table 1. Reference Architecture (S1).

System Requirements (SR) / Domain Attributes (DA)	Importance	Modular Approach	Uniform Emergency Signals (Alerts)	Relational Data Model	Open SQL data Language	Multiple Data Formats
Able to be connected on old systems	3	1	9	3	9	9
Data sharing	9	3	9	3	9	9
Able to interoperate with other architectures	9	3	9	3	9	9
Work with different type of crisis	3	3	9	3	9	9
Agile (good Performance and flexibility)	9	3	3	9	9	9
Easy to include new modules	9	9	9	9	9	9
Not Complex Systems	3	3	9	9	9	3
Aceptable for Governamental Services	3	9	9	1	9	9
Depiction (Physical Representation in a digital format of the environment)	3	0	1	3	3	9

Concerning the surface S2, the Table 2 concerns the DRIM analysis between DA and interoperability (I) concerns. The aim of this relational analysis is to bring to the interoperability perspectives (I) the assessment of disaster management attributes (DA) fulfillment. This DRIM acts as a basis for AHP structure design (DRIAM) shown in Figure 3. The first level corresponds to the goal of the AHP method. The second and third level represent the evaluation criteria, with the Interoperability Perspectives (I) and Domain Attributes (DA). The fourth and final level is the potential interoperability assessment.

Table 2. DRIAM QFD Method (S2).

System Requirements (SR) / Domain Attributes (DA)	Business	Process	Service	Data
Able to be connected on old systems	0	1	9	3
Data sharing	1	1	9	9
Able to interoperate with other architectures	0	1	9	3
Work with different type of crisis	9	3	1	1
Agile (good Performance and flexibility)	1	9	3	1
Easy to include new modules	3	9	3	3
Not Complex Systems	3	9	1	1
Aceptable for Governamental Services	9	3	3	1
Depiction (Physical Representation in a digital format of the environment)	3	1	3	1

Through AHP method and DRIAM, a diagnosis of the private or public entity capabilities, on each DA and under I perspectives, is carried out. As a result, the potential interoperability of the entity is assessed in order to infer about its capabilities

on disaster response management and the supporting of the referential DRMS architecture review (coherent to its capabilities).

Finally, the third face of the cube (S3) shows a diagnostic perspective on the system requirements (SR) with aspects of interoperability (I). This analysis step will contribute to the review of the referential architecture specification, in order to meet system interoperability requirements.

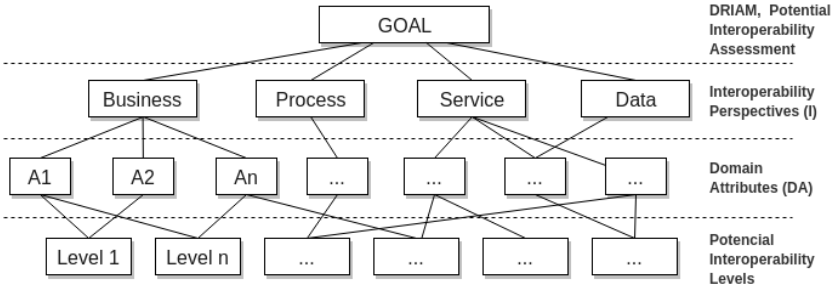

Figure 3. DRIAM AHP Method.

3. Conclusion

It has been shown that crisis management should be linked directly to interoperability issues, allowing an integrated operation of all involved entities during an event. In order to identify the potential interoperation in a disaster response management environment, it is proposed an interoperability assessment framework specific for domain. The proposed method is based on a reference architecture specification (domain attributes vs system requirements), an interoperability diagnosis (domain attributes vs interoperability concerns) of a locality or private or public entity, supporting an interoperable architecture (domains requirements vs interoperability aspects). The proposed framework promotes a review, evaluation and improvement the reference architecture according to the reality of the analyzed entity with respect to its interoperability capabilities. In addition to analyzing the use of other methods to support relational modeling and multicriteria analysis, such as Dematel, the research will continue towards to the improvement of the framework, verifying and validating the found results with ICT public institution of Curitiba and other public entities (civil defense, firefighters, traffic engineering) involved in disaster response management initiatives.

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