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A framework for interoperability assessment in crisis management

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Abstract

It is noticeable the growth of various types of concerns in large centers, whether by citizens or public officials. In that sense, an important dimension is 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 becomes a critical factor to promote improved performance of the actions taken in these situations. 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 focusing on a diagnostic step based on a multi-criteria decision analysis techniques (MCDA) 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 (DM) scenarios. In this paper the assessment method was based on the Analytic Hierarchy Process technique (AHP), and applied to a company involved in the DM domain, responsible for the information technology infrastructure of a city in the south of Brazil. The findings show the main gaps of the entity under the interoperability perspective, allowing the identification of key areas for improvement of its DM capabilities coherent to the DRMS deployment process.

Keywords: crisis management; disaster management system; interoperability assessment; disaster response; multi-criteria decision analysis.

1. Introduction

Regardless of its nature, a crisis is considered an abnormal situation, usually resulting from an instability that impacts a part of society with unacceptable consequences. A crisis situation can emerge in different contexts - political, military, economic, humanitarian, social, technological, environmental or healthcare. Lately, it is noticeable that authorities are increasingly seeking solutions to improve the management of crises. Part of this growth is due to increased citizen participation. Through the ubiquitous use of technology, people are both more collaborative in crisis moments and demanding more transparency by closely monitoring measures taken by the responsibles [1].

In this sense, crisis management is becoming more and more relevant. Managing a crisis involves the participation of various entities working together in an action cycle based on four main phases: mitigation, preparedness, response and recovery [2]. The response phase is both relevant for meeting performance requirements and critical for the support that may be provided to any impacted group of individuals. Efficiency in managing a crisis is measured by the speed and precision with which information is managed and exchanged among partners (i.e., organizations, people, and devices involved in the collaboration). This efficiency and performance therefore depend not only on information systems, but on associated dimensions such as strategy, processes, services and roles that guide the coordination of the entities involved. Thus, successful crisis management, particularly in response actions, requires full integration of all of the involved parties through different inter and intra-organizational concerns [3].

It is possible to analyze the management of a crisis considering the viewpoints of two important entities directly involved in this kind of unexpected situation - firefighters and police officers. For instance, in the case of notification of a large crash on a highway, information usually arrives simultaneously at more than one police or fire departments without proper control and information sharing. This results in more than one rescue team being sent to the scene and impairs mobility due to the concentration of rescue vehicles. This scenario may be even more complex when involving more extreme environments, such as the seas and oceans [4]. This highlights the importance of information exchange and integration of different services involved in providing response to an incident and shows the relevant role interoperability among these entities plays in these situations.

Interoperability can be defined as a broad concept encompassing the ability of entities (e.g., organizations or systems) to work together in pursuit of common, mutually beneficial goals. Thus, if two or more entities do not have the ability to collaborate, exchange information and coordinate actions, they cannot be considered interoperable [5]. For entities to become interoperable, they must meet certain common goals and requirements, which in turn must be set according to their application domain.

To identify their capabilities to interoperate, entities should be subject to an assessment, which allows stressing out how a particular entity is interoperable in its application domain. This refers to the definition of potential interoperability [6], particularly related to the crisis management domain, characterized by complex dynamics involving a priori undefined knowledge about entities expected to interoperate. The potential interoperability assessment represents an appropriate diagnostic tool for mapping the elements of influence on the efficiency and performance of involved entities. It should assist in identifying and reviewing technical and managerial requirements of entities' information systems and considered by a disaster management project lifecycle as advocated by Noran [7].

This paper presents a Disaster Response Management System (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 uses a multi-criteria decision analysis structure based on AHP (Analytic Hierarchy Process) and helps organizations perceive their strengths and weaknesses, devising actions closely related to their ICT capabilities to increase performance and maturity. The diagnosis results support the specification of a DRMS that fulfills interoperability requirements coherent to entity capabilities in disaster management.

The paper is structured as follows. Section 2 presents the main worldwide initiatives, as well as the literature review to investigate performance perspectives and the effectiveness of the actions taken in disaster management together with the principles of interoperability. Section 3 describes the interoperability assessment model for crisis management considering all the artifacts used in its development supported by a specific framework. In section 4 the assessment model is applied to a real case, allowing the evaluation of a given entity and its environment regarding its interoperability capabilities. The company responsible for Curitiba (southern capital of Brazil) municipal information technology infra-structure was chosen as an application case. Finally, in the conclusion section, the main outcomes, lessons learned and research perspectives are presented.

2. Scientific scenario and related works

2.1. Disaster Management

There are three main aspects to be considered in managing disasters - protection of life, property and the environment. Disasters are usually classified into natural or man-caused. The former are related to events such as earthquakes, floods, storms, hurricanes, tornadoes, cyclones and forest fires. The latter covers events such as the collapse of buildings or accidents involving air transportation. Regardless of the type of disaster, achieving an effective and coordinated action is a difficult task for first responders [8].

The different rescue organizations such as police and fire departments, health services, civil defense and others must 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 [3]. Thus, the exchange of information becomes an essential prerequisite for dealing with the different types of disasters in a fast and coordinated manner. Proper management and integration of participants is required in enabling the exchange of information targeted at prevention or mitigation of crisis situations [1]. Thus, the whole operation requires that information is kept as up to date as possible, requiring real-time communication between participants.

Such exchange of information may be easy to solve in some cases. But the problem can grow larger when a need for crisis control and recovery covers areas with greater difficulty in communication and access. One can mention wild environments and marine areas, that require adequate measures to minimize the damage caused by, for instance, an earthquake, especially in financial matters and life protection. To face this scenario, Wang and Tanaka [4] propose a system for optimizing the marine logistics in case of emergency or disaster (earthquake) by assigning ships to transport routes, considering all possible adversities imposed by this scenario.

Far from extreme environments, companies are also concerned with managing disasters. Some authors [9, 10] describe the factors of influence that increase the risks for such disasters, as environmental, logistical and external catastrophes, always proposing recovery methodologies. For instance, a supply chain risk assessment methodology to face disaster response requirements is proposed [9]. Although the model presented by the author suits the industrial context, it can also be adapted and applied to other domains. Such a model aims to improve resilience through matrices that confront samples of different disturbances that have led to different types of supply chain failures. These scenarios, whether in extreme environments or not, require greater care in order for communication to occur efficiently.

The real-time exchange of requirements in a crisis scenario drives the need to integrate information and communication technology systems (ICT) in delivering disaster management support, providing efficient and safe exchange and processing of information [3]. Most collaboration and communication issues in companies are supported by Information Systems (IS) without capabilities to face process coordination and information flows among heterogeneous entities and systems. The implementation of a Mediation Information System (MIS) supported by a Service Oriented Architecture (SOA) represents an interesting solution allowing an evolutionary monitoring of the crisis scenario, and the management of information among entities involved [11].

Thus, in the field of emergency and disaster, Crisis Information Management Systems (CIMS) or Disaster Management Interoperability Systems (DMIS) have been part of the prevailing concept in use in real cases as proposed in [12, 13]. Their main objective is to provide a complete set of ICT functions to address many needs of the players in crisis management. CIMS has been highlighted as a preferred system by entities to meet the main needs of crises situations, in particular, the exchange of information, enabling efficient joint and coordinated actions by those involved [12]. Multiple cross-organizational actions are performed by these types of systems [14]: ongoing assessment throughout the crisis period; start, maintain and control communications; identify the incident management strategy; decision-making based on resources available; request additional resources; develop an organizational command structure; continually review action plans; provide call continuation, transfer and termination.

Therefore, it is noticeable that efficient crisis management occurs when the information is exchanged and updated in real time among the organizations involved under an adequate enterprise architecture [15]. Communication is the common basis for execution of emergency response and is best approached from a systems perspective considering all the directional flows of information, instructions, and announcements [16]. These requirements suggest the use of technology tools to control and manage data according to each occurrence [3]. Most often the speed and accuracy with which information can be managed and exchanged between the partners (organizations, people, and devices involved in cooperation) contribute to the response efficiency levels achieved [1].

Information and communication technologies are not the only concerns in allowing the operation of entities. Organizations must adopt norms and standards established for their domains, contributing to the interoperation of activities. Given syntactic and semantic requirements, alignment of business aspects of the organization, such as processes and business, with the standard established is essential. The rules for the sector already address cultural and legislative aspects, different practices and many other factors that may contribute to loss of organizational interoperation [17].

Relevant interoperability frameworks, such as the Framework for Enterprise Interoperability (FEI) [18] and Enterprise Interoperability Framework (EIF 2.0) [19] are grounded on these multiple and integrated perspectives, highlighting the non-dissociative aspects of data-service-process-business faced by organizational, semantic and technological barriers to interoperation on crisis management. It has become possible to notice that the previous generation of systems were not based on standards and frameworks. Every time a new system was built, a new communication and networking scheme had to be built. In many cases, interoperability was not considered in the design of these systems [16] and lesser attention was devoted to cross-organizational interoperability concerns supported by a project management lifecycle [7].

With the need for better integration and management, organizations have also become concerned about the quality of their participation in the action domain. Entities are seeking to evaluate their interoperation capability, aiming to improve organizational performance and also contributing to a more efficient environment [7]. The assessment of a company's extended interoperability concerns is crucial in identifying its weaknesses. The literature reveals recent assessment approaches based on this multiple view of interoperability and derived from the interoperability frameworks such as FEI and EIF [20].

In terms of activities relative to crisis management, every improvement can be even more important, since this domain is directly linked to emergencies involving risk for citizens. Once the weaknesses have been identified, these activities can be improved and risks reduced, contributing to the efficiency of the process. Among the phases of crisis management, the response step is the most important because this phase does not allow errors, requiring coordinated and efficient actions, which is even more difficult with the participation of multiple entities. The interoperability aspects and their assessments contribute to the success of these activities [7].

2.2. Interoperability

Interoperability is considered progressive when organizations start to communicate and share information, and together create performance conditions that would be hard to achieve individually [21]. Going beyond people, machines and systems, interoperability is becoming a key success factor in all areas of industrial, private and public spheres. The concept of interoperable organizations and systems therefore requires considerable attention to ongoing assessment and improvement [17]. A broad concept, encompassing the ability of organizations to work together in pursuit of common and mutually beneficial goals, is representative of one of the definitions of interoperability [19].

Interoperability frameworks have a common understanding about the ability to interoperate within business, process, service and data concerns can be affected by conceptual, technological and organizational barriers. One can mention IDEAS (Interoperability Developments for Enterprise Application and Software) [22]; AIF (Athena Interoperability Framework) [23]; FEI (Framework for Enterprise Interoperability) [24]; EIF 2.0 (European Interoperability Framework for European public services) [19]. The relational representation of interoperability perspectives (concerns and barriers) acts as a referential structure in defining specific quadrants relating to enterprise performance influences and subject of interoperability assessment. Table 1 illustrates this structure [17] [18] [25] highlighting the conceptual proximity to disaster management concerns.

Table 1 – Interoperability Concerns and Barriers

Concern/Barriers	Conceptual	Technical	Organizational
Business	Enterprise visions, strategies, objectives, policies.	Infrastructure, technology, the ability of IT support business requirements.	Work methods, business rules, legislative requirements, organizational

			structure.
Process	Process models, content, coverage, syntax, semantic.	Workflow engines, business process management systems, business activity monitoring.	Process management, procedures, guidelines, responsibility.
Service	Service models, content, coverage, syntax, semantic.	Service architecture, tools and applications, interfaces.	Service and application management, rules, authority, responsibility.
Data	Data models, representation, content, coverage, syntax, semantic.	Data storage, format, protocol and exchange devices.	Data management, rules, responsibility, information ownership.

Enterprise Interoperability Assessment (EIA) allows the measurement of the degree of interoperation between entities, which in turn helps in specifying integrated solutions for the domain as well as the adjustment and adaptation to improve the activities of those involved [17]. 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.

Evaluations can be performed in comparison with other entities (a posteriori) or within a specific domain with unknown entities (a priori) [26]. The former relates to ‘compatibility’ measure between known partners, as well as ‘performance’ measure supported by specific indicators (time, cost, quality of service) during interoperation [27]. The latter (a priori) refers to ‘potential’ interoperability measure of an unknown entity aiming to infer its capabilities to interoperate under specific performance requirements as the one from disaster management. The present work follows this direction aiming to provide an ‘as-is’ diagnosis of entity capabilities and maturity in order to support a customized lifecycle DRMS deployment.

Literature presents several assessment methods and models [20]. Evaluations concerning potential interoperability meet on Interoperability Maturity Models (IMMs) adequate approaches to deal with the multi-perspectives of interoperability characterized in interoperability frameworks [28] and are closely related to crisis management scenarios. Assessment approaches should be deployed according to the domain to be assessed and require a survey to identify the attributes and criteria that best characterize the domain from interoperability perspectives [25]. In the context of this paper, the assessment approach relies on the application of interoperability concepts in order to evaluate the entity’s level of coverage in the crisis management domain, thereby allowing identifying possible adjustments in improving disaster response performance.

The need to interoperate in crisis management activities determines how operations and services are provided. 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 such as civil defense, firefighters, police, etc. According to [7], entities involved mainly in crisis management should work through a life cycle consisting of phases (actions): prevention (Prev), preparation (Prep), response (Resp) and recovery (Recv). The authors seek to identify relationships in each stage of the crisis process, promoting improvement of inefficient points and enhanced performance of Disaster Management Organizations (DMOs).

In [15] the authors advocate that the analysis and search for interoperability requirements focuses on integrating lifecycle approaches applying the Enterprise Architecture approach (EA). A GERA modeling framework section is related to a lifecycle-based formalism, mapping each phase (identification, concept, requirements, design, implementation, operation, decommission) into disaster management task force (DMTF) actions (Prev, Prep, Resp, Recv) [7]. Disaster management project lifecycles are then linked to Chen’s Framework for Enterprise Interoperability (FEI) [18] in order to highlight the degrees of importance of the FEI quadrants in DMTF actions. This approach is closely related to our proposal, differing in the fact that each interoperability concern and barrier in FEI should be equally addressed in order to assess entity and system interoperability capabilities.

2.3. Worldwide Initiatives

A survey of the initiatives within the crisis management domain collaborates with the identification of best practices and technical requirements capable of supporting the development cycle of Disaster Response Management System (DRMS). These systems are characterized as DMSs (Disaster Management Systems) and are mainly focused on the response to a particular occurrence. Some successful worldwide initiatives are presented next. They collaborated with the identification of relevant attributes with respect to disaster management scenario assessments, as well as in supporting a relational study between these attributes and ICT interoperability requirements.

The identification and extraction of such attributes is carried out by the authors and specialists from crisis management domain, by means of a deductive and relational process grounded on the concepts and methods of requirements engineering. The approach used undergoes procedural detailing through a specific framework presented in the next section that makes use of consensus and validation mechanisms of identified attributes, as well as relational analysis with the dimensions of interoperability. Each initiative is then presented next with a first step set of attributes subject to requirements (functional/non-functional) analysis from the point of view of interoperability.

SAFETRIP [29] - Satellite application for emergency handling, traffic alerts, road safety and incident prevention (France)

A noticeable increase can be perceived in driver assistance systems research and development. These systems are based on automated technologies and sensors capable of detecting the traffic situations around the vehicle and either warning the driver or automatically performing some mechanical action. 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 [29]. Along this line, 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 as it increases stakeholder mobility and information distribution. Vehicles can be interconnected via different media (called ICT) such as telephone channels, satellite and Wi-Fi, radio, etc. In order to enhance information exchange capabilities, new satellite technologies are being implemented to improve the communication in extreme environments and other problem situations [29].

From this initiative, the following attributes have been identified: automatic traffic detection sensors; alert degrees (different importance); preventive action; warnings to the vehicle driver; informative action; automatic mechanic actions; accidents reduction; roads improvements; increase stakeholder mobility; vehicles improvements; increase information distribution; intelligent communication system; interconnection between vehicles; devices interaction; different medias; two-way satellite communication; environment protection; new device integrated to the vehicle; mortality reduction.

DECIDE [30] - Decision Support System for Disaster Emergency Management (Greece)

This project aims to provide assistance during emergencies resulting from natural causes or by human action, targeting improving the capability of resources involved, as well as preventing future events. The development was motivated by the high complexity of the actions required in disaster situations. Quick responses and development of prevention plans are difficult due to this complexity. In minimizing these difficulties, DECIDE proposes an Intelligent Decision Support System (IDSS) to promote higher efficiency and enhance management capability of local stakeholders and entities responsible for effective response to all types of disasters. The system proposes some goals, encouraging the use of innovative solutions and technology bases in increasing the capability of local authorities in delivering effective and efficient coordination of prevention and response procedures. These procedures should address risks and enhance the capability of society and volunteers to support local disaster control, thus avoiding further losses. The main way of achieving these goals is through an IDDS with the main features shown below:

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

From this initiative, the following attributes have been identified: alert degrees (different importance); provide assistance during emergencies; provide allocation of civil protection units; improve the capabilities of the resources; network based in GIS; prevent future similar events; risk mapping based on GIS; ability to work with complex actions; viewer roles; quick responses; responsibilities roles; prevention plans; provide alerts and warnings; adaptation to work with all types of disasters; scenarios and users management; use of innovative solutions; multiple end user interface support (web, phone); response procedures.

SAVE ME [31] - System and Actions for Vehicles and transportation hubs to support Disaster Mitigation and Evacuation (United Kingdom)

In recent years, large numbers of people have died due to natural disasters, fires in tunnels and public transport terminals. In addition, governments still have face the difficult task of dealing with the threat of terrorist attacks. Man made or natural disasters always require fast and coordinated response often resulting in mass evacuation scenarios. Project SAVE ME aims to prevent these disasters by developing systems that detect both types of events. The system must support mass evacuation procedures in a very short time protecting the lives of all stakeholders. The system also provides features to handle all kinds of people, including people with disabilities [31]. To achieve its objectives, the project presents an ontological framework capable of recognizing the different types of threats, classifying them and proposing possible solutions for their reduction. The approach is based on a complex and innovative human behavior based algorithm (under stress, panic and strong emotions, etc.). These behaviors can be indicative of abnormal conditions and serve as alert triggers to be sent to the respective persons/entities responsible.

From this initiative, the following attributes have been identified: common semantic approach; support mass evacuation procedures in short time; innovative algorithms to detect hazard; handle all kinds of people; automatic hazard recognition; proposal of possible solutions for hazards; wireless sensor network; human stress detection; improve evacuation procedures; panic detection; indoor localization module; strong emotions detection; fast and coordinated responses; alert triggers; automatic disasters prevention; send alert to respective responsible.

e-PING [32] - Electronic Government Interoperability Standards (Brazil) e-Ping defines a minimum set of assumptions, policies and technical specifications that drive the use of Information and Communication Technologies (ICT) in the Brazilian federal government, establishing the integration terms with other branches and levels of government as well as society at large. Brazilian entities must be e-Ping compliant in system planning, acquisition of new equipment, implementation of IT services, during system developments or upgrades. Some entities are voluntarily adopting e-Ping through direct changes in their management or by contracting service companies already compliant to the new standards and this way increasing interoperability and security in their communication transactions [33].

In disaster scenarios, the adoption of open e-government [34] standards for all stakeholders involved will help in ensuring information and communication security, given this is one of the underpinning assumptions of e-Ping. Literature reviews corroborate the fact that adopting common standards during the development and implementation of new Disaster Management Systems was a common requirement of many systems currently in operation. Therefore, adopting e-Ping implies in increasing interoperability among entities involved, as well as facilitating the inclusion of new partners and technologies in the future.

From this initiative, the following attributes have been identified: present a minimum set of assumptions; interoperability improvement between systems; present a minimum set of policies; security improvement between transactions; present a minimum set of specifications; common standards during development; all systems should be e-ping compliant in all phases.

IsyCri [35] - Systems Interoperability In Crisis situation (France)

The IsyCri project began in 2007 and ended in 2010 and defined a MIS (Mediation Information System) devoted to connecting (at cell level) players responsible for the reduction of crisis situations and ensuring their interoperability, supervising their collaborative workflows. The general principle of IsyCri relies on the belief that integration between the parties is a crucial step towards the successful reduction of a crisis. Therefore, interoperability is IsyCri's central concern, ensuring integration and communication among partners, as well as defining collaborative maturity levels.

In a crisis context (natural disasters, accidents, conflicts, industrial accidents, etc.) different participants (medical units, police, etc.) have to work simultaneously and very quickly. Cooperation among them and the ability to coordinate their actions is essential in achieving a common goal – reduction of the crisis situation. In this sense, the main point of the ISyCri project was to provide partner organizations, involved in managing the crisis through MIS, capabilities to merge their heterogeneous and autonomous Information Systems (IS) into a global System (SoS - System of Systems). The following tasks were defined for its implementation:

- ontology construct of the system studied including, e.g. people, local nature, goods, and characterization of the crisis by identifying its elements such as type, severity, trigger, etc.;
- logical modeling of MIS (Mediation Information System);
- technical architecture modeling and projection of logical view of the technological vision;
- study of dynamics;
- experimenting acting as a generic part of the project, based on specific use cases in order to verify the described principles.

From this initiative, the following attributes have been identified: connect all cells responsible; actions of coordination; ensure the cells interoperability; logical modeling; workflows supervision; study of dynamics; parties integration; use cases; different participants work very quickly; technical architecture modeling; collaborative maturity levels; logical view of the technological vision; capability to merge heterogeneous information systems

3. DRMS development cycle framework

The proposed DRMS development cycle framework shown in Fig. 1 aims to provide a methodological basis that organizes specific components and methods in phases, to support an evolutionary cycle of interoperability assessment towards the development of an information system for disaster management. The multi-perspectives of interoperability are then considered to assess the capabilities of entities involved in crisis management, guiding the specification of a DRMS coherent to the level of maturity diagnosed. The idea of the proposal is to use the concepts found along with the aspects that directly reflect domain interoperability issues to achieve disaster management (DM) objectives, facilitating the prioritization of actions to improve the performance and maturity of involved entities in disaster management.

The proposed framework is then centered on a Disaster Interoperability Assessment Model (DIAM), focus of this paper, which aims to evaluate a reference DRMS architecture according to potential interoperability aspects of companies. Therefore, the diagnosis promoted by DIAM allows a granular assessment of capabilities in public or private entities involved in DM. This capability analysis enables the execution of a deeper relational review of the functional and technical requirements of the reference architecture with DM attributes. The main phases, steps and components of the development cycle framework are shown in Fig. 1 and described next.

Fig. 1 - DRMS development cycle framework

In **Phase 1 (Knowledge Acquisition)**, DRMS and DIAM involve knowledge that can be obtained from different sources, such successful initiatives, literature reviews and consultations with experts. The resulting knowledge base is divided into three aspects: (i) a large set of information that can be understood as DM attributes, consensus of disaster management specialist; (ii) system requirements benchmarked against existing DMS initiatives; (iii) interoperability aspects (concerns and barriers) identified from the main EIFs, aiming to organize DM knowledge and fulfilling assessment requirements imposed by DIAM.

The data set (DM attributes) consists primarily of needs found within the crisis management domain, such as connectivity, safety, flexibility, among others. Characteristics that enable identification of the necessary means to ensure that the needs are supported can also be identified, such as bandwidth, proxy settings and tools for system adaptation (system requirements). Use cases should also be included in system analyses and usually presented directly by stakeholders involved. All of these DM attributes must meet interoperability requirements (I), after undergoing a refining process.

After carrying out the research and consulting specialists (Phase 1), numerous DM system requirements and attributes will be listed and organized in **Phase 2 (Knowledge Organization)**, as shown in Fig. 1. The list will be classified by characteristics, allowing for a better structure, understanding and use of the knowledge. Thus, DM attributes and DMS requirements are separated by their characteristics based on software and system engineering guidelines. With respect to the interoperability aspects of these attributes, based on Chen’s Framework for Enterprise Interoperability [24], are then correlated and organized pursuant to business, process, service and data concerns.

Thus, phase 2 aims to separate the knowledge generated into four data sets (perspectives), facilitating the identification and use of the information obtained. First, as illustrated in Fig. 2, the characteristics will be classified into three perspectives: Functional requirements (FR), non-functional requirements (NFR) and technical solution (TS). The fourth, and last perspective, is the interoperability knowledge (I), which later serves to submit the related DM attributes identified to interoperability assessment.

Fig. 2. Knowledge organization excerpt

The first three perspectives (FR, NFR, TS) must be properly sorted according to their degree of importance, as some may be irrelevant regionally and others may be necessary in a first implementation. For example, ice detection device for the road does not make sense in a desert or tropical region where temperature never falls below 26 degrees Celsius. In order to find out which requirements/attributes should be implemented or discarded by undertaking a relational review and analysis, the QFD (Quality Function Deployment) method is used [36, 37]. Each QFD is represented by a matrix in which the characteristics are expressed in text and their relationships are represented numerically. For our proposal needs, this relational approach is shown to be appropriate in the way qualitative data is transformed into quantitative values or into design requirements that could be used by the engineering team.

The central objective of a QFD is to separate the DM requirements and attributes into groups, translating text expressions into quantitative values that will be applied to help engineers decide what should be implemented, or not. The QFD stages involved aim to help in choosing the more relevant requirements for the development of the proposed DRMS through its life cycle towards the review of the technical reference architecture with respect to the entity's capabilities diagnosed by DIAM (**Phase 3 – Assessment Cycle**, Fig. 1). These QFD stages are presented in more details next.

3.1. Knowledge organization and relational modeling process

To support the design of DIAM and the reference architecture specification, the relational modeling process is illustrated in Fig. 3. The diagram is based on two QFD structures (QFD1, QFD2) and a proposed specific relational structure (IRM – Interoperability Relational Matrix) characterizing two different development routing: (i) requirement identification, analysis and technical solution mapping acting as input for SysML specification and analysis of the reference architecture; (ii) requirement identification, analysis and DM attributes mapping across interoperability perspectives in order to support the DIAM - AHP based method construction and execution.

Fig. 3. Relational modeling process

Considering Fig. 3, two QFD design steps are provided in order to share and handle the same initial DM attributes and system requirements from phase 1 (Fig. 1). The first design step translates this data set into Functional Requirements (FR) and Non-Functional Requirements (NFR). Therefore, QFD1 aims to model and relate NFRs that will describe how the system works (capability, availability, accessibility, portability, maintenance, etc.) to the FRs that will describe what the system should do (business rules, administrative functions, authentication rules, external interfaces, GUI features, etc.). QFD1 construction is based on identifying the degree of correlation between FRs and NFRs, classifying them as weak (1), medium (3) or strong (9). A QFD1 statement is represented in Fig. 4.

Other data items that must be entered by experts are the importance of each perspective under evaluation. Thus, it is possible to infer that the FRs are validated and filtered according to the NFRs (NFR x FR – 1, 3 or 9) and level of DM importance input by experts (Fig. 4, A). The end result (Fig. 4, B) is the relative weighing of each FR (already in combination with NFR), where a cutoff value is applied leading to a new set of FRs, called from now 'FR-Result'. In this approach, the defined cutoff value is the average, considering only those values that are equal to or larger than the average (Fig. 4, C). The resulting new FRs (FR-Result) ensures that only the most important requirements for DM domain are sent to the next stage.

Fig. 4. QFD1 excerpt: Functional x Non-Functional Requirements

The analysis and results of QFD1 (most important requirements) will then support a second QFD design stage (QFD2) in order to represent the relationship between functional requirements (FR) of higher importance and possible technical solutions (TS). These are some technical solutions: use of clustered solutions, MySQL database, C# implementation, etc. The result of this second QFD step analysis will, in its turn, support the SysML diagram modeling relative to a Reference Architecture specification review. Furthermore, QFD1 will also be used as a basis for building a relational structure to analyze the interoperability layer (IRM – Interoperability Relational Matrix), providing support in designing AHP DIAM structure.

3.2. Three-dimensional relational model

The scheme presented in Fig. 5 illustrates, through a three-dimensional model (cube), the relationship among the perspectives mentioned (FR, TS and I). The use of the cube representation facilitates interpretation of the interrelated modeling process described previously as well as the DRMS framework dimensions (Fig. 1). The relational analysis that emerges from each perspective (cube surface) is carried out by the QFD and IRM structures presented in section 3.1.

Fig. 5. Mapping through the cube components

The **S1 cube surface**, relates to QFD2 in order to identify how DM needs are covered by technical requirements. This matrix allows calculating how technical solutions (TS) requirements should be improved to address functional requirements (FR-Result). These importance levels can be applied by specialists through brainstorming processes, use of cases study, the DEMATEL method [38], etc. Fig. 6 illustrates the cross-matching of data undertaken by QFD2, showing the degree of importance of each functional requirements (FR-Result) for the technical solution (TS).

Fig. 6. QF2 excerpt: FR-Result x TS (S1)

In relation to the **S2 cube surface**, the next step consists in an analysis of the interaction between FR-Result and interoperability (I) concerns by means of IRM (Interoperability Relational Matrix). The aim of this relational analysis, inspired on QFD and Axiomatic Design [39] methods, is to bring to the interoperability perspectives (I) the assessment of achievement of disaster management attributes (FR-Result). The concerns and barriers concepts were applied following Chen's EIF, in which the FR-Result is organized within the aspects of interoperability [25]. A similar approach is proposed in [40] concerning electronic government (e-government) attributes and interoperability perspectives. In order to facilitate a qualitative reasoning, IRM is based on the use of symbols as shown in Fig. 7 (FR-Result x Interoperability Concerns) and Fig. 8 (FR-Result x Interoperability Barriers).

Fig. 7. IRM: FR-Result x Concerns

Fig. 8. IRM: FR-Result x Barriers

Weights are assigned to each of the comparisons with values of 1, 2 and 4 for the barriers, and 9, 3 and 1 for concerns in order to position the FR-Result from QFD1 in more related interoperability barriers/concerns (Chen's EIF quadrants). After defining these perspectives, a new combined view is obtained in Fig. 9. Only the FR-Result with strong correlation to the disaster management domain will be retained.

Fig. 9. IRM: Product of concerns and barriers

Stemming from this reasoning, Fig. 10 shows an example of the IRM analysis of the interaction between FR-Result and interoperability (I) concerns and barriers. Based on the aspects of this research, for diagnosing purposes, it was defined that only the cells with strong relations would have their NF-

Result evaluated in the diagnosis phase. This way a certain importance for the disaster area can be assigned to the identified NF-Result, filtering out the ones with low relevance.

Fig. 10. IRM Matrix excerpt (S2)

This IRM structure acts as a basis for the AHP structure design of the DIAM proposed shown in Fig. 11. The first layer corresponds to the goal of the interoperability assessment (diagnosis of potential interoperability levels for DM entities). The second and third layers represent the interoperability perspectives (I- concerns and barriers) related to DM functional requirements (FR-Result) (fourth layer). The fifth and final layer represents the potential interoperability levels.

Fig. 11. DIAM AHP Structure

The AHP method [41] defines that each layer is composed by criteria/subcriteria organized through clusters. In DIAM's AHP structure the criteria represent the interoperability concerns (layer 2, one cluster); the subcriteria represent the barriers (layer 3, four clusters) and the FR-Result (layer 4, twelve clusters). Alternatives represent the potential interoperability levels (layer 5, one cluster). A cluster defines a comparison matrix and a pairwise weighting between the criteria/subcriteria following Saaty's scale (1-9). The resulted priority (eigen)vector associated to each cluster infers about the relative importance of its criteria/subcriteria.

The pairwise assessment approach of the AHP method relies on a logical consistency verification based on a transitive property (logic of preference). A consistency ratio is obtained for each comparison matrix (cluster) and should be less than 10% [41]. The assessment uncertainties are then considered by the method, qualifying the AHP as appropriate to deal with the complexity of the observation space modelled by the IRM structure.

A diagnosis of the private or public entity capabilities, for each DM FR-Result under I perspectives, applying the DIAM AHP-based relative reasoning, is then carried out. As a result, the potential interoperability of the entity is assessed in order to infer its capabilities in disaster response management and support the reference DRMS architecture review (coherent with its capabilities). In section 4, this model is applied in a real interoperability assessment application case.

Finally, the **S3 cube surface** shows a diagnostic perspective of the technical solution (TS) with aspects of interoperability (I). This analysis step, following the same relational analysis as applied in surface S2, will contribute to the review of the reference architecture specifications, in order to meet system interoperability requirements. This analysis does not belong to the scope of this paper and represents ongoing work.

4. Application case

The application case aims to apply the DIAM in diagnosing interoperability capabilities of a given entity for the criteria related to disaster management. The result can contribute to identifying its strengths and weaknesses, directing decision-making actions that will improve the organization's performance in disaster management by adopting a DRMS architecture. The evaluation was performed with the Super Decision tool that supports the use of the AHP method.

4.1. Entity characterization

The company responsible for the municipal technology sector of Curitiba was chosen for the execution of the assessment model. This choice is based on the fact that information technology control and municipal communication have a direct link to this entity. The city of Curitiba leads the ranking of the most digitized municipalities, according to the Digital Cities Brazil Index (DCBI) undertaken by the national Center for Research and Development in Telecommunications (CPqD), covering 100 Brazilian cities. The company selected is responsible for defining and identifying the needs of the municipality in ICT, delivering and supporting for all of the city administration departments.

For the assessment, company's experts were selected based on their managerial, operational and technical background as well as skills in crisis management. The interviews were conducted in pairs, and the answers were collected considering a consensus achieved through geometric means pursuant to AHP requirements. The entire data collection was carried out using the Super Decisions software. Once the collected, the diagnosis data were inserted in the tool, a complete analysis was then carried out applying the criteria and levels defined by the DIAM AHP structure (Fig. 11).

The assessment is based, as mentioned before, on pairwise comparison between criteria of a given cluster and layer. An example of this type of comparison can be seen in Fig. 12, which compares the overall interoperability aspects in the crisis management domain (Layer 1, Fig. 11).

Fig. 12. Layer 1, AHP structure I-concerns cluster pairwise comparisons

The assessment profile indicates a relative relevance for interoperability data and process concerns relative to disaster management. This is due the fact that the capability to extract and exchange data from heterogeneous sources is very important in being aware of the conditions on the ground and avoiding potentially life-threatening situations for all involved.

4.2. Results and analysis

Following the DIAM method, similar pairwise assessments are carried out in each level of the AHP structure (Fig. 11) resulting in partial rankings (eigen/priority vector) that highlight focal diagnosis (degree of importance) relative to entity capabilities. Fig. 12 shows the degree of importance attributed to Data and Process concerns from the resulting priority vector (Data: 0.57381; Process: 0.23883; Service: 0.13101; Business: 0.05634) with consistency ration smaller than 10% (2,91%).

The same reasoning is deployed through the AHP levels and criteria resulting in the values indicated in Figure 15. The structure of the figure follows Chen's FEI, closely related to AHP structures, thereby facilitating visualization of the overall priorities and entity capabilities. Each quadrant corresponds to an AHP cluster and its priority vector in FR-Result DM requirements (green bar graph). I-concerns (Layer 1) are indicated by the blue bar graph and I-concerns/barriers (Layer 2) are indicated by the orange bar graph).

The final cluster named 'Alternatives', relative to the last AHP level, corresponds to the maturity level of entity assessed. The final result can be seen in Fig. 13's radial chart. The positioning of the organization in the intermediary position (0.418295) slightly trending towards advanced (0.309910) can be identified. This result leads us to infer that the company still has several aspects to improve in increasing efficiency in the scenario discussed. Figure 15 provides a relevant support for this analysis and diagnosis, providing a complete view on the entity's interoperability capabilities.

Fig. 13. DIAM Maturity level diagnosis

Additionally, sensitivity analyses enable indicating the most adequate criteria for organizational improvement of its disaster management capabilities. For analysis purposes, in Fig. 14 it is possible to identify how NF-Result 'Report Supply Points' can influence in changing the final maturity levels. In this figure, it is possible to see that increasing priority levels of this NF-Result leads to a preferred maturity level change towards Level 3 (Advanced). This analysis acts as an important tool in driving corporate engineering efforts.

Fig. 14. Sensitivity analysis of 'Report Supply Points' NFR-Result

Fig. 15. Assessment in Disaster Management domain through interoperability concerns and barriers.

5. Conclusion

This paper focused on a disaster management knowledge identification and assessment approach based on the AHP-based model called DIAM. An in-depth relational analysis was conducted to face the complex analysis of disaster management requirements dealing with interoperability barriers. A total of 127 requirements were split into functional and non-functional requirements and technical solutions by means of a two-step QFD design. A new relational method called IRM was conceived in order to support mapping of the main (filtered) DM requirements (total of 26) into interoperability perspectives based on Chen's FEI [24]. The IRM acted as an important tool in designing the AHP structure of the DIAM, allowing a multi-layer diagnosis of the different organizational views – from the strategic level concerning business, conceptual and process interoperability perspectives down to a granular view on disaster management capabilities.

An application case based on an ICT company of southern Brazil, acting as a central entity in control of municipal information technology and communication infra-structure enabled relevant results and promising perspectives on the applicability of DIAM and DRMS improvements. Several unknown fragile capabilities are highlighted by the corroboration between DIAM and company experts and directors' perceptions in organizational performance in disaster management scenarios. Moreover, influence (sensitivity) analysis of the DM requirements identified on the company's overall maturity level, gave a preliminary support for a local agenda towards public and private efforts in facing municipal barriers.

It has been shown that crisis management should be directly linked to interoperability issues, allowing an integrated operation of all entities involved during an event. An interoperability assessment approach was then proposed to identify the potential interoperation in a disaster response management environment. The proposed DRMS development cycle framework was based on a set of reference architecture specifications (relating functional requirements to technical solutions), an interoperability diagnosis model (relating functional requirements to interoperability concerns) of a locality or private or public entity to achieve an interoperable architecture.

The DRMS promotes a review, evaluation and improvement the reference architecture for the reality of the entity analyzed with respect to its interoperability capabilities in DM scenarios. A SysML diagram modeling phase is also considered with a view to supporting DMIS specifications with special emphasis on DM and interoperability requirement modeling, as well as complex behavior analyses relative to disaster response dynamics. These steps represent ongoing working.

Future works in DIAM improvement rely on the integration of other methods to support causal modeling of influencing variables such as Dematel, and multi-criteria decision making/analysis (MCDM/DA) methods such as Electre TRI and Promethee. These methods allow do deal with quantitative and specific scales on criteria rating, very appropriate to support the third (S3) cube surface analysis related to reference architecture specifications. The research will then continue towards the improvement of the framework, verifying and validating the results found with other public/private entities (civil defense, firefighters, traffic engineering) involved in disaster response management initiatives. A broader picture of disaster management capabilities of Brazilian cities in disaster management can then be glimpsed.

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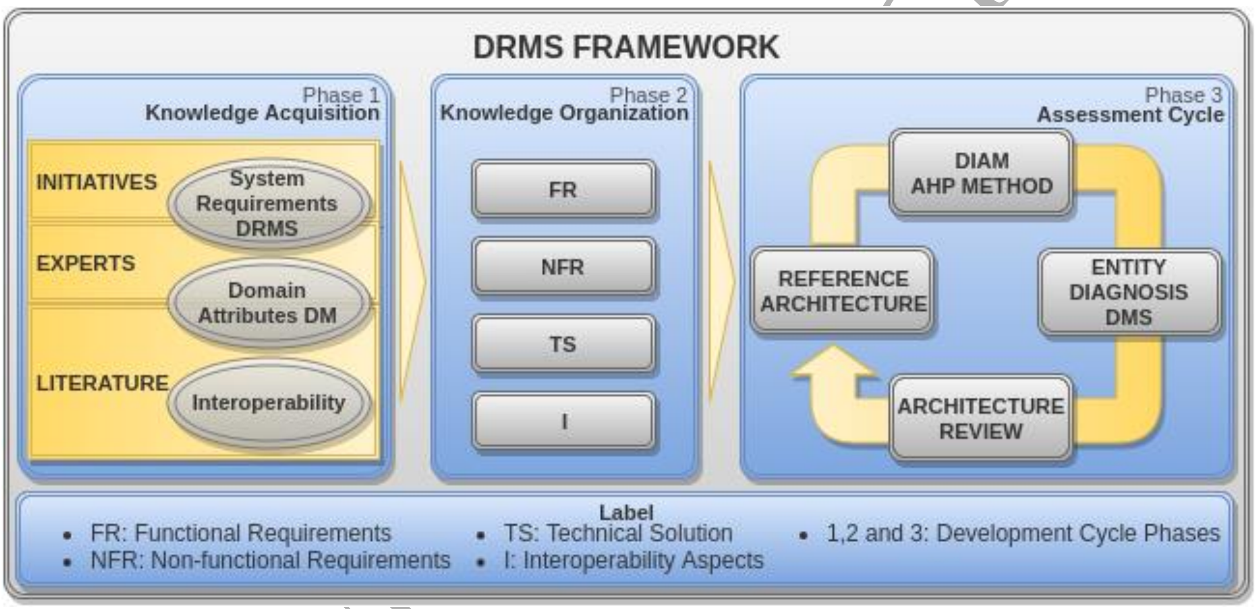


fig1.

ID	Knowledge	FR	NFR	TS
16	outside consulting	x		
17	false phone calls	x		
18	robust system		x	
19	user hierarchy			x
20	access levels	x		
21	reliability		x	

fig.2

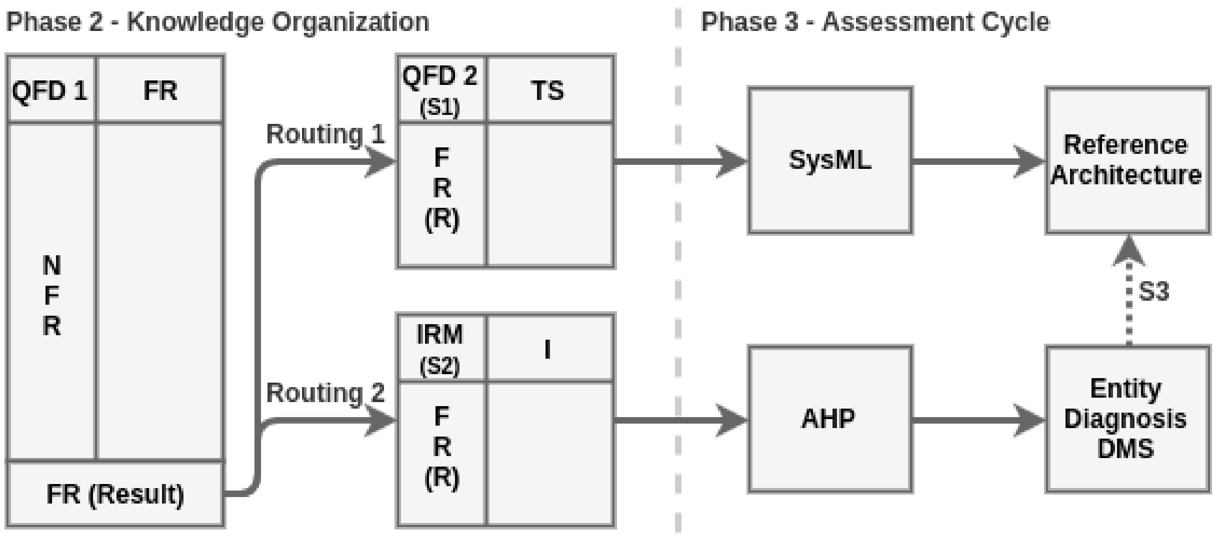


fig3.

Number	Non-functional Requirements \ Functional Requirements	A importance	1 warnings for hazardous areas	2 user support	3 usage tips	4 unregistered users receive only broadcasts	5 tracking responsible for data	6 structured query implementation	7 single set of rules	8 send personalized messages	9 run on different types of crisis	10 report supply points	11 report checkpoints	12 report alternative transport
1	user performance metrics	5	1	9	1	9	9	9	9	9	3	3	3	1
2	traffic control information	4	3	9	3	1	9	9	3	3	9	9	1	1
3	system requirements definitions	6	9	1	3	9	9	9	9	1	9	9	1	3
4	system performance metrics	5	3	9	1	9	9	9	9	3	9	3	3	1
5	special queries	4	1	1	1	9	3	9	9	9	9	1	3	1
6	sharing data	7	1	9	3	9	9	3	9	9	9	9	9	9
7	robust system	5	3	1	1	9	9	9	9	3	9	3	1	3
8	reliability	10	1	1	1	1	3	3	1	1	3	3	1	1
B	weight importance		146	214	80	334	330	312	334	226	324	232	130	124
	relative weight	100	5,24	7,68	2,87	12	11,8	11,2	12	8,11	11,6	8,33	4,67	4,45
C	average	232												

fig4.

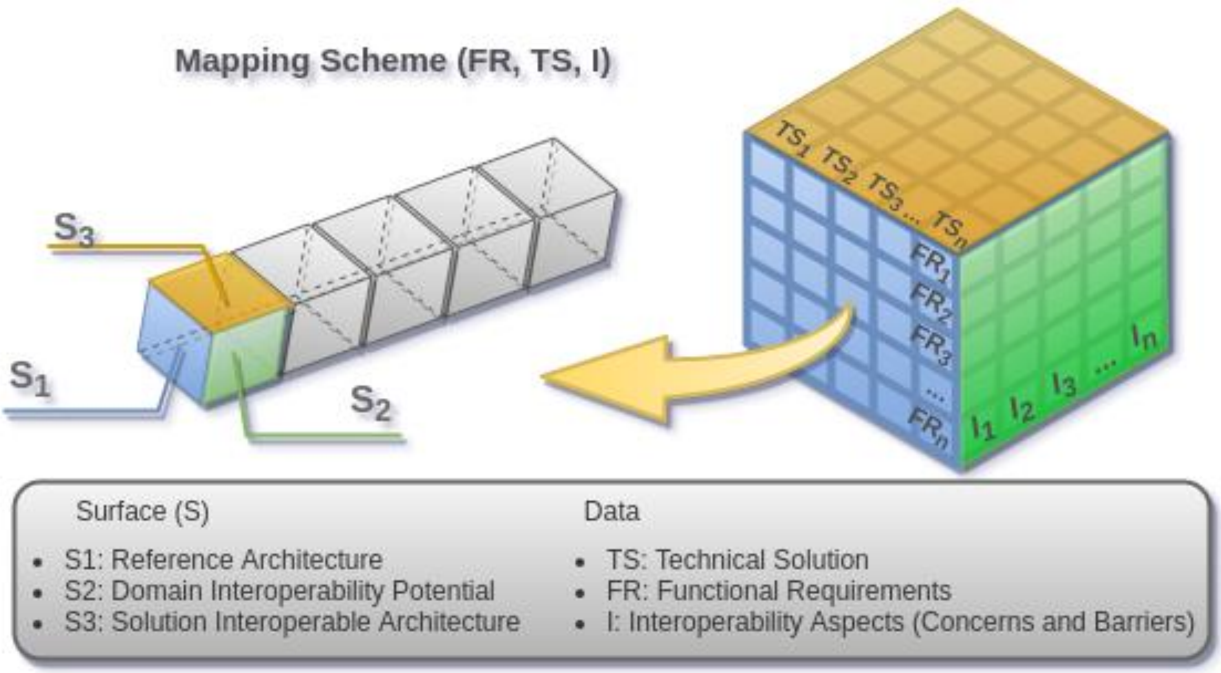


fig5.

Number	Technical Solution / Functional Requirements Result	importance	1 wireless communication	2 user hierarchy	3 use case based modeling	4 uniform emergency signals	5 unified file format and conversion and UML	6 systemized repository data	7 system constraints maps	8 SYSML	9 standart data specification	10 specielists encrypted messages	11 secure shell	12 report templates
1	user support	5	3	3	1	3	1	1	1	1	3	3	3	9
2	unregistered users receive only broadcasts	4	9	1	3	9	3	9	9	3	3	9	1	1
3	tracking responsible for data	6	9	1	9	3	1	9	3	1	9	9	1	3
4	structured query implementation	3	1	3	1	1	3	1	1	3	9	3	3	1
5	single set of rules	6	1	1	9	1	9	3	1	9	9	1	3	1
6	run on different types of crisis	10	9	3	3	3	3	3	9	1	1	9	9	9
7	report supply points	5	3	1	1	3	1	2	1	3	1	3	1	3
8	reduce the number of vehicles	9	3	1	1	9	1	3	3	1	3	3	1	1
	weight importance		246	84	172	204	130	183	190	120	204	252	156	190
	relative weight	100	11,5	3,94	8,07	9,57	6,1	8,59	8,92	5,63	9,57	11,8	7,32	8,92

fig6.

Functional Requirements Result \ Interoperability Concerns	importance	business	process	service	data
user reports	5	◆	◆	●	●
unregistered users receive only b	4	△	△	●	●
tracking responsible for data	6	△	●	△	◆
structured query implementatior	5	◆	●	△	△
single set of rules	4	△	●	◆	●

● = 9
△ = 3
◆ = 1

fig7.

Functional Requirements Result \ Interoperability Barriers	importance	conceptual	technological	organizational
user reports	5	◆	△	◆
unregistered users receive only b	4	◆	△	◆
tracking responsible for data	6	◆	△	△
structured query implementatior	5	●	◆	●
single set of rules	4	△	◆	◆

● = 4
△ = 2
◆ = 1

fig8.

		B		
	W	4	2	1
C	9	● 36	● 18	△
	3	△ 12	△ 6	◆
	1	◆ 4	◆ 2	◆

B: Barriers
C: Concerns
W: Weight

fig9.

row	max relationship value in row	relative weight	weight / importance	CONCERNS x BARRIERS / FR Result		adaptable financial realities	low maintenance cost	low cost software	hardware low cost	low database storage cost	low implementation cost	low training cost	low cost of integration	reduce the number of vehicle	report alternate routes	report alternative transport	warnings for hazardous areas	report checkpoints	report supply points	priority information
1	9	8,3	1,0	Business	**Conceptual**	◆	▲	▲	▲	▲	●	▲	●	◆	◆	◆	◆	◆	◆	●
2	9	8,3	1,0		**Technological**	◆	●	●	●	●	●	●	●	◆	◆	◆	◆	◆	◆	●
3	9	8,3	1,0		**Organizational**	◆	●	●	●	●	●	●	●	◆	◆	◆	◆	◆	◆	●
4	9	8,3	1,0	Process	**Conceptual**	▲	◆	◆	◆	▲	●	◆	▲	◆	▲	◆	◆	◆	●	▲
5	9	8,3	1,0		**Technological**	▲	▲	▲	▲	●	●	▲	▲	◆	▲	◆	◆	◆	●	▲
6	9	8,3	1,0		**Organizational**	◆	▲	▲	▲	●	●	▲	▲	▲	●	▲	◆	◆	▲	▲

Target or limit value															
Weight / Importance	0	299	374	299	448	672	299	598	75	149	75	0	0	224	598
Relative weight	0,0	2,5	3,1	2,5	3,7	5,6	2,5	4,9	0,6	1,2	0,6	0,0	0,0	1,9	4,9

fig10.

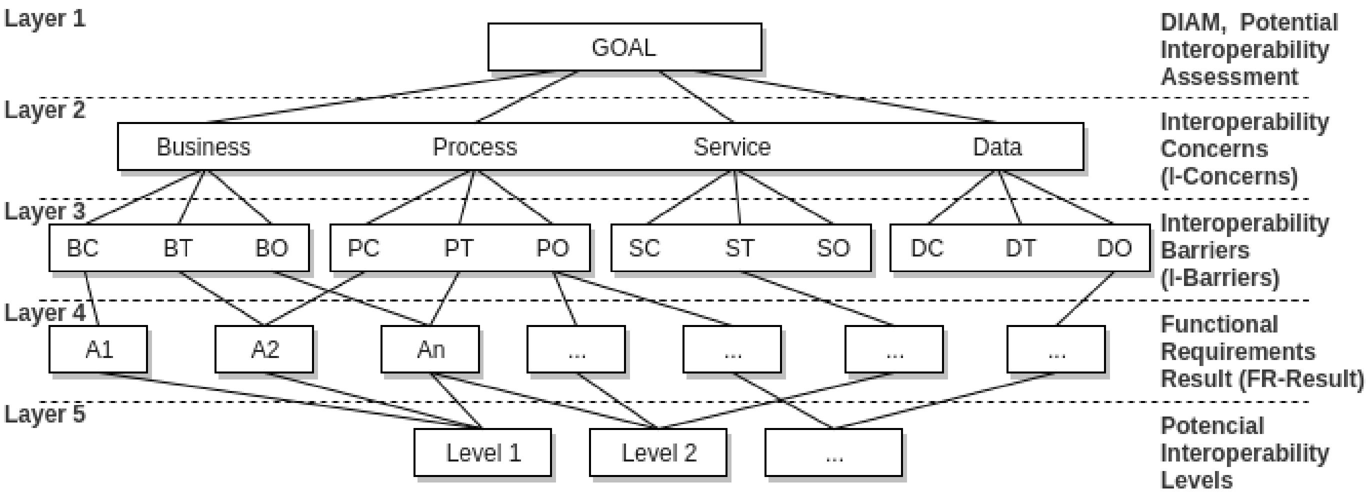
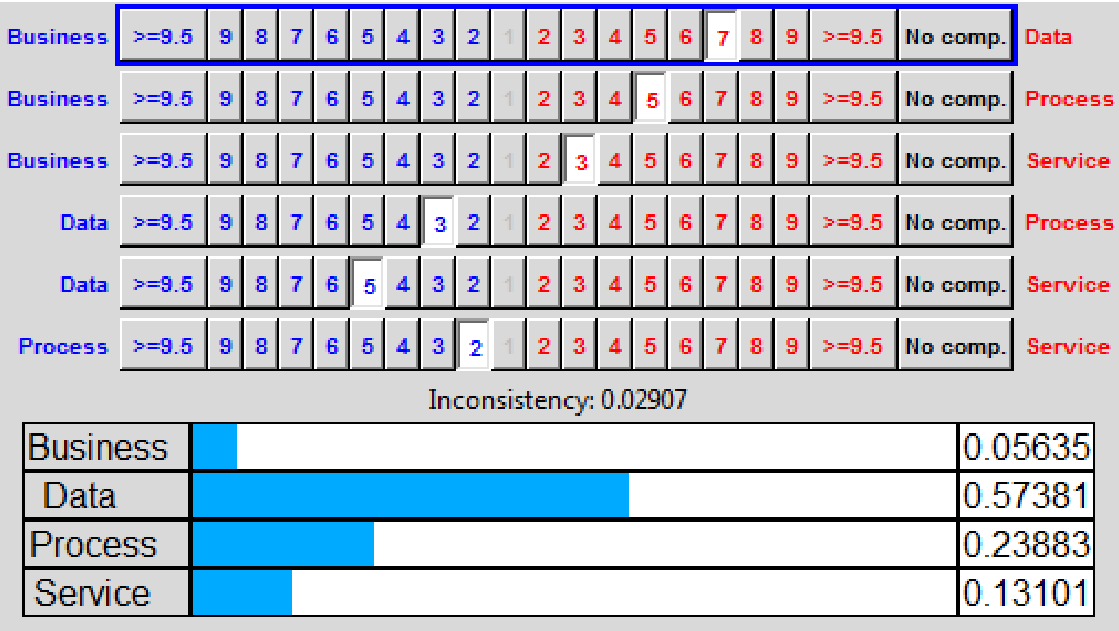
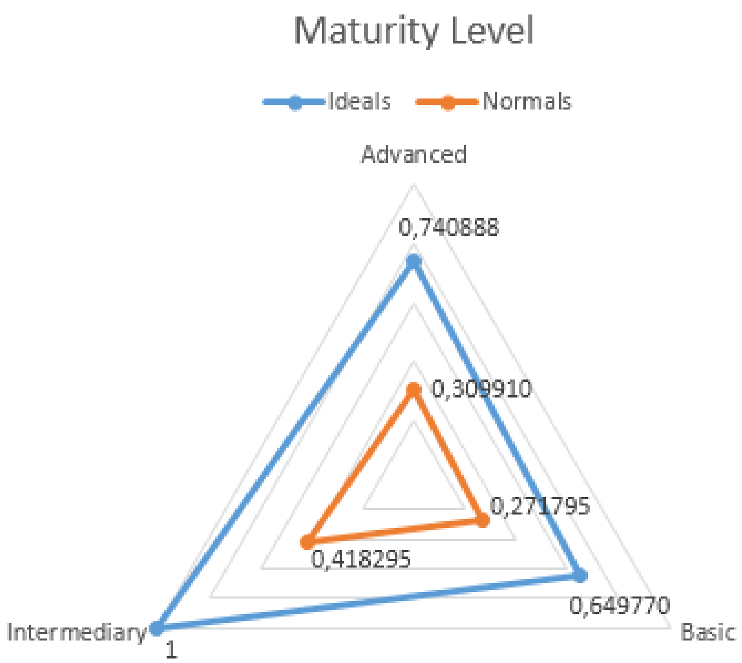


fig11.


Business >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Data
Business >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Process
Business >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Service
Data >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Process
Data >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Service
Process >=9.5 9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 >=9.5 No comp. Service
Inconsistency: 0.02907
Business 0.05635
Data 0.57381
Process 0.23883
Service 0.13101
fig12.


Maturity Level
Ideals
Normals
Advanced
0,740888
0,309910
0,271795
0,418295
0,649770
Intermediary
1
Basic
fig13.

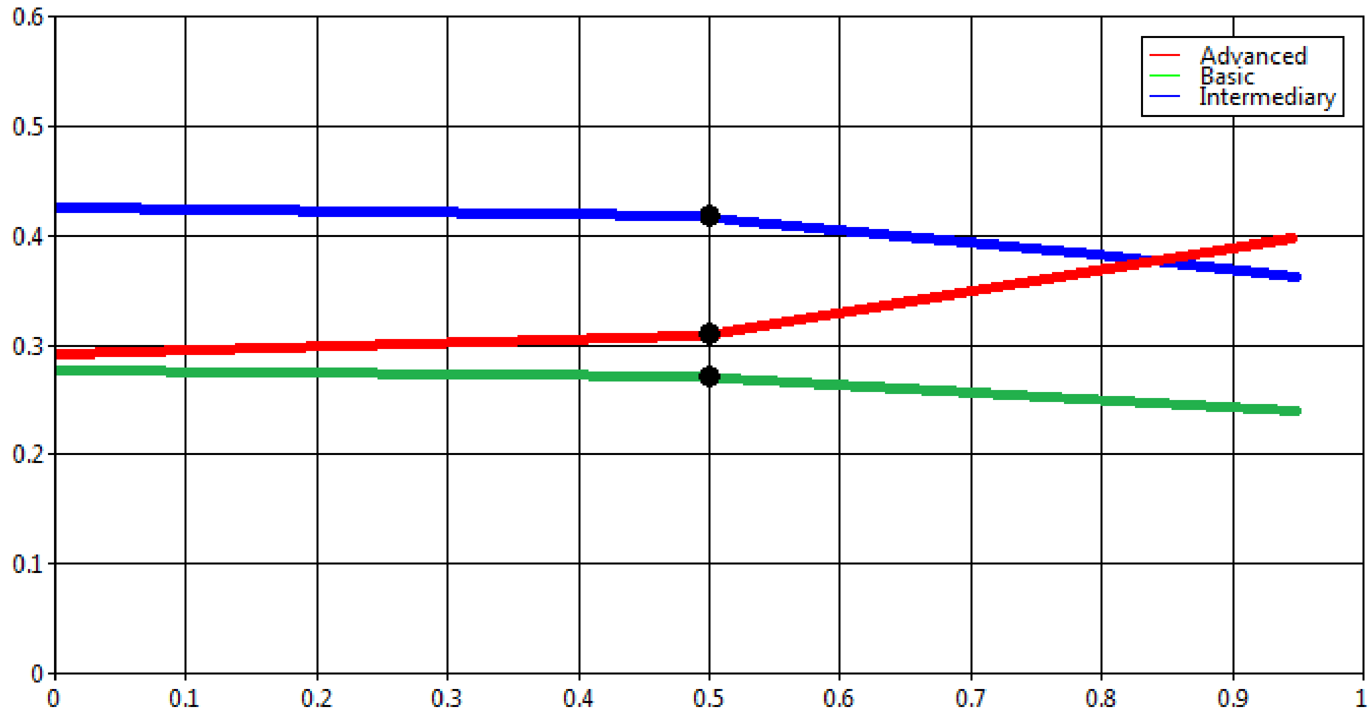
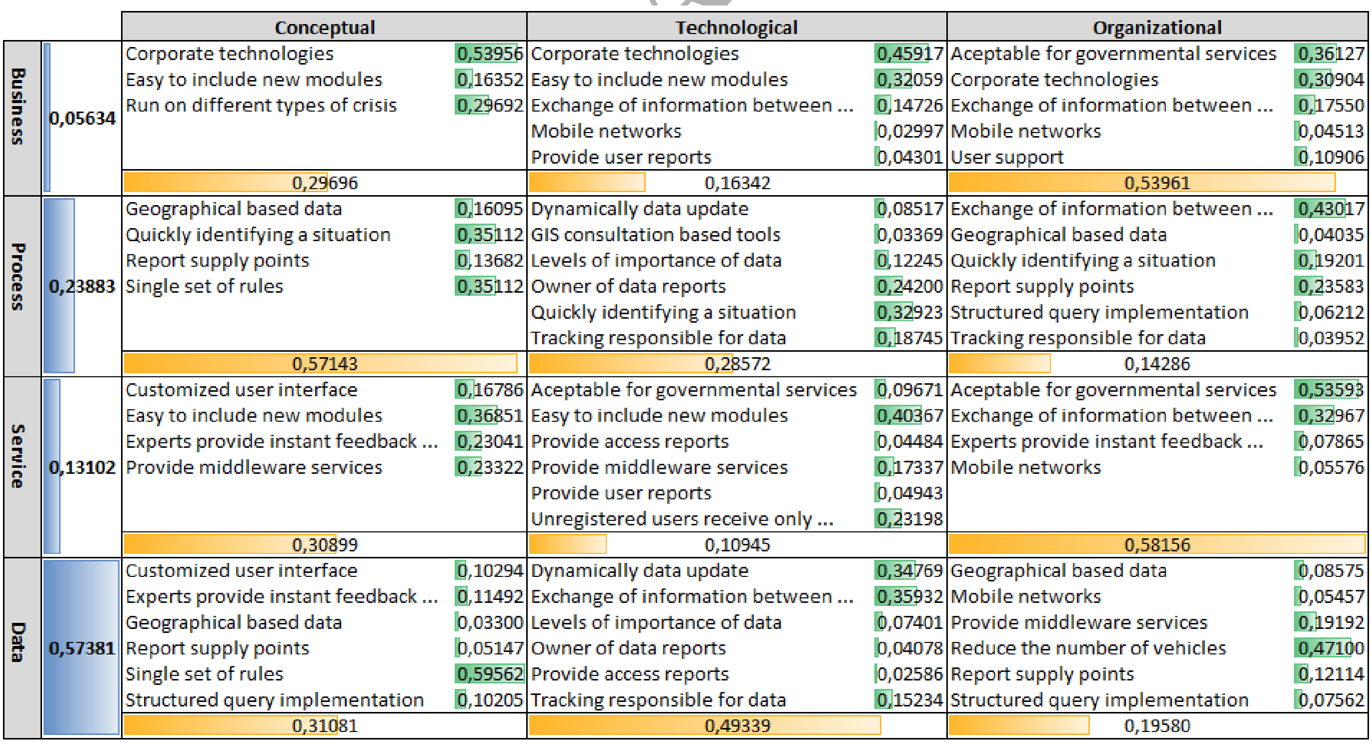


fig14.



		Conceptual		Technological		Organizational	
Business	0,05634	Corporate technologies	0,53956	Corporate technologies	0,45917	Aceptable for governmental services	0,36127
		Easy to include new modules	0,16352	Easy to include new modules	0,32059	Corporate technologies	0,30904
		Run on different types of crisis	0,29692	Exchange of information between ...	0,14726	Exchange of information between ...	0,17550
				Mobile networks	0,02997	Mobile networks	0,04513
				Provide user reports	0,04301	User support	0,10906
		0,29696		0,16342		0,53961	
Process	0,23883	Geographical based data	0,16095	Dynamically data update	0,08517	Exchange of information between ...	0,43017
		Quickly identifying a situation	0,35112	GIS consultation based tools	0,03369	Geographical based data	0,04035
		Report supply points	0,13682	Levels of importance of data	0,12245	Quickly identifying a situation	0,19201
		Single set of rules	0,35112	Owner of data reports	0,24200	Report supply points	0,23583
				Quickly identifying a situation	0,32923	Structured query implementation	0,06212
				Tracking responsible for data	0,18745	Tracking responsible for data	0,03952
		0,57143		0,28572		0,14286	
Service	0,13102	Customized user interface	0,16786	Aceptable for governmental services	0,09671	Aceptable for governmental services	0,53593
		Easy to include new modules	0,36851	Easy to include new modules	0,40367	Exchange of information between ...	0,32967
		Experts provide instant feedback ...	0,23041	Provide access reports	0,04484	Experts provide instant feedback ...	0,07865
		Provide middleware services	0,23322	Provide middleware services	0,17337	Mobile networks	0,05576
				Provide user reports	0,04943		
				Unregistered users receive only ...	0,23198		
		0,30899		0,10945		0,58156	
Data	0,57381	Customized user interface	0,10294	Dynamically data update	0,34769	Geographical based data	0,08575
		Experts provide instant feedback ...	0,11492	Exchange of information between ...	0,35932	Mobile networks	0,05457
		Geographical based data	0,03300	Levels of importance of data	0,07401	Provide middleware services	0,19192
		Report supply points	0,05147	Owner of data reports	0,04078	Reduce the number of vehicles	0,47100
		Single set of rules	0,59562	Provide access reports	0,02586	Report supply points	0,12114
		Structured query implementation	0,10205	Tracking responsible for data	0,15234	Structured query implementation	0,07562
		0,31081		0,49339		0,19580	

fig15.