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Towards a taxonomy for classifying Crisis Information Management Systems

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Abstract

In this chapter, we describe the process and the preliminary results of developing a taxonomy about Crisis Information Management Information Systems (CIMSs). Building the taxonomy, we aim at orienting the understanding of the area (main topics, interrelations, challenges, gaps, etc.) and guide the search of the literature and systems focused on the topic of interest. Following the iterative method proposed by Nickerson et al. in 2013, we focused on the emergency response stage of the emergency management lifecycle, and defined a taxonomy organized along seven dimensions, namely coordination, collaboration, information management, visualization, communication, intelligence and global support; for each dimension, a number of characteristics understood as features of CIMSs have been identified. The first version of the *Tax-CIM* taxonomy has been applied to the analysis of 15 CIMS, showing that some changes had to be made and led to a second and more robust version.

Keywords: Crisis Information Management Systems, Taxonomy, Emergency response

Towards a taxonomy for classifying Crisis Information Management Systems

Crisis Management is a transversal discipline -integrating results of many other areas-, so it takes time and a reasonable effort before being able to understand what its main topics, challenges and open issues are. Among these challenges, efficient information management emerged due to the need of response teams to improve situational awareness, to deliver quality information to the different stakeholders, and other features related to crisis management. Consequently, advances in the design, development, and application of the so-called Crisis Information Management Systems (CIMS) have received much attention by both academics and practitioners, as well as from the software industry. Professional associations like ISCRAM¹ have fueled research, development and innovation of tools covering completely or partially the crisis management lifecycle.

A great amount of research in the area of Crisis Information Management can be verified by the contents of two important digital reference libraries: the Disaster Information Research Library (DIRL2), with 3,933 references, and the ISCRAM Digital Library³, with 1,827 references, both at the time of writing this proposal. In the specific sub-area of Emergency Management Information Systems, a quick search in Google Scholar returns 1,410 results (1,210 of which correspond to work published in the last 20 years). The interest in the area has grown over the last five years, with the edition of several academic conferences and journals in the area, meaning that we can expect a rapid growth in the years ahead. In the context of this high amount of research work, it is difficult to navigate and find works that are relevant to a particular research or project. The use of keyword search has low precision and high recall, yielding unsatisfactory answers. In addition, it is difficult to navigate through the literature without a guiding framework that describes the relationship between the various topics addressed.

¹ Information Systems for Crisis Response And Management, <https://iscram.org>

² <http://faculty.washington.edu/jscholl/dirl/index.php>, accessed on 2022/01/20

³ <http://idl.iscram.org>

The diversity of the crisis management field has been propagated to the tools, too, and the high number of CIMSs available⁴ makes it difficult the comprehension of their features and the choice of the most appropriate according to an organization's specific needs. In this chapter, we describe the process and the preliminary results of developing a taxonomy about Crisis Information Management Information Systems (CIMSs). Building the taxonomy, which we called *Tax-CIM*, we aim at orienting the understanding of the area (main topics, interrelations, challenges, gaps, etc.) and guide the search of the literature focused on the topic of interest.

Several taxonomies have been proposed in the field of emergency management. A topic search of the term "Taxonomy" in the DIRM yields 10 references, none of which has studied the domain from the perspective of software support to emergency response and recovery. Rather, they cover specific aspects of the emergency management lifecycle. Consequently, a comprehensive view of the role of CIMS in response and recovery is still to come.

Tax-CIM aims at:

1. Being a guide for researchers, especially to help doing more focused literature searches as well as work descriptions.
2. Helping end-users (e.g., practitioners and civil defense authorities) to choose the right CIMS according to their particular context.
3. Discovering gaps in the research on CIMS, opening new opportunities for innovative solutions covering those gaps.
4. Finding inconsistencies in the use of terminology.

The multi-level classification developed in the taxonomy will help to structure knowledge about the role CIMS play in the emergency management lifecycle, and particularly in the response phase. *Tax-CIM* has been developed following the method proposed by Nickerson et al.

⁴ A search of the topic "Emergency Management Software" in the portal www.g2.com yields 61 tools that can be considered CIMS.

(2013). Specifically, we have performed an iterative process where empirical-to conceptual and conceptual-to-empirical approaches have been applied. Building on our long-time research experience in emergency management systems, we were able to define a hierarchy of dimensions of emergency response (namely, coordination, collaboration, information management, visualization, communication and intelligence), plus a set of characteristics for each dimension. Then, the analysis of different CIMSs based in the hierarchy has led to refinements of these dimensions and characteristics, resulting in the taxonomy we present here. *Tax-CIM* is not a static taxonomy; rather, we expect that further iterations of the process will result in refinements coming from the appearance on new characteristics, or the suppression of others due to different reasons.

This chapter is organized as follows. We first provide some background on existing taxonomies in the Emergency Management domain and introduce the research method followed in our work. Then, we describe in detail the development of *Tax-CIM*, which required two iterations of the method. A discussion on the results obtained and some conclusions close the chapter.

Antecedents

Turoff (2002) establishes the origins of CIMSs in the EMISARI system, developed in 1971 in the Office of Emergency Preparedness of the United States of America. According to Turoff, “past and future objectives [of CIMSs] remain the same in crises, providing relevant communities collaborative knowledge systems to exchange information” (p. 29) .

Some research has been focused on the design of CIMSs. Chen et al. (2005) present a framework to analyze the response to critical incidents. This framework conceptualizes four main elements for analysis: decision structure, information and resource structure, workflow structure, and responder structure. Other authors follow this path of proposing design principles

for CIMS (Kyng et al., 2006, Jennex, 2007). Among these publications we highlight the DERMIS model (Turoff et al., 2004), that proposes eight principles and five criteria (metaphor, human roles, notification, hypertext and context visibility) for CIMSs. These design principles are: System Directory, Information Source and Timeliness, Open Multi - Directional Communication, Content as Address, Up-to-Date Information and Data, Link Relevant Information and Data, Authority, Responsibility, and Accountability, Psychological and sociological factors.

Other papers have been oriented to propose ontologies for CIMSs. Di Maio (2007) points out the need of an ontology for information exchange between CIMSs. Xiang et al. (2008) build an ontology dividing the tasks of emergency response systems in four major phases: response preparation, emergency response, emergency rescue and aftermath handling. Liu et al. (2013) present 11 subject areas common to six ontologies useful in crisis management (resources, processes, people, organization, damage, disasters, infrastructure, geography, hydrology, meteorology and topography).

Closer to our aim, some authors propose taxonomies in the crisis management field. Rauner et al. (2018) present a skills taxonomy to improve the interoperability and cross-border communication of emergency responders from different countries. However, such taxonomy is not aimed at classifying CIMSs, but to best cope with major disasters by identifying main national emergency responders needed for key emergency interventions. In this sense, Simpson (2012) proposes a taxonomy for crisis management functions including Crisis Communications and Information Management as one function. Additionally, we can find other taxonomies in fields close to the CIMSs such as mobile emergency announcement systems (Addams-Moring et al., 2005), crisis management simulation tools (Barthe-Delanoë et al., 2015), community interaction in crises and disasters (Auferbauer et al., 2019), big data analytics, and IoT in disaster management (Shah et al., 2019)

These antecedents lead us to conclude that previous work on CIMSs has been mainly oriented towards establishing design principles, rather than building a functional classification based on their characteristics.

Research Methodology

An important problem for understanding the domain of CIMSs is the classification of systems into a framework that enables the identification of their purpose and usage. The Emergency Management has achieved a maturity level when many supporting systems are proposed and described but without allowing us to position them in the spectrum of existing systems and applications. Thus, an organized classification is very welcome. The making of a general classification is not an easy task due to the variety of systems and application approaches. A set of common keywords is useful, but it is not sufficient to understand the relationships among the systems and their purposes. A more systematic approach to the classification is required to reach this objective. Our proposal then is the development of a Taxonomy that should cover the main aspects of CIMSs into a classification based on a hierarchy of categories.

A taxonomy can be viewed as an evolution of a simple classification system, such as a set of keywords, and a previous step towards an ontology, which describes the relationship among objects as a graph instead of a hierarchy. The generation of a good taxonomy is not an easy task, though. The main characteristic of a good taxonomy is that it can differentiate between systems that have some variations at a relevant level of internal detail. In other words, they share the same roots of the hierarchy for coincident characteristics, but they belong to different branches for distinct characteristics. Due to its hierarchical nature, a taxonomy should be designed in such a way that the higher-level classes cover the more general categories leaving the more specific ones to the lower levels. This requires a systematic development and, most important, an evaluation that demonstrates its suitability for the domain.

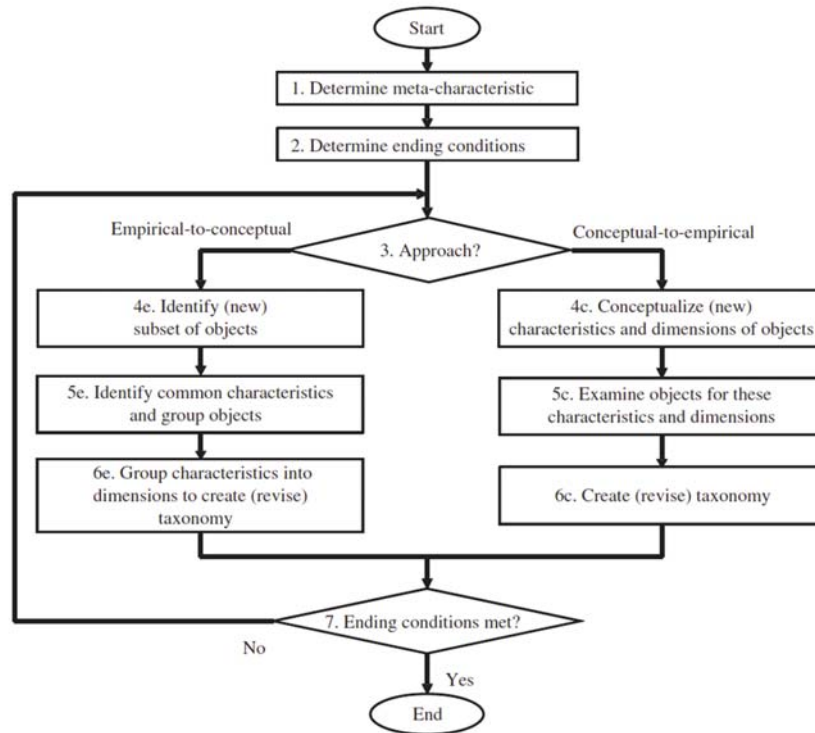
For the systematic development of the taxonomy, we adopted the method proposed in (Nickerson et al., 2013) that is aimed at guiding information system classification. To justify their proposal, the authors argue that “IS researchers have proposed a number of taxonomies over the years, but in many cases the development of these taxonomies has followed a largely ad hoc approach” (p. 337). The method they developed was based on the Design Science research paradigm, which aims to address new knowledge about artificial (i.e., manmade) objects that are designed to meet certain goals and provide utility to their users (Simon, 1969).

Figure 1 summarizes the iterative process defined by Nickerson et al. First of all, the scope of the taxonomy is defined in terms of the so-called meta-characteristic of the taxonomy; it is the most comprehensive characteristic in a domain that will serve to derive the remaining characteristics of the taxonomy, in a way that each characteristic added to it must be a logical consequence of the meta-characteristic. The next step in the process is the definition of the ending conditions, that will be used as criteria for finalizing the iterative process. Nickerson et al. (2013) distinguish two types of ending conditions. On one hand, the objective ones are those that help to ensure that the set of characteristics identified meets the requirements to be a taxonomy, that is, mutually exclusive dimensions and exhaustive characteristics in each dimension. On the other hand, subjective ending conditions need also to be examined to check that the following qualitative attributes are enforced; these conditions are (quoting their own words):

- Conciseness – “A taxonomy should contain a limited number of dimensions and a limited number of characteristics in each dimension, because an extensive classification scheme with many dimensions and many characteristics may exceed the cognitive load of the researcher and thus be difficult to comprehend and apply” (p. 341).

Figure 1

Method for taxonomy development as proposed in (Nickerson et al., 2013)



- Robustness – “A useful taxonomy should contain enough dimensions and characteristics to clearly differentiate the objects of interest. A taxonomy with few dimensions and characteristics may not be able to adequately differentiate among objects” (p. 341).
- Comprehensiveness – “A useful taxonomy can classify all known objects within the domain under considerations” (p. 341).
- Extendibility - “A useful taxonomy should allow for inclusion of additional dimensions and new characteristics within a dimension when new types of objects appear. A taxonomy that is not extendible may soon become obsolete” (p. 341).
- Explanatoriness: “A useful taxonomy contains dimensions and characteristics that do not describe every possible detail of the objects but, rather, provide useful explanations of the

nature of the objects under study or of future objects to help us understand the objects”
(p. 342).

Once the meta-characteristic and ending conditions are set, the iterative process can follow two alternative approaches, namely conceptual-to-empirical (C2E) and empirical-to-conceptual (E2C). The choice of which approach to use depends on the availability of data about objects under study and the knowledge. When little data are available, but the researcher has significant understanding of the domain, then starting with the conceptual-to-empirical approach would be advised, leading to the conceptualization of new characteristics, followed by the examination of the objects of interest for these characteristics, and revising the taxonomy. However, if the knowledge of the domain is not deep, but there are enough data about the objects in the domain available, an empirical-to conceptual approach can be followed; in this case, identifying new sets or subsets of objects is followed by their examination to find relevant characteristics, which can be added to the taxonomy.

The development of a good taxonomy is a big challenge. It should be comprehensible to users and must cover the domain of interest in enough detail to be useful. The iterative refinement process must adhere to the following guidelines:

- If the complete categorization of an object does not fit entirely into the categories of the taxonomy, one or more new categories/sub-categories must be created.
- If at the end of the categorization process a category has none or few objects, a targeted search is done using keywords that characterize the category. If a set of relevant articles cannot be added, grouping this category with another and putting all objects under the resulting category should be considered.
- If a category has too many objects, splitting the category into two or more categories/sub-categories and moving the objects associated with this category to the new ones should be an option.

In the remainder of the chapter, we show how we adapted and applied Nickerson et al.'s method to the development of *Tax-CIM*.

Development of the *Tax-CIM* taxonomy

In this section, we describe how we applied the method described in the previous section to the development of *Tax-CIM*. The steps are numbered according to the process depicted in Figure 1.

Begin of the process

Step 1. Definition of the meta-characteristic. The meta-characteristic chosen for our taxonomy is *Emergency Response*. Consequently, we will define a set of dimensions relevant to it and conceptualize sets of characteristics within each dimension.

Step 2. Determination of the ending conditions. Before starting the iterative development of the taxonomy, we must define the ending conditions of our process. Regarding the objective ending conditions, the iterative process could end when we are able to categorize every object of study into the categories of the taxonomy, and no new splitting of categories is found. On the other hand, reaching subjective ending conditions should be particularly sought. A description of the taxonomy building loop follows.

Iteration 1 (I1)

Step 3.I1. Choice of the approach. As stated above, the choice of the approach at each iteration depends on the current knowledge about the domain. After years of research on emergency management, we have got acquaintance of many research prototypes and/or commercial systems supporting different stages of the emergency management lifecycle, as well as of what are the key aspects influencing the effectiveness of a response. Consequently, we assumed that our own knowledge of the objects in the domain was enough to enable an E2C approach.

Step 4e.II. Identify (new) subset of objects. The goal of this stage is to define a set of objects of study that must be analyzed in the following step. Instead of creating a closed set of CIMSs, we relied on our previous research works (Canós et al., 2005; Canós et al., 2004), where we studied the nature of emergency responses, and identified six dimensions, namely *coordination, information management and retrieval, presentation, communication, collaboration, and intelligence*, each one with their characteristics. We added a seventh one, *general support*, to include more general but relevant aspects not covered by the former ones. This was the input for the next step, where the grouping of objects begun.

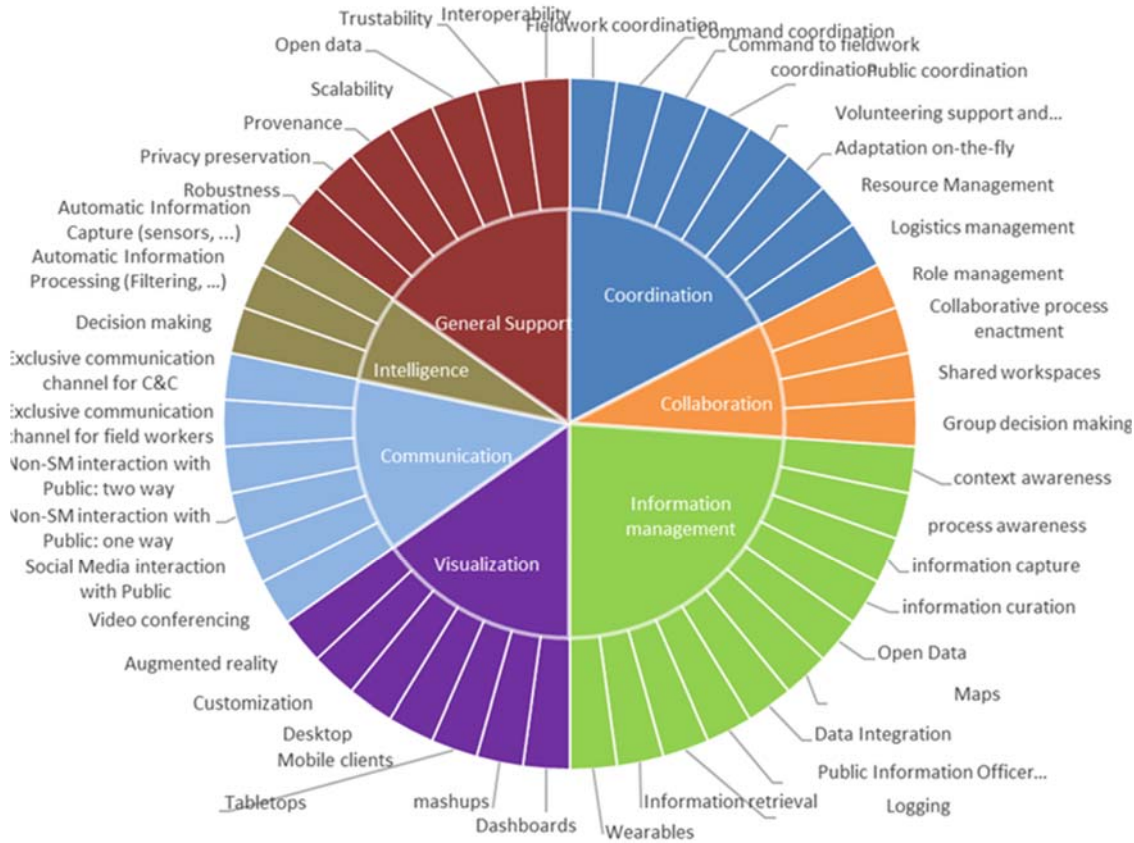
Step 5e.II. Identify common characteristics and group objects. From the set of all characteristics identified at the previous step, we started a process of selection of characteristics specifically related to the meta-characteristic, which were grouped by commonality relationships.

Step 6e.II. Group characteristics into dimensions to create (revise) taxonomy. Attending to the different nature of the characteristics found in the previous step, we defined seven dimensions that are shown in the inner part of Figure 2. Each dimension corresponds to a relevant aspect of emergency response, and groups a number of characteristics that we considered relevant and appear at the outer part of Figure 2. The number of dimensions and their characteristics was kept deliberately low to enforce the conciseness requirement of the ending conditions.

Step 7.II. Ending conditions met? The hierarchy of Figure 2 was the first version of *Tax-CIM*. When evaluating the ending conditions mentioned earlier, it was clear that the

Figure 2

Summary of Tax-CIM version 1



taxonomy needed some refinement and, more important, some validation against the objects of interest. This made us to go for a second iteration.

Iteration 2 (I2)

Step 3.I2.Choice of the approach. In this iteration, our goal was twofold. On one hand, and to enforce explanatoriness, we wanted to clearly define the meaning of each characteristic; on the other hand, and to enforce robustness and comprehensiveness, we wanted to check whether or not the objects of interest fit well into the taxonomy. Consequently, we decided to follow a C2E approach.

Step 4c.I2. Conceptualize (new) characteristics and dimensions of CIMs. The conceptualization of the first version of *Tax-CIM* was performed by adding a definition to each

characteristic. The full definition appears in Appendix A, and a summary of it follows, organized by dimension.

Coordination. The response to an emergency is the result of the coordinated effort of actors working in a variety of settings, so that coordination can be managed at different levels. At the operations field, the different response teams must act according to some well-established protocols than need to be enforced by team leaders (*fieldwork coordination*). Sometimes, action orders are sent to fieldworkers from the control room (*command-to-fieldwork coordination*). Some coordination is needed also inside the control room, where decision making processes are developed in a hierarchical manner (*command coordination*). Finally, in cases where volunteering can help in the resolution of a crisis, volunteers need guidance and protection from responders (*volunteering support and coordination*). Human resources coordination is complemented with the coordination of the access to resources (*resource management*) and *logistics management*.

Coordination is often based on protocols and procedures described in the emergency response plan; however, the unpredictable nature of crises makes it very difficult to cover all their possible development paths, and dynamic adaptation to the context is a valuable asset (*adaptation on-the-fly*).

Collaboration. Many of the emergency management tasks are collaborative in nature. For instance, once an alarm has been activated either by sensors or by some human communication, experts in different fields, playing one or more roles (*role management*) can be called to e-meetings to analyze the situation, assess damages, identify potential risks, and advice managers (*group decision making*). And after the emergency resolution, the same or other experts can perform collaborative assessments of the process and give safety managers insight for improving processes according to the experts' recommendations. In both cases, *shared workspaces* support the *collaborative process enactment*.

Information management. Information is a key factor in the successful resolution of a crisis. As we said above, CIMSs are complex systems, handling numerous information pieces of different types that are associated to the tasks the different actors must perform. Moreover, their relevance and/or validity may change according to the development of the emergency. Consequently, the information management problem in CIMSs is challenging. CIMSs should provide facilities for multimedia *information capture* from distinct sources, as well as *information curation* mechanisms to ensure the captured information is organized by means of descriptive metadata. Geo-tagged information (*maps*) and data coming from wearable devices of responders (*wearables*) are gaining relevance in the last years.

One of the key requirements we define for CIMSs is dynamic delivery of information; that is, the information a user needs to perform a given task must be retrieved and delivered just at the usage time (*process awareness*). The information delivered must be context-sensitive (*context-awareness*), eventually overriding information gathered previously. For instance, if a tunnel on a subway network has collapsed, the CIMS must not show a clean, open tunnel's video playback but a closed way symbol. Information resources can be owned by response organizations or be captured from some external sources, possibly heterogeneous and distributed (e.g., *open data* repositories). In these cases, *data integration* issues arise that need be managed using semantic interoperability techniques.

After being collected and organized, information must be usable. This means that appropriate *information retrieval* mechanisms such as (multimedia) content-based or keyword-based search must be provided. Using these facilities, not only responders will enhance their situational awareness, but also the public via the role of *Public Information Officer*. Last, but not least, *logging* every decision made and every action taken during a response is crucial to enable later analysis of the response.

Visualization. The emergency resolution process must be perceived in different ways by the different participating actors (*customization*). As stated above, the coordination mechanism must be able to “execute” all the actions composing the process in the appropriate order; most of these actions are manual, in the sense that they are to be performed by humans, where others can be done automatically. The set of tasks a given actor must perform are collected in a dynamic structure called the actor’s worklist, in which the tasks are ordered according to the response process definition. Besides the default *desktop*-based interaction, other means such as *mobile clients*, *tabletops*, or even *augmented reality* sets can improve the user experience. For control rooms, *dashboards* and *mashups* can be valuable assets for decision making.

Communication. During an emergency, plenty of communications take place. All the voice interaction between the participants in the emergency resolution needs to be supported by reliable communication channels. Also, *video conferencing* support needs to be provided. Sometimes, *exclusive communication channels for responders* and also *for control room* can ensure that no interference between both nodes exist, avoiding possible confusions.

Informing to the public is becoming more and more relevant. In the last decade, the use of social media (SM) to support crisis communication has been one of the most relevant research topics. *SM interaction with the public* has remarkably improved context awareness, although many challenges remain (Castillo, 2019). Besides SM interaction, other non-SM channels are still relevant. Specifically, *one-way non-SM interaction with Public* is used to broadcast information of interest to the residents in an area affected by a disaster; and *two-way non-SM interaction with public* allows establishing dialogs with the public as a way to gather context.

Intelligence. By intelligence we mean, on one hand, the ability of the system to generate value information from data coming from different sources. Sometimes these sources may be sensors or drones (*automatic information capture*), the data of which may be combined using information fusion techniques (*automatic information processing*) to provide the users of a

CIMS, rather than raw data, meaningful interpretations permitting time savings in so crucial moments (e.g., fire detection systems). On the other hand, advanced Artificial Intelligence techniques can support the *decision-making* processes.

General support. This dimension aims at including characteristics that, being relevant for the analysis of CIMSs, do not fit in the preceding ones. Many of them can be understood as non-functional requirements from a software engineering perspective, while others represent horizontal functionality affecting several dimensions. *Robustness* refers to how a CIMS deals with errors generated by unexpected data or actions during a response. *Privacy preservation* is key to ensure that sensible information is kept safe and only accessed by those actors allowed to do it. *Provenance* relates to the existence of information traceability mechanisms ensuring the accuracy or authenticity of information sources. Related to provenance, *trustability* focus on the definition and implementation of means to ensure the reliability of external sources. *Scalability* relates to the capacity of a CIMS to work not only at local level, but also at regional or nation-wide levels if required. *Interoperability* is a technical capability allowing a CIMSs to interact with other systems during the resolution of a crisis. From a semantic point of view, interoperability and trustability are related to the access and use *Open Data*.

A visual representation of the Taxonomy with its dimensions and characteristics is presented in Figure 2.

Step 5c.I2. Examine objects for these characteristics and dimensions. The first version of *Tax-CIM* was used as guide to examine a group of systems; to select them, we looked for “emergency management software” at the portal g2.com, a website specialized in reviews of software systems. We found 61 systems, from which we chose 12 for our study. We also selected three research systems to make a total of 15 objects of study (see Table 1).

Not all the systems in the portal were described in the same depth. In general, the information provided at g2.com was succinct, but usually a link to each CIMS's official vendor

Table 1

CIMSS analyzed during step I2.5c

CIMS	Type	Source
DisasterLAN	Commercial	https://www.buffalocomputergraphics.com/DLAN
D4H Readiness & Response	Commercial	https://d4htechnologies.com/incident-management/
Adashi C&C	Commercial	http://www.adashi.com/incident-command-software/
WhosOnLocation	Commercial	https://whosonlocation.com/visitor-management/#
VEOCI	Commercial	https://veoci.com/solution/emergency-management
CRISIS CONTROL	Commercial	https://www.crisis-control.com/solutions/public-alerting/
SAFE REACH	Commercial	https://safereach.com/en/emergency-notification-system/alert-app/
IBM Intelligent Operations Center for Emergency Management V1.6	Commercial	https://ibm.co/3rGrRJC
Cobra	Commercial	https://cobrasoftware.com/capabilities/
CEM Platform	Commercial	https://www.everbridge.com/platform/technology/
Konexus	Commercial	https://www.konexus.com/
Crisis Track	Commercial	http://www.crisistrack.com/products/emergency-management/
Mission Track	Research	https://www.missiontrack.es
Tabletop system for Situational awareness	Research	https://ieeexplore.ieee.org/document/5960190
Drones-to-Rescue: Drone system for capturing situation awareness during response	Research	https://bit.ly/3HJwE2p

website was found. There, the technical level of the descriptions was not uniform: while some systems had a reasonable number of features listed, others were described in a pure commercial

style, which made difficult their categorization. What follows is a summary of the analysis performed, and the changes introduced in each dimension to generate the version 2 of *Tax-CIM*.

Coordination. There was some difficulty in separating the *adaptation on-the-fly* done by the response teams and that done automatically based on a pre-defined script. This dimension was thought to describe the support to human adaptation. If the support is in the form of recommendation or automatic decision, this should be part of the Intelligence dimension and the *decision-making* characteristics. We changed the description of this characteristic and added the term ‘coordination’ to the decision-making characteristic of the Intelligence dimension. We do not foresee the need to separate the characteristics.

When dealing with volunteering, we found two sub dimensions. The first one arises when the response team deals directly with the volunteers, having to coordinate their tasks, whereas the second one is shown when the response team deals with Volunteer Organizations, such as Red Cross, which coordinate their volunteers themselves. These require different types of Coordination, and the taxonomy was adapted accordingly.

Collaboration. There is a clear relationship among Collaboration, Coordination and Communication features, as teamwork requires all three to achieve its goals. These features overlap, and systems sometimes do not separate them clearly. However, they play different functions, and the taxonomy should reflect this by assigning the system to different subcategories even when systems do not separate the support. We did not make any changes to this dimension.

Information management. Most systems analyzed in the first round provide and use some Information Management features. The characteristics in *Tax-CIM* covered all the systems. However, some of them were not found in the systems that we analyzed so far; this is the case, for instance, of systems that make use of open data. We decided to keep all the characteristics

unchanged, as we believe that some of them are quite new, appearing on academic proposals not yet implemented as a system. We foresee those future systems will include some of these features.

Visualization. Visualization through mobile clients and desktops are the most common features provided by the systems. The mobile devices have been increasingly used for many purposes and the characteristics might overlap when analyzing the systems. Mobile clients such as smartphones have some limitations to support image visualization due the limited size of the screen. Tablets, on the other hand, are frequently mentioned as a better device for visualization. In the future we may have to split the *mobile clients* characteristic into three or four sub-characteristics to cover for different devices.

Communication. The use of SM has been reported in many systems. The variety of solutions for SM with different characteristics might indicate the need for creating subcategories. In most cases, the SM channels have been used for one way communication, i.e., not direct interaction. The two-way communication has been used mostly to support communication among responders in the field and in the C&C. The radio communication is still very popular among responders, but their operation is rarely supported by a system. This is the reason it was not included as a category. There are some alternatives to radio communication, but it seems it will take a while to replace the radio. Currently, we have found no reason to include them as a subcategory.

Intelligence. Most of the intelligent systems provide recommendations; they do not provide autonomous decisions unless it is for simple decisions. In order to cover the recommendation feature, we changed the name of the characteristic to *Recommendation and automatic decision making*.

The characteristic *Automatic Information Processing* was considered too broad. Although some systems combine them into one single feature, there are others that either separate them or

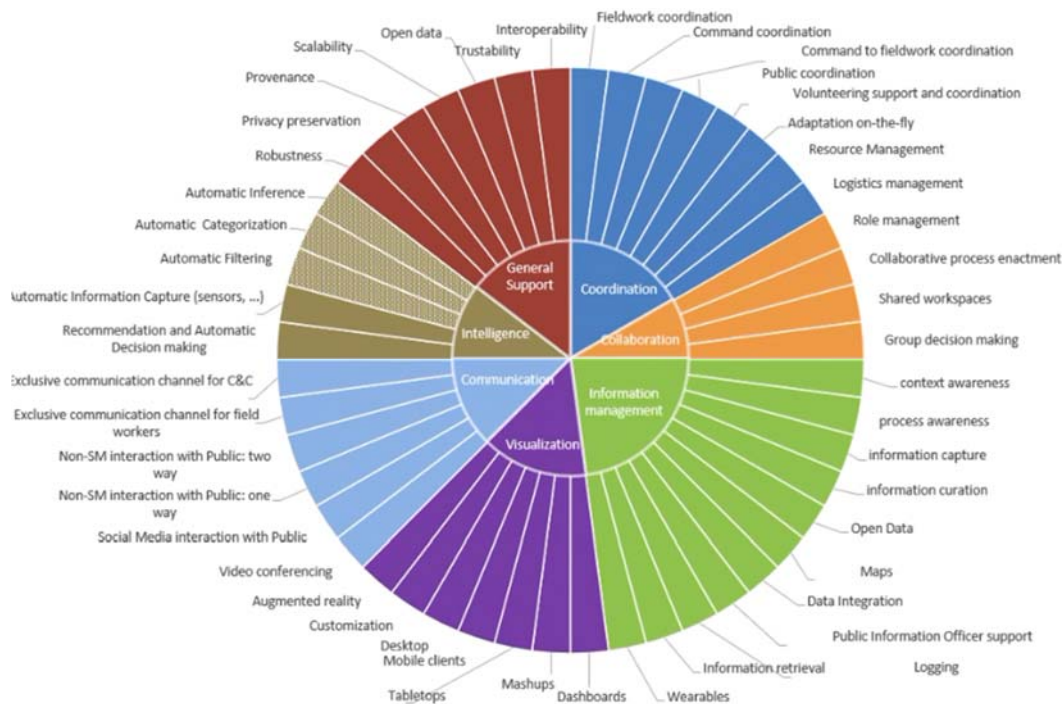
provide part of them. There should be some separation between these characteristics. We decided to split this category into three: *Automatic filtering*, *Automatic categorization* and *Automatic Inference*.

General support. The categories listed under this dimension seemed to cover all systems that have been analyzed. Some, such as *Open Data* and *Interoperability* have not been present in any system yet. We kept all features assuming they will appear in future systems.

Step 6c.I2. Create the taxonomy. We generated the version 2 of *Tax-CIM* according to the result of the analysis performed in step 5c.I2. Figure 3 shows the revised Taxonomy. The three characteristics that replaced *automatic information processing (filtering, ...)* at the intelligence dimension are highlighted. The small number of changes proved that version 1 was

Figure 3

Summary of Tax-CIM version 2



fairly comprehensive, but some refinements had to be made. A full definition of version 2 appears in Appendix B.

Limitations of the work

We have developed a taxonomy of CIMSs attending to their support to the response stage of the emergency management lifecycle. We consider that given the high functional diversity of current systems, and the growing interest in citizen and infrastructure protection of governments and organizations, a tool for helping users in the selection of the right system will be welcome. But there is still some work to do before reaching this goal, since the work described here has some limitations. Some relate to the application of Nickerson et al. method, whereas others refer to the type and number of systems analyzed.

In the first iteration of the method, we decided to follow a E2C approach, which requires the identification and analysis of the objects of study from where to draw characteristics. In our case, we did not perform such an analysis; rather, we based the identification of characteristics in our previous research experience on emergency management systems. From it, we obtained a substantial number of characteristics that proven to be sufficiently comprehensive in further steps of the method.

In the second iteration, we studied 15 systems out of 62. This could be considered a low number, but we decided to use a low number of systems since we were in an iterative process that will have more iterations, for sure. We expect to have many more systems analyzed in further refinements of the taxonomy. Another limitation comes from the bias towards commercial systems of our selection: an 80% of the studied systems are commercial. We are aware that research systems can offer advanced features still not available in commercial systems but, as a counterpart, information about them may not be available in the form of a product description. It is our intention to incorporate more research systems in further iterations of the taxonomy development process.

Conclusions and further work

CIMSSs are at the core of emergency management digital transformation processes. In a world where more and more information is produced every second, tools for capturing, organizing, and disseminating information are required to perform safer and more efficient responses to crises. The need for such tools has been recognized worldwide, which explains the development of a high number of systems catalogued as emergency response software in the last decade. On the positive side, such diversity is good since potential users have a wide range of options to choose from. On the other side, however, there is little guidance about how to select a particular system. A close look at the market of such systems shows much diversity in the way systems are described; often, the information found in the products' websites is sale-oriented, lacking a systematic description of the systems' features and capabilities. Consequently, support to product understanding and selection is still missing.

In this work, we have introduced the first steps of the development of *Tax-CIM*, a taxonomy aimed at uniformly classifying CIMSSs. We have identified and organized the characteristics of such systems around 7 dimensions relevant for emergency response following an iterative method combining conceptualizations with empirical study of the nature and features of CIMSSs. Using *Tax-CIM*, software vendors can produce systematic descriptions of their systems' features, while potential adapters of such systems can have an exhaustive description and comparison of the systems in the market, from which select the one best fitting to their requirements. Moreover, from an academic point of view, the taxonomy can serve as keyword set for the description and retrieval of research literature.

The development of *Tax-CIM* has not finished; rather, we estimate that at least one more iteration of the method should be made including the classification of more CIMSSs. We expect that a new refinement of the characteristics set will produce a more comprehensive classification of existing systems. In the mid-term, *Tax-CIM* is aimed at serving as a reference framework for

the classification of CIMSs, and expect the collaboration of system vendors in their elaboration.

Along with these goals, we want to explore the use of a similar technique to develop taxonomies for other stages of the emergency management lifecycle like preparedness or recovery, where there exists a similar heterogeneity of systems.

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Appendix A

Tax-CIM version 1

Dimensions	Characteristics	Description
Coordination	Fieldwork coordination	Coordination between the response teams working in the operations field.
	Command coordination	Coordination between the members of the control room
	Command to fieldwork coordination	Coordination of response teams from the control room
	Public coordination	Providing instructions for self-protection and/or to be 1st relief providers
	Volunteering support and coordination	calling, accepting and managing volunteerism (assignment of tasks, preparation assessment and improvement, coordination, etc.
	Adaptation on-the-fly	Ability to change the action plan according to context changes or unexpected situations.
	Resource Management	Acquisition, maintenance and allocation of material resources. Also, human resources management: allocation of duties, role assignment, etc.
	Logistics management	Definition of supply chains, fleet tracking, route optimization, etc.

Collaboration	Role management	Definition and assignment of roles to participants in the response
	Collaborative process enactment	Choreography of the response process, task lists, shared process awareness.
	Shared workspaces	Role-based shared data spaces, collaborative planning
	Group decision making	Support to the deliberation, voting and decision making by formal or ad-hoc groups
Information management	context awareness	users can access to fresh information coming from in-place sources that can overwrite the formal knowledge contained in the plan
	process awareness	Every actor participating in the response knows what actions to perform at each moment
	information capture	The system is able to catch information from different sources using video cameras, sensors of different types, UAVs, social media, etc.
	information curation	The information is organized in the form of multimedia digital collections that are described using standard metadata schemas, and eventually archived for further access or just preservation

	open data	Open data sources are accessed to provide context to the different actors
	maps	The information captures its geo-location and can be represented in spatial mashups
	data integration	Data coming from heterogeneous sources can be merged into the CIMS schema by means of semantic integration techniques
	Public Information Officer support	There are utilities for publication of information as well as for collecting requests and/or feedback from the public.
	logging	every decision and action in the systems is registered for further analysis
	Information retrieval	IR techniques allow the content-based retrieval of relevant information by means of text, picture or audio-based queries
	wearables	different wearable devices can capture and send information about the responders' environment (included their health relevant values)
Visualization	Dashboards	Functions for monitoring the situation awareness
	mashups	combining geo-located information with maps

	Tabletops	Use of interactive tablesps for both visualization and operation support
	Mobile clients	responsive user interfaces adapt the dissemination to the screen dimensions
	Desktop	Default feature
	Customization	Role-based dissemination of information
	Augmented reality	Systems that use augmented reality for visualizing the situation
Communication	Video conferencing	systems that promote communication through video conferencing either for discussing or present information about a crisis.
	Social Media interaction with Public	All types of interaction with the public through social media, either for receiving information or communicate information of common interest. It also includes requests to the public.
	Non-SM interaction with Public: one way	broadcasting information of interest to the public
	Non-SM interaction with Public: two way	establishment of dialogs with members of the public
	Exclusive communication channel for field workers	The same as C&C, but for field workers, either to support the communication with the C&C and between the personal operating in the field.

	Exclusive communication channel for C&C	There is usually intense communication among members of the C&C teams, i.e., those not operating in the field (another category). Systems that support this interaction are in this category.
Intelligence	Decision making	All processes of automatic decision or recommendation after processing information available.
	Automatic Information Processing (Filtering, ...)	After captured, the information has to be processed. This category embrace all processes that automatically filter, group and generate conclusions from an information set.
	Automatic Information Capture (sensors, drones, ...)	This category includes the dealing with all information coming from sources other than humans. It includes the selective and oriented capture of information without direct human intervention. Examples are sensors, autonomous drones, etc.
General Support	Robustness	How to deal with errors generated by unexpected data or actions in the system. There are systems that address this issue because during a disaster response the

		teams are under stress and can commit mistakes.
	Privacy preservation	In many crises the response teams deal with very sensitive information, such as the identification of people who are dead or injured. Functions in the system to preserve the authorized access to information are part of this category.
	Provenance	It refers to functions aimed to identify and preserve the provenance of information, not only for the purpose of trustability (another category) but maintain the history of information transformation.
	Scalability	It deals with how to evolve from a prototype or small number of users to a regional or national scale, particularly for crises involving teams from several regions/counties
	Open data	Some systems have their own data, others use data from open sources. There are some hybrid approaches, too. This category refers to systems that make use of open data.

	<p>Trustability</p>	<p>This is an important aspect when dealing with information from external sources, particularly those that are not part of network. Systems that deals with the trustability of the information sources are member of this category</p>
	<p>Interoperability</p>	<p>Two issues here: the first relates to make systems used by different teams to share information and actions. the second to make systems for the same purpose but managed by different groups can interoperate</p>

Appendix B

Tax-CIM version 2

New characteristics are included in blue typeface.

Dimensions	Characteristics	Description
Coordination	Fieldwork coordination	Coordination between the response teams working in the operations field.
	Command coordination	Coordination between the members of the control room
	Command to fieldwork coordination	Coordination of response teams from the control room
	Public coordination	Providing instructions for self-protection and/or to be 1st relief providers
	Coordinate with Volunteer Organizations	Coordinate actions with Volunteer organizations such as the Red Cross to avoid overlapping.
	Volunteering support and coordination	calling, accepting and managing volunteerism (assignment of tasks, preparation assessment and improvement, coordination, etc.
	Adaptation on-the-fly done by the response team	Ability to change the action plan according to context changes or unexpected situations.

	Resource Management	Acquisition, maintenance and allocation of material resources. Also, human resources management: allocation of duties, role assignment, etc.
	Logistics management	Definition of supply chains, fleet tracking, route optimization, etc.
Collaboration	Role management	Definition and assignment of roles to participants in the response
	Collaborative process enactment	Choreography of the response process, task lists, shared process awareness.
	Shared workspaces	Role-based shared data spaces, collaborative planning
	Group decision making	Support to the deliberation, voting and decision making by formal or ad-hoc groups
Information management	context awareness	users can access to fresh information coming from in-place sources that can overwrite the formal knowledge contained in the plan
	process awareness	Every actor participating in the response knows what actions to perform at each moment and has the information he or she needs for acting

	information capture	The system is able to catch information from different sources using video cameras, sensors of different types, UAVs, social media, etc.
	information curation	The information is organized in the form of multimedia digital collections that are described using standard metadata schemas, and eventually archived for further access or just preservation
	open data	Open data sources are accessed to provide context to the different actors
	Maps	The information captures is geo-located and can be represented in spatial mashups
	Data integration	Data coming from heterogeneous sources can be merged into the CIMS schema by means of semantic integration techniques
	Public Information Officer support	There are utilities for publication of information as well as for collecting requests and/or feedback from the public.
	Logging	every decision and action in the systems is registered for further analysis
	Information retrieval	IR techniques allow the content-based retrieval of relevant information by

		means of text, picture or audio-based queries
	Wearables	different wearable devices can capture and send information about the responders' environment (included their health relevant values)
Visualization	Dashboards	Functions for monitoring the situation awareness
	Mashups	combining geo-located information with maps
	Tabletops	Use of interactive tabletops for both visualization and operation support
	Mobile clients	responsive user interfaces adapt the dissemination to the screen dimensions
	Desktop	Default feature
	Customization	Role-based dissemination of information
	Augmented reality	Systems that use augmented reality for visualizing the situation
Communication	Video conferencing	systems that promote communication through video conferencing either for discussing or present information about a crisis.

	Social Media interaction with Public	All types of interaction with the public through social media, either for receiving information or communicate information of common interest. It also includes requests to the public.
	Non-SM interaction with Public: one way	broadcasting information of interest to the public
	Non-SM interaction with Public: two way	establishment of dialogs with members of the public
	Exclusive communication channel for field workers	The same as C&C, but for field workers, either to support the communication with the C&C and between the personal operating in the field.
	Exclusive communication channel for C&C	There is usually intense communication among members of the C&C teams, i.e., those not operating in the field (another category). Systems that support this interaction are in this category.
Intelligence	Recommendation and Automatic Decision making	All processes of automatic decision or recommendation after processing information available.
	Automatic Information Capture (sensors, drones, ...)	This category includes the dealing with all information coming from sources other than humans. It includes the selective and oriented capture of

		information without direct human intervention. Examples are sensors, autonomous drones, etc.
	Automatic Information Filtering	After captured, the information has to be processed. This category embrace all processes that automatically filter the data captured using some relevance criteria.
	Automatic Information Categorization	This category embraces all processes that automatically classify the data according to the predicted usage.
	Automatic Inference	This category embraces all processes that automatically generate conclusions from an information set.
General Support	Robustness	How to deal with errors generated by unexpected data or actions in the system. There are systems that address this issue because during a disaster response the teams are under stress and can comit mistakes.
	Privacy preservation	In many crisis the response teams deal with very sensitive information, such as the identification of people who are dead or injured. Functions in the system to

		preserve the authorized access to information are also part of this category.
	Provenance	It refers to functions aimed to identify and preserve the provenance of information, not only for the purpose of trustability (another category) but maintain the history of information transformation.
	Scalability	It deals with how to evolve from a prototype or small number of users to a regional or national scale, particularly for crises involving teams from several regions/counties
	Open data	Some systems have their own data, others use data from open sources. There are some hybrid approaches, too. This category refers to systems that make use of open data.
	Trustability	Trust is an important aspect when dealing with information from external sources, particularly those that are not part of network. Systems that deals with

		the trustability of the information sources are member of this category
	Interoperability	Two issues here: the first relates to make systems used by different teams to share information and actions. the second to make systems for the same purpose but managed by different groups can interoperate