Towards an Interoperable Operational Emergency Response System for Large-Scale Situations: POLARISC

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ABSTRACT

After a lot of recent natural and human-made disasters all over the world, the large-scale emergency response process is becoming very critical and challenging. Lives can be lost and property can be harmed. To respond to these major threats, an effective operational emergency response system needs to address the necessity of data sharing, information exchange and coordination between the different involved Emergency Responders (ERs) including firefighters, police, healthcare services, army, municipality and so on to successfully respond to large-scale disasters. Therefore, the goal of this paper is to introduce POLARISC, an interoperable software solution based on a common modular ontology shared by all the ERs. Its main objective is to solve the problem of heterogeneity of data, to guarantee a common understanding among the various ERs, and to enable interoperability among them in order to coordinate their interventions and to obtain a real-time operational picture of the situation.

Keywords

Emergency response, Emergency Response System, Semantic interoperability, Ontology.

INTRODUCTION

Today, people are threatened by disaster situations, whether they are natural or human-made, disasters have been happening all around the world, every day and every single hour. Disasters can be defined as a sudden, accidental event of great magnitude that may cause deaths, severe injuries and property damage if not handled properly. For a safer future and to reduce disaster impacts, a large network of heterogeneous services of Emergency Responders (ERs) from various Emergency Response Organizations (EROs) including firefighters, police, healthcare services, army, municipality and so on are working hard to manage the large-scale disasters. The need to face these threats make the emergency response process very critical and challenging. Emergency response can be divided into three phases: (1) pre-crisis is about prevention and preparation, (2) crisis response is when management must actually respond to a crisis, and (3) post-crisis phase looks for better ways to prepare for the next crisis (Coombs, 2007). In this context, we will focus on the crisis response phase. In fact, in crisis response, ERs necessitate an ample need of timely information sharing and data exchange to obtain a real-time operational picture of the situation. But, each ERs has deployed its own information system. As a direct result of this situation, the main ambiguity that shows up is that information is heterogeneous; they are stored in different data sources, with different semantics and in different formats. Moreover, the major drawback is the deficiency of interoperability between the different information systems of the ERs. These issues lead to the misunderstanding and lack of coordination and data sharing among the ERs. Accordingly, almost without exception, reports and reflections after disasters express concerns over the EROs' abilities to collaborate. A recent example of this can be found in the concluding report on the terror attack in Norway on June 22, 2011, stating that the various EROs (firefighters, police, healthcare services, etc.) were unable to effectively communicate and coordinate their effort (Eide et al., 2012). Thus, an effective operational emergency response system needs to address two key challenges; First, information interoperability is primordial among the different stakeholders during a crisis. Second, information should be semantically understandable by all the ERs since each stakeholder requests information in their own vocabulary, data representation and graphical charter (various color codes, different graphical symbols).

To address these challenges, in this paper, we introduce a novel solution POLARISC («*Plateforme OpérationnelLe d'Actualisation du Renseignement Interservices pour la Sécurité Civile*»), an ontology-based operational emergency response system. It is a new French project which started in 2017. It is an interoperable inter-services software solution for reliable and timely information sharing for the operational management of large-scale crisis situations. The focus is about offering to all ERs a real-time operation picture of the situation in order to enable multi-stakeholders and multi-level coordination within the EROs including firefighters, police, healthcare services, army and other government services. The rest of this paper is organized as follows. First, we describe the French structure of civil protection and emergency response. Later, a literature review on recent works and projects on emergency response is presented. Then, section 4 goes into the details of the proposed solution and the system architecture. At last, the conclusion and the future work are presented.

FRENCH STRUCTURE AND LEVELS OF EMERGENCY RESPONSE

Each country has its own culture and structure of Emergency Response Organizations in emergency situations. As regards the French Republic, it is a unitary state that includes four levels as shown in Figure 1. At the national level, the prime minister of France is responsible for the civil protection in the whole country. He takes control of the COGIC («*Centre Opérationnel de Gestion Interministérielle de Crise*», inter-ministerial operational crisis management center). It ensures round-the-clock monitoring of large-scale rescue operations and coordinates the use of resources in the event of a major incident. Afterward, at the zone level, the zone prefects are in charge of the COZ («*Centre Opérationnel de Zone*», Zonal Operations Centre) that ensures the coordination of the aid and rescue operations. Next, local branches of central ministries are directly controlled by prefects. Then, at department level, the prefect governs the COD («*Centre Opérationnel Départemental*», Departmental Operations Centre), he counts on the PCO («*Poste de Commandement Opérationnel*», Operations Command Post), which is located in a safe place near the crisis area and in charge of coordinating the various actors in the field. Finally, at the communal level, each commune has its own mayor, responsible for everyday public safety and security on the territory of the municipality. In case of disaster, the mayor is the first to step in. As the "emergency operations director" during crises, he manages resources and coordinates communication between firefighters' brigade, police, healthcare services and all actors who may be implicated in a crisis (Coste et al., 2013).

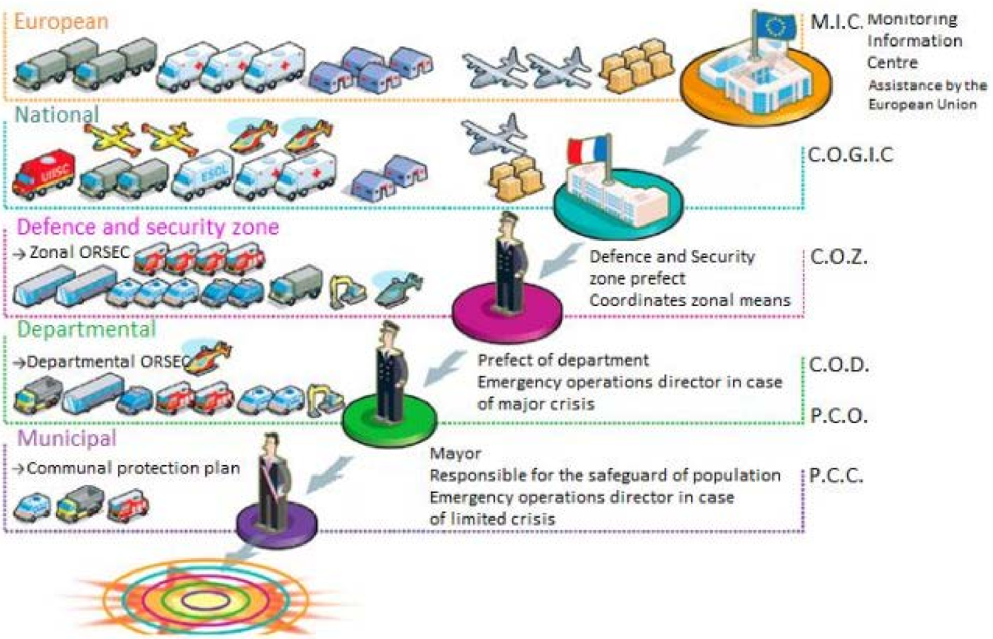

Figure 1. French Structure of Emergency Response
(Source: Ministry of the Interior, 2009)

The ORSEC («*Organisation de la Réponse de SEcurité Civile*», Organization of the civil security response) plan provides the general framework for the civil security response. It is the basis of inter-services operational management regardless the origin of the major event affecting the population (natural or human-made disasters). Since 1999, major events have occurred in France, such as the 1999 storm of the century, the 2001 explosion at the AZF factory (Toulouse), the 2003 heat wave and the Xynthia storm (2010), specifically contributed to raising awareness, highlighting the complexity of the civil security organization (Coste et al., 2013). The feedback from the Xynthia storm, which caused at least 53 of persons killed and about 1.2 billion Euros of damage (Le Parisien, 2010), elaborated by the SDIS («*Services départementaux d'incendie et de secours*», Departmental fire and emergency services) of "Charente Maritime" highlights that information remains the essential element in crisis response. It should be treated in terms of content and flow. Indeed, this feedback brought to light a number of weaknesses that should be improved including:

- The necessity of the development of a common semantic terminology between the SDIS and the COD.
- The need of a common visualization tool of the tactical situation (SITAC) among COD, SDIS and PCO to obtain a real-time operational picture of the situation.
- A better coordination and cooperation between stakeholders.
- An essential improvement in terms of data sharing and information among stakeholders.

To conclude, the French structure of emergency response is characterized by the multiplicity of the involved actors and their cultures. To deal with this diversity, an efficient coordination is a primordial requirement. Therefore, the need for an interoperable multi-level and multi-stakeholders' operational emergency response system based on a common understanding of the meaning of terminologies for the operational management of large-scale disasters has been recognized.

STATE OF THE ART

For many years, there have been considerable efforts and growing interest to propose improvements in the emergency response field. Many solutions have been developed trying to solve real issues that cause slower and inefficient decision making in responding to emergency situations such as semantic heterogeneity of data, deficiency of interoperability in emergency management systems, misunderstanding and the lack of coordination and data sharing between all stakeholders.
At a national level, the project POLARIS is an essential component of the rescue operations developed by the society EXYZT (Σ: the set of, X, Y, Z: spatial landmark (3D), T: temporal dimension) in 2011. More specifically, it is an operational emergency response system used by the firefighters' tactical chain of command. This software allows the SDIS to coordinate all their interventions according to the topology of the field, the weather, the direction and strength of the wind, the available means, etc. It is built based on the national graphical charter GOC («*Gestion Opérationnelle de Commandement*», Operational Management of Commandment) (Figure 2). It allows each level of the firefighters' chain of command to have a real-time operational picture of the situation and also to add new tactical information. It has been able to manage important intervention such as the European exercise RICHTER-2012.

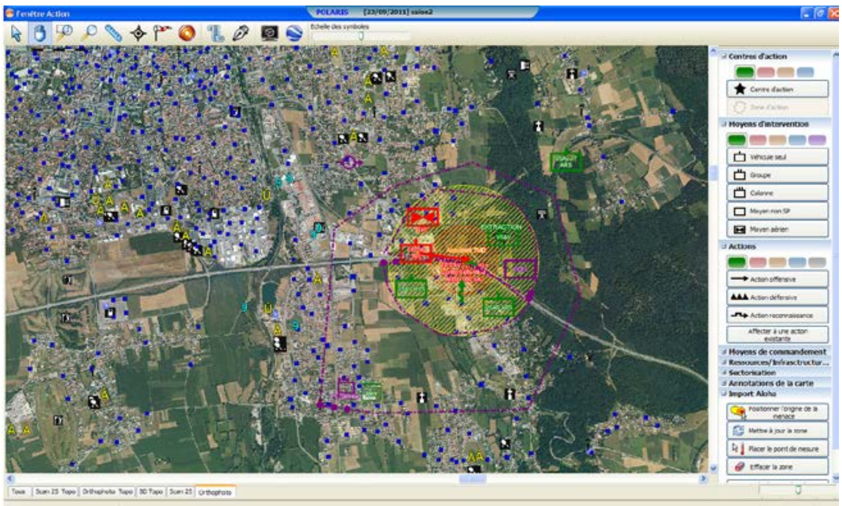

Figure 2. Example of an intervention managed by POLARIS

This software is used nowadays by the French firefighters. But, its major drawback is the fact of not enabling communication and information sharing among stakeholders. Disappointingly, operational ERs still communicate and coordinate through the prefect by means of telephones rather than information systems. If this kind of operational software, POLARIS, oversteps firefighters to include the different stakeholders, the result will be so advantageous to the emergency response field.

At the European level, there are a few research projects that have been working on the field of cross-border collaboration in emergency response such as DISASTER (Data Interoperability Solution At Stakeholders Emergencies Reaction) (Casado, et al., 2014). It tries to solve linguistic, semantic and cultural difference between countries by proposing a methodical basis for connecting and translating emergency management systems. It transforms the needed resources to the appropriate language, vocabularies, formats and protocols. In the same context, another project named INCA (A Decision Support Framework for Improving Cross-border Area Resilience to Disasters) focusses on the resilience of medical dependent citizens and the management of volunteers in a cross-border area (Lotter et al., 2017). They develop a resilience framework that helps decision-makers before and during cross-border incidents specifically on the French and on the German side. They propose a set of scenarios and guidelines to figure out the most appropriate measures.

Furthermore, DRIVER (Driving Innovation in Crisis Management for European Resilience) (van der Ven and Stolk, 2015) proposes a distributed Pan-European test-bed to provide guidelines on how to perform experiments as well as a framework to evaluate results. It is about three major thematic: First, Civil Society Resilience focus on citizens and civil society actors that are not professionally trained in crisis management, then, Strengthened Responders shows the benefits of innovative solutions to professional stakeholders. Finally, Evolved Learning aims to enhance the capabilities of professionals by performing a series of training modules to all the actors from first responders to the highest level of decision makers. In fact, the test-bed implies on a portfolio of Crisis Management tools where researchers, citizens and stakeholders can progress on new solutions. In the same context, Driver has some related ongoing project such as DARWIN2. It aims to provide emergency responders guidelines so as to facilitate crisis response. However, in these works, authors don't propose an end-user emergency response system.

Another European project named SecInCoRe (Secure Dynamic Cloud for Information, Communication and Resource Interoperability based on Pan-European Disaster Inventory) (Petersen and Büscher, 2017), looks for improving interoperability and data sharing among stakeholders by means of the development of a common information space based on information systems employed in past disaster events by first responders and police authorities by providing cloud-based semantic services. To do this, authors did a Pan-European inventory of disasters and their consequences and then elaborated a dynamic cloud-based communication system concept basing on a formulated knowledge base. In fact, it is a common information space concept documentation rather than an operational emergency response system.

Indeed, most of the proposed emergency response systems in literature lack a proper support to semantic interoperability. The interoperability among the various ERs requires a common ontology to overcome semantic heterogeneity. To do so and to guarantee a consistent shared understanding of the meaning of information, the use of ontologies is crucial (Antunes et al., 2013). Ontologies are expressed in a logic-based language, so that accurate, consistent, and meaningful distinctions can be made among the classes, instances, properties, attributes, and relations to reveal the implicit and hidden knowledge in order to understand the meaning of the data. Thus, they offer the richest representations of machine-interpretable semantics for systems and databases (Obrst, 2013). They serve as both knowledge representation and as mediation to enable heterogeneous systems interoperability (Song et al., 2013).

In (Fan and Zlatanova, 2011), authors looked for solving the problem of spatial data heterogeneity in emergency situations and their transmission to stakeholders. For this purpose, they proposed an ontology model that focuses on two types of data static data (topographic data such as TOP10) and dynamic data (data gathered after a disaster; damaged building, damaged car). Unfortunately, the work proposed is still at a very early stage and no ontology exist that can be used in emergency response.

In fact, in crisis response, there are two levels of intervention in the conduct of a crisis, namely, the crisis management level that includes political, strategic and tactical stages and the operational management level. As regards the French Republic, in case of a large scale situation, the president of the Republic and the prime minister take charge of political and strategic actions. The Ministry of Interior is responsible for activating, if required, the inter-ministerial crisis committee (CIC). Then, the CIC is in charge of the transmission of decisions from the political level to the operational centers respectively within the national firefighters, gendarmerie, police and civil security services.

To conclude, few systems are presented to enhance the field of large-scale emergency response. These systems are typically specific to certain aspects of emergency response, but unable to cover all of them. In addition, they are concerned about crisis management at a higher level (strategic level) but there is no system that focusses on the inter-services operational level, unlike POLARISC that includes all actors involved in operational emergency response level (Figure 3) such as healthcare services, firefighters, police department, etc. At last, in the literature, there is a lack of a common terminology or standard. Therefore, our solution aims to overcome these limits by proposing an inter-services operational emergency response system for large-scale situations basing on a common modular ontology that covers all the stakeholders' knowledge.

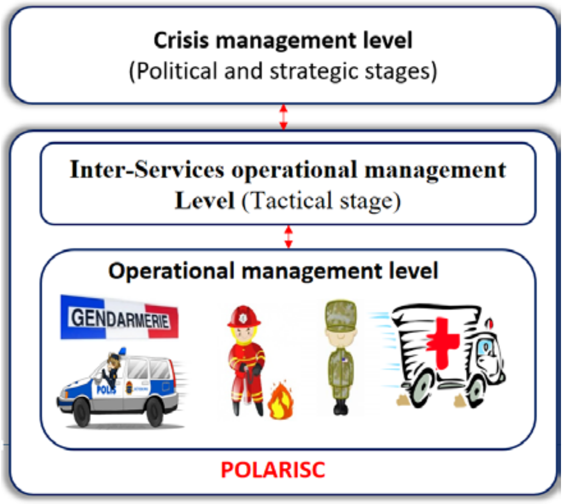

Figure 3. POLARISC positioning compared to other systems

THE PROPOSED SOLUTION

Information accessibility and availability is vital during a large-scale emergency response. For this purpose, POLARISC aims to offer a common operational picture, timely access to the needed information, data sharing and coordination among stakeholders. Figure 4 illustrates the architecture of POLARISC as a whole system and also shows the proposed modular ontology for semantic interoperability between stakeholders. POLARISC is mainly a software solution that plays the role of mediation between ERs that require coordination and cooperation for large-scale operations. It is composed of three layers; First, the users' layer is composed of the different stakeholders that will use the system (firefighters, police, healthcare services, etc.).
Second, the integrated services layer is about suggesting a set of services designed to support the ERs in emergency response. Among these services, Evacuation of victims' service allows finding as quickly as possible the appropriate health care institutions and reserves it according to the patient state (Mhadhbi et al., 2015). Messaging service will ensure a semantically adaptive information exchange between the different stakeholders in order to consolidate information and also to send the appropriate information to the appropriate actor by taking into account the hierarchical levels of commandment. Geospatial service provides to stakeholders a smart cartography to have a real time operational picture of what happen on the field and also to add on the map the different interventions (the involved means, stakeholders, etc.). Operational service is about means management on the field. The tactical service proposes a decision support tool for prevision and simulation of emergency response. Then, mediators layer is responsible of transforming the data according to the appropriate vocabulary and graphical charter (color codes and graphical symbols) of the stakeholder. It is a gateway between end-user systems, the services layer and the data layer. As a result, each stakeholder receives information and uses the proposed services in accordance with his vocabulary and checks the operational picture of what is happening exactly in the field according to his graphical charter.
At last, the data layer is the core of the proposed system. To overcome semantic heterogeneity among stakeholders, the definition of a common terminology is essential. Thus, we resort to ontology to reveal the ERs' complex knowledge in order to understand the meaning of the data and transmit it to the correct ERs. The ontology encompasses ERs vocabulary to contain also the different process, workflows and rules.

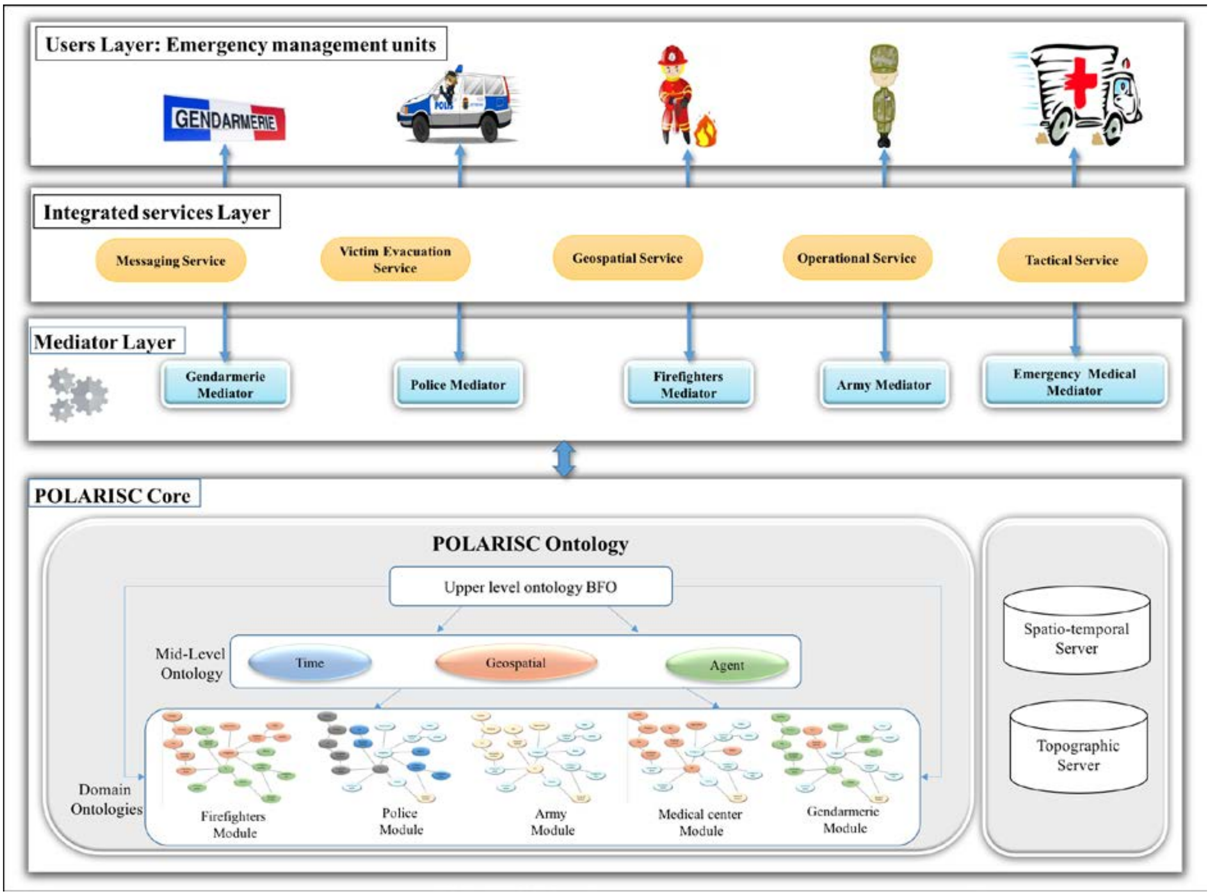

Figure 4. POLARISC architecture

To develop our proposed modular ontology (a module for each stakeholder), first, we reused an upper-level ontology. Indeed, the use of upper-level ontologies facilitates the alignment between several domain ontologies and enable interoperability between them. In other words, if the ontologies to be mapped are driven from a stander upper-level ontology, this will make the mapping task very easy. In addition, upper-level ontologies play the same role as libraries in software programming tasks. Once they are used, one could reuse the defined concepts and relationships and so as to inherit the inferencing capabilities furnished by them. In this way, developing a domain ontology is an easier task that requires less time than usual. Moreover, the aim is to avoid having several incompatible domain ontologies. The usage of upper-level ontologies for integrating information and sharing knowledge among heterogeneous sources has been motivated in various related works (Baumgartner and Retschitzegger, 2006).

To select the appropriate upper-level ontology, we first looked for a realist upper ontology that represents the world as is and not underlying natural language and human common-sense. Then, to ensure that the upper-level ontology can be extended to an emergency management ontology, it should be universal. Universal classes are often characterized as natural classes that abstract or generalize over similar particular things. Person, Location, Process, etc., are examples of universals (Semy etal., 2004). Accordingly, in this work, we employed Basic Formal Ontology (BFO) as an upper-level ontology (Smith and Ceusters, 2010) (Seppälä etl., 2014). — We might say that the ontology encapsulates the knowledge of the world that is associated with the general terms used by scientists in the corresponding domain (Arp et al., 2015). As a starting point, BFO uses the term «*entity*» as a common representation of anything that exists in the world from the point of view whether of philosophers or scientific researchers. Then, it incorporates two categories of entity «*Continuants*» and «*Occurrents*» in a single framework as a top-level distinction between entities. Continuants are entities that persist through time including three axes; objects (Material entity) or and spatial regions (Immaterial entities) as Independent continuant, functions and qualities as Specifically independent continuant and finally, Generically dependent continuant. Occurrents are entities that happen or develop over time such as process.

As a mid-level ontology, we decide that Common Core Ontology (CCO) meets most our requirements since it inherits from BFO as an upper-level ontology and defines a modular set of extensible classes and relations that can be connected to our domain ontology. The ten mid-level ontologies that compose the common core ontology are: The Information Entity Ontology, the Agent Ontology, the Quality Ontology, the Event Ontology, the Artifact Ontology, the Time Ontology, the Geospatial Ontology, the Units of Measure Ontology, the Currency

Unit Ontology, and the Extended Relation Ontology (Ron, 2016). In our work, we reused only three modules that will be extended according to the domain level needs which are Agent Ontology, Time Ontology and Geospatial Ontology.
Concerning the domain ontologies and to develop the different modules, interviews were conducted with stakeholders so as to capture their needs and to identify their technical vocabulary (Commandment hierarchy, means, types of intervention, roles, etc.).
We started first by firefighters' module. At the end of this stage, the firefighters' ontology had around 429 classes and 246 relations. The classes are labeled in English and in French. The final step consists on the evaluation of the proposed ontology by domain experts in term of inconsistency, incompleteness and redundancy. To summarize, the ontology we created, once it is complete and all the emergency management actors' modules are integrated, it will be instantiated to test it by means of a concrete use case and it will be used in an Emergency Management System as a common shared vocabulary. Domain expert and users should then evaluate and validate the obtained results.

CONCLUSION AND FUTURE WORK

In large-scale disasters, coordination of emergency responders is challenging due to the heterogeneity of systems in use. In this paper, we have introduced POLARISC, an inter-services operational emergency response system for data sharing among heterogeneous ERO in large-scale situations. It offers a real-time operation picture of the situation. In addition, we have highlighted the use of POLARISC Ontology, a common modular ontology, that ensures semantic interoperability in emergency response and guarantees a common understanding between stakeholders. For all we know, the modular ontology proposed in this paper is the first ontology based on BFO and CCO that aims to define the emergency responders' knowledge. As a future work, we will develop the rest of the stakeholders' modules and then integrate them in a global ontology that will be validated by domain experts. As future directions, the project can be extended to take into account more actors such as volunteers and people with disabilities or limited language skills.

ACKNOWLEDGMENTS

This research was conducted as part of the POLARISC (*Plateforme OpérationnelLe d'Actualisation du Renseignement Interservices pour la Sécurité Civile*) project. It was funded by the regional operational program FEDER/FSE « Midi-Pyrénées et Garonne 2014-2020 » as part of the call for projects "Easynov2016".

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