Software services for supporting remote crisis management

Boukaye Boubacar Traore[a,b], Bernard Kamsu-Foguem[a,*], Fana Tangara[b], Pierre Tiako[c]

[a] *Toulouse University, Toulouse INP-ENIT, Laboratoire Génie de Production, Ecole Nationale d'Ingénieurs de Tarbes 47, Avenue Azereix, BP 1629, F-65016 Tarbes Cedex, France*

[b] *Université des Sciences, des Techniques et des Technologies de Bamako (USTTB), Faculté des Sciences et Techniques Colline de Badalabougou, Ancien Lycée Badala B.P. E 28 11, FST, 223 Bamako, Mali*

[c] *Center for Information Technology Research & Development (CITRD), Tiako University, 1911 Linwood Blvd., Oklahoma City, OK 73106, USA*

Keywords:
Crisis management
Collaboration
Software as a Service (SaaS)
Information System
Tsunami alert

A B S T R A C T

Crisis management specifies a series of functions or processes for the identification, analysis and forecasting of crisis issues, and the statement of specific ways that would enable an organization to prevent or cope with a crisis. There are some existing techniques for crisis management. However, to our knowledge none of them is focused on the integration of telemedicine acts especially during transportation phase and also between health structures for saving more lives. Therefore, we propose a novel methodological framework for remote crisis management with three main phases: (1) Crisis definition (2) Crisis Analysis and (3) Crisis Management. The Crisis Management phase is based on the organized collaboration of various acts of telemedicine: Teleconsultation, Teleexpertise, Telemonitoring, Teleassistance, and Medical regulation. Each act of telemedicine provides services to others and can be represented in Software as a Service (SaaS). SaaS design principle considers a software application as a service from which we propose some collaborative services to solve complex crisis management problems. The case studied and modeled concerns the simulation exercise on the Tsunami crisis management in Cannes (France), especially during the transportation phase of patients to various health structures. The proposed methodology adds an additional layer in terms of remote collaboration and information management to improve the management of emergencies and safety, with a view for contributing to protect and save lives when minimizing damages. The expected benefits (main findings) for using the considered approach are not only to provide crisis managers with a relevant computerized decision support system, but also to minimize financial costs, reduce the response time and positively impact the crisis management.

1. Introduction

The world in various places is now facing a multitude of crises that may affect human health, climate, and environment (Son & Thanh, 2018). A crisis is defined as the appearance of a state of disorder, abnormal, dysfunction, deep imbalance, serious disorder (Girard, Lalande, Salmi, Le Bouler, & Delannoy, 2006). Crisis management is "a series of functions or processes to identify, study and forecast crisis issues, and set forth specific ways that would enable an organization to prevent or cope with a crisis (Kash & Darling, 1998)". Crisis management is a complex topic since it needs the best understanding of the involved phenomena with its consequences (including scenarios, events, and outcomes), the knowledge of the underlying processes and the considered root causes analysis (Jensen & Aven, 2018). Crisis can be caused by two types of major risks: natural risks and technology risks (Table 1).

The resolutions of all these crises have a common denominator: crisis management to return to a normal situation and also minimize the consequences of such a crisis in a safe and effective manner (Vardarlıer, 2016). A good crisis management requires a number of preconditions. It must be planned, prepared and executed in the appropriate way and this process can be divided into three main stages, as shown in Fig. 1: (1) dissemination of the alert message, (2) evacuation and (3) protection of evacuated areas (crisis recovery) in order to save more lives and to reduce the severity of collateral and environmental damage (Devlin, 2006; Zhou, Wu, Xu, & Fujita, 2018).

In emergency contexts, the remote medical activities delivered by telemedicine are interesting for the protection of human life in crisis management. The crisis managers and actors will thus be better equipped to face risk and sensitive situations and to reduce the impact of the complex medical problems caused by the natural or industrial risks. In addition, the development of telemedicine software and platforms have made significant advances in recent years, involving a

* Corresponding author.
E-mail address: Bernard.Kamsu-Foguem@enit.fr (B. Kamsu-Foguem).

Table 1
Classification of major risks (Gupta, Suresh, Misra, & Yunus, 2002).

Natural risk	Technology risk
Floods and heavy rains	Industrial accident
Forest fire	Electrical accident
Abundant snowfall	Chemical accident
Avalanches	Nuclear accident
Cyclones	Dam failure
Earthquake	Transport of dangerous goods
Movement of land	Toxic gas release
Volcanic eruption	Toxic liquid release

substantial increase in the number of communications and network collaboration tools. So, there is a strong need for interoperable information systems to facilitate their effective communication which involves the sharing and exchange of data between these systems (Patient medical record, X-ray image, medical analysis data, etc.).

The main objective of this study is to provide a new methodological framework for remote crisis management integrating information modeling on the collaboration of telemedicine acts. This methodology is based on a formal specification of information flows and how to exploit them to provide crisis managers with relevant ways for collaboration towards critical decision-making. The application of this methodology highlights two main interests: (1) the strengthening of remote collaboration based on existing of telemedicine software (Saidi, Kattan, Jayasinghe, Hettiaratchi, & Taron, 2018) and (2) the improvement of medical attention in order to reduce the number of deaths due to lack of medical assistance (ASIP, 2012). Knowing that such medical attention can be done during the transport phase of the victims and also with a remote support from health structures to fill the lack of medical professionals or specialists.

In general, remote crisis management is supported by a collaborative work environment using workflow systems thus, helping decision makers to manage and resolve the crisis (Mak, Mallard, Bui, & Au, 1999). In this work, the conceptual modeling can be applied to all types of crises involving victims who need medical attention. Therefore, telemedicine acts are relevant in the context of collaborative information systems in helping the victims of crisis. Telemedicine is the use of telecommunication and information technologies in order to provide clinical health care at a distance (Najeeb, 2012). The French Law with the decree number 2010–1229 on October 19, 2010 (articles R.6316-1–R.6316-9 of the Public Health Code) specifies the following five achievable acts of telemedicine (Fig. 2):

- **Tele-consultation**: a doctor gives a remote consultation to a patient, which may be assisted by a health professional. The patient and/or the health professional at his side provide the information, the doctor can also remotely make the diagnosis;
- **Tele-expertise**: a doctor remotely seeks the opinion of one or several colleagues on the basis of medical information related to the care of a patient;
- **Tele-monitoring**: a doctor remotely monitors and interprets medical parameters of a patient. The recording and transmission of data can be automated or performed by the patient himself or by a health professional;
- **Tele-assistance**: a doctor remotely assists another healthcare professional during the performance of an act;
- **Medical regulation**: doctors of emergency medical services use the telephone to establish an initial diagnosis to determine and to trigger the most adapted response to the nature of the call.

The integration of telemedicine is part of an initiative to improve crisis management. Indeed, telemedicine aims to promote remote health services and the exchange of medical information related thereto. Its use can, therefore, be beneficial for the medical care of victims of crises and help communities to improve the implementation of a crisis management policy. Telemedicine and its four acts provide valuable assistance in crisis management through the sharing of information, consultation between health professionals, and communication between all the actors involved (for example between the command post and the logistics team) in a crisis. This is useful for the implementation of medical care, making it possible to greatly improve the quality and responsiveness of the management of victims in crisis situation. Indeed, it is important to ensure proper initial reception of victims, and the establishment of conditions suitable to their situation, since this can be decisive for avoiding or reducing serious medical consequences and possible deaths.

In this case, teleconsultation can help establish the levels of priority that determine the order in which patients will be treated and evacuated. The purpose of this triage is to save the maximum number of victims.

From an information technology (IT) point of view, every act of telemedicine is considered as a separate application that provides services to other applications. This telemedicine software collaboration is supported by both (1) technical interoperability for supporting effective exchange and sharing of healthcare data while ensuring the confidentiality of that data, and (2) semantic interoperability in order to process and understand the meaning of data based on common medical terminologies (ASIP, 2012). Interoperability of telemedicine software could be implemented by Service-Oriented Architectures (SOA) based on Extensible Markup Language (XML) and Model Driven Architecture (MDA) (Benaben, Truptil, Lauras, & Salatge, 2015; Traore, Kamsu-Foguem, & Tangara, 2016) or other existing technologies such as cloud computing (Church, Goscinski, & Lefèvre, 2015). Everything (software, data, and hardware) is a service in cloud computing and provide three types of service models: Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) (Liu, Wang, Liu, Peng, & Wu, 2017).

This paper is organized as follows: Section 2 presents a state-of-the-art review of crisis management situations. The suggested methodology and associated methods for crisis managements are presented in Section 3. Then in Section 4, we propose the case study on the simulation of Tsunami crisis in Cannes (France). The results obtained are discussed in Section 5. Finally, Section 6 focuses on the conclusion, remarks, and some future research.

2. Theoretical background and motivating issues

The world in various places is marked by an alternation of crises, ranging from climate and environmental crisis, health crisis, floods, tsunami, forest fire and so on. These are serious challenges to the sustainable development of our society. The main objective of crisis management is to reduce material and human damages, in particular through an organized Emergency Decision-Making (EDM). Zhou et al. (2017) defined EDM into the following stages: disaster mitigation, disaster preparedness, disaster response and disaster recovery, as shown

Fig. 1. Crisis Management Stages.

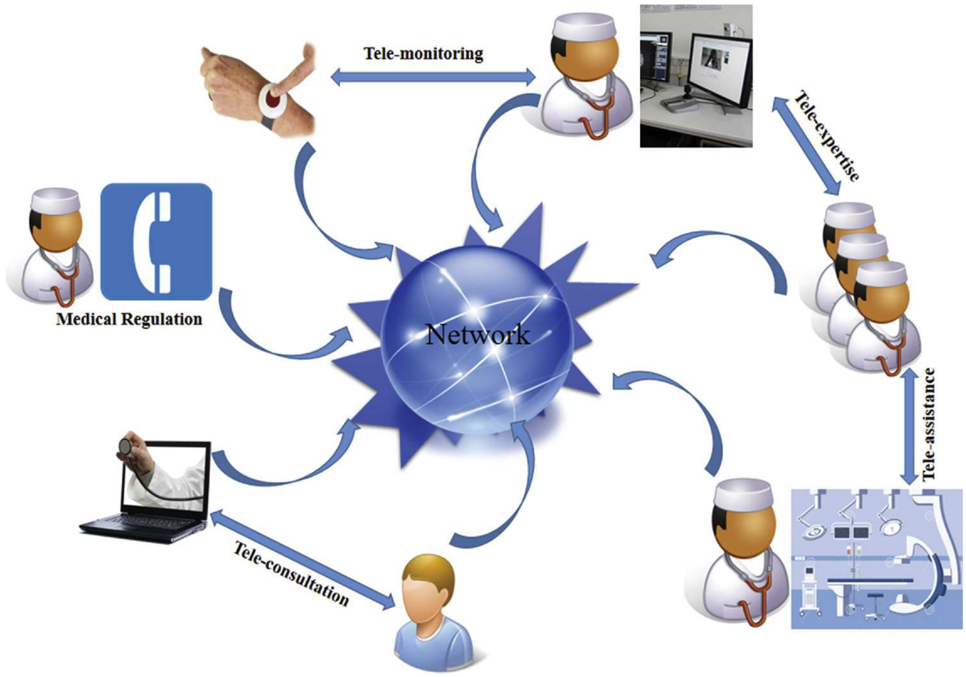

Fig. 2. The different acts of telemedicine.

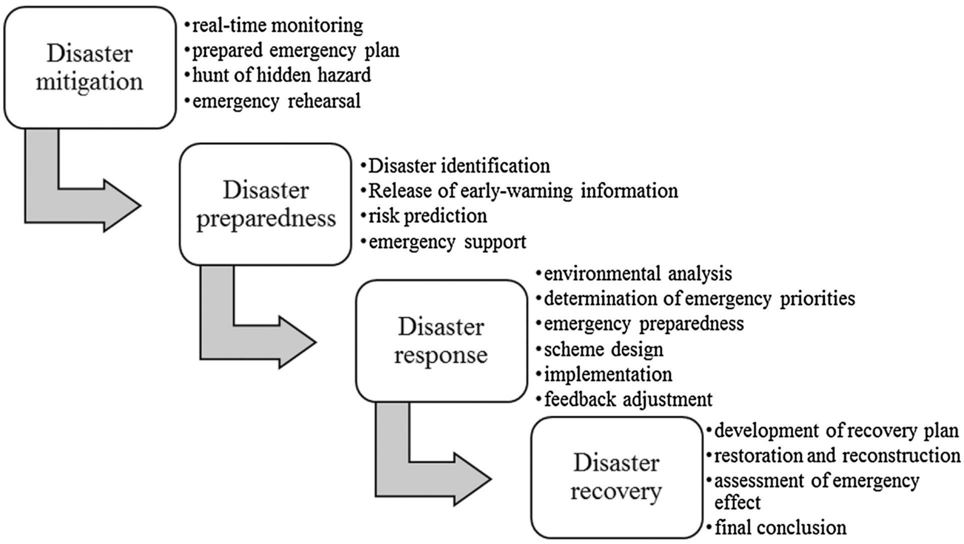

Fig. 3. EDM stages of natural disasters management.

in Fig. 3.

There are three main trends to deal with EDM: mathematical models, emergency decision support systems (Geographic information systems – GIS, Agent, Case-based reasoning and combining machine learning and natural language processing) and research stage (Zhou et al., 2018). For emergency decision support systems, Vescoukis, Doulamis, and Karagiorgou (2012) proposed a flexible service-oriented architecture (SOA) technologies for planning and decision support in environmental crisis management using GIS tools. The use of SOA technologies relates to dynamic configuration and service selection achieving heterogeneous platform interoperability. For forest fires crisis management in Southern Europe, Keramitsoglou, Kiranoudis, Sarimvels, and Sifakis (2004) proposed an approach based on GIS, and other researchers (Traore, Kamsu-Foguem, & Tangara, 2017; Voigt et al., 2007) used satellite remote sensing technologies as best options to support decisions regarding dispatching of utilities, equipment, and personnel that could act with appropriately, and importantly in a timely manner on the ground. Slam and his colleagues (Slam, Wang, Xue, & Wang, 2015) proposed a framework for crisis response decision-support systems integrating uncertainties, reasoning and learning with real-time responses for supporting intelligent decision-making in the crisis responses. Ben Othman, Zgaya, Dotoli, and Hammadi (2017) took a similar approach based on a multi-agent-based architecture for the management of Emergency Supply Chains, and the multi-agent cooperation guarantees the delivery of resources from the supplying zones to the crisis-affected areas (Ben Othman et al., 2017). However, in emergency crisis management, it is difficult to know exactly in advance different affected areas. According to a previous empirical investigation of decision support systems (Arnott & Pervan, 2005), the issue of relevance is the weak point across many research categories, since there is a poor identification of the actors, clients, and users of the various applications. It is thus essential to adapt decision support systems for crisis management, by taking into account the desirability degrees measuring the outcomes of the decisions made for the crisis conditions (e.g. in gas transmission networks) (Nokhbeh Foghahaayee, Menhaj, & Torbati, 2014). A conceptual framework for evaluating consular emergency management proposed by (Tindall & Hart, 2011) has defined key crisis response functions at strategic level (Sense making, Decision making and coordination and Meaning making) and operational level (Managing the operational environment, Managing mass information flows and Engaging individuals in a mass event context).

In this work, our studies are oriented towards emergency decision support systems. While much research has been conducted in this field, to our knowledge none of them have placed real emphasis on the collaborative use of telemedicine acts for emergency decision support systems, especially its uses during evacuation and between health structures for saving times and lives, during crisis management. The success of crisis management is linked not only to a well-developed process but also to the practical analysis based on the full inclusion of different actors involved in the crisis management process (Arnott & Pervan, 2005). For instance, in France, the communal safeguard plan clearly defines the role and the composition of a crisis management unit. The crisis management unit is an interdisciplinary think tank that can react immediately to severe events or major risks in order to allow the Mayor of an administrative district (called commune) concerned to take the most appropriate measures. This crisis unit then constitutes a Command Post (PC) and it must advise and propose to the Mayor concrete actions to limit the effects of disaster, to secure and protect the population. For the composition of a crisis management unit, we can distinguish two categories of actors: (i) Permanent staff that can be convened regardless of the type of disaster that the unit faces; and (ii) Services or technical advisers that are professionals or specialists of a particular risk. Crisis management units can be structured in several teams: one command post, one communication team, one logistics team, and one reception team for receiving the public and phone calls, as shown in Fig. 4.

This kind of crisis management unit can be deployed during the Tsunami crisis, and the main objectives to achieve are surveillance, the safety of dangerous areas, information of the populations, evacuation from affected areas, and accommodation of evacuees. To show the importance of Tsunami preparedness, Scheer, Varela, and Eftychidis (2012) proposed a generic framework for Tsunami evacuation planning defined in three steps as follows: (i) to generate a fully valid first instance of an evacuation plan (ii) to install and disseminate the evacuation plan and deploy it (iii) to integrate and maintain the plan in a long-term. The proposed methodology is based on the use of dedicated GIS and simulation tools. The different types of floods (e.g. river floods, sea floods, flash floods and urban floods) are also other sources of crisis. Participatory community mapping and crowdsourced flood mapping are potential means to overcome urban flood hazards while raising disaster awareness among populations (Padawangi et al., 2016). The concept of resilience (evaluated from the different points of view: engineering, economy, ecology, and society) also plays an important part in the crisis management, since it deeply impacts regional planning, development, and disaster management (Peng, Yuan, Gu, Peng, & Ming, 2017).

As a complement to the previous stages of disaster response (Fig. 3), remote crisis management focuses on the use of telemedicine acts to deal with emergency medical service (EMS), allowing, for instance, the transportation of crisis victims to the proper health structures. Aboueljinane, Sahin, and Jemai (2013) provided a survey of simulation models applied to EMS operations. They describe EMS as medical regulation and public safety systems responsible for the pre-hospital stabilization and transportation of accident victims or dealing with critical medical conditions (malaise, illness, or pregnancy). EMS applications involve central operations for managing different calls and an external operation for transporting and providing first aid activities to patients. A description of the steps associated with central and external operations is presented in Fig. 5. EMS operations handle three types of decisions:

- Long-term decisions are political decisions in terms of social, economy to achieve the objectives in relation to human resources, equipment, and location of the service.
- Midterm decisions determine the number of rescue teams in each base and it consists of establishing schedules for each vehicle on duty (“vehicle base” assignment problem) and each human resource (“resource vehicle” and “shift-resource” assignment problems). This aims to satisfy the demand for rescue teams in each condition required to the implementation and outcome.

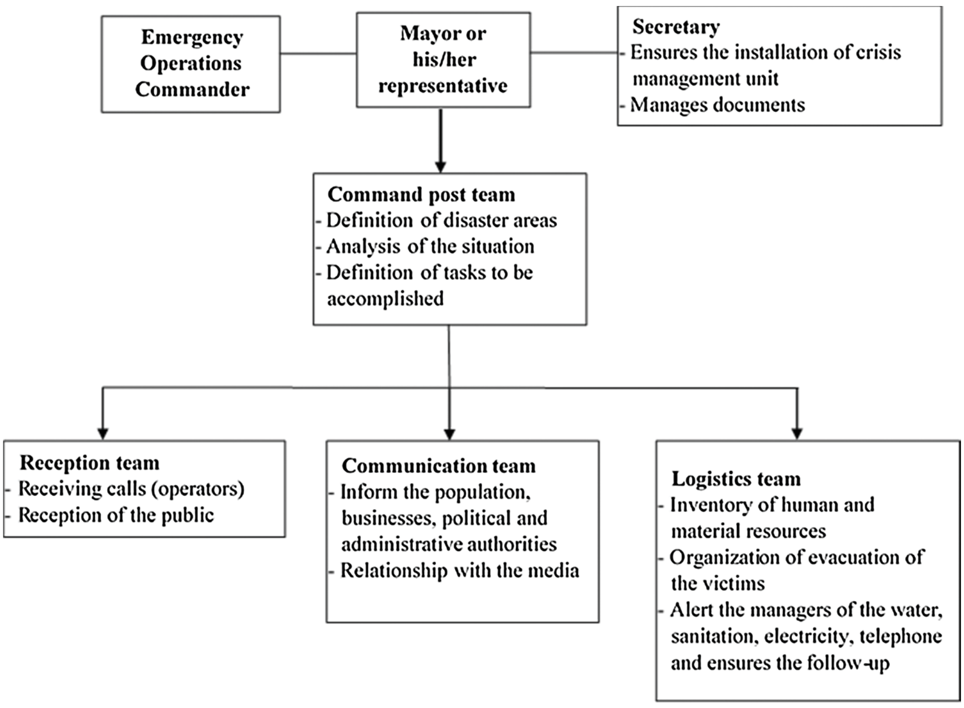

Fig. 4. Organization of the crisis management unit (SIRACEDPC and CYPRES, 2014).

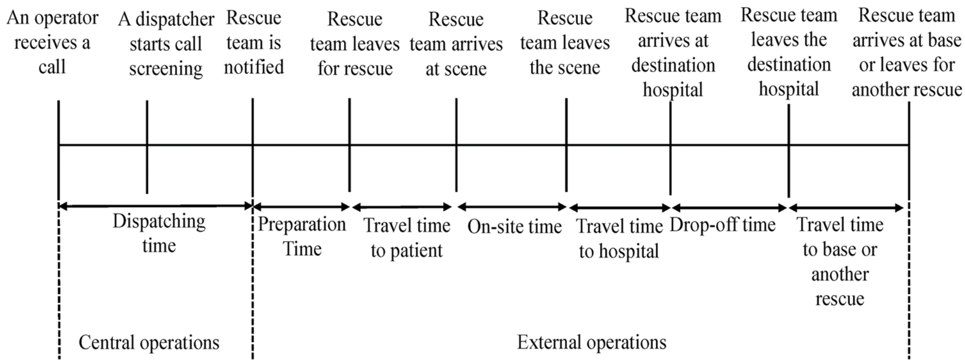

Fig. 5. The typical EMS process (Aboueljinane et al., 2013).

- Short term decisions describe the following rules: (i) the organization sends rescue teams to a call in order to reduce the response time; (ii) the choice of the right hospital to reduce transportation time; (iii) a strategic redeployment to ensure better coverage for future incoming calls; (iv) time management of vehicle preparation (cleaning, replacement of equipment) for a new intervention.

There are three main types of performance measures used in EMS simulation models that are: timeliness, survival rates, and costs.

- Many works have focused on timeliness, and several features have been included which are: the response time, the round trip time, the service time, the dispatching time, the waiting time, the total mileage, the loss ratio, and the overtime;
- The survival rate is the second category of performance measure used in EMS that aims to know the percentage of patients who survived the incident for a given period of time. The main objective of the EMS is to save many lives of patients, which explains the importance of this feature;
- Cost is an important aspect of the characterization of EMS that includes capital and operating costs, in order to improve any of the above-mentioned metrics. However, the study of a cost-effectiveness analysis comparing the costs of each alternative to saving time or improving the survival rate is an important area of research to achieve the desired objectives i.e. interventions at a lower cost.

For crisis management, Bénaben (2016) proposed an abstract and generic formal framework based on two main structuring elements: the nature of available or required information and the functions that should be able to use them to provide a crisis management domain with a relevant decision support system. According to Bénaben (2016), the crisis concepts can be characterized by location, type, and gravity. For crisis management, it should also be considered concepts such as context, partners and objectives. The formal description of crisis concepts and management are defined below in the next subsection.

2.1. The functional description of crisis management

To perform a relevant and efficient crisis management, the three main objectives are: to define the response, to realize the response (considering that it is not because the response schema is correctly described that it will be performed) and to maintain the response (considering also that the crisis situation may evolve or the crisis response may not have the expected consequences). These three objectives are described as functions: First, let us consider O as a set of crisis management objectives O_i (mainly "prevent a risk" or "treat an effect"), F as a set of partners functions F_i and P as a set of crisis management business processes p. So, we have:

Define: $O^n \ x \ F^n \rightarrow P$

$([O_1 \ldots O_n], [F_1 \ldots F_n]) \rightarrow P$ = the process reaching the objectives with the available functions.

Define function is in charge of taking into account the actual objectives of the management of the crisis situation (the objective vector) and the available functions of partners (the function vector) to build the business process dedicated to reach these objectives with these functions. Obviously, there might be several processes built through several invocations of the *Define* function.

Realize: $Px \ F^n \ x \ O^n \rightarrow O^n$

$(p, [F_1 \ldots F_n], [O_1 \ldots O_n]) \rightarrow [O'_1 \ldots O'_n]$ = the status of the objectives updated "on-the-fly", according to the progress of the process.

Realize function is in charge of performing the process built by the *Define* function. Consequently, it is dedicated to invoke the relevant functions of partners according to the schema proposed by the process. Furthermore, the *Realize* function continuously provides a set of updated objectives. These objectives are the expected status of the crisis situation according to the progress of the process (i.e. the expected situation at this stage). There might be several executions of multiple processes through numerous invocation of *Realize* function.

Maintain: $O^n \ x \ O^n \ x \ F^p \rightarrow P$

$([O_1 \ldots O_n], [O'_1 \ldots O'_n], [F_1 \ldots F_n]) \rightarrow p'$ = the process that fits the best with update objectives.

Maintain function is in charge of performing agility in the response. Actually, this function aims at comparing the expected situation (objectives provided by *Realize* function) and the real situation (objectives from the realistic picture of the situation). So, this function compares both these sets of objectives and then, according to the potential differences between these sets of objectives, it uses *Define* function, the set of current objectives and the set of functions to infer a new process that is more adapted to the current situation.

2.2. The information flows related to the functions of crisis management

The crisis concepts can be characterized by the first identification parameters (location, type, and gravity). Let us consider G as the set of geographical/social areas l_i (used to describe the location and the perimeter of a crisis situation), T as the set of types of crisis situations t_i (such as natural disaster, industrial accident, terrorist attack, etc.) and the g gravity defined as a value between 0 and 1 (no matter how it is calculated). Let us also consider S as the set of stakes S_i, IR/ER as the set of intrinsic/emerging risks IRi/ERi, and E as the set of effects Ei. Accordingly, we can describe:

Function: $G \ x \ T \ x]0,1[\rightarrow F^n$

$(l_i,t_i,g_i) \rightarrow [F_1 \ldots F_n]$ = the set of available and serviceable functions

The function is in charge of delimiting the impacted subpart of the world to infer, from the type and the gravity as well, the available responders and their competencies.

Stake: $G \times T \times]0,1[\rightarrow S^n$

$(l_i,t_i,g_i) \rightarrow [S_1 \ldots S_n]$ = the set of potentially impacted stakes

Stake function is in charge of delimiting the impacted subpart of the world to infer, from the type and the gravity as well, the possibly threatened stakes in the area.

IntrinsicRisk: $G \times T \times]0,1[\rightarrow IR^n$

$(l_i,t_i,g_i) \rightarrow [IR_1 \ldots IR_n]$ = the set of intrinsic risks to take into account

IntrinsicRisk function is in charge of delimiting the impacted subpart of the world to infer, from the type and the gravity as well, the intrinsic risks to consider in the area.

Objective: $S^n \times IR^n \times ER^n \times E^n \rightarrow O^n$

$([S_1 \ldots S_n], [IR_1 \ldots IR_n], [ER_1 \ldots ER_n], [E_1 \ldots E_n]) \rightarrow [O_1 \ldots O_n]$ = the set of objectives of crisis management, based on all concerned risks, effects and stakes.

The *Objective* function is in charge of identifying the entire list of objectives of the crisis management by considering all risks (intrinsic and emerging ones), all effects and impacted stakes as well.

The first three functions of crisis management (*Function, Stake, IntrinsicRisk*) are very similar: delimitation of a geographical/social area impacted by an identified crisis (in terms of types and gravity) in order to infer the available functions, the concerned intrinsic risks and the threatened stakes. Specifically, the third one (*Objective*) concerns the aggregation of risks and effects (with regards to impacted stakes) to build a set of objectives (the prevention of risks or mitigation of effects) to drive the crisis management plan.

The generic framework of crisis management (Fig. 6) is described as a functional diagram where: (i) information is used as inputs for the whole structure, (ii) functional description are grouped in the crisis management box, and (iii) functional description is distributed in the crisis definition and crisis analysis boxes. In the following part, we propose our methodology whose main objectives are to save lives, reduce damage and protect the environment.

3. Methodology and approaches adopted: remote crisis management process

Telemedicine software and platforms have made significant advances in recent years, involving a strong need for standardization to facilitate their interoperability. This interoperability concerned the sharing and exchange of data between the involved information systems, especially in a crisis requiring evacuation (e.g. information systems communicating with the emergency services system in France called SAMU - Service d'Aide Médicale Urgente) and requiring immediate medical attention (e.g. tsunami, industrial accident, epidemic, etc.). Data collected and exchanged as part of a telemedicine act is data from medical devices (measurements: pressure, pulse, temperature, blood glucose …), patient medical record, medical imaging, report and medical prescriptions made from telemedicine act, etc. In emergency medicine, it can be provided at a distance: teleradiology, telepsychiatry, telecardiology teleophthalmology, teleaudiology, teledentistry, teledermatology, etc.

This methodology aims to describe a formal and relevant computerized collaborative system (using telemedicine applications), dedicated to efficiently support crisis management and provide decision makers with relevant and timely information. Telemedicine applications must collaborate to manage the health aspects of crisis situations based on the concept of a flexible service-oriented architecture (SOA) technologies to allow medical applications interoperability (Benaben et al., 2015; Traore et al., 2016; Vescoukis et al., 2012). Every act of telemedicine is considered to be used in the remote access to medical services, so we can consider the concept of software as a service (SaaS). The development of high-performance computing (HPC) and sequential applications exposed as SaaS clouds provide an interesting framework supporting scientific research, particularly in biology and medicine (Church et al., 2015). Therefore, the service delivery models can be improved by the distribution of software services supporting the tedious analysis procedures that are present in scientific applications, for instance, during data pre-processing. By establishing a scheme of collaborative applications providing the distribution of information and interpretation of services, very specialized applications could be shared as services while decreasing deployment times. As a result, practical models can be implemented using the principles of simplified service delivery, cloud scalability, and resource sharing in order to improve the response times of emergency services.

3.1. Remote crisis management process

The proposed methodology supporting three phases gives a representation of sequential processes using telemedicine applications to deal with crisis management: (1) *Crisis definition* (2) *Crisis Analysis* and (3) *Crisis Management* (Fig. 7).

In crisis management, appropriate decisions must be taken to minimize the damage caused by natural or industrial risks, in order to facilitate a return to a normal situation with protection and support of victims. For this, the right questions must be asked and answered.

3.2. Crisis definition

- Location: Where? What perimeter? These parameters define and

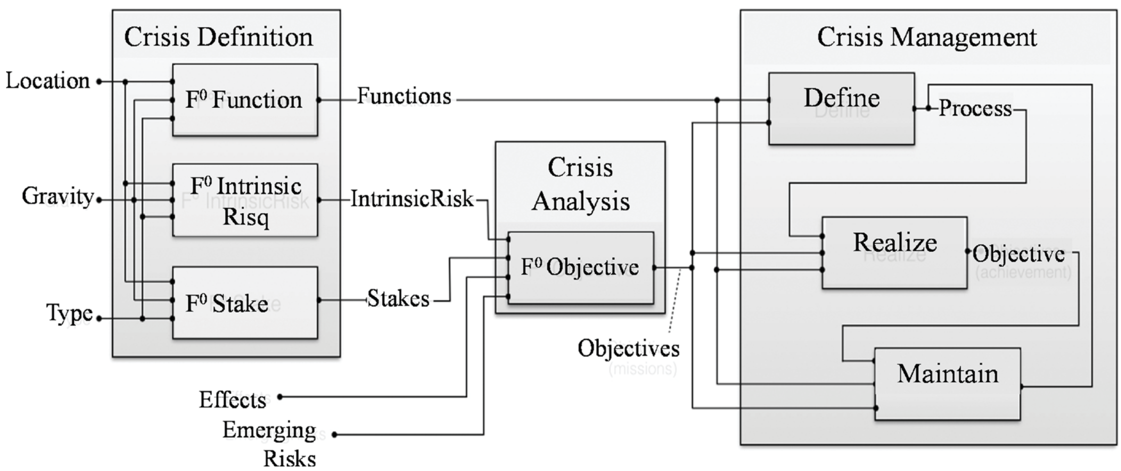

Fig. 6. Generic Framework of Crisis Management (Benaben et al., 2015).

Analysis and (3) *Crisis Management* (Figure 7).

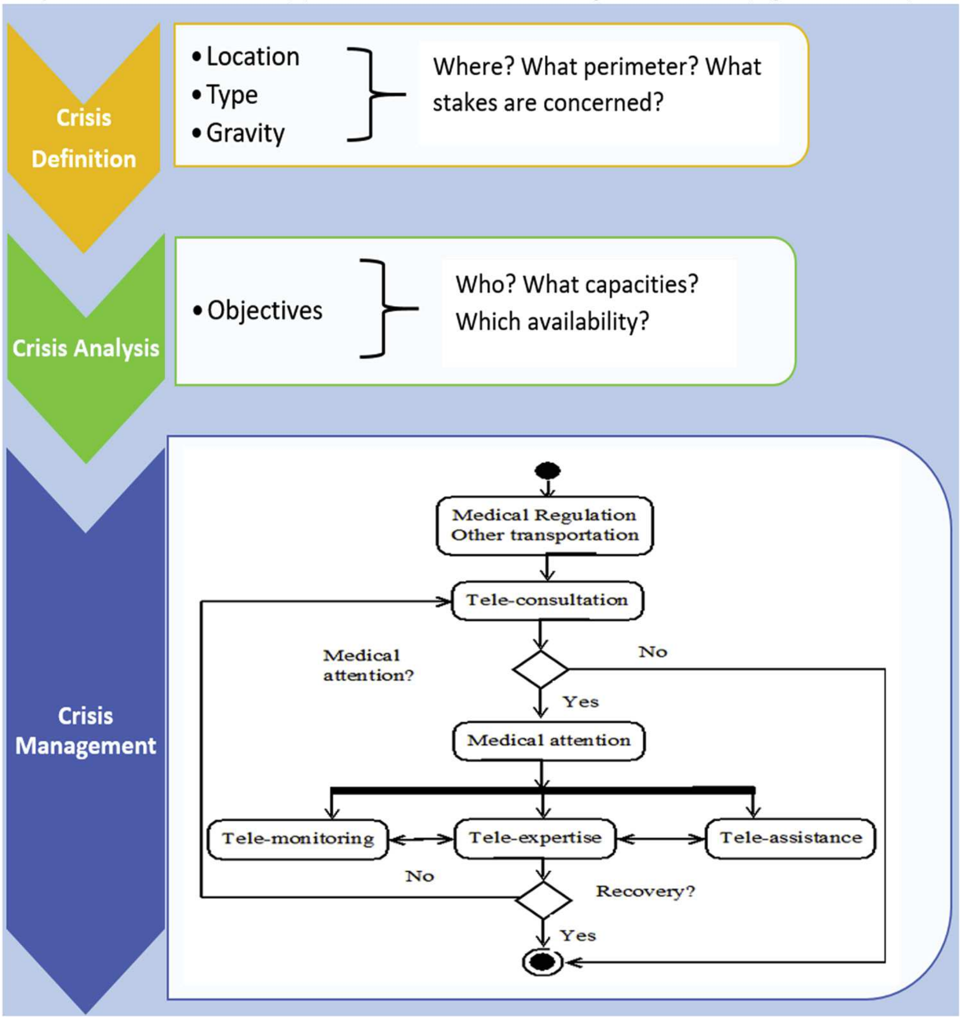

Fig. 7. Remote Crisis Management Process.

delimit the crisis geographic area in order to prepare an emergency plan and help to significantly reduce any surprises. For example, in a flood crisis, we can establish the list of rivers, the list of inhabited areas under threats.

- Type: Crisis categorization parameters help decision makers to identify the nature of crisis to, qualify it, and insert it in a crisis management category and that through the relevant questions: What is it about? And what type of crisis it is? For instance, in the Tsunami crisis, real-time monitoring specialized centers can be requested for more details.
- Gravity: What stakes are concerned? This parameter helps to determine the emergency priorities in terms of saving lives, infrastructures and the economy. Therefore, there is a need to identify human and material resources and plan various activities for achieving relevant crisis management.

3.3. *Crisis analysis for goal attainment*

- What are the major mistakes to avoid? It must boost the ability to identify weak links of a device, flexibility of response, avoid the negligence;
- Which networks of actors? This applies to both the sensitivity of the surveillance and monitoring networks, responsiveness with respect to the alert generation process and crisis management capacity;
- What are the initiatives to be implemented to mobilize the energies? The search for alternative solutions for managing and rationalizing resources that may have technical and functional failures (problems affecting various networks of water, electricity, gas, and communications) caused by the crisis. We must prepare for diversification of fundamental resources (e.g. use of alternative and renewable energies).

3.4. *Crisis management: comprehensive medical attention of all the victims of the crisis*

- First, medical regulation transport victims in a health structure in appropriate conditions. Victims can also take other means of transportation to reach hospitals for critical or emergency care;
- Second, the first medical examinations are made by the tele-consultation act during the transportation process (temperature measurement, questionnaires, clinical observations, etc.). After that, if there is a need, the medical attention has to start;
- Third, the victim is placed in tele-monitoring, and to save time;
- Finally, at the same time, the medical staff can solicit two acts of telemedicine namely: tele-assistance and tele-expertise. After tele-assistance or tele-expertise phases, if the victim is not recovered, we can reapply tele-consultation and repeat again the same process.

Each act has a particular and specific functionality in the victim support services. Thus, these five acts are partially or totally used depending on contextual needs i.e. with adaptations from one crisis to another or different affected areas within the same crisis. The acts are used depending on contextual needs, thus, for a given crisis situation according to the local medical requirements five acts will be partially or fully deployed in separate geographical areas. The telemedicine acts collaborate to offer quality services and suitable advice to the population in a timely manner. This collaboration must be well organized to take full advantage of all the benefits of all telemedicine acts. There must be a process from beginning to end to not only deal with a medical emergency as soon as the first sign occurs but also to deal with primary care until the end of the recovery with successful treatment. In this perspective, we proposed a methodology (Fig. 7) to improve collaboration between telemedicine acts.

The advantages of this methodology are:

- the lives of first victims that represent any group of individuals including the medical professionals are saved through the coordinated use of telemedicine acts,
- the time to provide medical care in a crisis situation is reduced,
- the spread of the crisis is controlled in time and in space.

For better results, four conditions are considered to assess the accuracy of the model:

- appoint a general coordinator to ensure the coherence of activities because it involves a large number of partners including health structures, emergency services, political decision makers, etc.;
- equip the rescue cars and health structure with the appropriate telemedical devices;
- train the manipulators of telemedicine equipment, in order to significantly reduce the response time;
- rely on a deep knowledge of the crisis by providing right parameters to have a relevant decision support system.

The effectiveness of an alert system is strictly linked to deep knowledge of the crisis. For instance, in Tsunami landslides, earthquakes, withdrawals from the sea, tidal bore, whirlpools are relevant parameters to consider. Research aimed at specifying areas at risk of the tsunami should, therefore, be continued. Also, on-site investigations and post-tsunami studies are therefore essential for a better understanding of the crisis. From the perspective of an early warning system, modeling is also essential to know the impact of a Tsunami on the coast. However, they are only effective if the bathymetry approaching the coast is sufficiently accurate to account for site effects.

To respond appropriately in the event of the occurrence of the crisis, an effective warning center must be able to issue a message 24 of 24, indicating the occurrence of an earthquake likely to generate a Tsunami (e.g. Tsunami Warning Center – CENALT, France). The message must also reach the competent authorities responsible for the organization of the relief and that the latter know perfectly what they have to do at all level. Given the very short reaction times and a large number of actors involved, improvisation must be avoided. The design of flood and evacuation maps should be encouraged as they allow in particular to assess in advance the extent of the damage and to identify the routes that can be used for the delivery of relief supplies. Main ports and highly populated coastal areas should be covered first. In addition, training and simulation exercises are essential to identify dysfunctions and improve the effectiveness of crisis management (e.g. Tsunami simulation exercise in Cannes, France).

3.5. Mathematical modeling

Mathematical modeling concerns the crisis management phase. Let us consider a set of telemedicine acts $(TAct_1, \ldots, TAct_n)$ which are intended to taking care of crisis victims. In this modeling process, crisis victim corresponds to the medical patient. The global plan for the orchestration has been presented above in Fig. 7.

Let us define a domain *D: (C, P)* composed by a set of telemedicine acts $C = (TAct_1, \ldots, TAct_n)$ and a set of predicate types $P = \{p_1, p_2, \ldots, p_n\}$ to specify the eventual properties of objects (Patients, Medical professionals, Generated documents by Information and communications technology (ICT) software) and relations between them. Concretely, we have adopted this codification: Tele-consultation (*TC*), Tele-monitoring (*TM*), Tele-assistance (*TA*), Tele-expertise (*TE*), Medical Regulation (*MR*) and so, by replacing $TAct_{1\ldots n}$ by different telemedicine acts cited above we obtain *C = (TC, TM, TA, TE, MR)* and a set of predicates defined by *P = (vulnerableCase P, confirmedCase P, recovery P, deceased P)* where *P* is a victim in person. The predicate *vulnerableCase P* is a property of a person which means that *P* is more vulnerable to diseases (e.g. an epidemic or serious threats) vulnerable.

A telemedicine act is defined by *TAct = (Pin, Pout, Pinout, Prec, Effect)* where:

- $Pin = \{pin_1, \ldots, pin_n\}$ is the set of input parameters of *TAct*,
- $Pout = \{pout_1, \ldots, pout_n\}$ is the set of output parameters of *TAct*,
- $Pinout = \{pinout_1, \ldots, pinout_n\}$ is the set of input-output parameters of *TAct*,
- *Prec* is a set of conditions to be satisfied by the objects of *Pin*,
- *Effect* is the set of explicit execution effects of the telemedicine act application of the current state.

TC acts are formalized as follows:

- *Pin = {AttendingPhysician, Patient, PatientMedicalRecord}*
- *Pout = {MedicalPrescription, TCReport, RequestAnotherTA}*
- *Pinout = {ICTPlatform}*
- *Prec = {vulnerableCase Patient, operational ICTPlatform, available PatientMedicalRecord}*
- *Effect = {generated MedicalPrescription, indicateIf RequestAnotherTA, generated TCReport}*

To realize *TC*, we have *inputs* that are: the attending physician, the patient and his/her medical record. *Outputs* are: the medical prescription, the full report of *TC* that can request another *TAct*. Then ICT platform is required to realize all *TAct* at *input* and *output*. We also have some preconditions to be satisfied: the patient must be a vulnerable case, ICT Platform must be operational, the patient medical record available. Finally, the results of *TC* are: generations of medical prescriptions, *TC* reports and suggestions if another *TAct* is required.

TM acts are formalized as follows:

- *Pin = {AttendingPhysician, Patient, MedicalMonitoringData}*
- *Pout = {InterpretationResult, TMReport, RequestAnotherTA}*
- *Pinout = {ICTPlatform}*
- *Prec = {confirmedCase Patient, operational ICTPlatform}*
- *Effect = {generated InterpretationResult, indicateIf RequestAnotherTA, generated TMReport}*

To realize *TM*, *inputs* are: the attending physician, the patient and his/her medical monitoring data (a clinical, radiological and biological indicator). Also, *outputs* are: the interpretation results, the full report of *TM* that can also request another *TAct*. Then ICT platform is required to realize all *TAct* at *input* and *output*. And also, we have some preconditions to be satisfied: the patient must be a confirmed case and ICT platform must be operational. Finally, the results of *TM* are: generations of the interpretation results to the medical examinations and analysis of such results, *TM* report and suggestion if another *TAct* is required.

TE acts are formalized as follows:

- *Pin = {RequestingPhysician, RequiredPhysicians, PatientMedicalRecord}*
- *Pout = {ExpertAdvice, TEReport, RequestAnotherTA}*
- *Pinout = {ICTPlatform}*

- *Prec = {operational ICTPlatform, available PatientMedicalRecord}*
- *Effect = {generated ExpertAdvice, indicateIf RequestAnotherTA, generated TEReport}*

To realize *TE*, *inputs* are: the requesting physician, the required physicians and the patient medical record. *Outputs* are: the expert advice, the full report of TE that also can request another *TAct*. Then, ICT platform is required to realize all *TAct* at *input* and *output*. And also, we have some preconditions to be satisfied: ICT platform must be operational and the patient medical record must be available. Finally, the results of *TE* are: generations of expert advice, *TE* reports, and suggestions if another *TAct* is required.

TA acts are formalized as follows:

- *Pin = {RequestingPhysician, RequiredPhysicians, MedicalAct}*
- *Pout = {TAReport, RequestAnotherTA}*
- *Pinout = {ICTPlatform}*
- *Prec = {operational ICTPlatform, available PatientMedicalRecord}*
- *Effect = {ExpertAssistance, indicateIf RequestAnotherTA, generated TAReport}*

To realize *TA*, *inputs* are: the requesting physician, the required physicians and the medical act to perform. *Outputs* are: the full report of *TA* that can also request another *TAct*. Then ICT platform is required to realize all *TAct* at *input* and *output*. And also we have some preconditions to be satisfied: ICT platform must be operational and the patient medical record must be available. Finally, the results of *TA* are: assistance of experts, *TA* reports, and suggestions if another *TAct* is required.

3.6. Proposed algorithm

The proposed algorithm is derived from the suggested methodology (Fig. 7). We present the main steps of the proposed algorithm as follows: step 1 provides crisis definition information; step 2 provides crisis analysis information and step 3 presents the process of taking care of patients from patient transportation to his/her recovery using telemedicine acts (Tele-consultation, Tele-monitoring, Tele-assistance, Tele-expertise, Medical Regulation). The different functions and parameters of telemedicine acts are defined. The theoretical analysis of steps 1 and 2 are reduced by using two nested loops in step 3, thereby reducing the computational complexity of this algorithm that exhibits a square growth rate (O (N^2)).

```
Algorithm: Remote_Crisis_Management

Step 1: Crisis_definition // Provide crisis definition information
        Location  ← where;
        Type ← what_is_it_about;
        Gravity ← what_stakes_are_concerned;
End
Step 2: Crisis_analysis // Provides crisis analysis information
        Objectives ← what_objectives;
        Available_Resources← what_Available_Resources;
        Limits ←what_limits;
End
Step 3: Crisis_management
        For each Patient Pi ϵ Pn do
            HealthStructure← MedicalRegulation(Pi); // transportation phase
            Pi←Tele-consultation (AttendingPhysician, Pi, Pi.MedicalRecord); /* The patient
            undergoes a tele-consultation to confirm or not if the patient need a medical attention */
            Pi. confirmed_case←yes||no; //result of tele-consultation for medical attention
            While (Pi.confirmed_case=yes && Pi.recovery=no) do /* for each confirmed case and not
                patient's recovery, the same process is applied: first the medical attention and second,
                the patient can undergo other tele-medicine acts */
                Pi←Medical_Traitement (Pi.MedicalPrescription);
                Switch (Pi.RequestAnotherTA) // function call for the requested telemedicine act.
                        Case Tele-monitoring then
                            Pi←Tele_monitoring(AttendingPhysician, Pi, Pi.MonitoringData);
                        Case Tele-expertise then
                            Pi←Tele_expertise(RequestingPhysician, RequiredPhysicians[],
                                              Pi.MedicalRecord);
                        Case Tele-assistance then
                            Pi←Tele_assistance(RequestingPhysician, RequiredPhysicians[],
                                               MedicalAct);
                        Default: Pi.recovery←yes|no|death;
                EndSwitch
                If (Pi.recovery=no) then
                        Pi←Tele-consultation (AttendingPhysician,Pi , Pi. MedicalRecord);
                        Pi.confirmed_case←yes;
                EndIf
            EndWhile /* The loop is stopped when the patient has a recovery or has succumbed to
                crisis. */
        EndFor
End
```

```
Function Tele-consultation (AttendingPhysician, Patient, PatientMedicalRecord) /* Definition of tele-
  consultation function */
Began
    If (Patient.vulnerableCase=yes && ICTPlatform.operational=yes &&
        PatientMedicalRecord.available=yes) then // The preconditions must be satisfied
            PatientMedicalPrescription← Realize_Tele-consultation(); /* The attending physician
            Carrying out the Tele-consultation on the patient using ICT platform */
            RequestAnotherTAct←Tele-monitoring||Tele-assistance||Tele-expertise||Null;
            //Indicate if another tele_medicine act is necessary
            TCReport←Report; // Report files of the tele-consultation process
    EndIf
    Return (PatientMedicalPrescription, RequestAnotherTAct, TCReport);

End

Function Tele-monitoring (AttendingPhysician, Patient, MonitoringData) /* Definition of tele-
  monitoring function */
Began
    If (Patient.vulnerableCase=yes && ICTPlatform.operational=yes) then /* The preconditions
        must be satisfied*/
            InterpretationResult ←Realize_Tele-monitoring(); /* The attending physician
            Carrying out the tele-monitoring on the patient using ICT platform and MonitoringData
            */
            RequestAnotherTAct ←Tele-consultation||Tele-assistance||Tele-expertise||Null;
            //Indicate if another Tele_medicine act is necessary
            TMReport←Report; // Report files of Tele-monitoring process
    EndIf
    Return (InterpretationResult, RequestAnotherTAct, TMReport);
End

Function Tele-expertise (RequestingPhysician, RequiredPhysicians [], PatientMedicalRecord)
  // Definition of tele-expertise function
Began
    If (PatientMedicalRecord. available =yes && ICTPlatform.operational=yes) then /*
        Preconditions must be satisfied*/
          ExpertAdvice ←Realize_Tele-expertise (); /* The requesting physician and the required
          physicians carrying out tele-expertise on the Patient Medical Record using ICT platform */
          RequestAnotherTAct←Tele-monitoring||Tele-assistance||Tele-consultation||Null;
          //Indicate if another tele_medicine act is necessary
          TMReport←Report; // Report files of tele-expertise process
    EndIf

    Return (InterpretationResult, RequestAnotherTAct, TMReport);
End

Function Tele-assistance (RequestingPhysician, RequiredPhysicians[], MedicalAct) /* Definition of
  tele-assistance function */
Began
    If (PatientMedicalRecord.available =yes && ICTPlatform.operational=yes) then
            //The preconditions must be satisfied//
            ExpertAssistance ←Realize_Tele-assistance (); /* The requesting physician and the
            required physicians carrying out tele-assistance during the medical act using ICT
            platform */
            RequestAnotherTAct←Tele-monitoring||Tele-consultation||Tele-expertise||Null;
            //Indicate if another tele_medicine act is necessary
            TAReport←Report; // Report files of tele-expertise process
    EndIf
    Return (ExpertAssistance, RequestAnotherTAct, TAReport);
End
```

Table 2
Tsunami characteristics.

Tsunami characteristics	Magnitude or volume	Maximum amplitude of waves on the shore	Arrival time	French coastal area concerned
Algerian northern margin earthquake	M = 7,2	4 m at St-Tropez, Cannes 3 m at La Ciotat, Nice, Villefranche	95′–100′	From Marseille to Menton (including Cannes)

The development of SaaS principles is interesting considering the growth and expansion of complex and collaborative ecosystems in which the issue of sustainable interoperability is a real challenge for networked information systems. The characteristics of model-driven and knowledge-based approaches can be applied together to enhance the design and alignment of emerging networked information systems in the scope of sustainable interoperability. Therefore, the deployment of SaaS applications in virtual information systems within a collaborative environment can be simplified by connecting ontology-based models with technical-level architectures through model-driven engineering methods for service-oriented architectures. Managing a crisis is a complex procedure requiring a collaborative support to emergency responses with interoperable information systems. Four major trends towards a sustainable interoperability in networked information systems can be identified in a research framework (Agostinho et al., 2016): self-explanatory models and semantic unification, commutability and scalability, automated model mapping identification, dynamic transformations and incrementally. There is, especially in crisis management, a need to consider more dynamic and intelligent methods for the deployment of information systems in meeting these challenges of sustainable interoperability (Hamdi, Chalouf, Ouattara, & Krief, 2014).

4. Case study

The case study is based on the simulation of a Tsunami exercises in Cannes (Binacchi, 2017; Lioult, 2017). Tsunamis from the geological origin are caused by the penetration or disappearance (with regard to earthquakes, rather evoking uplift and/or subsidence) in the seabed of a significant amount of geological materials, resulting in the displacement of a large body of water. Three types of events are likely to cause a Tsunami: underwater or coastal earthquakes, landslides and volcanic explosions (Ando et al., 2018; Röbke & Vött, 2017). The Tsunami exercise in Cannes was strictly limited to professionals who must intervene in a crisis unit that is the Operational Crisis Management Center (COGIC). Tsunami Warning Center (CENALT) sends information to COGIC that an earthquake of magnitude 7.2 on the Algerian plate is likely to cause a Tsunami on the Mediterranean coasts. The "tsunamigenic" characteristics are checked, the wave and its speed are calculated as well as the time of the arrival of these waves on the French coasts as is shown in Table 2.

For a dynamic management of the crisis, it is important to consider the parameters relating to the height and depth of onshore flooding, but also the duration and number of tsunamigenic waves that spread on land as well as the direction and the speed of the currents. In addition, it is also necessary to integrate the development parameters (buildings and infrastructure) along the coastal zone, the latter being able to generate modifications in the propagation of the water on lands. Indeed, for a dynamic management of the Tsunami crisis, these parameters impact the transport of the victims, the determination of the evacuation zones and supplies of water, food, medicines, blankets and basic necessities.

These parameters are transmitted immediately by the COGIC to the national and departmental authorities (Prefecture). As a result, Prefecture of the Alpes-Maritimes relays the information to the Mayor of Cannes about an hour before the arrival of the first big wave of elements. The City Council steers the management of the event within the Crisis Staff with the support of CENALT and COGIC as follows:

1. the evacuation of ports, beaches, and coastlines with protective measures;
2. crisis management during the duration of the Tsunami;
3. rescue and mitigation (measures for minimizing effects) of risk after the Tsunami.

In order to achieve these goals, by applying our methodology for crisis management we obtain:

Step 1: Earthquake crisis definition

Location ⟵ Cannes;

Type ⟵ earthquake;

Gravity ⟵ magnitude 7.2;

Step 2: Earthquake crisis analysis//to provide crisis analysis information

Objectives ⟵ Save lives;

Available_Resources ⟵ COGIC (Operational Crisis Management Center), CENALT (Tsunami Warning Center), CYPRES (Information Center for the Prevention of Major Risks);

Limits ⟵ Material and human resources, time;

Step 3: Earthquake crisis management

1. Coordination of activities of different resources: COGIC, CENALT, CYPRES

1.1 Organization of a communal command post

1.2 Drafting of warning messages

1.3 Updating of a communal information folder on major risks

2. Calculate the height of the wave, its speed and time of arrival on the coast.

3. Evacuation of ports and coastlines, an organization of relief using telemedicine acts:

3.1 For each Patient in transportation phases do:

Tele-consultation (Patient)
Tele-monitoring (Patient)
Tele-assistance (Patient)
Tele-expertise (Patient)

} These acts are partially or totally used depending on contextual needs which can significantly save time.

This simulation exercises on the management of the Tsunami crisis in Cannes is a part of its Safeguard Plan allowed us to validate our methodology in three steps. The coordinated use of different telemedicine acts is very important during the transportation phase to the specialized structures because it allows improving evacuation process with interesting results in terms of reducing the intervention time and risks of medical complications. These improvements are significantly contributing factors in saving lives. The different interactions between different actors in crisis management are represented by the Unified Modeling Language (UML) sequence diagram (Fig. 8).

Through this diagram, we can observe a collaborative management of a possible Tsunami crisis that can be occurred in Cannes, France (a city situated on the French Riviera). At first, the CENALT issues a Tsunami alert to the COGIC that informs Prefecture with the relevant parameters of the Tsunami namely the magnitude, the height of the wave, its speed and time of arrival on the coast. Then, Prefecture alerts the mayor one hour before the first large wave of the Tsunami. After that, the rescue service evacuates the ports, beaches, and the entire coastline. During the transportation phase, rescue services make telemedicine activities (in the boat, plane, fire engine…) namely tele-consultation, tele-monitoring, tele-assistance, tele-expertise partially or totally delivered depending on the contextual needs in order to provide optimum medical care, so that we can save more lives. The people not wounded are transported to safe places (e.g. educational establishments, multipurpose rooms, gymnasiums, hotels, cottages …). Different reports from rescue services, health structures, and safe places will be returned to the town hall in order to evaluate the Tsunami crisis management. The lessons learned with the identified strengths and weaknesses from the experience feedback can provide some ways of improvement and new propositions for crisis management.

5. Results and discussions

Time management and situation awareness, in order to reduce the effects of the crisis, are important features during a crisis situation.

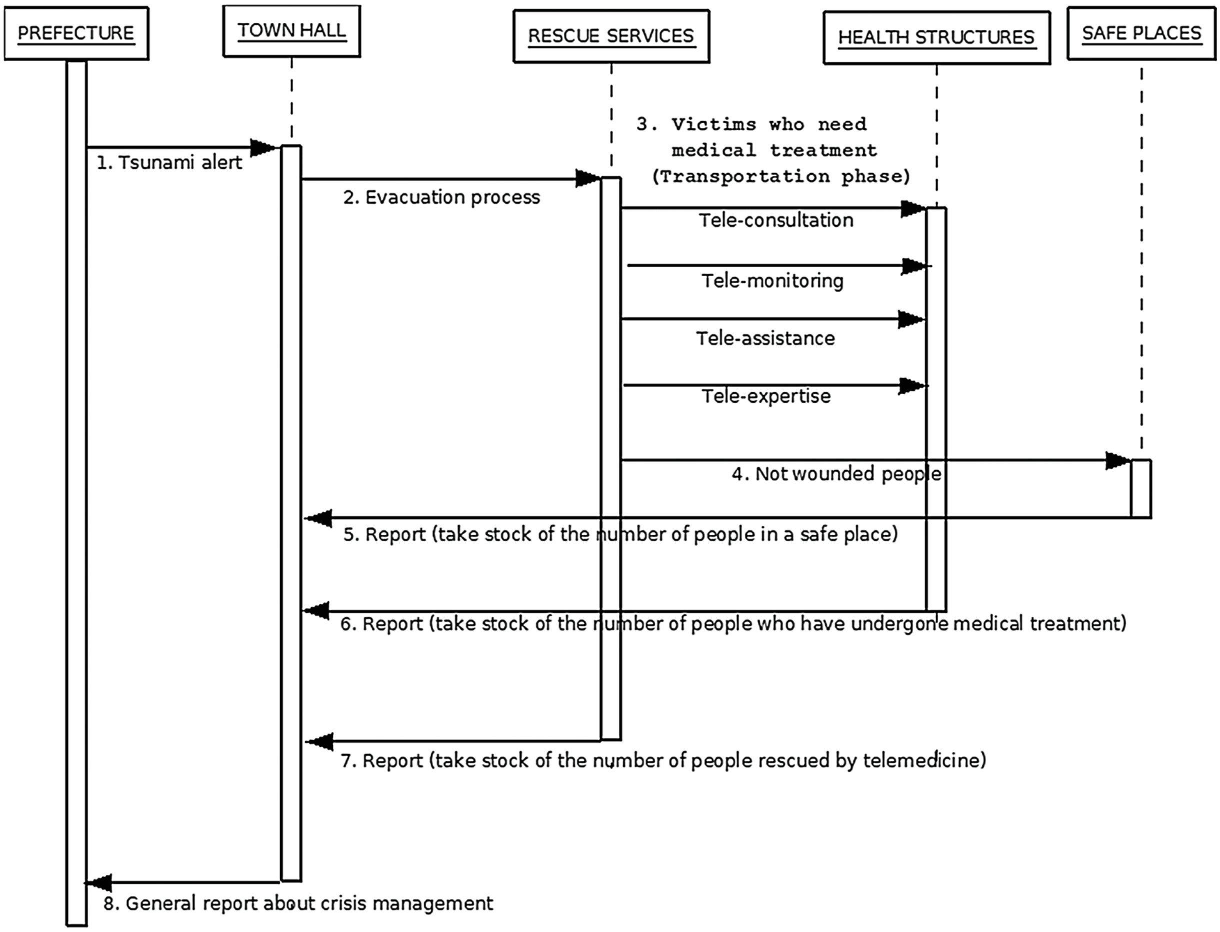

Fig. 8. Remote crisis management of the Tsunami simulation exercise in Cannes.

When a crisis occurs, the various activities involved must be coordinated. There are several existing approaches but, very few of them involve a collaboration of telemedicine software for the prevention or the management of crises. Our methodology considers telemedicine acts as a remote access to medical services that may collaborate to deal with a crisis situation for the protection of victims by reducing physical damage or saving lives in critical care.

The proposed methodology (Fig. 7) is based on a mathematical formalization of crisis management. This formalization concerns all telemedicine acts by specifying *input, output, input-output* parameters, the preconditions to be satisfied before performing telemedicine act and the eventual results after performing each telemedicine act. Therefore, a generic algorithm has been presented to allow a concrete implementation of a computer framework for crisis management. This computer framework will promote the information exchange, sharing and processing for the efficient remote collaboration of health professionals during patients' medical care and his transportation.

The main objective was to provide an enhanced model for computer-supported collaborative work for remote crisis management based on telemedicine acts. This methodology offers better results insofar as it saves more lives with the practice of telemedicine between the health structures and also during the transport phase of the victims. More there are lives saved by telemedicine, better is the result. Therefore, the method used to assess the accuracy of the model could be the counting of the number of victims saved by the practice of telemedicine. The success of the model is strictly related to the interoperability of telemedicine software, the adequate equipment of health structures and rescue vehicles, the training of manipulators of telemedicine equipment. However, while the deployment of this methodology is a benefit in crisis management, we must be aware of its limitations namely: equipment of health structures and rescue vehicles need considerable costs, and also the training of manipulators of telemedicine equipment requires considerable costs.

Among other factors we identified the use of meteorological, climatic, environmental data for making decision systems on a time scale of one minute, one hour or even a century, to help decision makers in decision-making, information and public awareness campaigns (Brunet et al., 2010). There are also in crises, systems or devices emitting distress signals using satellites as a means of communication for delocalization (Balogh et al., 2010) but such systems are lacking the involvement of other actors such as rescue teams, policymakers, and interoperability aspect of medical software applications, and health structures involved in the management of difficult cases. This explains the development of some simulation models applied to the management of emergency medical service (EMS) systems from the appearance of a crisis situation until the delivery of the patient in a hospital. EMS is interesting for a good coordination of the work of rescue teams to define short-term decisions, medium-term, and long-term in order to reduce the response time, choose the nearest hospital to minimize the access time, prepare a new rescue team for new calls to avoid any delay, finally proceed with the preparation of the old team (Aboueljinane et al., 2013). EMS is a part of our approach as it is taken into account by the medical regulator phase and also it is limited solely to the good delivery of emergency in the nearest health facilities.

France can rely on effective reference organizations for the development of a Tsunami warning system. However, the establishment of interoperable services of international dimensions does not spare the scientific institutions that must constantly ensure the proper communication of information on the phases of prevention, management, and recovery of the crisis. It is obvious that if France have to play a leading role in the Mediterranean in the construction of an early warning system, the information systems of national scientific institutions (e.g. Institute for Exploitation of the Sea, Naval Hydrographic and Oceanographic Service, meteorological service …) would be closely associated with this project, thus strengthening their credibility at the international level. In this case, the interoperability of the appropriate measurement tools is essential both at national and international level (at least in the Mediterranean basin). Any effective warning device relies on seismic stations, tide gauges and tsunameters that transmit their data in real time. In addition, taking into account the risk of landslide Tsunami involves a dynamic of interoperability in the exploitation of sensor data such as hydrophones.

6. Conclusion

A new methodological framework for remote crisis management is presented in this work that is modeled on the collaboration of telemedicine acts; thus, providing crisis managers a relevant computerized decision support system. Each telemedicine acts (Teleconsultation, Teleexpertise, Telemonitoring, and Teleassistance) is represented by its corresponding software application that provides services to others and vice versa. The proposed methodology was applied to the simulation of a Tsunami exercises in Cannes (France) and results assessments improve understanding of the applicability and limitations of the proposed model. The major findings achieved from this study are: (i) a methodological approach for better sustainable protection of cities against large waves generally caused after an earthquake, (ii) information systems with interoperable components for better medical care of victims, (iii) a formal risk management framework for capitalizing on experiences and exploiting lessons learned.

As future works, it would be interesting to reflect on the positioning of crisis management induced by the risk of a Tsunami in a multi-risk perspective. The idea of extending the missions of Tsunami information systems (warning systems, telemedicine systems, etc.) to the monitoring and prevention of other risks of coastal submersion of marine origin aims to encourage the collaborations between crisis managers. This requires the establishment of communication channels between a Tsunami warning system and other warning systems in order to ensure the sustainability of collaborative policies with an interoperability strategy for information systems by strengthening the legitimacy of the global warning center by increasing its missions. This idea is also based on the observation that all coastal flood risks use tide gauges to verify and quantify risks. Taking into account the multiple applications of sea level measuring instruments should, therefore, help to justify their acquisition and upgrading. Likewise, accurate mapping of coastal areas (encompassing bathymetry and altimetry) is used for forecasting and managing all marine coastal hazards. As a result, this multi-risk approach could expand the collaborative environment with a possible expansion of the shared knowledge space from various experience feedback enriched by semantic interoperability.

Acknowledgements

This work is supported by a funding within the grant of “Programme de Formation des Formateurs des Universités de Bamako”, delivered by the Malian government. We want to thank the two anonymous reviewers whose significant comments have contributed to improve the content of the paper. We congratulate Shester GUEUWOU for his linguistic ability of proofreading as a native English speaker.

References

ASIP, S. (2012). *Cadre d'Interopérabilité des systèmes d'Information de santé (CI-SIS)|esante.gouv.fr.* le portail de l'ASIP Santé [WWW Document] [URL http://esante.gouv.fr/services/referentiels/referentiels-d-interoperabilite/cadre-d-interoperabilite-des-systemes-d. (Accessed 18 December 2017)].

Abouelјinane, L., Sahin, E., & Jemai, Z. (2013). A review on simulation models applied to emergency medical service operations. *Computers & Industrial Engineering, 66*, 734–750. http://dx.doi.org/10.1016/j.cie.2013.09.017.

Agostinho, C., Ducq, Y., Zacharewicz, G., Sarraipa, J., Lampathaki, F., Poler, R., et al. (2016). Towards a sustainable interoperability in networked enterprise information systems: Trends of knowledge and model-driven technology. *Computers in Industry, 79*, 64–76. http://dx.doi.org/10.1016/j.compind.2015.07.001 [Special Issue on Future Perspectives On Next Generation Enterprise Information Systems].

Ando, M., Kitamura, A., Tu, Y., Ohashi, Y., Imai, T., Nakamura, M., et al. (2018). Source of high tsunamis along the southernmost Ryukyu trench inferred from tsunami stratigraphy. *Tectonophysics, 722*, 265–276. http://dx.doi.org/10.1016/j.tecto.2017.11.007.

Arnott, D., & Pervan, G. (2005). A critical analysis of decision support systems research. *Journal of Information Technology, 20*, 67–87. http://dx.doi.org/10.1057/palgrave.jit.2000035.

Bénaben, F. (2016). A formal framework for crisis management describing information flows and functional structure. *Procedia Engineering, 159*, 353–356.

Balogh, W., Canturk, L., Chernikov, S., Doi, T., Gadimova, S., Haubold, H., et al. (2010). The United Nations programme on space applications: Status and direction for 2010. *Space Policy, 26*, 185–188. http://dx.doi.org/10.1016/j.spacepol.2010.03.008.

Ben Othman, S., Zgaya, H., Dotoli, M., & Hammadi, S. (2017). An agent-based decision support system for resources' scheduling in emergency supply chains. *Control Engineering Practice, 59*, 27–43. http://dx.doi.org/10.1016/j.conengprac.2016.11.014.

Benaben, F., Truptil, S., Lauras, M., & Salatge, N. (2015). Management of collaborative behavior through a service-oriented mediation system: The case of crisis management. *2015 IEEE international conference on services computing (SCC)* (pp. 554–561).

Binacchi, F. (2017). Cannes: La cité des festivals en «alerte tsunami» (pour un exercice), c'est une première en France [WWW Document]. URL http://www.20minutes.fr/planete/2160695-20171031-cannes-cite-festivals-alerte-tsunami-exercice-premiere-france. (Accessed 18 December 2017).

Brunet, G., Shapiro, M., Hoskins, B., Moncrieff, M., Dole, R., Kiladis, G. N., et al. (2010). Collaboration of the weather and climate communities to advance subseasonal-to-seasonal prediction. *Bulletin of the American Meteorological Society, 91*(Oct. (10)), 1397–1406.

Church, P., Goscinski, A., & Lefèvre, C. (2015). Exposing HPC and sequential applications as services through the development and deployment of a SaaS cloud. *Future Generation Computer Systems, 43–44*, 24–37. http://dx.doi.org/10.1016/j.future.2014.10.001.

Devlin, E. S. (2006). *Crisis management planning and execution.* CRC Press.

Girard, J.-F., Lalande, F., Salmi, L.-R., Le Bouler, S., & Delannoy, L. (2006). *Rapport de la mission d'évaluation et d'expertise de la veille sanitaire en France. Doc. Fr.* .

Gupta, A. K., Suresh, I. V., Misra, J., & Yunus, M. (2002). Environmental risk mapping approach: Risk minimization tool for development of industrial growth centres in developing countries. *Journal of Cleaner Production, 10*, 271–281. http://dx.doi.org/10.1016/S0959-6526(01)00023-3.

Hamdi, O., Chalouf, M. A., Ouattara, D., & Krief, F. (2014). eHealth: Survey on research projects, comparative study of telemonitoring architectures and main issues. *Journal of Network and Computer Applications, 46*, 100–112. http://dx.doi.org/10.1016/j.jnca.2014.07.026.

Jensen, A., & Aven, T. (2018). A new definition of complexity in a risk analysis setting. *Reliability Engineering and System Safety, 171*, 169–173. http://dx.doi.org/10.1016/j.ress.2017.11.018.

Kash, T. J., & Darling, J. R. (1998). Crisis management: Prevention, diagnosis and intervention. *Leadership & Organization Development Journal, 19*, 179–186.

Keramitsoglou, I., Kiranoudis, C. T., Sarimvels, H., & Sifakis, N. (2004). A multidisciplinary decision support system for forest fire crisis management. *Environmental Management, 33*, 212–225. http://dx.doi.org/10.1007/s00267-003-0092-4.

Lioult, C. (2017). Exercice de simulation d'un tsunami à Cannes [WWW Document]. URL https://france3-regions.francetvinfo.fr/provence-alpes-cote-d-azur/alpes-maritimes/cannes/exercice-simulation-tsunami-cannes-1357539.html. (Accessed 18 December 2017).

Liu, Q., Wang, G., Liu, X., Peng, T., & Wu, J. (2017). Achieving reliable and secure services in cloud computing environments. *Computers & Electrical Engineering, 59*, 153–164. http://dx.doi.org/10.1016/j.compeleceng.2016.10.005.

Mak, H.-Y., Mallard, A. P., Bui, T., & Au, G. (1999). Building online crisis management support using workflow systems. *Decision Support Systems, 25*, 209–224. http://dx.doi.org/10.1016/S0167-9236(99)00007-X.

Najeeb, A.-S. (2012). Tele-epidemiology and tele-health 7–8 February 2012, Vienna, Austria.

Nokhbeh Foghahaayee, H., Menhaj, M. B., & Torbati, H. M. (2014). Fuzzy decision support software for crisis management in gas transmission networks. *Applied Soft Computing, 18*, 82–90. http://dx.doi.org/10.1016/j.asoc.2014.01.019.

Padawangi, R., Turpin, E., Herlily, Prescott, M. F., Lee, I., & Shepherd, A. (2016). Mapping an alternative community river: The case of the Ciliwung. *Sustainable Cities and Society, 20*, 147–157.

Peng, C., Yuan, M., Gu, C., Peng, Z., & Ming, T. (2017). A review of the theory and practice of regional resilience. *Sustainable Cities and Society, 29*, 86–96.

Röbke, B. R., & Vött, A. (2017). The tsunami phenomenon. *Progress in Oceanography, 159*, 296–322. http://dx.doi.org/10.1016/j.pocean.2017.09.003.

SIRACEDPC, & CYPRES (2014). *Guide d'elaboration d'un plan communal*.

Saidi, S., Kattan, L., Jayasinghe, P., Hettiaratchi, P., & Taron, J. (2018). Integrated infrastructure systems—A review. *Sustainable Cities and Society, 36*, 1–11.

Scheer, S. J., Varela, V., & Eftychidis, G. (2012). A generic framework for tsunami evacuation planning. *Physics and Chemistry of the Earth Parts ABC, 49*, 79–91. http://dx.doi.org/10.1016/j.pce.2011.12.001 [Innovative modelling approaches for disaster

risk reduction].
Slam, N., Wang, W., Xue, G., & Wang, P. (2015). A framework with reasoning capabilities for crisis response decision–support systems. *Engineering Applications of Artificial Intelligence, 46*, 346–353. http://dx.doi.org/10.1016/j.engappai.2015.06.017 [Innovative Artificial Intelligence Solutions for Crisis Management].
Son, N.-T., & Thanh, B.-X. (2018). Decadal assessment of urban sprawl and its effects on local temperature using Landsat data in Cantho city, Vietnam. *Sustainable Cities and Society, 36*, 81–91. http://dx.doi.org/10.1016/j.scs.2017.10.010.
Tindall, K., & Hart, P. (2011). Evaluating government performance during consular emergencies: Toward an analytical framework. *Policy and Society, Success and Failure in Crisis Management, 30*, 137–149. http://dx.doi.org/10.1016/j.polsoc.2011.03.001.
Traore, B. B., Kamsu-Foguem, B., & Tangara, F. (2016). Integrating MDA and SOA for improving telemedicine services. *Telematics and Informatics, 33*, 733–741. http://dx.doi.org/10.1016/j.tele.2015.11.009.
Traore, B. B., Kamsu-Foguem, B., & Tangara, F. (2017). Data mining techniques on satellite images for discovery of risk areas. *Expert Systems with Applications, 72*, 443–456. http://dx.doi.org/10.1016/j.eswa.2016.10.010.
Vardarlıer, P. (2016). Strategic approach to human resources management during crisis. procedia – Soc. behav. sci. *12th international strategic management conference* (pp. 463–472). . http://dx.doi.org/10.1016/j.sbspro.2016.11.057.
Vescoukis, V., Doulamis, N., & Karagiorgou, S. (2012). A service oriented architecture for decision support systems in environmental crisis management. *Future Generation Computer Systems, 28*, 593–604. http://dx.doi.org/10.1016/j.future.2011.03.010.
Voigt, S., Kemper, T., Riedlinger, T., Kiefl, R., Scholte, K., & Mehl, H. (2007). Satellite image analysis for disaster and crisis-management support. *IEEE Transactions on Geoscience and Remote Sensing, 45*, 1520–1528. http://dx.doi.org/10.1109/TGRS.2007.895830.
Zhou, L., Wu, X., Xu, Z., & Fujita, H. (2018). Emergency decision making for natural disasters: An overview. *International Journal of Disaster Risk Reduction, 27*(March), 567–576.