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e-Flooding: Crisis Management Through Two Temporal Loops

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Abstract

Floods, particularly fast ones, are recurrent natural disasters with a large impact on people and infrastructures. In order to mitigate their impact most countries created regulatory frameworks to coordinate the large number of actors participating to the response of these crises. Several levels from rescue to infrastructure restoration are involved. This article proposes to improve the management of risk and resilience in areas subject to flash floods. The innovative autonomic approach presented in this article is twofold: A short-term feedback loop using a large range of information to help managing the current flood; A long-term feedback loop aiming at improving the resilience of the area to reduce the impact of future crises. The originality of these two loops consists in their link which helps improving the quality of both by feeding each other. This article also describes a scenario showing several benefits of the proposed approach.

1. Introduction

Each year comes with its new natural disaster like flooding. These floods can be devastating both for human beings and infrastructures (from households, industry, to energy or water distribution for instance). Recent years have seen the dramatic development of IT technologies: sensors to detect high water levels on river courses [1, 2], weather prediction to anticipate heavy rains and potential flooded areas [3, 4], satellite or aerial images to analyze flooding basins [5, 6, 7, 8], learning technologies to build on past events in order to get ready at best for future occurrences [4, 2]. Slow floods have received more attention in large water basin, where the event can be considered as slow (in the timescale of days). Several countries have developed alert systems based on observation and hydraulic models, where decade or century flooding events history plays a crucial role. For instance, France created in 2015 the brand *Vigicrues* in order to gather information from various services related to flood prediction. Flash floods have received less attention [9, 10]: they are more difficult to handle when the crisis occurs, and their anticipation is more challenging due to the sporadic nature of the event. The timescale is in the order of hours for the first responders. Recovering back to normal takes weeks, months or even years, if possible.

The motivation of this work comes from the low integration of short- and long-term responses to fast flood events, the lack of coordination and usage of the numerous available data sources (sensors, images) and the valorization of all events and corresponding decisions in a shared knowledge base (learning). Our innovative approach to the management of risk and resilience in territories subject to flash flood consists in constructing feedback loops for different timescales, where loops feed each other through careful analysis of the impact of executed tasks and decisions from a shared knowledge base. Furthermore we believe than one way to better handle crises is to formally reason on the manipulated objects/actors of crisis management (by means of a mathematical model, promptly sketched in this article). This model is likely to be used in an optimization process with prioritized objectives, in order to propose a set of evaluated response paths to the crisis management team. It is also used in a machine learning process to improve the answer to the crisis, from both a short- and long-term perspective.

The rest of the paper is organized as follows: Next section overviews the state of the art, Section 3 presents the e-flooding project and its challenges. Section 4 details the usage of two autonomic loops to deal with different timescale (short- and long-term). Section 5 proposes evaluation scenarios of the work, detailing challenges and related issues, and proposes a prototype architecture. Section 6 discusses the choices and the limits of our proposals. Section 7 concludes and gives short-term perspectives of the work.

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2. State of the Art

Floods, crisis management and risk prevention is an active research community. Specialized conferences such as FloodRisk[1] welcome this large community and propose a large number of interesting researches linked to the problematic of flooding.

State services also contribute to the development and to the usage of methods, cartography, and design of flooding models. It is primary done using the regulation framework and for reducing the vulnerability of territories [11, 12].

Funding of flooding management projects mainly comes from the States. They usually require multi-criteria evaluation of the submitted project in order to evaluate their relevance for state agencies. These projects usually encompass not only the infrastructure point of view, but also population safety and economic one. In France, academic laboratories contributed to the specifications of the national regulation framework used by the Ministry of environment, energy and sea (MEES).

2.1. Documented Past Crisis

In order to prepare for future events, most emergency services rely on precisely documented past events encompassing the description of the crisis but also the feedback of the different actors such as emergency services, infrastructure operators, *etc.*

In [13], authors studied the risk management related to flooding in Mediterranean France. Concerning flash floods, [9, 10] propose a detailed overview of several flash floods, from a physical point of view but also from a societal and economic one.

Similarly most work on the state of the art focuses on a particular area depending on the authors expertise. These types of research are found worldwide from several point of view: cartography along with geographical information systems and satellite images in Roumania [5]; Sociological studies on management of risks and understanding on the vulnerability to flash floods in Mediterranean sea [14]; Economic studies on the cost of natural hazards and possible adaptation and mitigation strategies [15]; Local strategies and their comparison in term of cost-benefits in four European countries [15]. In [2], authors proposed to use neural networks to predict river level to prevent flooding, while [4] used neural networks to forecast groundwater levels. From several points of view, the proposed approach described in this article uses these previous researches as inputs.

European INUNDO[2] project produces a historical database of European flooding. We plan to use information from this project to define our validation scenarii.

In our project we will rely on these documented past experiences in order to tune the scope and capabilities of our tools.

2.2. Data for Crisis Management

To make relevant decisions, emergency services rely on a large number of data sources and data treatment tools.

In the domain of remote sensing applied to flooding observation, the SERTIT lab from Strasbourg, France and MEES proposed to use satellite [6] or aerial [7] observations to improve knowledge on events. Research of the Remote Sensing Center [8] developed several characterization methods for flooded plains (2D and 3D) using optical and radar data. Several international agreements grant access to images and data during major environmental events [16].

Several geomatic tools exist to process hydraulic data, such as CARTINO and CARTOZI [3]. These tools help modeling the possible flooding and provide necessary information to rescue and crisis unit during climatic events. For wider audience, several web sites also propose related information such as Vigicrues[3] from French government, the collaborative efforts on keeping traces of historical flooding levels[4] or the RHyTMME[5] web site aiming at providing information on hydro-meteorological risks.

As these tools and data sources are widely used and relied upon by emergency services, our approach is to also rely on these trusted data sources.

2.3. Evaluation of Resilience

Several projects aims at evaluating the resilience of a territory.

The RETINA project [17] has focused on the resilience of territories after flooding and explored the different post-flooding recoveries. This project evaluates the long-term impact on the decision taken to rebuild the area. These decisions can derive from personal choices (move from the area or stay in the same house) or from infrastructure consideration (change the localization of a road). These impacts are to be evaluated depending on their context along with two dimensions: related to the risk and related to public action for flooding prevention.

BRIGAID[6] proposes financial schema for flooding-related innovative solutions and could be leveraged for

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[1] `http://floodrisk2016.net/`

[2] `https://cordis.europa.eu/project/rcn/207424_en.html`

[3] `http://www.vigicrues.gouv.fr`

[4] `https://www.reperesdecrues.developpement-durable.gouv.fr/`

[5] `https://rhytmme.cemagref.fr/`

[6] `https://brigaid.eu/`

the exploitation of our approach results. SMARTRESILIENCE[7] project proposes resilience indicators that can be utilized as metrics to evaluate the results of our approach.

MobiCLIMEx [18] focuses on the question of exposing humans to flash floods in Mediterranean zone.

These means of resilience evaluation are particularly useful for our approach in order to evaluate the quality of the short-term and long-term proposition.

2.4. Short-term Risk Management Tools

Several tools exist to help emergency services to manage the crisis in real-time.

ResiWater [1] project focuses on improving resilience of water-related infrastructure with tools, models and dedicated sensor networks. The GénéPi [19] project focuses on the right level of granularity needed during crisis management with models of the processes and the cooperation of distributed information systems.

ANYWHERE[8] (EnhANcing emergencY management and response to extreme WeatHER and climate Events) project focuses on the phases before and during the crisis, not on the reconstruction phase.

Only a few system actually address the real-time management of a crisis due to the difficulty to be accepted by the large number of actors (emergency services, water and electricity operators, officials, *etc.*).

2.5. Long-term Risk Management Tools

At a different timescale, several projects aim at mitigating the possible risks and to evaluate the possible impact of such crises depending on political or economical decision in a territory.

In France the RGC4 project[9] addresses urban resilience and crisis management in a context of slow rising flooding. In this context it develops tools to help the management of critical technical networks.

Economic evaluation of damages resulting from flooding uses mainly the concept of damage functions based on the estimation of the cost incurred when returning to the situation before the flooding [20, 21]. As defined by Gallopin [22], these damage functions are simplified models of vulnerability and relate vulnerability, resilience and adaptive capacity.

Concerning the long-term consequences of the flooding, several researches [23, 24] showed that adaptation leading to another state than the one before the event can be put in place. In RETINA project [17] several of these strategies are described. The long-term part of the approach presented here will help with the evaluation of these different reconstruction possibilities.

RAITAP [25] investigates what would be the requirements on the post-flooding, so that resilience is improved while damage cost are reduced. It links the different timescales, which leads to a reduced vulnerability of an area.

BE-AWARE[10] (Enhancing decision support and management services in extreme weather climate events) tackles mainly the preparation phase but has also an autonomic management of the long-term which is similar to the autonomic process that we envision. I-REACT[11] improves area resilience using satellite images and data integration in an information system.

One of the goal of our approach is to associate cost and benefits to the characteristic of these actions and to take them into account during short- and long-term decision making processes. Several of the presented projects are similar to our approach but none of them encompass the two timescales: during the crisis and long-term timing to go back to a stable situation, but also the notion of human sensors and flash floods.

3. e-Flooding: Project Presentation

The national policy of flood risk management has been renovated and revitalized by the European directive relative to the evaluation and to the risk management of flood of 2007 and transposed into French law in July, 2010. At “hydrographic district” scale, this directive proposes works on management plans of flood risks. The National Strategy of Risk management of Flood has three major objectives: 1) increase the safety of the exposed populations; 2) stabilize in the short-term, and reduce in the medium term, the cost of the damages bound to the flood; 3) shorten strongly the deadline on returning to normal of the stricken territories. The e-Flooding project is in the context of the last two objectives. The national policy deals with four challenges: develop the governance and the appropriate project ownership, know better to act better; improve territories resilience; learn to live with the floods.

e-Flooding project aims at modeling flash floods in term of risk management and impact on the infrastructures using data collected by technological or human sensors. The project integrates technical expertise to handle flash floods in crisis management and resilience through an autonomic approach that provides smooth adaptation to the evolution and to the events. The project[12] is funded by the French Research Agency

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[7] `http://www.smartresilience.eu-vri.eu/`

[8] `http://anywhere-h2020.eu/`

[9] `https://rgc4.wordpress.com/`

[10] `http://beaware-project.eu/`

[11] `http://www.i-react.eu/`

[12] `https://www.irit.fr/i-nondations/`

(ANR) and plans to tackle different technical and scientific challenges. At the technical level, the main challenges come from the integration of many complementary skills from the different actors involved during a crisis and from the heterogeneity of the data and processes taken into account: usual data coming from sensors but also, data from drone, satellites, ... Technical challenges will be to deal with the interoperability and multi-disciplinarity. The project addresses different scientific challenges: Challenge 1 improves and proposes hydrological models to characterize the flood (The height of water, its flow...), Challenge 2 makes use of pattern recognition for example using some machine learning process to recognize crisis and reuse/help in its management. This challenge aims at learning from the past to better react in the future. Challenge 3 improves territories resilience by using resilience metrics. A resilient infrastructure is able to anticipate disturbances, to minimize their effects, to react to them, to evolve dynamically towards a new state protecting its features. Challenge 4 manages risk by integrating in a dynamic autonomic loop the different processes engaged during a crisis. A risk appears when a hazard impacts stakes and can be handled by engaging resources (for example firefighters who will make emergency actions). This challenge will be solved with two temporal loops as detailed in the next section.

4. Two Temporal Loops

The project suggests managing three phases: before, during, and after a crisis in a feedback loop coming from the autonomic field called MAPE-K loop [26, 27]. It is based on four steps: Monitoring, Analysis, Planning and Execution with a Knowledge database. The Knowledge database will be filled continuously in order to identify similarity between events, study answers (and optimize answers) and construct different solutions to handle crisis. The MAPE-K loop is a meta model of the literature, it will be applied in the project to the use case of crisis management. The originality and novelty is to use two loops: one for short-term timescale and one for long-term. Both loops instantiate the same MAPE-K model (i.e. the same four steps). The short-term loop aims at handling the crisis while the long-term one aims at being prepared to other crisis. Both loops will interact. The main reasons of having two loops are because each loop has different objectives and the actors involved are different.

These two loops help to model the system dynamic through four modules: Monitoring, Analysis, Planning, Execution and a knowledge database. After a monitoring phase of the system, risks and threats are analyzed by the analysis module. Then, decisions are made to handle the crisis and to provide a workflow of the tasks which correspond to different possible strategies to come back to a normal state or deal with the risks encountered. Then, for example, the appropriate response would be given by fire brigade or other public organizations (in the Execution module). These concrete actions modify the system state and the loop is reproduced with monitoring update and so on.

We make an assumption in this work that it is important to deal with the different timescales of a crisis to model the different problems and each dynamic. One loop called *short-term loop* handles the crisis management and the other one called *long-term loop* handles risk prevention.

Next subsections detail the loops and the different steps shown in figure 1.

4.1. Short-term Loop

Short-term loop manages the crisis for the time window covering the day before the flood until about ten days after. This period is usually what can be observed in feedback documents written by firefighters after flash floods crisis. It covers two steps:

- urgent answers to ensure citizen security, infrastructures protection, prevention of commercial damages, prevention of environmental damages.
- recovery actions for impacted areas in order to come back to a normal state.

During this loop, the Monitoring module detects events happening ; in our case sensors will give water indications. Data coming from social networks can complement measured data, just like satellites imagery. Each data source has a confidence indicator, *e.g.* in images, technological sensor has a precision. Data measured directly on the field can be more precise than remote sensors measurement. The monitoring detects emerging risks and calls the Analysis module.

The analysis is based on the monitored data (height of water, speed, *etc.*). The aim is to characterize the currently happening event: the flood span, its dynamism (fast/slow) and the impacts (*e.g.* vulnerable buildings, impacted roads, the predictable damages associated with the occurrence probability for the selected threat based on the territory topology, hydrological models and statistics). This data is then to be used by the Planning.

The Planning focuses on ways to overcome the crisis by finding relevant strategies to limit emergency situations. It is essential to take quick decisions. During flooding events, decision-makers are responsible for providing suitable measures responding to and recover-

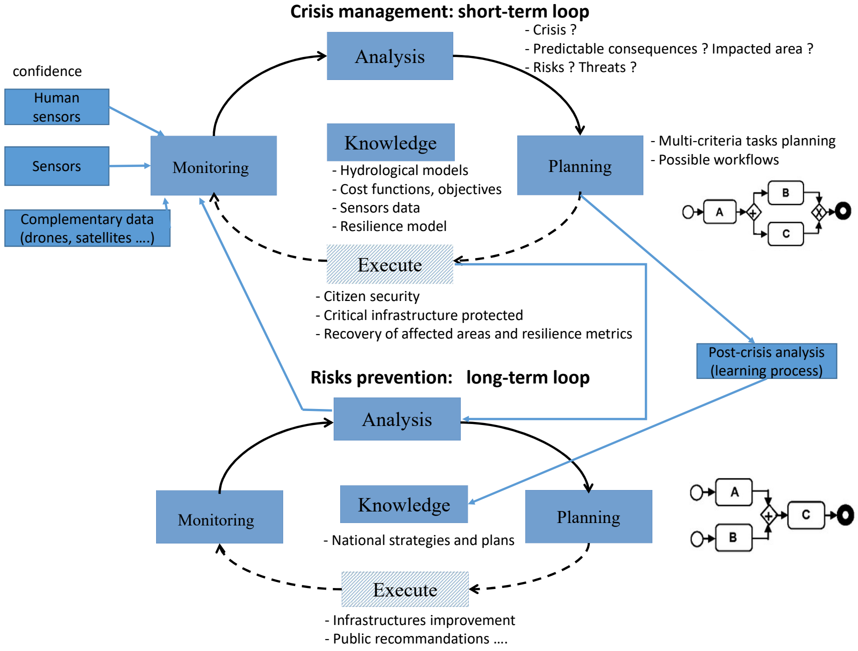

Figure 1. MAPE-K Loops

ing from crisis. In addition, public and private stakeholders are involved in the decision process and pursue partly conflicting objectives, which complicates the decision process. The aim is to help them to pick the "best" strategy according to various metrics and objectives. This can be formalized by a mathematical multi-objective optimization problem. The objective is to be able to compare the solutions calculated automatically with the implemented tasks to enrich then the models and the analyses of crisis situations in the long-term. The optimization problem takes as an input all the necessary data to represent mathematically the crisis. Also we take into account the consequences of the crisis (flooded roads, impacted infrastructures, impacted buildings, lives in danger, *etc.*) along with their associated costs, and the possible actions that can be pursued (*e.g.* rerouting of the road traffic, the evacuation of the populations) according to generic objectives (the protection of people, the damages in the infrastructure, the impact on the environment and the time to return to normal). The set of solutions will be sorted, each action workflow will be associated with a cost and a profit. The problem can be solved with various objective functions which can be combined (*e.g.* minimization of financial losses for the municipality by restoring activities as quickly as possible, maximization of the number of saved lives).

In real life, the Execute would implement the chosen workflow. In the case of the project, this step will be simulated to evaluate the effects and enrich the knowledge database.

The Knowledge in Figure 1 represents the database storing each data item from each module of the loops. It includes sensors data, formalizations such as hydrological and mathematical models, and the vulnerability indicators which are the outputs of the long-term loop. It will integrate the different skills of the different organizations involved in the emergency response.

4.2. Long-term Loop

Long-term loop aims at dealing with post-crisis analysis in order to improve the risks prevention. The time window starts five years after a crisis and lasts for five years. This long-term loop benefits from the feedback of the previous crisis and develops various management plans of crisis. Urban maps or infrastructures schemes may be modified to prevent future disasters. The outcome of the short-term loop may also influence the state of the territory in the long run (damage, reconstructions, adaptations). The final goal is to have a resilient territory. This loop interacts with the short one: it uses the short-term loop to evaluate different conditions of events and threats. The results of the short-term loop are inputs of the analysis step of the long-term loop. In a certain way by calling many times with different inputs the short-term loop we will be able to enrich the knowledge and learn from the past.

The Monitoring step of this long-term loop is based on results from the Execute step of the short-term loop (*i.e.* based on a post-crisis situation).

The Analysis step aims at understanding past crisis: their impacts, the vulnerabilities identified on the territory. This analysis will provide both similarity functions which allow during the short-term loop to predict consequences more accurately, and damage functions that will be passed as an input to the Planning step in particular the multi-objective optimization.

The Planning step deal with the optimization of the long-term restoration by studying and valuating alternative trajectories; for instance, is it relevant to rebuild at the same place in the same way? or is it necessary to provide collective protection, to give more incentives for individuals to adapt their dwellings or to restrict building ? The objective of the optimization problem is here to improve the resilience of the territory.

The Execute step implements the solutions of the Planning step. The expected results are recommendations which we could propose to public policy makers to contain and limit the impact of future crises and help in the management of the next crises.

The long-term loop enriches the short-term one: the results of the Execute step (*e.g.* the modifications of the city plans for citizen protection) are stored in the knowledge database of the short-term loop.

5. Use Case: Roadmap for Evaluation

5.1. Metrics

In the short term, the goal of the approach is to improve the efficiency of the rescue operations. In a longer term, it aims at improving, for the next floods, the range of possibilities for rescue operations but also the resiliency of the area.

The proposed metrics used to evaluate our multi-loop approach are mainly based on the concept of *Damage Functions* which is the estimation of the cost needed to go back to a situation equivalent to before the crisis [20, 21]. These damage functions consist in a simplified model of vulnerability as defined by Gallopin [22] : the inclination to be damaged, to recover and to adapt after a crisis.

Using Damage Functions, it is possible to compare impact on different categories such as the destruction of a road or the time needed to bring back electricity to an area.

The area resilience (identification of vulnerabilities and resilience indicators) is the metric used for the long-term loop as an increased resilience will lead to lower costs for the next crisis.

Concerning short-term metrics, additionally to the Damage Functions, several rescue-related elements are taken into account to have a better understanding of the impact of our approach: Number of saved lives, number of rescued people, Damage on buildings, number of sites disconnected from the infrastructure (electricity, water, network). Indeed these metrics will help to compare following our priorities: people, properties, environment.

5.2. Mathematical Tools

In the context of flood management, a number of state variables can be defined for the different objects manipulated in the project. For instance, one integer can hold the number of members of a rescue team linked to a task. One binary variable can state if one rescue member possess one ability or not (such as driving a heavy truck), or if a sensor is present in an area or not. An intrinsic risk can be linked to a cost and a profit, *etc.* After defining the list of actors in the system, the list of their potential tasks, the intrinsic risks, the threats, the hazard itself using such mathematical definition, one can derive some mathematical constraints expressing the links between them. For instance, a rescue team needs at least one member with the ability to drive a truck to move on a certain area with a truck. Objectives such as the maximization of saved lives or the minimization of the costs for saving people can be derived in the same way.

Using all these variables and constraints, a linear program can be expressed and solutions for the objectives can be computed with the help of dedicated software such as Gurobi or CPLEX for instance. However such an approach suffers from two main difficulties: uncertainty and scalability. In a crisis management process, some data pieces may be missing or are uncertain. Confidence intervals are attached to the variables of the model, complexifying the mathematical model and extending its solving time, in particular at large scale (*i.e.* with long time windows or large area). Heuristic methods and fuzzy logic will probably be necessary to handle the problem.

5.3. Case of Study

5.3.1. Disaster Characterization. A disaster, especially flash flood considered in the e-Flooding project, is generally characterized by:

- The context in which it occurs, which describes the stakes to be preserved (schools, hospitals, retirement home, residential, campsites, patrimony, roads, economic activities, ...) and disruptive elements (rivers, forests, ...) that can generate disasters characterized by their probability of occur-

rence, their durations and their intensities and that it will be necessary to circumscribe. This context also includes a more or less rich observation system, consisting of technological components (sensors, satellite, drones, ...) or humans.
- Actors involved: monitoring and forecasting services (fire evolution, water level, loss of sensors, *etc.*), fire department, police, ..., characterized by the skills they bring in and the resources they offer. Collectively, these actors must decide on priorities and resources to be allocated to actions.
- Observed or predicted events (rising water levels, fire spread, road cuts, electricity or water supply disruption, bridge destruction, loss of sensors, etc.), which must be responded to by triggering the actions judged most appropriate when the decision is made, to repair or prevent the consequences (evacuation of populations, closing of roads, ...).

5.3.2. Luchon's Disaster Example. The flood caused in France by the river Pique in June 2013 at *Bagnères-de-Luchon*, in south-western of France (mountain area in the Pyrénées) is used to evaluate the proposed approach. The map of the area [13] is shown in Figure 2. We can see in different colors the different hazards.

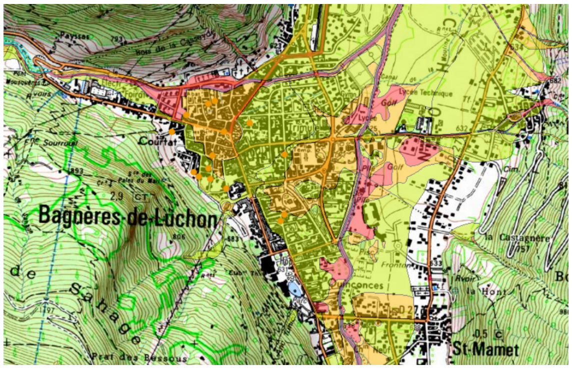

Figure 2. Map of the Area

The main hazard is the Pique. The region has experienced many floods in the past (water level at the same observation point, 4.25 m in 1897, 3.8 m in 1875 ... and 3.5 m in June 2013). The monitoring system leveraged many alarms (very snowy winter, cold early spring delaying snowmelt, late warm spring causing an accelerated snowmelt with saturated soils) and it had warned of the risks of flood. The heavy rainfall that followed confirmed the forecasts. In the past, many stakes had been impacted: flooded roads or washed away, destroyed bridges, flooded houses and buildings ... During the floods of 2013, there were various impacted stakes: flooded campsites, totally isolated village, road were cut, breakage of a dike, threatened retirement homes, evacuated schools, evacuated equestrian center, electricity and water distribution were cut, *etc.* Many actors have been involved in the management (both operational and “political”) of the crisis, with various skills and expertises:

- Firefighters (recognition of damage, aid, security or evacuation of the population, emergency pumping, especially to protect or restore essential infrastructure, *etc.*).
- EMS (Emergency Medical Service), to provide medical aid, to assess risk, to evacuate, *etc.*
- Police services (to control traffic, to evacuate, to prevent looting, *etc.*).
- Infrastructure services: roads, building, electrical, communication services expertise, *etc.*
- Governmental services: prioritization and monitoring of actions, with the setting up of pilot structures (for instance, the Departmental Fire and Rescue and Civil Security Operational Center).

The committed resources were also important:

- Humans: up to 200 firefighters, including specialists in aquatic, and canyon rescue, in chemical risks with civil associations to help professional staffs....
- Nearly 60 emergency vehicles engaged;
- 6 helicopters (firefighters, gendarmerie, EMS, army), as well as a private drone with embedded camera;
- Heavy equipments for pumping and evacuating sludge and sewage;
- Logistics (communication, accommodation, food, fuel, *etc.*).

These resources were involved to react in real time to the events as urgent actions: evacuation, putting in security without evacuation, winching, to evaluate threats, to cut road, *etc.* Among the subsequent feedbacks from experience, was emphasized the need to better coordinate the various actors, especially to optimize the commitment of resources, to share knowledge of situations and to obtain decisions that are more in line with the reality observed in the field. The e-Flooding project will endeavour to strengthen the links between the various actors. A decision system, built around a shared information system recording events occurring during the crisis currently managed, but also memorizing the feedback cumulated from past crises, and a multi-objective

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[13] `http://carto.geo-ide.application.developpement-durable.gouv.fr/131/Risque_inondation.map`

optimization algorithm, can enable the various actors involved to best ensure this collective responsibility.

The MAPE-K loop represents our decision system as described in section 4. To implement it, on both its short- and long-terms, and to validate the described approach, the different entities involved in the management of a flash flood are described in a computer prototype. This will allow us to play several scenarios developed with the rescue services and, in particular, to replay the events observed during the crises selected in this project to evaluate the actions proposed by our multi-criteria optimization algorithms. The diagram depicted in Figure 3 describes the overall architecture of the prototype planned but not yet implemented and the connections between the different entities identified.

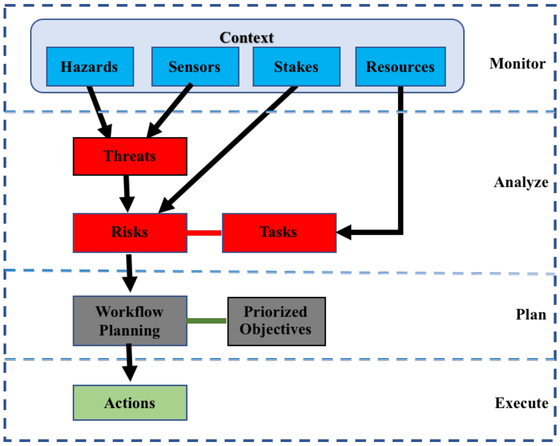

Figure 3. Prototype Implementation Planned

5.3.3. Prototype. The description of the initial context is given in input. This context will then evolve as the proposed actions are executed. The observation of the managed environment, carried out in the Monitor phase, in particular through the sensors and the data transmitted by the institutional services (like *VigiCrues* in France), feeds the information system and thus allows updating the overall state of the information system. This global state is taken into account in the Analyze / Threats phase to evaluate, from the list of hazards identified in the observed geographical area, a list of threats (*e.g.* rising water, power failure). This list of threats is confronted, in the Analyze / Risks phase, with the stakes described in the managed context, to establish the list of risks incurred by the impacted stakes. Each risk (flood of a retirement home, a campsite, a road cut, *etc.*) is characterized by:

- the impacted stake, with the estimate of the potential damage incurred (human, environmental, financial, economic, *etc.*);
- its temporal deadline;
- the associated tasks, to be carried out to prevent or remedy it, with an estimation for each of these tasks of the resources necessary. Tasks and the partners concerned (emergency services, electricity distribution, *etc.*) are described in a knowledge base.

These information are used in the Plan / "Workflow Planning" phase, which performs a multi-criteria optimization that takes into account the risks previously identified and the imposed priorities between the objectives (Priorized Objectives). It is indeed very common to prioritize the objectives as follows: human first, then goods, and then environment. As a result of this optimization, several strategies for the handling of these risks are proposed to the crisis management team, so that it determines which one to retain. Each proposed strategy is represented by a task workflow to be executed. In the Execute / Actions phase, the selected workflow is activated. Its execution leads to a new state of the system, which will be taken into account in the handling of subsequent events.

For the second MAPE-K loop, which takes into account the long-term crisis, our decision system will take into account proposed changes in the observed environment to assess their impacts, by replaying past crises or newly developed crisis scenarios:

- its *Monitor* phase consists in acquiring the evolutions brought to the observed context;
- its *Analyze* phase analyzes the envisioned evolutions, by activating the short-term MAPE-K loop applied to the new context resulting from these evolutions;
- its *Plan* phase takes into account the metrics obtained by the previous simulations, to propose long-term evolutions of the observed environment.

Several approaches have been presented to design such systems and capitalize on the gained experience, since responses are often transferable between disasters, such as evacuation of people. [28] aims at providing partners involved in crisis management with an agile Mediation Information System (MIS) to elaborate a common and sharable reference model built to characterize crisis situations support the interoperability of the partners' information systems and to coordinate their activities through a collaborative process. [29, 30] present an approach to unify Disaster Management (DM) knowledge to create a Decision Support System (DSS) that combines and matches different disaster management activities to suit the disaster on hand. They aim first to appropriately represent DM knowledge and to warehouse DM knowledge in an appropriate form to later allow mixing and matching DM experiences. In [31], the authors observe that “roles involved in DM processes often cut across many organizational boundaries and are dynamic. Knowledge involved is enormous and diverse.”. So they address the knowledge sharing challenge by providing a knowledge based systems approach to facilitate collaboration and DM knowledge sharing. [32] tackled the specifics of managing a road traffic crisis caused by heavy snowfall. In this article, from a collaborative metamodel core that offers generic concepts, the authors propose a specific projection to describe and manage the road crisis. They use the Business Process Model notation (BPMn) language [33] to describe the collaborative processes used to respond to the crisis.

To represent our task workflows, BPMn, which both describes the sequence of tasks and their synchronization, but also the cooperation between different actors, seems appropriate. For this purpose, we study various frameworks supporting BPMn, including RIO-SUITE used in the project [34]. RIO-SUITE is a software suite that embeds a set of tools dedicated to support efficiently inter-organizational collaborations like crisis management and that are used for different purpose (visualization of the collaborative situation, monitoring of the collaboration, risks management, *etc.*).

6. Discussion

We propose to model risk management for flash flood by use of an autonomic approach with two nested temporal loop: one for the short-term dealing with the emergency response and one for the long-term dealing with the improvement of the territory resilience. As presented in the literature review, there are many works studying flooding. Some approaches are close to ours but none of them considers at the same time emergency crisis management and prevention, restoration, thus dealing with short-term and long-term problems. The results of the project could then be integrated in tools already used during flood crisis management. The output of the decision system presented will be different valuated trajectories (workflows of possible actions to react in an optimal way for different objectives). The command post would be able to use the decision system to take the best decision after having compared different possibilities. During emergency response different organizations are involved and need to work together, a system like the prototype planned to be implemented would help to model the different resources and skills which would be stored in the “Knowledge” module. State services would be able to use the decision system to simulate different hazards, threats and risks to reduce the vulnerability of the territory and learn from past crisis.

7. Conclusion

In this paper we presented a preliminary work for handling flash flood crisis thanks to an autonomic approach, based on two loops feeding each other. We proposed a prototyping scenario able to test several conditions to analyze the benefit of the MAPE-K approach.

The first findings of this work, which is still in its infancy, are the following: The project aims at using data from different sources to reason on them. Data comes from water sensors, satellite images, field studies, hydrological models, GIS, *etc.* The diversity of these sources poses the problem of the integration in a common information system linked with a dedicated simulation environment able to manipulate several input/output formats. Moreover, a given area may lack some data (for instance satellite images partial unavailability due to cloud coverage), making the reasoning process more challenging. However we take these two issues as leverages of innovation. The first issue pulls the necessary simplification and formal abstraction of the available data while the second issue asks for the design of optimization models and machine learning techniques prone to missing or incomplete data.

Next short term steps are the mathematical formulation of the problem at hand, and the development of associated algorithm for optimization purpose in order to find the most appropriate task workflows.

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References

[1] O. Piller, F. Sedehizade, T. Bernard, M. Braun, N. Cheifetz, J. Deuerlein, A. Korth, E. Lapébie, I. Trick, J.-M. Weber, *et al.*, “Resiwater: A franco-german project for augmented resilience of water distribution systems following severe abnormal events,” in *14th CCWI international conference, Computing and Control in Water Industry*, pp. 7–p, 2016.

[2] M. Campolo, P. Andreussi, and A. Soldati, “River flood forecasting with a neural network model,” *Water Resources Research*, vol. 35, pp. 1191–1197, 04 1999.

[3] A. Escudier, P.-A. Hans, C. Astier, and J.-L. Souldadié, “From high waters forecasts to flooded areas forecasts,” in *E3S Web of Conferences*, vol. 7, p. 18008, EDP Sciences, 2016.

[4] J. Adamowski and H. F. Chan, “A wavelet neural network conjunction model for groundwater level forecasting,” *Journal of Hydrology*, vol. 407, no. 1, pp. 28 – 40, 2011.

[5] G. Stancalie, V. Craciunescu, and A. Irimescu, "Development of a downstream emergency response service for flood and related risks in romania based on satellite data," in *E3S Web of Conferences*, vol. 7, p. 17007, EDP Sciences, 2016.

[6] M. De Michele, A. Giros, H. Yésou, D. Raucoules, and H. De Boissezon, "Kal-Haïti: a database for research, risk management and sustainable reconstruction in Haiti.," in *EGU 2011*, (Vienne, Austria), Apr. 2011.

[7] M. Shahbazi, J. Théau, and P. Ménard, "Recent applications of unmanned aerial imagery in natural resource management," *GIScience & Remote Sensing*, vol. 51, no. 4, pp. 339–365, 2014.

[8] G. Schumann, R. Hostache, C. Puech, L. Hoffmann, P. Matgen, F. Pappenberger, and L. Pfister, "High-resolution 3-d flood information from radar imagery for flood hazard management," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 45, no. 6, pp. 1715–1725, 2007.

[9] F. Vinet, D. Lumbroso, S. Defossez, and L. Boissier, "A comparative analysis of the loss of life during two recent floods in france: the sea surge caused by the storm xynthia and the flash flood in var," *Natural hazards*, vol. 61, no. 3, pp. 1179–1201, 2012.

[10] J. Douvinet, "Flash flood hazard assessment in small agricultural basins coupling gis-data and cellular automata modelling: First experimentations in upper-normandy (france)," *International Journal of Agricultural and Environmental Information Systems (IJAEIS)*, vol. 5, no. 1, pp. 59–80, 2014.

[11] D. D. Bradlow, A. Palmieri, and S. M. Salman, *Regulatory frameworks for dam safety: A comparative study*. World Bank Publications, 2002.

[12] B. B. Clary, "The evolution and structure of natural hazard policies," *Public Administration Review*, vol. 45, pp. 20–28, 1985.

[13] S. Defossez, T. Rey, F. Vinet, and L. Boissier, "Flood risk management: cases studies in french mediterranean area," in *E3S Web of Conferences*, vol. 7, p. 20019, EDP Sciences, 2016.

[14] S. Durand, C. Lutoff, S. Duvillard, I. Andr-Poyaud, M. Bertran-Rojo, and C.-A. Choquet, "A sociological case study of residential practices in floodplain. understanding vulnerability to flashflood," in *FloodRisk*, 2016.

[15] P. Bubeck, W. Botzen, H. Kreibich, and J. Aerts, "Detailed insights into the influence of flood-coping appraisals on mitigation behaviour," in *Global Environmental Change*, vol. 23, pp. 1327–1338, 2013.

[16] J.-L. Bessis, J. Bequignon, and A. Mahmood, "The international charter space and major disasters initiative," *Acta Astronautica*, vol. 54, no. 3, pp. 183–190, 2004.

[17] P. Brémond, B. Bonte, K. Erdlenbruch, F. Grelot, and C. Richert, "Long term post-flood damage assessments to analyze the strategies of adaptation at individual scale," in *EGU General Assembly Conference Abstracts*, vol. 17 of *EGU General Assembly Conference Abstracts*, p. 6099, Apr. 2015.

[18] S. Debionne, I. Ruin, S. Shabou, C. Lutoff, and J.-D. Creutin, "Assessment of commuters daily exposure to flash flooding over the roads of the gard region, france," *Journal of Hydrology*, vol. 541, pp. 636–648, 2016.

[19] A. Fertier, A. Montarnal, A.-M. Barthe-Delanoë, S. Truptil, and F. Bénaben, "Adoption of big data in crisis management toward a better support in decision-making," in *Proceedings of Conference on Information System for Crisis Response And Management (ISCRAM 16)*, 2016.

[20] V. Meyer, N. Becker, V. Markantonis, R. Schwarze, J. Van Den Bergh, L. Bouwer, P. Bubeck, P. Ciavola, E. Genovese, C. H. Green, *et al.*, "Assessing the costs of natural hazards-state of the art and knowledge gaps," *Natural Hazards and Earth System Sciences*, vol. 13, no. 5, pp. 1351–1373, 2013.

[21] L. Shabman and K. Stephenson, "Searching for the correct benefit estimate: empirical evidence for an alternative perspective," *Land Economics*, pp. 433–449, 1996.

[22] G. C. Gallopín, "Linkages between vulnerability, resilience, and adaptive capacity," *Global environmental change*, vol. 16, no. 3, pp. 293–303, 2006.

[23] J. K. Poussin, W. W. Botzen, and J. C. Aerts, "Factors of influence on flood damage mitigation behaviour by households," *Environmental Science & Policy*, vol. 40, pp. 69–77, 2014.

[24] H. Kreibich, P. Bubeck, M. Van Vliet, and H. De Moel, "A review of damage-reducing measures to manage fluvial flood risks in a changing climate," *Mitigation and adaptation strategies for global change*, vol. 20, no. 6, pp. 967–989, 2015.

[25] J. Gwenal and T. Rgis, "How to build back better after a flood disaster?," in *Water, Megacities and Global Change*, 2015.

[26] J. Kephart and D. Chess, "The vision of autonomic computing," *Computer*, vol. 36, no. 1, pp. 41–50, 2003.

[27] P. Horn, "Autonomic computing : Ibms perspective on the state of information technology," *Technical report*, 2001.

[28] H. C. L. M. C. P. C. V. Benaben, F., "A metamodel and its ontology to guide crisis characterization and its collaborative management.," in *Proceedings of the 5th International ISCRAM Conference*, pp. 189–196–303, 2008.

[29] G. B. Siti Hajar Othman, "Metamodel-based decision support system for disaster management," *Proceedings of the Fifth International Conference on Software and Data Technologies ICSOFT 2010, Athens, Greece, July 22-24*, vol. 2, 2010.

[30] G. B. Siti Hajar Othman, "Metamodelling approach towards a disaster management decision support system," *Artifical Intelligence and Soft Computing, 10th International Conference, ICAISC 2010*, 2010.

[31] G. B. Siti Hajar Othman, "A metamodel-based knowledge sharing system for disaster management," *Expert Systems with Applications*, vol. 63, pp. 49–65, 2016.

[32] M. L. G. Mace Ramete, J. Lamothe and F. Benaben, "A road crisis management metamodel for an information decision support system," *6th IEEE International Conference on Digital Ecosystems Technologies (DEST)*, 2012.

[33] O. ManagementGroup, "Business process model and notation (bpmn) version 2.0," *Object Management Group*, 2011.

[34] F. Benaben, A. Montarnal, S. Truptil, M. Lauras, A. Fertier, N. Salatge, and S. Rebiere, "A conceptual framework and a suite of tools to support crisis management," in *Proceedings of the 50th Hawaii International Conference on System Sciences*, 2017.