

# Design of Real Time Early Response Systems for Natural Disaster Management Based On Automation and Control Technologies

C. Pacheco, A. Cipriano

**Abstract**—A new concept of response system is proposed for filling the gap that exists in reducing vulnerability during immediate response to natural disasters. Real Time Early Response Systems (RTERSs) incorporate real time information as feedback data for closing control loop and for generating real time situation assessment. A review of the state of the art on works that fit the concept of RTERS is presented, and it is found that they are mainly focused on manmade disasters. At the same time, in response phase of natural disaster management many works are involved in creating early warning systems, but just few efforts have been put on deciding what to do once an alarm is activated. In this context a RTERS arises as a useful tool for supporting people in their decision making process during natural disasters after an event is detected, and also as an innovative context for applying well-known automation technologies and automatic control concepts and tools.

**Keywords**—Disaster management, emergency response system, natural disasters, real time.

## I. INTRODUCTION

DISASTER management is a complex subject that involves many different situations and participants. Due to its large scope, it is usually addressed in the well-known four phases emergency management cycle shown in Fig. 1, composed of mitigation, preparedness, response and recovery [1]. These phases are distributed before, during and after the disastrous event, and are focused on reducing risks and minimizing property damage and casualties.



Fig. 1 Emergency Management Cycle

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Specifically the third phase of the emergency management cycle, called “response”, corresponds to “the provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected” [2].

In response phase of natural disaster management, many efforts have been focused on understanding natural forces, mainly for detecting and estimating natural hazards as soon as possible in order to alert population in time when a disaster occurs. Those systems, called Early Warning Systems (EWSs), have been developed for different natural disasters like earthquakes [3], tsunamis [4], [5], flash floods, among others. Besides Early Warning Systems, in response phase some interest also has been placed in developing management methodologies for guaranteeing the fast action of rescuers [6]-[8], rapid generation of high-quality information about the event [9], [10], accurate situation assessment [11], [12], and efficient resource allocation [13].

It is evident that detecting an emergency in its first moments can help saving lives and reducing property damage, but an opportune alarm results useless if it is not followed by appropriated actions [14]. The main gap in the way response phase is currently addressed is that most effort is centered in the detection of the event or in the response after the event ends, but procedures activated by EWSs that could help during the event are infrequently taken into account.

In this context we define a Real Time Early Response System (RTERS) as a system that uses real time information for creating a dynamic response to control a situation in its first moments. Some works have been found in literature that fit our RTERS definition [15]-[18], but they are mainly focused on manmade emergency situations. Therefore in this paper we address the problem of identifying the challenges that natural disasters context implies for RTERSs design and how automation technologies and automatic control concepts and tools can help to face them.

This document is structured as follows: in Section II basic aspects of automatic control and automation technologies are presented; in Section III we present factors that define RTERSs and some related works from literature are analyzed; in Section IV natural disaster management context is discussed; in Section V RTERS design challenges are identified for using automatic control tools in natural disasters context; and finally in Section VI main conclusions are presented.

## II. AUTOMATIC CONTROL AND AUTOMATION TECHNOLOGIES

Automatic control aims to regulate processes without the specific intervention of humans. We can identify two main philosophies for that purpose: open loop controllers and closed loop controllers, whose basic diagrams are depicted in Fig. 2. Any control scheme must consider at least two elements: the dynamic system to be controlled and the controller, device that meant to monitor and regulate dynamic system conditions.

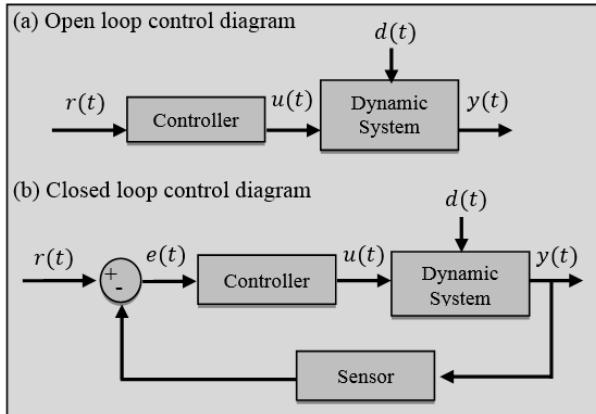


Fig. 2 (a) Open loop and (b) Closed loop control diagrams

“The quantity or condition that is measured and controlled” [19] is denominated controlled variable, which normally corresponds to the output of the system  $y(t)$ . The reference signal  $r(t)$  corresponds to the desired value for the controlled variable, so the control error  $e(t)$  is usually defined as the difference between reference signal  $r(t)$  and controlled variable  $y(t)$ . The manipulated variable or control signal  $u(t)$  is “the quantity or condition that is varied by the controller so as to affect the value of the controlled variable” [19]. Finally, an external disturbance  $d(t)$  is a signal generated outside the system that tends to adversely affect the value of the output  $y(t)$  [19].

On the one hand, open loop controllers are characterized by a control signal  $u(t)$  which depends on the desired output  $r(t)$  but does not depend on the actual process output  $y(t)$  (a classic open loop control example is simple traffic control using semaphores). On the other hand, in closed loop control sensors measurements of the process output  $y(t)$  are obtained for generating an error signal  $e(t)$ , which is considered as an input to the controller.

Open loop controllers are simpler than closed loop ones, but they are not frequently used because they require accurate predictions of the output variable  $y(t)$  since they are not robust enough for disturbed environments. Closed loop control schemes overcome those problems through feedback information from sensors.

Controllers interact with the environment through two types of devices: sensors and actuators. A sensor is any device that captures information from environment and allows control system to perceive it. By the other side, actuators are devices that allow control systems to deliver information to the

environment. A simple example of closed loop control is on-off level control for a tank, in which the controller perceives water level through a capacitance probe (sensor) and uses that information for activating an on-off valve (actuator) in order to regulate water flow incoming to the tank.

This example is simple because there is only one controlled variable (water level) in a very limited environment (tank). However, more complex systems are common, in which a large process can be subdivided into subsystems (interconnected tanks, for instance) or many processes are involved so it becomes necessary to consider multiple variables. In that context many architecture control approaches arise, which can be classified as centralized, decentralized or distributed.

In centralized control all subsystems are controlled via a single unit [20]. This approach is useful because it can consider every interaction between subsystems for generating a suitable control action. Nevertheless, coordinating and maintaining such systems is difficult because all the operations rely upon the central agent, which makes the system also less robust.

On the other side, in decentralized control each subsystem is controlled independently and network interactions are ignored and treated as local subsystem disturbances. Decentralized approach is used because is simple, but it is well known that it does not work well when interactions between subsystems are strong.

Distributed control arises as an intermediate approach, in which decentralized structure is preserved but interactions between subsystems are considered, so global characteristics of the whole system can also be guaranteed.

In general terms control theory works with abstractions of actual processes for handling main characteristics of them in a simplified way. These representations of reality are called models, and they are particularly important in a special control technique known as Model Predictive Control (MPC). In MPC an online optimization problem is solved for determining the manipulated variable value that maximizes a specific objective function (commonly a compromise between fast achieving a desired condition for the dynamic system and saving energy) subject to proper constraints (related to the dynamic system, the control architecture or the environment). That problem is solved considering near future system outputs through predictions generated with models of it.

Such as presented for MPC, automatic control methodologies generally consider modelling for identifying the system that will be controlled, simulations are deployed to estimate system output and for testing different control strategies, optimization is used for obtaining the best control signal under specific criteria, and expert systems or fuzzy logic are used for developing suitable control algorithms, among others.

Many automation technologies have been developed in order to deploy such automatic control methodologies for optimizing production and services. DCSs (Distributed Control Systems) for complex systems, SCADA (Supervisory Control And Data Acquisition) systems for control and

acquisition, PLCs (Programmable Logic Controllers) for implementing logic algorithms, PI system by Osisoft for real time data integration, and G2 by Gensym for real time expert systems are just few examples. We want to take advantage of all these technologies that have been developed for automatic control, and use them in RTERS implementation.

Therefore, there are some relevant concepts and aspects that it is necessary to define for formulating a control problem, such as system, model, variables, and control architecture, among others. In next section we describe how some automatic control tools have been applied to emergency management, and below in Section V we discuss how to apply them in natural disaster management.

### III. REAL TIME EARLY RESPONSE SYSTEMS

As stated before, we define a Real Time Early Response System (RTERS) as a system that uses real time information for creating a dynamic response to control a situation in its first moments. It corresponds to a special kind of Emergency Response System, as such its temporal domain is placed immediately after an event is detected, and it benefits from the use of information systems for reducing decision making time and facilitating coordination between the participating units [21].

#### A. Factors that Define RTERSs

The features of RTERSs are diverse and depend on the kind of event they address. Even though, as shown in Fig. 3, we can identify some common factors that allow us to categorize them: context in which they act; their system architecture; their decision algorithm; and the representation of the world that they use. Next, we describe each of these elements.

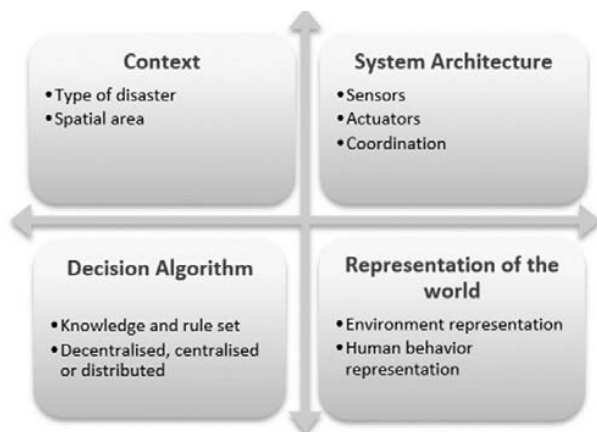


Fig. 3 Main factors that determine RTERSs features

#### 1. Context

The context is defined by two features: the type of disaster that the RTERS addresses, and the spatial size of its domain. Related to the former, it can correspond to earthquakes, fires, tsunamis, flash floods, among others. The last one can be classified in room level, building level, city level, and country level, for example.

#### 2. System Architecture

The system architecture is defined by sensors, actuators and coordination mechanisms between them. It is interesting to remark that the system architecture must be strongly related with the context in which the RTERS acts. For example, sensors related to a fire emergency are intrinsically different from those related to tsunamis; and actuators utilized for a country level system must have bigger scope than those designed for operating in a room level one. So system architecture design must be focused on the context in which the RTERS will be developed.

#### 3. Decision Algorithm

A Decision Support System (DSS) is an entity that helps decision makers in their decision making process within a determined context [22]. It must consider all the relevant information about a problem and make a decision based in the application of a rule set over this information to achieve an unbiased advice for the decision maker.

The DSS is composed of 5 subsystems: External data, Models, Knowledge, Rule Set and Graphic User Interface (GUI) [22]. So decision algorithm is the core of the DSS, where external data, models and knowledge are integrated through a rule set for disseminating a suitable suggestion on the GUI.

In our concept of RTERS, the DSS must integrate real time information from sensors with previously set representations of the world, process that information and make a suggestion that allows the accomplishment of decision makers' objectives. Those objectives depend on the specific RTERS design, but they are commonly related to avoiding risks and minimizing losses.

#### 4. Representation of the World

As RTERSs are designed for helping in emergency situations, they must act quickly for helping population when decision making is needed. Therefore they cannot wait the development of the disaster for executing actions, so they must use previously set structures for representing the world and studying possible near future scenarios.

For RTERSs we require to characterize mainly two aspects: environment and human behavior. Environment representations correspond to those which describe both, static environment such as walls, halls and exits of a building, and dynamic situations such as the development of the hazard or risk spreading. By the other side, even though human behavior characterization could be considered as an environment representation since for an individual agent the crowd behavior could be interpreted as part of the environment, we have decided to consider human behavior representation separately because of its complexity, and because it represents the system we aim to control.

#### B. Some Works Related to RTERS

In this section we analyze four systems that we have recognized as related to RTERS concept, which validate the suitability of the concept here introduced. Their main features are presented and their constitutive elements are identified

according to the factors depicted in Fig. 3.

### 1. Crowd Guidance Optimization [15]

In [15] an optimization problem is formulated to evacuate as many people and as fast as possible whereas reduce the relevant risks through appropriate guidance of crowds.

- *Context:* The article [15] addresses building evacuation because of fire.
- *System Architecture:* A dynamical guide is presented to the people in the building. The fire spread and the fact that not all the people will follow the guidance are considered, but they are not explicitly measured. There is no specification of sensors and actuators.
- *Decision Algorithm:* It can be seen as an open loop distributed control algorithm. An optimization problem is formulated, and it is solved using the divide-and-conquer approach. The sum of the expected number of total people evacuated and the expected cumulative number of people evacuated is maximized, and a risk measurement is minimized. Because of the distributed nature of the approach, the output of the DSS is a different dynamic guidance for each group of people inside the building.
- *Representation of the world:* It uses a macroscopic dynamical model for human behavior characterization, a room-and-path model for static environment representation and a probabilistic cell model for fire spread.

Main contributions of [15] are the formulation of the optimization problem for crowd guidance, and the integration of microscopic issues, like impatience and trust on the guidance, on the macroscopic model of crowd behavior.

### 2. Real Time Distributed DSS [16]

In [16] a decision support system implemented as a dynamical and distributed indicating evacuation system is presented. It is part of ALADDIN project ('Autonomous Learning Agents for Decentralised Data and Information Networks') [23].

- *Context:* A strategy for building evacuation due to the spreading of a hazard (e.g. a fire or hazardous gas) is presented in [16].
- *System Architecture:* It considers a sensor network, where each sensor is capable of detecting the presence and intensity of the hazard. Also it considers a network of decision nodes distributed through the analyzed area. The suggestion of a decision node is communicated to people in its vicinity via a visual indicator (such as a smart panel) or a wireless communication device.
- *Decision Algorithm:* The approach used corresponds to open loop distributed control. Each decision node uses information from local sensor nodes and its adjacent decision nodes for calculating the most suitable evacuation direction considering the distance to the closest exit and the hazard quantification of the path.
- *Representation of the world:* The environment is characterized as a directed graph composed of decision nodes, and the design does not consider human behavior

representations. Fire spread is simulated for testing the system, but it is not considered on the decision algorithm.

Work presented in [16] contributes in directly considering real time information from sensors in the Early Response System, and also presenting a novel distributed DSS, where every decision is made in a local scope.

### 3. RTERS using Feedback Control [17]

In [17] feedback information is considered for controlling building evacuation. It states that egress performance can be improved by real time adaptation of escape routes depending on feedback from the real scenario.

- *Context:* It is presented as building evacuation, but the simulations are presented for room level. The type of emergency is not specified, since it is mainly centered on avoiding congestion for minimizing total evacuation time independently of the particular hazard.
- *System Architecture:* It considers as sensors not only fire, smoke and hazardous gases detectors, but also devices (such as cameras and radio localizers) developed to count and monitor people and foresee panic phenomena. About actuators, it states that the instructions are provided in the form of colored symbols, to be more intuitive and immediate to read. Also the frequency of the message depends on the level of danger.
- *Decision Algorithm:* It corresponds to feedback supervisory control. The time needed for total evacuation and final number of evacuees is predicted; also the current evacuation rate is estimated in order to calculate the congestion state of each exit.
- *Representation of the world:* Environment is characterized through exits with nominal capacity, and for representing human behavior it uses a macroscopic model of the cumulative number of evacuated people. Spreading of the hazard is not considered.

The main contribution of [17] is establishing the role that feedback information can play in a RTERS, being a useful tool for incorporating real time information of the distribution of individuals in different places of the environment, the availability of doors, or the flow in critical points in the control strategy.

### 4. RTERS Using Networks Concepts [18]

The method presented in [18] for evacuation guidance is unusual, since it considers similarities between package routing in networks and people guidance during an emergency. Thereby people are modeled as clients with different exigencies (Quality of Service QoS) for allowing personalized evacuation suggestions.

- *Context:* It addresses building evacuation because of fire.
- *System Architecture:* It considers sensors for both crowd behavior and fire spread. Portable devices and visual indicators are used as actuators.
- *Decision Algorithm:* The approach presented can be seen as feedback decentralized control. When an evacuee arrives to a PoI, the best route is calculated according to his/her chosen criterion (energy metric, safety metric,

time metric or distance metric) and considering the current state of fire spread.

- *Representation of the world:* The physical world is represented by a set of “point of interest” (PoI), each of which is described as a single server with one queue. People are considered as clients with different kind of interests, so they can choose which kind of path follow according to their specific features. Hazard extent is characterized through hazard spread rates and hazard growth rates.

In [18] an interesting approach is presented applying network concepts to people routing. Also, it considers that not all the individuals will prefer the shortest path (or the safest path) because that decision depends on their specific characteristics. This personalized approach could allow to improve people disposition to follow the guidance.

The four works presented above, through different approaches, generate dynamic responses to emergency situations helping people in their decision making process. Nevertheless, they are mainly designed for fires or other manmade disasters, so they are not directly applicable for natural disasters. In next section we discuss the main characteristics of natural disaster management context that should be considered for a RTERS design.

#### IV. NATURAL DISASTERS MANAGEMENT CONTEXT

Understanding natural disasters is not an easy task, mainly because it is a concept that involves many different and complex dimensions. Firstly, is important to distinguish a crisis from a disaster: whereas crisis are situations that have negative effects but their root cause is, to some extent, self-inflicted through such problems as inept management structures and practices; disasters commonly arise when people is confronted with sudden unpredictable catastrophic changes over which they have little control [24].

Physical natural disasters are a specific type of disaster defined according to their origin. They are events that are precipitated by the occurrence of natural extreme events such as earthquakes, fires, volcanic eruptions, floods, and tsunamis, and have a profound effect on property, life, economy, or environment, beyond the coping ability of the affected party [25].

In general terms, the “disaster” quality is directly related to the intensity of their consequences in human context [25] (e.g. a big flood in an uninhabited area can hardly be considered as a natural disaster). Since in a disaster context people face an unfortunate event but have little control over its occurrence, disaster management must put effort on mitigation and preparedness phases for preventing a crisis triggered by a natural disaster, but it is also important taking measures that allow a suitable population response for minimizing their vulnerability to the event.

Since it seems beyond our capabilities to avoid the occurrence of a natural event, through a suitable response could be possible limit its associated risks for population reducing its vulnerability.

Currently most efforts on response phase of natural disaster

management are focused on developing Early Warning Systems (EWSs) for providing a suitable alert to the population, assuming that potential impact of large natural disasters on urban societies can be reduced by timely and correct action after a disastrous event [10]. The EWS design strongly depends on the intrinsic features of the specific event that it addresses, for instance earthquake EWSs are centered on characterizing and detecting ground movements of the first moments of the event [10], and tsunami EWSs study strong seismic events and their possible influence in sea levels [4], [5]. There are lots of works focused on studying and designing EWSs for different kind of disasters, and it is evident that they are useful tools for informing population of an incoming event, but multiple efforts put on designing EWSs that generate a well-timed alarm are not fully exploited if their outputs are not used for activating suitable response actions [14].

Therefore, it is clearly important addressing the step that follows EWSs, i.e., once a truthful alarm is disseminated it is imperative defining how to use that information for minimizing associated risks and losses. In that perspective, Real Time Earthquake Information Consortium (REIC) is a Japanese institution dedicated to develop research about how to achieve practical effectiveness of EWS in earthquake response [26], through which different automatic and semiautomatic plans have been generated for emergency response using as input the alert from an EWS. Their applications include disconnecting hazardous gases and chemical supplies in semiconductors plants as can be seen in Fig. 4 [27], emergency protocols during surgeries, and even consider automatic cut off of heat sources and automatic door opening in domestic evacuation routes.

Other systems for addressing response phase in natural disasters context are the called “Rapid Response Systems”, and their main objective is to provide reliable information for accurate and effective characterization of the event in short period of time after it is detected [10].

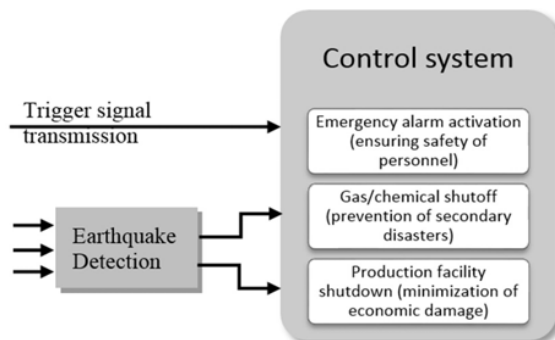


Fig. 4 Some countermeasures in Japanese semiconductors plant after an earthquake detection [27]

In [9] a Prompt Assessment of Global Earthquakes for Response (PAGER) is presented for California. Different developments are integrated for generating a quickly estimation of the shaking intensity and the number of people

exposed to it. It creates a one page summary of the main features of the event in short period of time, which is available online and represents a very useful tool.

In [10] an Earthquake Rapid Response and Early Warning System is presented for Istanbul (IRREWS), which aim is to detect in short time earthquakes for opportunely alerting population and providing fast and accurate information for damage assessment. They identify that an Earthquake Early Warning in urban and industrial areas would be helpful for clean emergency shutdown of systems susceptible to damage such as power stations, transportation, computer centers and telephone systems, but they do not specifically address the problem of designing such a system for those post-detection actions.

In summary, natural disasters context is full of uncontrollable issues, which are mainly related to their occurrence and constitute large disturbances for the system we aim to control. Nevertheless, suitable and informed response actions can avoid that their consequences form a catastrophe. In literature the response phase for natural disasters management has been largely addressed, mainly focused on detecting the natural event as soon as possible for alerting population in time, or on generating fast and accurate information for disseminating, but systems for guiding immediately post-detection actions have been barely addressed. We propose that RTERSs can fill that gap, so next section discusses the requirements that a RTERS must consider for natural disaster management, the challenges that must face on each one of its design factors, and how automation technologies and automatic control can contribute in this subject.

## V. RTERS DESIGN CHALLENGES

Emergency situations are continuously changing during their first moments, not all the previous knowledge remains valid after a disastrous event, people can get blocked by stress, and their decision making process can be affected by their emotional state [28]. Therefore it is important to develop a system that could help them in real time.

By definition a real time system must react to stimuli from its environment within intervals dictated by its own environment [29]. In that sense, there is a common myth that real time systems must be fast [30], of course they have to be fast enough for guaranteeing the required deadlines, but their time scale is dominated by environment, and consequently their performance is measured according to that response time.

Understanding that it is necessary to reduce people vulnerability to natural disasters, our long term goal is designing a RTERS for helping people in their decision making process during evacuation, so we aim to contribute on one of the factors that affect vulnerability: immediate response [31]. The idea is to integrate concepts and tools from automation technologies and automatic control presented in Section II to address that problem. Next we discuss the main challenges that we must face in the each one of the RTERS design factors.

### A. Context

RTERS design for natural disasters will be strongly dependent of the type of disaster it addresses, since its requirements will be ruled by the time of its context. In that sense, Table I shows a classification of natural hazards according to the duration of their impact [32], in which we can see, for example, that would be unrealistic designing a RTERS for addressing the immediate response of population to a lightning, because the duration of its impact is just an instant. So it is essential to be sure that the technical capabilities of the system can manage the specific event time scale.

For choosing the spatial scope of the RTERS we must integrate the natural hazard spatial extent, the amount of people in that area, and technologic capabilities of the system. For instance, a tsunami can cover thousands of miles but affect just a small town, so the RTERS must be designed for acting in that town scope. If technologic resources are not enough, RTERS design must prioritize helping most vulnerable population of the town.

### B. System Architecture

Once defined the context of the RTERS, it corresponds to define the RTERS architecture. As stated before, of course it has to be related to the specific hazard and the scope of the RTERS.

TABLE I  
CLASSIFICATION OF NATURAL HAZARDS BY DURATION OF IMPACT [32]

Type of Disaster	Duration of Impact
<i>Lightning</i>	Instant
<i>Avalanche</i>	Seconds-minutes
<i>Earthquake</i>	Seconds-minutes
<i>Tornado</i>	Seconds-hours
<i>Landslide</i>	Seconds-decades
<i>Tsunami</i>	Minutes-hours
<i>Floods</i>	Minutes-days
<i>Subsidence</i>	Minutes-decades
<i>Windstorm</i>	Hours
<i>Hurricane</i>	Hours
<i>Snowstorm</i>	Hours
<i>Environmental fire</i>	Hours-days
<i>Volcanic Eruption</i>	Hours-years
<i>Coastal erosion</i>	Hours-years
<i>Accelerated Erosion</i>	Hours-millennia
<i>Drought</i>	Days-months
<i>Expansive soil</i>	Months-years
<i>Desertification</i>	Years-decades

Since our aim is controlling human behavior during evacuation through suitable suggestions, and considering that multiple disturbances are presented in emergency situations, it becomes mandatory closing the control loop through feedback information from sensors. In that sense, we must access to real time measurements about both hazard and human behavior. Hazard measurements should be acquired through appropriate sensors for making threat assessment in real time and for trying to quantify some disturbances. On the other side, the measurements about human behavior are required for closing the control loop with observations from cameras or other devices. The amount and resolution of sensors will depend on the extension and characteristics of RTERS control domain,

and automation technologies can contribute to integrate real time data through some products like PI system by Osisoft.

As a control system, RTERS acts upon manipulated variables for influencing the dynamical system behavior. In this case, since RTERS suggestion is delivered to decision makers through actuators, they must be defined in close relationship with the manipulated variables. They can be visual indicators, lights, readable messages or audible alarms, and can be deployed in building, streets and houses or can be activated in mobile devices. For deciding which kind of actuators the system should use, it is important to consider that the main aim of the system is helping people, so we cannot forget human factors. Emergency situations make people insecure since not all the previous knowledge remains valid and they need some guide, but at the same time their interpretation of risk affects their decision making process and they could have no disposition to follow the guidance [33]. Considering these aspects we can find the best way for delivering a message that makes sense for people in emergency situations. Also defining RTERS actuators depends on the spatial range previously defined, mainly for estimating the number of devices needed and their position.

Coordination mechanisms for system architecture could be largely discussed, because they depend specifically on the components and the application. Nevertheless, as a first approach distributed mechanisms seems to be the most appropriated since allow cooperation between different devices, they are more robust than centralized approaches and they have more available information than completely decentralized ones.

### C. Decision Algorithm

Decision algorithm is the backbone of the RTERS, because the assumptions made and the way it integrates models, real time measurements and historical knowledge will determine the suggestions that population will receive, and hopefully, their actions in immediate response.

The RTERS should be triggered by an EWS alarm, initiating the following steps:

1. Make a real time risk assessment of current situation using sensor information.
2. Generate predictions of possible near future scenarios combining current measurements, previous knowledge, representations of environment, hazard spreading and people behavior.
3. Create risk quantifications for the calculated scenarios.
4. Provide suggestions to people that allow minimizing risk or other personalized established criterion following a rule set.
5. Return to step 1.

Steps explained before can be seen as a basic structure for creating a RTERS, therefore they can be complemented with multiple procedures. For example an adjustment of model parameters can be made using real time measurements for obtaining more accurate predictions in step 2, or a verification of people following the guidance can be made in step 1 for providing a personalized suggestion in step 4.

The rule set of the DSS must consider some relevant aspects of emergency situations, such as the highly unpredictable behavior of humans, the uncertainties due to the large environment disturbances, the static environment restrictions such as number and location of exits, and common interactions between people.

The implementation of the decision algorithm can be made using suitable automation technologies such as Programmable Logic Controllers (PLCs), Distributed Control Systems (DCSS) or G2 for real time expert systems.

### D. Representation of the World

Representations of the world are fundamental tools in RTERSs because they allow to estimate and to predict scenarios for making decisions in advance. On the one hand we need to characterize the environment for describing static features such as buildings, halls and streets so it is possible to consider their restrictions for guiding people in the area; and for modelling hazard spread, such as tsunami extent, impact of earthquake in some area or fire spreading before it occurs. On the other hand we must use representations of human behavior for both trying to understand people conduct in order to make realistic suggestions that make sense to them, and trying to predict complex situations like congestion or group behaviors.

There are many approaches in literature for addressing those types of models. For static environment room-and-path [16], directed and undirected graphs [17], and cells [11], [13], [34] are common. For hazard spreading modelling depends on the specific hazard, but many works also use cells models [11], [15].

For human behavior there are two different approaches: macroscopic approaches that use dynamical deterministic or probabilistic models for estimating aggregated behavior of people, which do not consider personalized characteristics or heterogeneity of people but are useful for design purposes; and microscopic dynamic models that incorporate observed factors such as stress effects, congestion, familiarity with evacuation routes, group behavior and trust in external suggestion, but because of their complexity they are used just for testing evacuation strategies but not for designing them [15]. We would like to incorporate some of those microscopic issues in the design process of the RTERS, because we consider that those details related to human behavior are the main sources of crisis in emergency situations [35].

For instance, a well-known approach used in automatic control for characterizing human reasoning is fuzzy logic [36], which results as a natural link for communicating social features and control systems, and could be helpful for addressing this problem.

Therefore, the main challenge in the application of automatic control tools to this problem is the fact that we want to control population, which a priori is no controllable, hard to model and highly susceptible to disturbances, so the behavior representation that we consider for control purposes will be the key for the practical success of the RTERS interacting with real people in emergency situations.

In order to illustrate what has been presented, Fig. 5 shows

a general schema of the RTERS structure proposed, where the way in which RTERS interacts with the system (environment, hazard and population) is depicted.

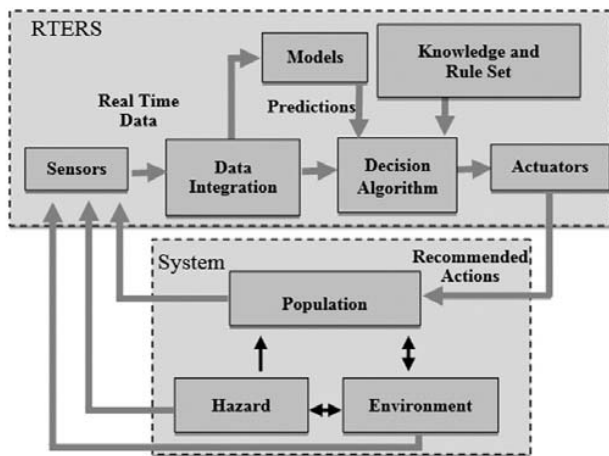


Fig. 5 RTERS schema

## VI. CONCLUSION

This paper presents a new concept of response system that considers real time information for generating suggestions that could help population in their decision making process during a natural disaster. Real Time Early Response Systems (RTERS) respond to the need of minimizing vulnerability during the immediate response to natural disasters, mainly considering that emergency situations are continuously changing and people may need guidance for reacting appropriately.

We have identified the main challenges that natural disaster context incorporates for a RTERS design, and we have proposed a general scheme for addressing them using automation technologies and automatic control concepts. Therefore our future work will be focused on choosing, based on solid reasons, every element that composes a RTERS designed for a specific context.

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