The Contribution Of Radio Sciences to Disaster Management

Tullio Joseph Tanzi, François Lefeuvre

THE CONTRIBUTION OF RADIO SCIENCES TO DISASTER MANAGEMENT

T. J. Tanzi[a], F. Lefeuvre[b]

[a] CNRS/LTCI. Centre for Research on Risks and Crises, Mines-ParisTech
Rue Claude Daunesse, B.P. 207, 06904 Sophia-Antipolis Cedex, France
[b] CNRS/LPCE. 3A, avenue de la recherche scientifique, 45071 Orléans Cedex 02, France

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ABSTRACT:

When a natural disaster occurs, the fast and effective organization of emergency assistance assumes the rapid provision of reliable information concerning the state of the infrastructure; the creation, in almost real-time, of a response chain and the reconfiguration of telecommunications systems. This article proposes a chain which incorporates algorithms from recent research, with particular focus on communication systems and reconfiguration techniques. The problems of image reliability and the effects created by ionospheric propagation and turbulent surfaces are discussed.

1. INTRODUCTION

The smooth operation of communication and observation services is critical at all levels of disaster management. Radio communication is essential for transmitting alarm messages, the exchange and sharing of information between the various humanitarian intervention teams (Tanzi & Servigne, 1998), the definition and coordination of action plans, and the dissemination of information to private and public services, and the population at large (Iapichino *et al.*, 2008). Remote observation services (available twenty-four hours per day in all atmospheric conditions) are essential in order to evaluate damage, to quickly detect meteorological, geophysical or hydraulic events (earthquakes, tsunamis, hurricanes, etc.), and to provide the information needed for the planning and management of rescue activities.

Access to this observational data is facilitated by the international 'Space and Major Disasters' charter which has been signed by many space agencies. This charter aims to provide a unified system of data acquisition and its delivery to public and private services in the areas affected, together with the emergency services of other countries which may provide assistance, via the concept of 'authorized users' (Rodriguez *et al.*, 2009). Many bodies of this type exist. Notably, SAFER (SAFER implements and validates the preoperational versions of the GMES Emergency Response Service.) and ERCS (Emergency Response Core Service) in the GMES (Global Monitoring for Environment and Security) context; SPIDER (Space-based Information for Disaster Management and Emergency Response), developed by UNOOSA (United Nations Office for Outer Space Affairs) and SENTINEL ASIA which brings together approximately fifteen Asian countries.

When available, remote sensing satellite images are the best source of information for disaster management (Yamazaki, 2001). They can be rapidly collected and cover wide geographical areas. Photo-interpreters can use them to rapidly provide summary maps to bodies responsible for disaster management (government ministries, civil protection agencies, regional and local administrations, offices of the United Nations, non-governmental organizations, etc.).

When a natural disaster occurs in a populated area, the fast and effective organization of disaster management is paramount in order to bring relief to the affected population, to reduce the number of victims and to limit the economic impact (Chatterjee *et al.*, 2006; Fruneau *et al.*, 2005). A lack of, or inappropriate organization causes delays in the relief effort. This makes operations more difficult, increases losses and delays, and can even prevent the return to a normal situation. In a crisis, time is a critical factor.

New technological approaches are necessary to make risk management more effective, before, during and after a potential crisis. They must take into account specific actions to be undertaken at each stage of the crisis and the particular tools needed. New methodologies are needed to devise systems which combine the use of telecommunication tools, e.g. remote sensing (Pampaloni & Saranboni, 2004), and databases designed to handle the spatial and temporal aspects of information and which implement the various rules appropriate to risk situations (Barlier, 2008).

Risk prevention and crisis management imply the communication of 'the right information to the right person in the shortest possible time' (Tanzi & Perrot, 2009). When a risk becomes a disaster, crisis management requires simultaneous access to various databases (technical, phenomenological, environmental and regulatory). The framework and software used for these communications databases have a significant impact in terms of implementation, performance and architecture.

A description of these facilities and their operating conditions are therefore crucial pieces of information which must be made available to rescue teams as soon as possible (Trebossen *et al.*, 2005). The operation of such a system highlights two aspects of the development of risk. The first aspect is temporal; it is necessary to determine the appropriate time to raise the alert, to inform the population, to deploy support tools and to identify unusable roads. Secondly, the location of the most critical sectors must be clearly established as quickly as possible.

In addition to image acquisition, this type of system comprises four principal areas of work, or subsystems, involving various scientific disciplines.

1. This subsystem enables communication in crisis conditions. Its main properties are ease of deployment, and reliable and

robust communications, together with the ability of various networks to communicate with each other.

2. This subsystem deals with management of information from databases and geographical information (GIS).

3. This area concerns the acquisition of information mainly from satellite images, which can be integrated with data from other sources e.g. sensors, the Internet, etc.

4. The final area of work synthesises information from many different sources, intended for operational relief teams.

The objective of this article is to consider an architecture adapted to disaster management (Yamazaki, 2001), and to identify the scientific bottlenecks.

2. GENERAL OUTLINE

A system of this type must be able to provide answers at several levels (Tanzi & Servigne, 1997; Laurini, 1998). When the sequence of events constituting a crisis are analysed, successive stages become apparent. In each of these stages, the events, their consequences, and the working conditions of those managing the crisis will vary, which will variously impact the relative importance of the actions to be carried out. Operators will prioritise those actions which seem essential in the current context.

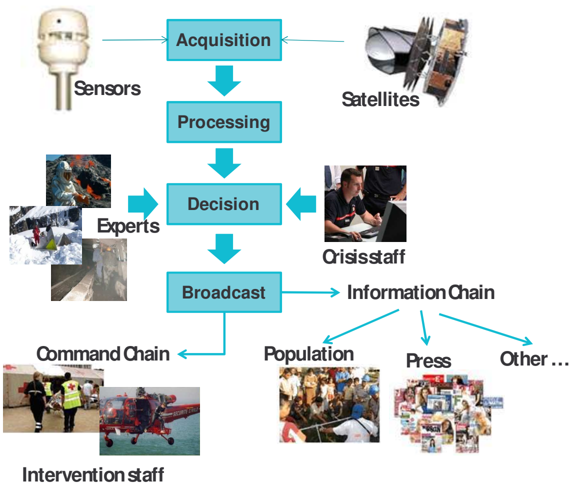

Figure 1: Temporal cycle of a disaster

The key objective during a crisis is the resolution of that crisis, i.e. everything is done in order to avoid or reduce the consequences of the incident. The question of why or how the incident arose is not considered at this time, even if this information would make it easier to understand the event. This process is delayed until a more favourable time.

It is only when the crisis has been overcome, and conditions have returned to their normal state (i.e. comparable to those of before the incident), that the time comes to attempt to understand exactly what occurred. Integration of this knowledge into revised procedures may make it possible to prevent the recurrence of this type of incident, or if it is not possible to avoid it completely, to facilitate the management of the crisis, and reduce its consequences.

The challenge of risk requires consideration of the following successive temporal aspects (Tanzi & Servigne, 1998):

- During the crisis: a rapid response which aims to facilitate decision making in order to control the immediate problem,
- After the crisis: a deeper analysis of the unfolding of the problem in order to draw lessons for the future:
  - To prevent a recurrence of the incident, or
  - To improve crisis management (if a recurrence cannot be prevented).
- Long-term actions: the capacity to carry out analyses based on the nature of the situation, in order to understand the various processes and to integrate counter-measures into operating procedures.

3. INFORMATION ACQUISITION

Information collected by the earth's observation satellites can be used to extract physical, biological and human data. These images provide an overview of vast territories and make it possible, through repeated observations of the same areas, to study the evolution of certain phenomena such as desertification, drought, pollution, land use, urbanization, etc.

There is no one satellite or constellation of satellites dedicated to disaster management. Table 1 is a non-exhaustive list of the principal satellites in orbit and the various space agencies that control them.

Table 1: Satellites and space agencies

Agency	Satellite
ESA	ERS, ENVISAT
CNES	SPOT
CSA	RADARSAT
ISRO	IRS
NOAA	POES, GOES
CONAE	SAC-C
JAXA	ALOS
USGS	Landsat, Quickbird, GeoEye-1
DMC	ALSAT-1, NigeriaSat, BILSAT-1 UK-DMC, TopSat
CNSA	FY, SJ, ZY satellite series

These satellites have resolutions ranging from 60 cm to several hundreds of meters. Their footprint varies from 8 km^2 to 100 km^2 (or more). They implement various technologies: optics (panchromatic, multi-spectral), radar, infra-red, etc.

Although the use of remote sensing images for mapping is an interesting area of work, it does not respond to every need. Images from space can be taken shortly after an event and can cover a wide territory. The idea is to quickly produce mapping of the infrastructure soon after the disaster. However, comprehensive mapping is not always possible. Optical images can become unusable when there is too much cloud cover. In this case, they must be supplemented by radio images such as those obtained by SAR (Synthetic Aperture Radar) which are not affected by cloud cover. Nevertheless, radio images, like optical images only show what their resolution makes it possible to detect and only provide partial information on conditions and infrastructure. To mitigate this problem the information they provide can be integrated into a comprehensive spatial information system where it is fleshed out by information from other sources.

Cross-referencing with textual data facilitates the semantic definition of objects extracted from the optical image, depending on their context. For example, the simultaneous use of information from high-definition optical images with descriptive information (e.g. administrative boundaries) can remove doubts about how an object should be classified, depending on whether it is in the city or a forest. This strongly increases the potential power of the analysis provided by the system.

The quality of radio observation services depends mainly on the resolution and coverage of the images and, for satellites, when they last visited the area. A search for hidden information in an image (the number of destroyed buildings, possible locations for a refugee camp, accessible highways, etc.) requires the removal of all distortion. Operational systems, which can make atmospheric corrections, do not make ionospheric corrections (e.g. the effects of scintillation on positioning, and Faraday rotation on data from synthetic aperture radar).

4. COMMUNICATIONS

Telecommunications systems have three principal functions: to link crisis management centres, to gather observational data and disseminate it to all users, and to distribute analyses and forecasts prepared by data processing centres. This demonstrates the extent of their role (in terms of monitoring and management) in predicting the potentially devastating effects of observed phenomena, in order to take suitable and timely remedial action.

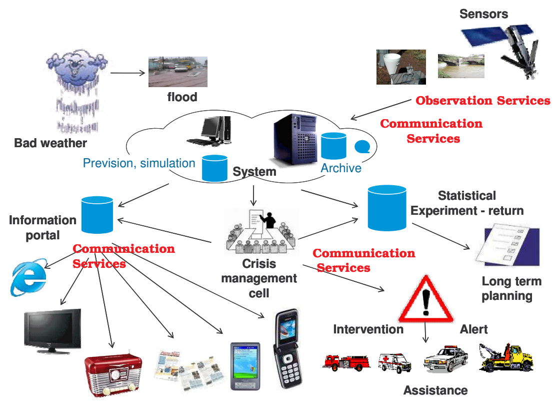

Figure 2: Example of a communication system

Depending on the location and the needs of the user, the available communication services can vary: satellite links (including wireless), high-frequency and very-high frequency (HF and VHF), fixed line telephony, etc.

The challenge relates to the creation of a secure communication system available to all actors (information providers, data analysis specialists, crisis management cells, emergency teams, the general public), before (forecasting), during (management) and after the crisis (feedback from experience).

During the crisis period, radio communication depends on:

- The available communication systems;
- Damage to fixed infrastructure;
- Potential upper atmosphere 'space weather' effects (in particular on HF and VHF communications); and
- The type of disaster (e.g. wild fires, strong magnetic interference, miscellaneous radiation).

Mobile ad-hoc networks which do not require an existing infrastructure can be deployed. However their particularities must be taken into account, namely: limited capacity, potential external intrusion, and the use of unallocated frequencies.

5. IMAGE PROCESSING

Real-time spatial analysis techniques make a powerful contribution to decision-making in critical situations. One of these is the creation of an executive information system (digital dashboard/tableau de bord de gestion), which enables collaborative decisions to be taken for the management and control of risk (Tanzi & Perrot, 2009). However, there are important constraints. These are due mainly to the fact that critical systems are implemented using a multiplicity of data sources and sensors which are geographically distant and highly distributed. The spatial and temporal aspects of information, the dynamic monitoring of mobile sources, and the enormous amount of database information to be analysed constitutes a significant source of difficulty. In addition, the multidisciplinary efforts necessary for this type of approach to work well poses a considerable problem.

Rescue teams need information that is directly relevant to their situation (be it an earthquake, volcanic eruption, flood etc.). It should be strategic, and help in decision making. Syntheses must be developed from traditional space-time data managed by current information systems. The quality of results issuing from this process can be improved by an enhanced analysis of database information, which goes beyond simple geo-referencing capabilities.

The general question concerns how to best use all the support offered by technology in order to provide an operational summary to relief teams on the ground. The provision of this kind of support calls for scientific, algorithmic and architectural analyses.

5.1 Principal image processing functionalities

Four types of image processing functionality are particularly useful to a risk manager.

Zoning. Zoning consists of partitioning the image according to defined criteria. 'Big picture' zoning aims to identify the main classes of land use, such as urban, industrial, forest, agricultural, or networks (e.g. roads, waterways). Zoning can then be re-applied to a particular area of the image. A typical example is the division of an urban zone into densely and sparsely populated areas.

Counting. Counting the objects present in a zone enables an assessment to be made of the impact of the event. This information provides valuable input to the decisions that have to be made when preparing relief plans. Among the most important data is a count of buildings, which enables the definition of appropriate relief and logistical measures. It also facilitates monitoring of the deployment of refugee camps (official or otherwise), which provides information on the whereabouts of local populations.

Identification of roads. The identification of roads and more generally, networks (roadsroads, railways) enables an assessment to be made of access to the affected zone. This information makes it possible to define various routes for the provision of relief.

Damage evaluation. Damage evaluation is an important phase. It can provide an overview of damage in a zone where a rescue team is needed. It also makes it possible to define the equipment and measures required in the intervention. The principal data resulting from this evaluation are the level of damage to houses, and an estimate of the number of people dead, wounded or homeless. An evaluation of the damage to the communication network (roads, railways) is also important for the design of the intervention plan.

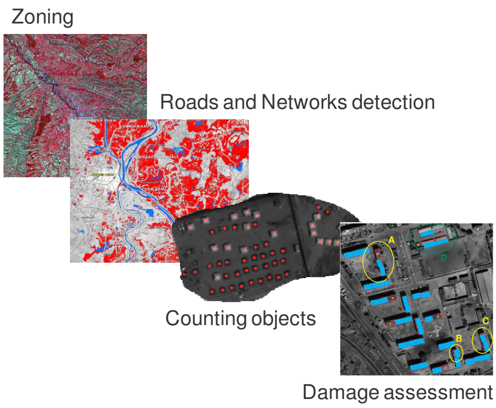

Figure 3: Image processing functionalities

Detailed maps are produced from the images available at the beginning of the crisis. However, these may misrepresent the current situation. Figure 4 is a temporal diagram of operations. It shows the organisation of feedback, which enables the initial maps to be corrected and updated.

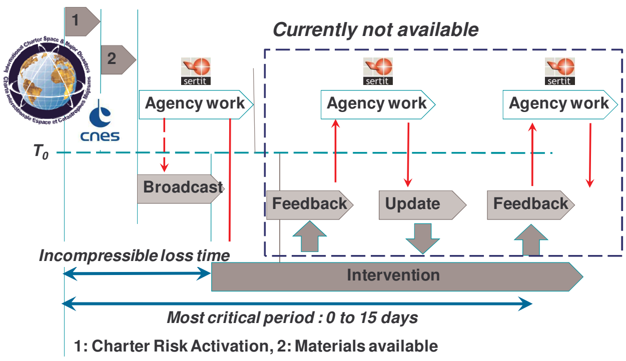

Figure 4: Organisation of feedback

If images of the affected zone prior to the event are available, tools can be rescheduled. This may identify changes which can help to measure more precisely the level and characteristics of damage (total destruction, collapsed roofs, structural damage etc.). However, when before-and-after images of the disaster are not available, work must be carried out with only one, or a few, post-event images.

6. DISCUSSION

The challenge posed by risk management crucially requires solutions coming from telecommunications and radio science in order to operate more effectively. A very simple formulation of the paradigm to be addressed is, 'to provide the right information, to the right person, at the right time, for the right decision'. In practice, this consists of providing those involved in safety with technical solutions that enable them: to be informed, to have useful tools (e.g. visualisation using support mapping, simulations), and to transmit instructions in order to ensure the smooth conduct of operations. This requires the deployment of sophisticated solutions and calls for the combination of two types of skills:

- The 'trade' skills of those who, as a result of their expertise, know how to act effectively and are aware of the risks engendered by crisis situations,

- The information and communication technology skills of those who able to provide the technical solutions likely to help their colleagues in their work.

The use of simple image processing functionalities makes it possible to compile information for disaster management services. When coupled with communication systems using a mesh topology (mesh networks) it becomes possible to very quickly deploy a solution in a hostile environment, such as a disaster area. The choice of this type of technology is motivated by the very great flexibility it brings. It makes it possible for all the active elements in the network to be fully connected, and avoids a ground deployment in remote regions where the characteristics are not known.

Radio Science, in particular, Commission F (Wave Propagation and Remote Sensing) of the International Union of Radio Science (URSI) has made a significant contribution to risk management. In combining: (1) upstream studies of wave propagation in non-ionised environments and interactions with ground and underground surfaces (oceans, ice, etc.), with (2) downstream studies linked to specific applications in the domains of telecommunications and communications, the Commission has contributed to the development of tools suitable for use in crises. However, several other URSI Commissions have carried out initiatives in liaison with Commission F. Interventions are on three levels, depending on whether the crisis is predicted, active, or over.

Before a crisis, the priority is to reinforce all forecasting services. Several services, related to space meteorology are already in place. They can issue warnings: (i) if there is a risk of black-out in HF and VHF communications, (ii) of predicted disruption to GPS signals and the effect on the local area, (iii) potential degradation to SAR imagery etc. In all these areas, where significant modelling efforts are essential to refine forecasts and quantify consequences, URSI's Commission G (Ionospheric Radio and Propagation), which deals specifically with aspects of ionospheric communications and remote sensing of ionized media, has an essential role.

However, other contributions are possible. For example, Commission J (Radio Astronomy) is involved in the radio detection of variations in solar activity; Commission H (Waves in Plasmas) studies, amongst other things, the physical modelling of radiation belts and Commission E (Electromagnetic Environment and Interference) provides advice on any electromagnetic compatibility issue. In addition, several studies are underway which attempt to predict the effects of a disaster directly. The use of the ionospheric signature of tsunamis which enables the temporal and spatial development of the event to be monitored. The search for the identification of electromagnetic precursors above seismic regions should also be noted. On the other hand, analysis of the characteristics of the propogation of electro-magnetic waves (the DEMETER programme) makes it possible to detect earthquakes as they create (tiny) disturbances in the propogation of the wave. (Barewald, 1981).

During a crisis, communication is paramount. For all communication services that detect changes in the ionosphere, it is essential to continuously monitor changes in solar activity; in consultation, as necessary, with space weather forecasting services. At the same time, it is important to monitor the validity of the available imagery, in order to avoid data 'holes', caused by a too fast or too conservative validation, which increases the time lag between observations. In addition, there is a longer-term problem which is the subject of URSI's Commission C (Radiocommunication Systems and Signal Processing). This is the need for free radio frequencies in areas where the majority of the frequencies have already been allocated, which may entail a reconfiguration of communication systems.

In all the phases of a crisis remote sensing systems, (especially those based on onboard radars and radiometers which are not sensitive to cloud cover), are particularly effective - as much for the acquisition of data that monitors the movements of weather phenomena (cyclones, hurricanes, rainstorms, etc.), as for follow-up of the consequences (e.g. flooding). Changes in the landscape can be identified and used to confirm the different scenarios during and after the disaster. However, supporting information is also important: data from optical instruments, from radar and radiometers on the ground, and that picked up from the analysis of GPS signals (GPS metrology).

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