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DISASTER MANAGEMENT SIMULATION AND RESEARCH INTEGRATION´S VIRTUAL TEST BED
PROPOSAL FOR THE CHILEAN NATIONAL RESEARCH CENTER FOR INTEGRATED NATURAL DISASTER MANAGEMENT (CIGIDEN)

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ABSTRACT

The Chilean National Research Center for Integrated Natural Disaster Management, CIGIDEN, was created in 2011 to develop, integrate, and transfer scientific knowledge to reduce the social consequences of extreme natural events. As one of its transfer products, CIGIDEN created a Disaster Management Simulation Lab (DMSLab) to deliver a practical training solution for disaster management. We propose a Virtual Test Bed to support the DMSLab by providing a simulation based, multi-disciplinary risk analysis platform. It will strengthen CIGIDEN's transfer and research integration capabilities, offering the tools and methodologies already being developed by the Center for emergency-based decision-making, optimization through simulation and humanitarian aid. A case study of a virtual disaster scenario developed with the Chilean National Emergency Office (ONEMI) is presented, to illustrate how the Virtual Test Bed can support research application in real scenarios.

1 INTRODUCTION

Each year between 1994 and 2013, more than 218 million people were affected by natural disasters (Centre for Research on the Epidemiology of Disasters 2015). The management of these events is challenging, given their consequences are hard to anticipate and the incidents are getting more complex, lengthy and costly (Barnes and Goonetilleke 2014). For example, in 2013 USD$22 billion were spent in humanitarian aid (Scott 2015). Despite this, the quality of the response after an emergency is degrading because there is no pre-planning for disasters and the communication between the responders is poor (Whybark 2015).

The Chilean National Research Center for Integrated Natural Disaster Management (CIGIDEN) was created in 2011 to meet the technical, societal and political challenges of natural disasters from an interdisciplinary perspective. As one of its transfer products, the Disaster Management Simulation Lab (DMSLab) was created. Its aim is to support the identification of vulnerabilities in the response cycle, by developing a simulation environment of extreme events within a specific geographic zone. In particular, the DMSLab was designed to test and improve the performance of decision-makers and administrative personnel from government agencies in disaster management, in the event of an earthquake or a tsunami. The interaction between CIGIDEN's research and the DMSLab and is depicted in Figure 1.

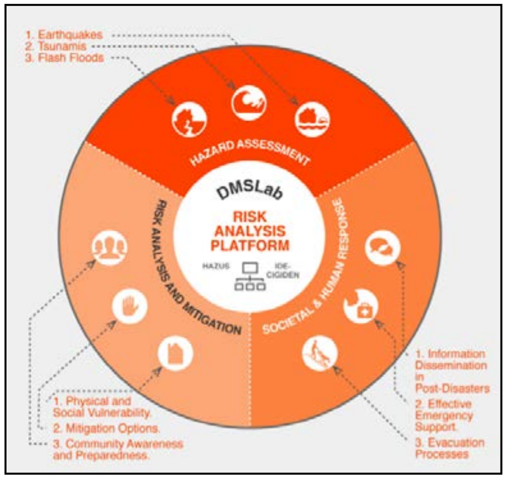

Figure 1: DMSLab and CIGIDEN Research Areas interaction.

The sole purpose of training, as the initial definition of the DMSLab, shows a self-induced restriction when considering CIGIDEN’s need of integrating its research lines. Given this, we propose the creation of a Virtual Test Bed (VTB) as a multidisciplinary risk analysis, simulation-based platform to promote the synergy between CIGIDEN’s research areas.

2 BACKGROUND

One of the main reasons why multi-institution emergency management teams fail is the lack of preparation for decision-making and organization during crisis (Kapucu and Garayev 2011). The literature presents different approaches to prepare personnel to deal with disasters, two approaches being development of training centers and training systems.

Training centers help build critical skills for people who are responsible for the protection and preservation of life, property and the environment during an emergency. These skills include those necessary to prevent, prepare, respond, recover and mitigate the potential effects of catastrophic events (FEMA 2014).

Training and simulation systems are another approach to improve and facilitate decision-making during emergencies (Kapucu and Garayev 2011). These computational platforms considers all entities that participate in the disaster management cycle, to develop a better surge capacity through representation of catastrophic events and situations (Jain and McLean 2003).

A key characteristic of these systems is the ability to run different training scenarios. Scenarios provide a context of danger, vulnerability and risk to rebuild past events and make hypothesis about future catastrophes (Alexander 2000). This response training can deliver better results when using scientific data and mathematical models to define these scenarios. It is also beneficial to provide personalization and flow modification options during training for each scenario (Mapar et al. 2012).

Natural disasters and crisis response require fast decision-making in threatening environments, making it difficult to gather relevant information, assess it and conduct a plan of action (Zhang, Zhou, and Nunamaker Jr 2002). To evaluate decision-making ability in training scenarios, it is necessary to simulate work under pressure and sensorial stimuli related to the disaster (Lai et al. 2015). Because of this, mobile devices and sensors are of great help to develop a learning experience closer to reality (Linnell, Bareiss, and Pantic 2013).

During the disaster management cycle each independent unit is responsible for specific tasks (Khorram-Manesh et al. 2015). Even if each participant institution has their own response protocols, preparedness for emergency should be exercised in an integrated manner. Training using independent solutions for each institution have not demonstrated improvement to future response capacity (Sinclair et al. 2012). Even more, if emergency exercise and management are focused on the collaboration aspects between organizations, the impact of the training during real execution is higher (Berlin and Carlström 2015).

Training systems and centers should also support learning activities after the emergency. Two process related to learning from incidents can be boosted using technology: analysis of events, and sharing and storage of information (Drupsteen and Guldenmund 2014). For the analysis, artificial intelligence techniques (such as data mining and classifiers) are already been used to improve response to future emergencies (Bartoli et al. 2015; Romanowski et al. 2015). Further, cloud systems allow to store and process big volumes of data, reducing technological infrastructure costs (Hashem et al. 2015).

3 PLATFORM PROPOSAL: VIRTUAL TEST BED FOR A DISASTER MANAGEMENT SIMULATION LABORATORY

VTB is a platform for research integration, designed to support crisis and/or disaster management through modeling and simulation for decision-making. Its main purpose is the synthesis of all research efforts of CIGIDEN, strengthening the already developed capabilities of its DMSLab so to improve the quality of the early response when facing a disaster.

For instance, models from different hazards (developed by CIGIDEN) can be applied during training sessions or while running simulated scenarios. By generating virtual environments using these models, it is possible to evaluate vulnerabilities, mitigation options, information dissemination and performance of early-responders.

Given this, VTB will be able to support CIGIDEN's research broadly. The design and implementation of each exercise will generate information regarding how risk assessment and mitigation plans are developed and executed in different settings (as public or private institutions). The training itself will be a tool to monitor the response of different actors when managing a crisis, including how protocols are actually implemented. Guidelines, models, maps and databases generated by CIGIDEN can be tested using VTB. By including these results into the simulations and exercises, the system will provide feedback to the researchers, while strengthening the platform capabilities for its final users. Finally, given VTB's nature, new research opportunities may emerge from the data analysis that it will produce.

Figure 2 presents an overview of DMSLab's Virtual Test Bed. From the design of a single training system, it is possible to provide solutions for disaster management in different situations. This differentiation will be accomplished by using specific tools and techniques, which will be developed by three areas of the laboratory: decision making, optimization through simulation and humanitarian response. Broadly, these areas will rely on predictive models and script writing to provide a case-based solution for emergency management. Continuous data analysis of the information generated while using the solution will provide feedback both for the predictive models and for the users of the platform.

VTB's areas will be supported by a common computational ground, facilitating the creation of tailored solutions for emergency training, management and post-event learning. This includes the use of cloud infrastructure to store and process the information, so as to accelerate the data mining and analysis process; an API to incorporate contextual information from sensors and mobile devices into the proposed platform; and media streaming capabilities to deliver a realistic experience during training and to complement the management process.

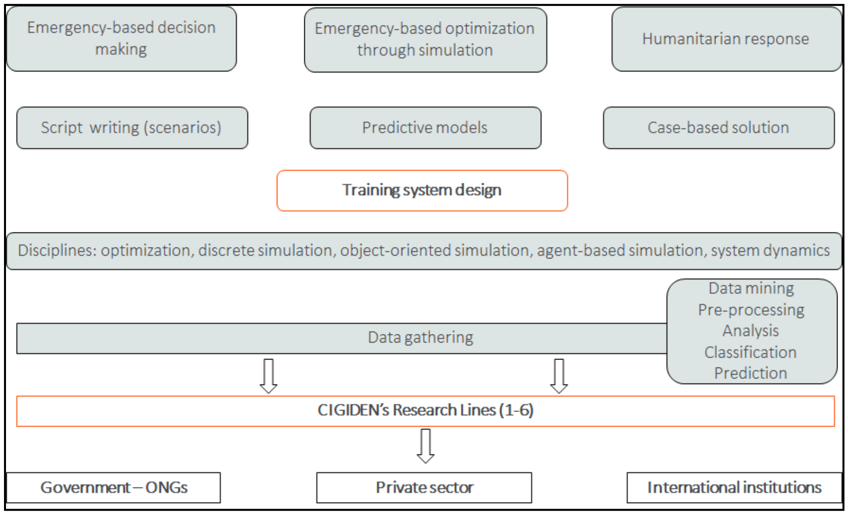

Figure 2: Virtual Test Bed DMSLab's overview.

This organization allows solving different problems using an integrated approach. For example, an emergency management issue may require process modeling and analysis through training. From this training specific improvement needs may be detected, which can then be simulated and redesigned. All these processes may be implemented in the VTB, with the different areas working at the same time to solve the issue. To explain this collaboration, the next sections provides details regarding each area's approach.

3.1 Area: "Emergency-based Decision Making"

This area of the VTB will be focused on delivering a training and simulation platform to leverage the preparation of the decision-makers and team coordinators during disasters. This area is directly related to the existent DMSLab. An overview of similar solutions is presented, to understand the common elements necessary for this kind of system.

A very interesting system is ENSAYO (Nikolai et al. 2009). ENSAYO is a prototype of a computational infrastructure to simulate disaster scenarios, used as training for EOC staff and for testing emergency management policies. It includes GIS capabilities, an internal chat application, scripting modules to define events, and real time feedback for participants through a dashboard. Jain and McLean (2003) propose a system architecture that merges games and simulations to train first responders and decision-makers in an integrated fashion. This platform aims to provide a highly customizable scenario, to model different types of emergencies within the same system. We also found The GAMMA-EC System (Stolk et al. 2001), a system that was developed to train environmental emergency staff in decision-making and communication. It uses representations of accidents, which follow predefined steps to assess the trainee's response. The representation includes interacting objects, a definition of players (with different authorizations to view or manipulate objects) and functionality to influence the representation status during the training. Another tool is PANDORA (Bacon, Windall, and MacKinnon 2012), a training system which aims to create immersive crisis simulations to practice decision-making and negotiation skills under stress situations. To replicate these situations, it sends emotional and affective information to the trainees manipulating environmental conditions inside the simulation, generating specific multimedia assets and making the players interact with non-playing characters (NPC).

From these related works, the following elements for this area are defined:

1. Exercise design: An exercise is a structured form of training, which provides context to test a response plan and the personnel's ability to execute it (Perry 2004). The quality of response is directly related to the knowledge and skills of the emergency staff (Schaafstal, Johnston, and Oser 2001). The VTB will provide exercise design through scripting (Makrodimitris and Douligeris 2015), allowing the definition of multilevel tasks to maximize the benefits of exercises (Sinclair et al. 2012). The script should include unfamiliar events during the simulation, to stress and emotionally affect the response of the participants (Barnett, Wong, and Westley 2011).
2. Inclusion of protocols: Protocols are part of the mechanisms of coordination and support during the emergency response management cycle (Chen et al. 2008). Even if the protocols are explicitly written, training is needed to ensure that they can effectively be used by responders and decision-makers (Perry and Lindell 2003). The VTB will permit the explicit inclusion of protocols, processes and procedures of the participant institutions into the script development, so to evaluate its implementation in realistic settings.
3. Assessment of the exercise: Assessment helps identifying potential areas for future training, by showing the differences between the expected outcome of the training and what actually occurred (Wilson 2012). The VTB will log the interaction between the participants and the actions taken during the exercise, and will provide data mining and visualization techniques to support the evaluation process.

Using this set of tools and methodologies, VTB can measure and detect an organization´s capacity to manage the emergency and to measure behavior under stress, among others. For example, Key Performance Indicators (KPIs) focus on the organizational performance, and thus are critical for its success (Parmenter 2015). During emergency planning, KPIs can be used to monitor the execution of plans and protocols (Fishwick 2010). Other areas of applicability are interoperability capacity, team work dynamics, flaws in implementation of procedures, and special needs of training.

VTB can fit in different areas related to emergency management. Some of them are early warning systems or centers, logistics (pre, post or reverse), evacuation (route planning, shelter locations, and timing) and training (as a measure of performance).

Figure 3 shows a diagram of elements included in the design of this area of the VTB.

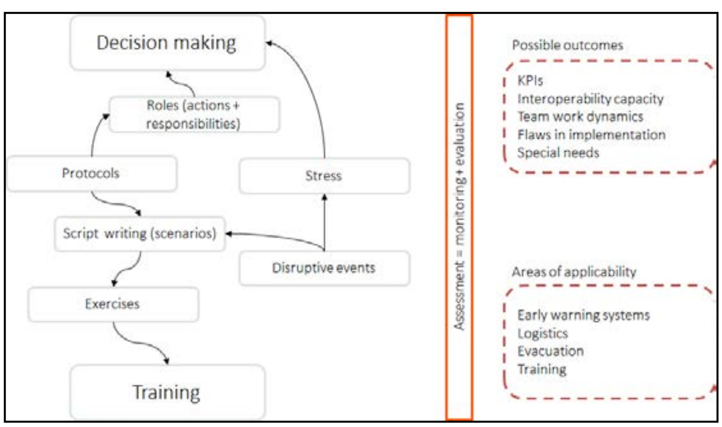

Figure 3: System Design of VTB "Emergency-based decision making" area.

3.2 Area "Emergency-based Optimization Through Simulation"

For the second area, the focus is on providing different simulation methods based on the characteristics of the organization. The Emergency-based Optimization Through Simulation area of VTB provides tools for managing crisis that develop in complex scenarios. These scenarios should take into account context-specific elements, whose interaction and configuration directly affect the outcome of the exercise.

In their most general form, simulations consider entities, queues and resources. When varying these elements, different events occur in the simulation changing the state of the system (Chung 2003). It is then possible to evaluate the effect of these events on the overall simulation by programmatically changing their configuration. When using simulations for training, each trainee's response to different setups can be monitored. This information may then be used to improve response protocols during emergency.

Different simulation techniques, like discrete-event, agent-based, and system dynamics, will be available as modules of the VTB. Each technique presents characteristics that can leverage emergency process optimization and evaluation, as shown in Figure 4. For example, if protocols and plans exists beforehand, they can be used as input for designing models, abstractions and interactions for the simulation. If no protocols exists, the VTB can support hypothesis testing for elaborating and validating emergency plans. In this situation, an after simulation review can deliver information for process discovery and elaboration of future standard procedures. Moreover, abstraction, modeling and policy evaluation are useful concepts to support decision-making and can complement the work of VTB's previously presented area (see section 3.1).

3.3 Area "Humanitarian Response"

The VTB considers the special needs of institutions working in humanitarian labor, focusing the tools previously presented to support management and planning in the unique conditions of large-scale disasters.

Humanitarian aid refers to the action of saving lives and alleviating suffering during a crisis, while strengthening preparedness for the occurrence of such situations in the future (Global Humanitarian Fund 2015). Worldwide, there are different institutions and non-governmental organizations (NGO's) dedicated to provide humanitarian support. For example, the United Nations Office for Coordination of Humanitarian Affairs (UN OCHA) provides emergency relief through coordinating different entities that provide food, health services and protection for those in need (United Nations). Another example is the Japan International Cooperation Agency (JICA). JICA was established in 2003 with the objective of contributing to the growth of Japan trough supporting the socioeconomic development and stability of developing regions (JICA 2015). JICA work is focused in 19 thematic issues, including disaster management and peace-building.

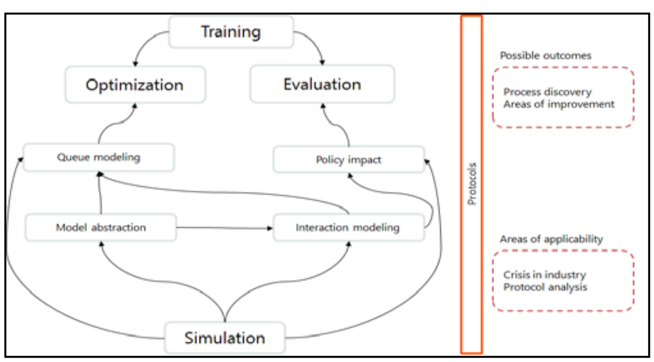

Figure 4: System design of VTB "Emergency-based optimization through simulation" area.

The damage costs of disasters has increased since 2000, challenging the institutions that work in humanitarian response to provide sufficient resources to fulfill the needs of the people they help (Whybark 2015). For 2016, the United Nations has asked governments for over USD $20 billion to provide help to almost 88 million people in 37 countries (Cumming-Bruce 2015).

One of the iconic cases of humanitarian aid is Haiti. The Caribbean island is the poorest country in the western hemisphere, a condition that has been increased by its political instability and the occurrence of frequent natural disasters (CIA 2015). One of the most recent events was the 2010 earthquake, registering 7.0 in the Richter scale. It affected over 3.5 million people directly, and approximately 230.000 people died (CNN Library 2015). Because of the massive response of the international humanitarian community, this earthquake was studied by the Organization for Economic Co-operation and Development (OECD) from the humanitarian response viewpoint (Patrick 2011). Among their recommendations, was the relevance of studying and reflecting upon lessons from previous disasters, to improve the future implementation of humanitarian response. It is also important to provide mechanisms of coordination between the participant organizations, so to avoid overlaps and gaps in the delivery of assistance.

In line with these findings, the 2005 report of the UN OCHA concludes that the low level of preparedness of the humanitarian organizations is affecting the quality and timing of the response during emergencies (Adinolfi et al. 2005). The same report points out two reasons for this. First, it is difficult to gather the number of qualified staff necessary for an emergency mission. Second, collaboration between different humanitarian networks needs to improve.

Considering the tools presented in the previous stages, some areas in which VTB can support humanitarian response are logistics of basic supplies, network planning (for communications, supplies delivery and air relief), simulation of epidemic spreading, handling of diseases and health-related issues. This can be seen in Figure 5.

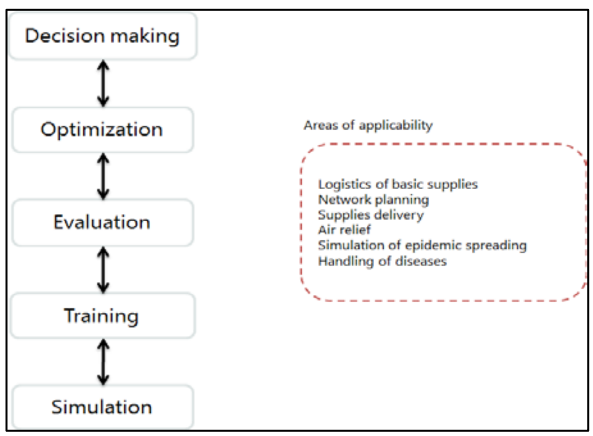

Figure 5: DMSLab's support to humanitarian response.

4 PRACTICAL USE CASE: EARLY WARNING SYSTEM FOR THE NATIONAL EMERGENCY OFFICE

The Chilean's National Emergency Office (ONEMI, for its initials in Spanish), is a technical organization dependent of the Secretary of the State and Public Security. Its mission is to coordinate the institutions that comprise the National System of Civil Protection, to deploy actions of preparedness, response and recovery when facing risk situations. The Early Warning System Office (CAT, in Spanish) is a unit inside ONEMI that checks the national territory 24/7, to detect and give notice of potential threats.

After Chile's 2010 earthquake, ONEMI reviewed its practices and protocols to improve the early response and recovery during earthquakes and tsunami. In this context, in 2015, the DMSLab developed a software that has been used to train CAT staff. The following sections describe the details of this process.

4.1 Description of the Problem

On February 27th 2010, Chile was hit by an 8.8 Mw earthquake and subsequent tsunami. It was felt strongly in 6 regions of the country, around 700 km in distance, directly affecting 2 million people (Economic Commission for Latin America and the Caribbean 2010). Over 520 people were killed and 370.000 houses were destroyed, in part because of the confusion and slow reaction of the emergency management organizations during the event (Núñez 2015).

The previously mentioned consequences of this earthquake motivated a deep revision of ONEMI's responsibilities and protocols. This entity, together with the Hydrographic and Oceanographic Service of the Chilean Navy, have been working to detect and overcome the main weaknesses of the response during the 2010 earthquake. These weaknesses are related to lack of communication protocols (including information flow) between the institutions and people at every level, weak definitions and implementation of roles during the emergency, and the need to practice the interaction with international agencies (like the Pacific Tsunami Warning Center.

4.2 Analysis

Given this, ONEMI has established 4 main objectives to support its institutional strategy during the 2014-2018 period (ONEMI 2014):

1. To develop efficient and effective logistics.
2. To manage the collaborative work with the National Civil Protection Service, to ensure the activation of alerts and a standardized and efficient response.
3. To manage the development of capacities to increase prevention and resilience, with both the community and the National Civil Protection Service.
4. To assure an effective and timely communication and dissemination of information.

To meet these objectives, ONEMI has connected with different technical institutions, exchanging bulletins and reports related to events of different nature. This communication permits the coordination needed to notify, evacuate and protect the population that could be affected by an emergency. This relationship is established using different operational protocols, with collaborating institutions such as the Hydrographic and Oceanographic Service of the Chilean Navy for tsunami alerts and procedures.

ONEMI also has detailed policies for its internal operation. For the DMSLab, the case of the Early Warning System Office (CAT) is of special interest because it is the head of the emergency information system. This unit is in charge of setting and broadcasting alerts to the National Civil Protection System, promoting the coordination needed to respond to emergency events appropriately. CAT's main functions include:

1. Constant monitoring of current and potential risks (natural or man-made) to the national territory, coming from inside or outside Chile.
2. Controlling the operational status of infrastructure and communication channels to be used in case of an emergency.
3. Gathering the information required by ONEMI, to assess the current situation and declare an alert (if needed).
4. Keeping records of the relevant information generated before, during and after an emergency response, so to identify and implement actions of performance improvement.

Today, the CAT team is composed of 25 people working in shifts. Each shift has a manager, a professional to handle specific tasks, a journalist and radio-operators. In each region there is a local CAT office, to channel the information flow at the regional level. After the 2010 earthquake, an Emergency

Operation Center (EOC) was added as part of CAT. At a national level, the EOC is called in major emergencies that affect two or more regions and it is chaired by the Secretary of State.

The CAT operation is defined by its status, which is related to the international typology of alert levels (Villagrán de León, Pruessner, and Breedlove 2013). Each alert level establishes certain roles and activities to be performed by CAT staff. These include communication with technical institutions, report generation and evaluation of the situational status (to determine evacuation procedures, for example). When in red alert operation, CAT coordinates the information flow between regional CATs and the National EOC.

To perform its tasks, CAT has an integrated telecommunications system with mobile and land line channels. It includes telephones, cellphones, satellite phones and different radio systems (HF, VHF and UHF). There is also Internet connection to the Secretary of State's network, local area network connection and satellite Internet, both wired and using Wi-Fi, and a microwave link to the National Seismic Service.

Given its key role in emergency preparedness and response, it is critical to support CAT labor as needed. Important elements of its work include the ability to coordinate different institutions, to facilitate the communication flow and to make decisions with changing data from different sources, so as to provide a timely and effective response.

4.3 Solution

Currently, DMSLab is working with CAT developing a virtual disaster scenario for training (FONDAP project number 15110017) inserted in to the Emergency-based Decision Making area of the VTB.

An exercise script was developed with ONEMI staff, simulating an earthquake and subsequent tsunami, with main and secondary events, in Iquique (Tarapaca region, Chile). The objective of this exercise was to measure the response time of the participants during the first three hours after the disaster.

The planning of the virtual disaster scenario started by modeling ONEMI's and CAT's functional structure, considering their inner organization and their collaboration with technical institutions. This information was collected from existing protocols, business processes and site visits, to determine the training characteristics.

During real emergencies, the main activity of the CAT staff includes sending messages for internal communication and for coordinating with technical institutions. Given this, a messaging service was included as a key component of the training system. The participants received the information related to the simulated events, asked for additional data and sent the standardized reports through this system, as they would do in a real situation. The rules of communication, including valid sender-receipt pairs and available documentation for each participant, were incorporated into the system according to current protocols.

Flooding maps and existent cartography are used as sources of information by CAT when an earthquake occurs near a coastal region. CIGIDEN's previously developed layers for HAZUS, a Federal Emergency Management Agency´s (FEMA) software, are used as input to the training system, to allow the participants to visualize actual models of possible floods, destruction to infrastructure and damage to population.

The system is constantly logging the communication between team members and with the simulated technical institutions. The response time of each message, its sender, receiver and content is registered and compared to the guidelines provided in the protocols. This data is filtered and presented to CAT directive, so they can use it to evaluate their performance metrics and discover KPIs.

5 CONCLUSIONS

The Virtual Tests Bed (VTB) of CIGIDEN's Disaster Management Simulation Laboratory (DMSLab) is a simulation based, multi-disciplinary risk analysis platform developed to support the integration of research results into disaster management. VTB is organized in to three areas, Emergency-based Decision Making, Emergency-based Optimization Through Simulation and Humanitarian Response, providing a case-based environment to test research outcomes in a realistic setting.

Today, DMSLab is working with the Chilean National Emergency Office to develop an emergency response training system. By studying its protocols and process, the VTB is delivering a software to train the Early Warning System staff simulating a disaster scenario in Tarapaca region, Chile. The simulation uses mathematical models previously developed by CIGIDEN, as a decision-making input during training.

The information gathered from the usage of this system is being used to detect improvement opportunities and to develop performance metrics, both for emergency workers and CIGIDEN's researchers.

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