JJEES

Volume 6, Number 1, September, 2014
ISSN 1995-6681
Pages 1- 7

Jordan Journal of Earth and Environmental Sciences

# What Can Be Learnt from Past Disasters? Analysis of the Mw 8.8 Mega Earthquake of Central Chile with MORT

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Received 29 May, 2014; Accepted 27 August, 2014

## Abstract

The impact, in its various facets, caused by natural disasters, is increasing sharply. Poor resilience contributes to increasing the impact on society, throughout history; natural disasters have exerted a heavy toll of death and suffering. Given this, natural disasters present a big challenge to society today concerning how they are to be mitigated so as to produce an acceptable risk is a question which has come to the fore in extreme ways recently. The Mw 8.8 Maule earthquake of 27 February 2010 has been studied in detail. The paper presents some preliminary results of the analysis of the Chilean earthquake that occurred in February 2010, by applying the Management Oversight Risk Tree (MORT) model. Some of the key questions that have been addressed are: what can be learnt from mega earthquakes? Can MORT be applied to the analysis of mega earthquakes? The MORT may be regarded as a structured checklist in the form of a complex fault tree model that is intended to ensure that all aspects of an organization's management are looked into when assessing the possible causes of an incident. The MORT accident investigation model has been applied widely to the analysis of accident/incidents that have occurred in industries, such as the oil and gas, nuclear, aviation, etc. It may be argued that the model has the potentiality to be applied to the analysis of natural disasters such as mega earthquakes. It is hoped that by conducting such analysis lessons can be learnt so that the impact of natural disasters such as the Chile´s Mega Earthquake can be mitigated in future similar events.



**Keywords:** Analysis, Chile, Disasters, Mega Earthquake, MORT.

## 1. Introduction

The occurrence of natural phenomena, which are part of the processes of our own planet, and the link with a non-resilient society, can promote natural disasters, whose intensity depends on the maturity level of the community in question. It may be argued that once a disaster has occurred, the affected countries or communities tend to recover from it and implement 'measures', in the best cases, intended to be better prepared for future undesirable events. However, there is little evidence of a detailed and explicit analysis of disasters in order to understand what went wrong and what went right, so that lessons can be learnt. Moreover, there is little evidence in the literature concerning explicit models or methodologies aiming at analysis past disasters triggered by natural hazards, such as earthquakes. On the other hand, in the so called socio-technical systems (i.e., nuclear, petrochemical, transport, and aviation industries), a number of accident models and methodologies have been developed to analyze past failure incidents. That is, when a major accident occurs in any of these systems, usually an inquiry is set up to look at it and draw some recommendations aiming at preventing recurrence in the future. Earthquakes have exerted a heavy toll of death and suffering and are increasing in recent years: for example those occurred at Wenchuan province on 12 may 2008, China (Zhao et al., 2009), L. Aquila on 6 April 2009, Italy (Rupakhety and Sigbjornsson, 2010), (Alexander, 2012a) and (Alexander, 2012b), 12 January 2010 Italy, (USGS, 2010), 27 February, Chile (Grant, 2010), and 14 April 2010, China (BBC, 2010a-d). In addition, trends suggest that the impact of natural disasters is intensifying, with an increasing effect on poor nations largely due to growing populations and a greater vulnerability to natural hazards. Researchers, governmental and non-governmental organizations (NGO) have published a vast amount of reports and publications on the management of natural disasters. The above stresses the importance of prevention, mitigation and preparedness including evacuation planning in order to limit the impact of natural disasters. Disaster prevention includes all those activities intended to avoid the adverse impact of natural hazards (e.g. a decision not to build houses in a disaster-prone area). Mitigation, on the other hand, refers to measures that should be taken in advance of a disaster order to decrease its impact on society (e.g. developing building codes). Finally, disaster preparedness includes pre- and post- emergency measures that are intended to minimize the loss of life, and to organize and facilitate timely effective rescue, relief, and rehabilitation in case of disaster (e.g. organizing simulation activities to prepare for an eventual disaster relief operation). We must promote a mature society prone to resilience. This raises the following questions: What can be learnt from past natural disasters?, in particular, What can be learnt from mega earthquakes?

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The paper addresses the analysis of the mega earthquake disaster that occurred off the coast of central Chile on Saturday, 27 February 2010, at 03:34 local time, with a magnitude of 8.8 on the moment magnitude scale, which ranks as the sixth largest earthquake ever to be recorded by a seismograph; the approach has been the application of the Management Oversight Risk Tree (MORT) accident investigation model. The paper gives an accounting of the analysis and application of the MORT model. The present paper argues that approaches such as the Management Oversight Risk Tree (MORT) (NRI-1, 2002) can be applied to such analysis (Santos-Reyes et al., 2010; Alvarado-Corona, and Santos-Reyes, 2012). Accidents may be regarded as unplanned and unintentional events that result in the loss of human life, property, production, etc. (Gavious et al., 2009; LaBelle, 2000). Moreover, these losses increase an organization's operating cost, decrease efficiency, and some undesirable long term effects such as an unfavorable public opinion (Cullen, 1990). A number of accident and seismic analysis tools have been developed to address this, see for example, PRISMA (Van der Schaaf, 1996); STAMP (Leverson, 2004); MORT (Johnson, 1980); Accimap (Rasmussen, 1997; Hopkins, 2000); see also Hale et al. (1997) and Deng et al. (2014). It may be argued that accident analysis tools are intended to help to identify 'root causes' of accidents so that lessons can be learnt and prevent recurrence. Some authors, such as Johnson (2003) has addressed this by proposing some useful causal concepts based on early works on causation by Lewis (1973, 1986) and Mackie (1993). Some authors (Absolon, 1994; Jeynes, 2002), define Risk management as a decision making process that takes into consideration multiple factors with relevant risk assessments relating to a potential hazard, so it is known that every logistic company has a lot of risks (Siu-Lun et al., 2009). Some other analytical tools for service industries, and Risk Based Models, such as Risk Management Model for Merger and Acquisition (Chui, 2011) would be interesting for an extended and preliminary analysis, particularly in changing information technology environments (Tak 2011; Olla and Patel, 2002). It is important to notice Chile's long experience on quakes. A preliminary analysis of an extreme event (mega quake), that occurred in Chile on 27 February 2010 (USGS, 2010), Chile is presented.

## 2. The 8.8 Mega Earthquake

An 8.8 magnitude mega quake struck the Chilean coast on February 27, 2010, despite the magnitude of the mega earthquake, Chile suffered relatively little impact. Chile´s massive mega earthquake caused widespread damage, knocking down buildings, bridges and roads in many areas, land and water level variations were reported (Farías et al,. 2010), also triggered a tsunami that devastated some coastal areas of the country. Electricity, water and phone lines were cut. The earthquake occurred at the boundary between the Nazca and South American tectonic plates. At least 523 people killed, 24 missing, about 12,000 injured, 800,000 displaced and at least 370,000 houses, 4,013 schools, 79 hospitals and 4,200 boats damaged or destroyed by the earthquake and tsunami in the Valparaiso-Concepcion-Temuco area. In addition, 1.8 million people were affected in Araucania, Bio-Bio, Maule, O'Higgins, Region Metropolitana and Valparaiso. The economic loss in Chile was estimated at 30 billion US dollars. Electricity, telecommunications and water supplies were disrupted and the airports at Concepcion and Santiago suffered minor damage. The tsunami damaged many buildings and roads at Concepcion, Constitucion, Dichato and Pichilemu and damaged boats and a dock in the San Diego area, USA. Maximum acceleration of 0.65g was recorded at Concepcion and more than 2 m of uplift along the coast was observed near Arauco.

The mega earthquake was generated at the gently sloping fault that conveys the Nazca plate eastward and downward beneath the South American plate. The two plates are converging at 7 meters per century. The fault rupture, largely offshore, exceeded 100 km in width and extended nearly 500 km parallel to the coast. The rupture began deep beneath the coast and spread westward, northward, and southward. As it spread, the fault slip generated earthquake shaking. Some investigations have attempted to determine features of the rupture propagation to clarify why the Maule incident became a mega earthquake with the use of GPS technology (Vigny et al., 2011). The fault slip also warped the ocean floor, setting off the tsunami along the fault-rupture area. Liquefaction was observed to have occurred over a large area of Chile affected by the earthquake. The widespread presence of river sediments and the long duration of the event most likely contributed to the large number of observations of liquefaction. This was the strongest earthquake affecting Chile since the magnitude 9.5 1960 Valdivia earthquake (the most energetic earthquake ever measured in the world), and it was the strongest earthquake worldwide since the 2004 Indian Ocean earthquake and until the 2011 Tōhoku earthquake. It is tied with the 1906 Ecuador-Colombia and 1833 Sumatra earthquakes as the sixth strongest earthquake ever measured, approximately 500 times more powerful than the 7.0 Mw earthquake in Haiti in January 2010. Seismologists estimate that the earthquake was so powerful that it may have shortened the length of the day by 1.26 microseconds and moved the Earth's Figure axis by 8 cm. Nearly half the places in the country were declared "catastrophe zones", and curfews were imposed in some areas of looting and public disorder. A day after the mega earthquake, some affected cities were chaotic, with extensive looting of supermarkets in Concepción. Items stolen included not only food and other necessities, but also electronic goods and other durable merchandise. To control vandalism, a special police was sent to disperse rioters with tear gas and water cannons. The outgoing president didn't want to remind people of the Dictatorship years by militarizing the streets, thus failed to provide assistance on time to the city. When the situation became unsustainable and all sectors of the population were demanding actions, the government authorized the use of the military to control the affected cities. Despite these and other government acts, pillaging continued in both urban and rural areas of the affected zones. According to "Shake Map" of the Geological Survey of the United States (NEIC-USGS, 2010), the maximum intensities and the Epicenter of the mega earthquake are shown in Fig 1.

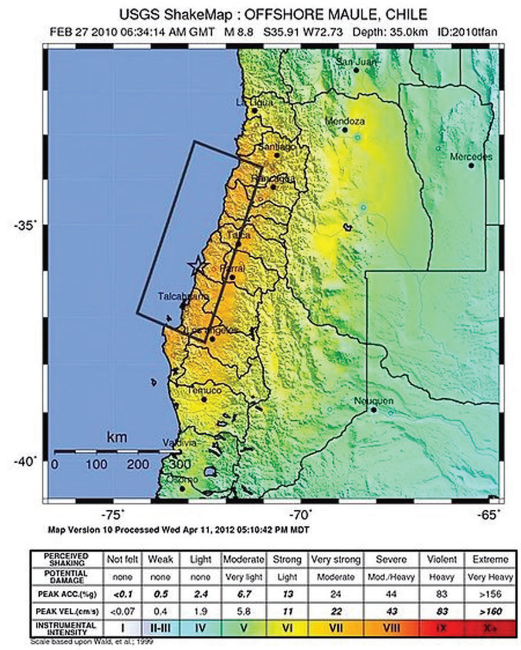


**Figure 1**: Epicenter of the Mega Earthquake on February 27 in Chile (USGS, 2010).

Several factors contributed overall to the low casualty rate and rapid recovery. A major factor is the strong building code in Chile and its comprehensive enforcement. In particular, Chile has a law that holds building owners accountable for losses in a building they build for 10 years. A second factor was the limited number of fires after the quake. Third, in many areas, the local emergency response was very effective. The fourth factor was the overall high level of knowledge about earthquakes and tsunamis the population. Some efforts look for anticipate the occurrence of mega earthquakes in the Andean subduction zone (Moreno et al., 2010). Table 1 Summarizes the Consequences of the 2010 Mega Earthquake.

Large undersea earthquakes usually cause tsunamis and tsunami waves travel fast. A tsunami warning was first declared for Chile and Peru. The warning was later extended to a Pacific Ocean-wide warning, covering all coastal areas on the Pacific Ocean except the west coast of the United States, British Columbia, and Alaska. Hawaiian media reported that tsunami-warning sirens first sounded at 06:00 local time. The U.S. Tsunami Warning Center issued advisories about potential tidal waves of less than 1m striking the Pacific Ocean coastline between California and most of Alaska late in the afternoon or through the evening 12 or more hours after the initial earthquake. Although the mega earthquake killed far fewer people than the Haitian earthquake less than 7 weeks prior, it was still devastating. Tsunamis tend to come in several waves, of which the first may not be the highest. The U.S. National Weather Service's Pacific Tsunami Warning Center issued a tsunami warning throughout a huge swathe of the Pacific region, including Antarctica. Figure 2 shows an energy propagation pattern of the 27 February 2010 tsunami calculated with MOST forecast model according to the National Oceanic and Atmospheric Administration (NOAA). Filled colors show maximum computed tsunami amplitude in cm during 24 hours of wave propagation. Black contours show computed tsunami arrival time..

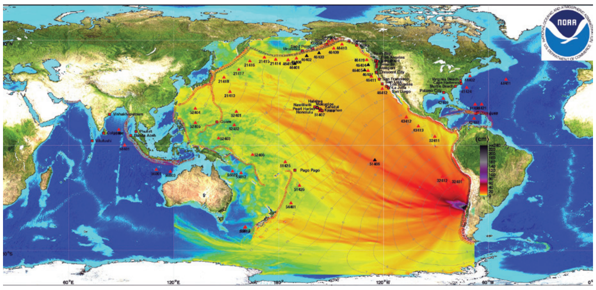

**Figure 2**: Energy Propagation Pattern of the 27 February 2010 Tsunami (NOAA, 2014).

**Table 1**: Consequences of the Disaster (American Red Cross Multi-Disciplinary Team, 2011).

| Mega Earthquake and Tsunami | People Killed and Missing Persons | Estimated Population Affected | Homes and Buildings Affected | Estimated Economical Losses |
|---|---|---|---|---|
| The moment magnitude 8.8 Maule Mega Earthquake struck at 3:34 a.m. on Saturday, February 27, 2010.<br><br>A Tsunami measuring up to 8 feet struck coastal areas between Concepcion and Valparaiso. | According to official information, 521 people were killed and 56 considered missing. | 1.5 to 2 million affected | 370,000 homes were destroyed or severely damaged.<br>The quake affected 73 hospitals and 221 bridges.<br>More than 3,049 schools, housing 1.25 million students were damaged or destroyed | $30 billion of US Dollars |

## 3. The Mort and the Accident Analysis Techniques (Fault Trees)

Inside accident analysis techniques, fault trees extend concepts and relations from systems engineering to support the analysis of adverse incidents based on the idea that the causes of a complex event can be analyzed by a conjunction of simpler interrelated precursors.

This section presents a brief overview of the Management Oversight Risk Tree (MORT) tool that has been applied to the analysis of the mega earthquake. In addition, a summary of the main findings so far are presented in section 3.2.

### *3.1. The Accident Investigation Model (MORT)*

The Management Oversight and Risk Tree (MORT) is an analytical procedure for determining causes and contributing factors. In MORT, accidents are defined as "unplanned events that produce harm or damage, that is, losses" (NRI-l, 2002). Losses occur when a harmful agent comes into contact with a person or asset. This contact can occur either because of a failure of prevention or, as an unfortunate but acceptable outcome of a risk that has been properly assessed and acted-on (a so-called "assumed risk"). MORT analysis always evaluates the "failure" route before considering the "assumed

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risk" hypothesis. In MORT analysis, most of the effort is directed at identifying problems in the control of a work/ process and deficiencies in the protective barriers associated with it. These problems are then analyzed for their origins in planning, design, policy, etc. In order to use MORT key episodes in the sequence of events should be identified first; each episode can be characterized as: (a) a vulnerable target exposed to; (b) an agent of harm in the; (c) absence of adequate barriers.

The "Barrier analysis" is intended to produce a clear set of episodes for MORT analysis. It is an essen¬tial preparation for MORT analysis. The barrier analysis embraces three key concepts, namely: (a) "energy"; (b) "target"; and (c) "barrier". "Energy" refers to the harmful agent that threatens or actually damages a "Target" that is exposed to it. "Targets" can be people, things or processes - anything, in fact, that should be protected or would be better undisturbed by the "Energy". In MORT, an incident can result either from exposure to an energy flow without injuries or damage, or the damage of a target with no intrinsic value.

MORT may be regarded as an analytical technique that has been widely used in accident analysis of socio-technical systems MORT is in essence a graphical checklist that contains generic questions that the analysts attempt to answer using available factual data. MORT technique helps to identify multiple causal factors that contribute to an undesirable event or incident, i.e., a natural disaster. Fig. 3 shows the basic structure of the MORT chart.

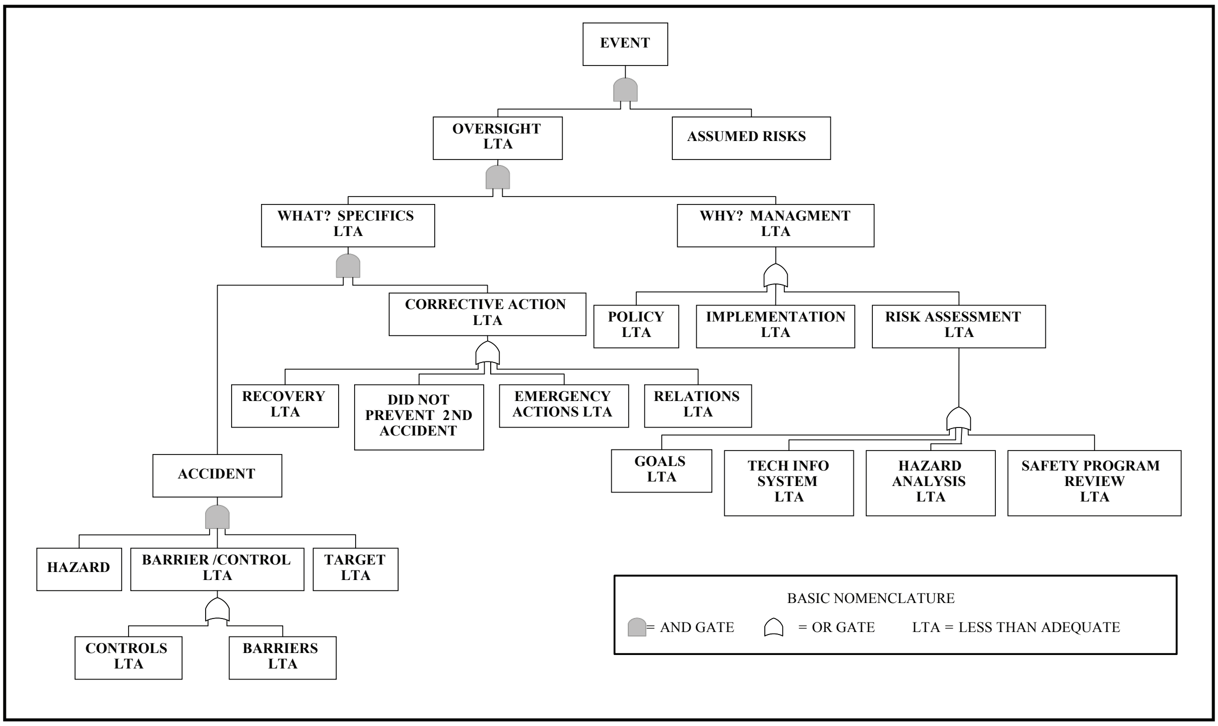


**Figure 3**: Overview of the Basic Structure of MORT (Adapted from NRI-1, 2002).

In MORT, accidents are defined as "unplanned events that contribute to a mishap and produce harm or damage, that is, losses" (NRI-1, 2002) as shown in Fig. 1. "The losses" represent the top event (T), beneath which are its two alternative causes; i-e. (a) "Oversight and omissions", and (b) "Assumed risks". In MORT all the contributing factors in the accident sequence are treated as "Oversights and Omissions unless they are transferred to "Assumed Risk" branch of the tree. "Specific Control Factors LTA" (S) and "Management System Factors LTA" (M) are inputs to the "Oversights and omissions" event (S/M).

Moreover, both inputs are through and AND logic gate; this means that problems manifest in the specific control of work activities, necessarily involve issues in the management process that govern them. Furthermore, both "Specific Control Factors LTA" and "Management System Factors LTA" are broken down into further events that should be look at when analyzing accidents (see NRI-1, 2002) for further details about these.

### *3.2. The Analysis*

MORT is a generic technique, in MORT analysis, most of the effort is directed at identifying problems in the control of a "work/process" and deficiencies in the protective barriers associated with it. These "problems" are then analyzed for their origins in planning, design, policy, etc. A color code has been used to conduct the analysis; i.e., if an event was considered to be deficient or "Less Than Adequate-LTA", then it was marked 'red'; an event that is 'satisfactory' was marked green. On the other hand, if an issue is considered to be relevant but there is not enough information to assess it, then this was marked blue.

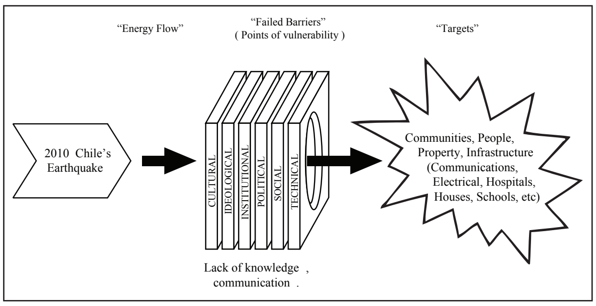


**Figure 4**: Barrier Analysis in 2010 Chile´s Mega Earthquake.

In order to conduct the analysis of the disaster by applying MORT, a “barrier analysis” needs to be conducted. The “barrier analysis” is intended to produce a clear set of episodes for MORT analysis embraces three key concepts. “Energy”, “Target” and “Barrier”, “Energy” refers to the harmful agent that threatens or actually damages a “target” that is exposed to it. Fig. 4 illustrates the three concepts that have been considered for the analysis applying the accident investigation model (MORT). “Targets” have been defined as the population, infrastructure, etc. that should be protected or would be better undisturbed by the “Energy” (i.e., a mega earthquake). “Barriers”, on the other hand, may be regarded as the means by which “Targets” are kept safe from “Energies”. Figures 5 and 5.1, show the initial and condensed results of the diagnostic for the Energy Flow obtained from the barrier analysis.

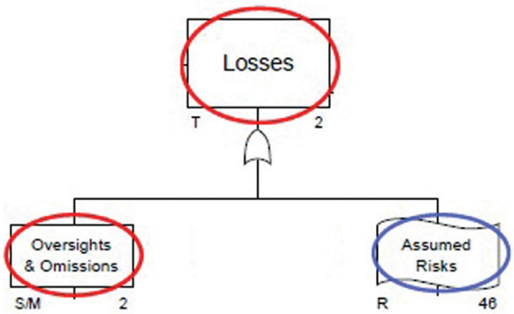


**Figure 5**: Initial Results of the Diagnostic for the Energy Flow Obtained from the Barrier Analysis. (Red: problems that contributed to the outcome. Blue: need more information. Green: is judged to have been satisfactory) (Adapted from NRI-2, 2002).

Examples of the branches of the tree shown in the above are presented in following Figs. 6 and 7. For example, Figure 6 shows the deficiencies and/or omissions (in red) that were found when assessed the branch indicated as “SB1-Flow of Energy or Harmful Condition.” On the other hand, deficiencies found when assessed the branch indicated as “SA2-Stabilisation and Restoration” are shown in Fig. 7. This branch has been used to assess whether actions have been preplanned as opposed to occurring fortuitously at the time of the disaster.

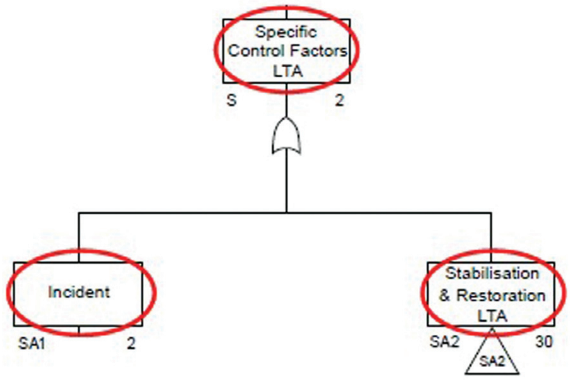


**Figure 5.1**: Specific Control Factors Branch: Condensed Results of the Diagnostic for the Energy Flow. (Red: problems that contributed to the outcome. Blue: need more information. Green: is judged to have been satisfactory (Adapted from NRI-2, 2002).

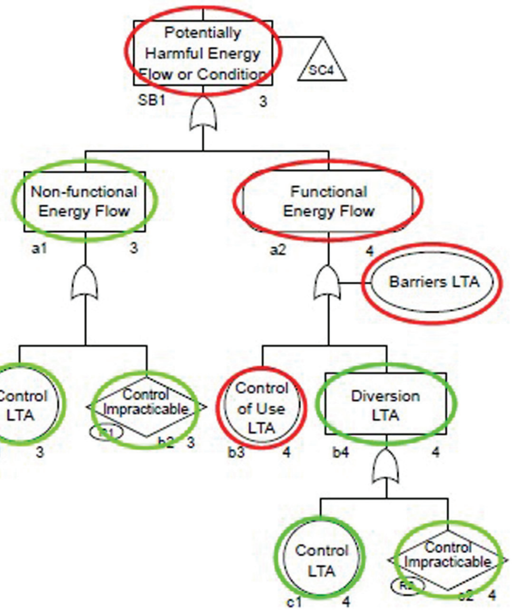


**Figure 6**: Branch Indicated as "SB1-Flow of Energy or Harmful Condition."

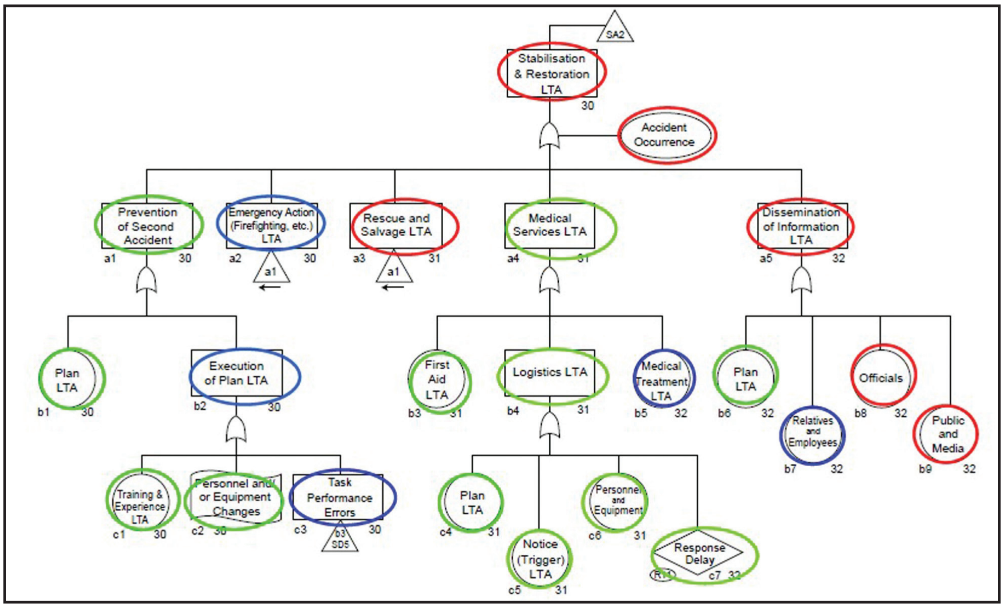


**Figure 7**: Branch Indicated as "SA2-Stabilisation and Restoration LTA."

**Table 2**: Some of the Causal Factors Identified on the what? Branch of MORT

| No. | Description |
|---|---|
| 1 | Some barriers failed at the time of the disaster; i.e. there were not adequate early warning systems. Moreover, in some cases building codes aiming at reducing the vulnerability of buildings to earthquakes were not adequately followed. Furthermore, some key organizations dealing with natural disasters were damaged and had to be restructured. |
| 2 | Inadequacy of technical information related to early warning, etc. |
| 3 | Lack of knowledge from codes and manuals regarding the construction of buildings. Furthermore, people did not know exactly what to do under such circumstances; i.e. how to act and evacuate from buildings, homes, etc. |
| 4 | There have been a number of mega earthquakes and tsunamis in the past. However, lessons were not adequately learned from them. |
| 5 | Inadequacy of communication knowledge of the disaster severity amongst the authorities, local civil protection and the population. |
| 6 | Deficiencies of the internal communication; i.e. the population did not know exactly what to do and there was confusion. |
| 7 | The “operational readiness” was not assured at the time of the disaster; i.e. the population has not been well prepared how to act when earthquake and a tsunami of such magnitude struck. |
| 8 | Inadequate coordination amongst key organizations involved in dealing with disasters at the time. |
| 9 | Deficiencies in the process of evacuation and rescue. Organizations such as explicit “civil protection” failed at the time of the disaster. |
| 10 | Without evidence of decision-making based on risk assessment. |

## 4. Conclusions and Future Directions

This paper discusses the application of an accident investigation model to the case of natural disasters. Some preliminary results of the 2010 Chile’s mega earthquake that occurred in February 27, 2010, at 03:34 local time, have been presented. The approach has been the application of the Management Oversight and Risk Tree (MORT) accident investigation model. The MORT accident investigation model has highlighted a number of causal factors leading to the earthquake. It may be argued that most of the causal factors identified by the application of the model can be broadly grouped within the ‘hazard analysis process’, based on Briscoe´s categories (Briscoe, 1991; Johnson, 2003), and has the potentiality (and presumably other accident analysis techniques) to be used to identify causal factors to the case of natural and technological disasters. MORT has been used extensively to the analysis of failure of socio-technical systems (i.e., nuclear, oil and gas, transport, petrochemical, etc.). For example, to identify why the factors pointed on the what-branch of MORT happened (see Table 2). Also, it may be argued that a prepared community response saves lives. However, further research is needed in order to draw some final lessons and conclusions from the 2010 Chile´s mega earthquake. This may be achieved by applying other accident analysis approaches, such as PRISMA (Van der Schaaf ,1996), Accimap (Rasmussen, 1997; Hopkins, 2000) and the SDMS model (Santos-Reyes and Beard, 2010), and others that could be relevant. The present paper argues that by analyzing past mega earthquake disasters, such as the 2010 Chile’s mega earthquake, lessons can be learnt so that the consequences of similar events can be mitigated and it is hoped that by conducting such analysis the resilience capacity can be improved in the future to reduce natural disasters impact.

## Acknowledgements

The authors wish to express their sincere thanks to NOAA and USGS Agencies (Among others). This project was funded by SEP, CONACyT, TESCI and IPN (www.ipn.mx).

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