Developing a New Framework for Earthquake Resilience: Stakeholders' Needs Assessment

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Community resilience to an earthquake hazard still lags behind the improvements achieved in mitigating the risk of other natural hazards. From a scientific point of view, addressing seismic hazard is a challenge: although risk exposures are predictable in the medium long-range, the timing and location of seismic events are largely unknown. Consequently, risk metrics are substantially used for informing construction engineering and urban planning; and adopting the emergency management cycle over the long-term to protect the population. As a result, direct cost-based earthquake damage assessment leads to prioritizing assets over business activities, limiting their inclusion in decision making about seismic risk. The paper starts from the analysis of Cosmetecor earthquake near future warning system proven in operation since 1990. Then, a systematic assessment of stakeholders' needs is used to design framework for anticipatory responses to earthquakes on a business level. The research methodology grounds on literature review and semi-structured interviews of different decision makers within the earthquake risk management eco-system. Results demonstrate that a proper use of Cosmetecor capabilities has the potential to change the expectations and the practices implemented by different businesses to mitigate their risk exposure to earthquakes. Taking into account interdependencies between businesses, essential services and critical infrastructure, it emerges that alerts offered by Cosmetecor platform could help in developing more robust business continuity plans and enhance community resilience.

Keywords: Cosmetecor, earthquake hazard, community resilience, business continuity, near-future warning, stakeholder

1. Introduction

Since the beginning of XXI century, the resilience concept has been adopted at organizational, institutional and societal levels to highlight the importance of going beyond the traditional risk and emergency management approaches to take a more holistic view of how to cope with unavoidable and unexpected events by developing flexibility, adaptability and agility capabilities (Sheffi Y. 2007). The Sendai Framework (2015) focuses on aspects of who and what is vulnerable to what type of threat or hazard, and, in particular, on the central role played by community resilience. We adopt the view of community resilience as "a process oriented construct that reflects how communities anticipate, prepare for, react to and recover from adversity and either maintain or regain a positive trajectory following substantial hardship" (Norris et al., 2008). In the context of societal hazards, resilience also means that the relationships between key stakeholders might persist steadily in structure and function during the course of a disaster (Holling, 1973).

Historically, stakeholders' needs and their role in mitigating seismic risk are major concern for many scholars and practitioners such as seismologists and geologists (Mulargia, 2017), engineers (Kircher, 2006), economists (Lindell and Prater, 2003), social scientists (Tate, 2012), and policy makers (Handmer & Dovers, 2007). In the context of seismic risk, the majority of literature has emphasized the role and performance of public sector organizations and how the needs of different community members are met in the aftermath of an earthquake (Rodríguez et.al., 2007). Scholars (Lettieri, et.al, 2009) acknowledge that while communities are the main target of mitigation and response actions, little research has addressed societal needs at large engaging different stakeholder groups in preparing to a major event in the short term (Mileti 1999). McKnight and Linnenluecke (2019, p. 834) argue that "further research could investigate the connections between firm responses and the resilience of firm's respective communities. Community resilience depends, in no small part, on how firms respond to natural disasters, and this relationship remains understudied".

The primary objective of the present study is to respond to this need and contribute to a better understanding of why and how diverse needs and

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priorities of businesses come together with capabilities needed for community resilience in responding to earthquakes. In this context, this study concentrates on anticipatory practices ensuring business continuity (Herbane 2010). This is particularly relevant for natural disasters, since Stewart et.al. (2009) found that private companies provide 85% of the products, services, and infrastructure to a community in the aftermath of a disaster. At the same time earthquakes damage private sector assets and infrastructure which are often critical to local communities. For instance, the 2011 earthquake in Japan had significant economic losses totalling over USD 335 billion in direct losses and indirect losses were estimated to be around 260 USD billion (Daniell et al., 2011).

The second objective of the present study counters the role of the novel Cosmetecor technology unpacking how increasing the forewarning time (days in advance) of earthquakes helps companies to better prepare to keep facilities operational, manage and coordinate suppliers, continue satisfy customers and maintain staffing (Herbane, 2010). The central thesis of the new framework is that the capabilities of the Cosmetecor technology has more to do with the institutions, business enterprises and social interactions among the multiple stakeholders involved in the building community resilience. As the role of community's members (families, households) and public sector organizations that have been responsible for responding to earthquakes dominates the literature on mitigation natural disasters, our study offers a strong focus on the business and managerial perspective. To our best knowledge, this study is the first in the field, because current emergency management systems and business continuity plans are built on a contestable assumption that earthquakes are not predictable in advance -– i.e. their time, magnitude and location.

The research draws on stakeholder theory (Freeman, 1984) in order to make assessment of the needs and expectation of stakeholders to understand how the reconfiguration of the emergency management system and the availability of new risk metrics may contribute to higher community resilience thanks to Cosmetecor technology. It represents what contemporary risk management conceives as a stakeholder ecosystem within which the strategy and priorities of one stakeholder may influence the others. Different stakeholder groups (Mitchell et al. 1997) are identified along with their needs and priorities through a case study approach. Semi-structured interviews with experts, managers, and first responders are used to understand how different practices come together in the course of an earthquake disaster. The set of risk management practices within each stakeholder group, which create value in what we call community resilience, is assumed as unit of analysis.

The paper is organised as follows. We firstly introduce the scientific foundations and the state of the art on Cosmetecor technology development. Section 3, reports on a literature review of the current seismic risk metrics adopted by different stakeholders as a way to indirectly extract needs and priorities from the existing knowledge. In Section 4 the qualitative part of the research is introduced, highlighting the adopted methodology and the findings. Discussion of results is reported in Section 5 before the Conclusions.

2. Cosmetecor: scientific foundations and technological development

An earthquake near-future warning system can be developed by the monitoring of the physical process of protons (nuclei of hydrogen atom) migration from Earth's core that drives an earthquake to happen (V. I. Vernadski, 1912; V.I. Larin 1970). During hydrogen migration processes large quantities of protons and small quantities of deuterons are transferred from low mantle to magnetosphere, causing all tectonic processes in the Earth's interior. Unlike tectonic plates, which move slowly year after year, or sound elastic waves, which are detected in seconds by seismometers at user locations, the physical process governs the dynamics of a local proton migration imbalance manifesting globally in the upper portions of the mantle and in the portions of the lithosphere (B. Gutenberg, 1927; M. Båth, 1966).

Kuznetsov (1991) proposed an interpretation model and an observational technique for interfacing with the Earth system. Proton migration changes balance in the earth's portions at different rates depending on their properties. When migration intensity increases, the response of earth's portion to influence such as proton migration is changed due to the earth's portion permeability. These overall effects are spatially electric offsets in the region, resulting in a total response that is an earthquake preparation. There is an ongoing debate among scholars on the topic. However, a growing body of literature is already available which demonstrates how cycles of hydrogen and water become separated at the lower mantle which influence the structure, composition and stratification of Earth's interior (Hu et. al., 2017) and how proton migration processes are precursors of all types of seismic events (Bobrovskiy, 2017).

Relying on this physical process, Cosmetecor provides earthquake near-future warning when the seismic event is looming. Similar to hurricane warning, Cosmetecor warning can come days in advance of severe seismic events, reporting on location and a lead time for seismic event that builds over the course of 23 days before the seismic event occurs. As time passes, near future warning (NFW) can be specified within the two-days interval.

Cosmetecor technology is made of an observational method and a data interpretation model. Cosmetecor multi-electrode stations detect the pattern of a looming earthquake rupture by automatically data recorded with the multichannel voltmeter logger. Following the logging run, data are transferred from the local computer to Cosmetecor data server for analysis. Interpretation model is used for the estimation of the parameters of a looming earthquake – i.e. epicentre, time interval and magnitude. Thus, the capabilities of Cosmetecor earthquake near-future warning system largely depend on:

- how many stations are installed in a region and worldwide; and
- on the accumulated knowledge used to interpret data in real time during the process of earthquake preparation.

3. Literature review on seismic risk metrics

Risk metrics represent components or properties of risk that can be measured. Different decision makers or stakeholders are generally interested in different risk metrics according to their specific risk perception, needs and priorities. Thus, mapping what types of seismic risk metrics are being commonly used by different stakeholders can be assumed as a way to infer and compare their needs and priorities.

3.1 *Literature search methodology*

The purpose of this literature review is to identify relevant seismic risk issues addressed in the scientific literature between 1970 and 2019 and to put forward an analysis of what is being developed by the scientific community since the start of the 21st century. The aim is to guide further research in the area and to identify clear research gaps for assessing Cosmetecor capabilities in supporting risk-related decisions taken by different stakeholders. Papers related to earthquake hazard and risk metrics were searched into the Scopus database using the following search string: (“earthquake” OR “seismic”) AND ("risk analys*" OR "risk metric*" OR "risk indic*" OR "risk model*"). The query returned 1639 articles in peer-reviewed journals, books, and conference proceedings published between 1970 and 2019. Exclusion criteria were applied to refine the results such as (C1): Articles written in any language other than English; (C2): Articles written in any other subject area than Social Sciences, Business, Management and Accounting, Decision Sciences and Economics; (C3): Articles that did not offer a risk analysis and metrics contributing to the decisions on ex-ante and ex-post anti-seismic strategies. A subset of 124 articles resulted from the application of the exclusion criteria, which was then supplemented with 6 additional peer-reviewed articles identified within the references of previously selected papers (snowballing technique).

3.2 *Main findings from literature review*

The main finding is that managing the risk of earthquake events is consolidated around two main subjects. The primary focus of the scientific literature (71% of selected sources) is on the mitigation activities to provide benefits in the form of avoided losses. Engineering codes and practices for built environment, land-use and insurance to offset losses from earthquakes are considered the most effective mitigation strategies. Secondly, 29% of the papers addressed the response and recovery stages of a disaster. Post-earthquake identification, warning systems, rapid response, evacuation and assisting with recovery are regarded as benefits by the emergency management community. These two major topics has entered the seismic risk management debate with seminal papers in the mid-2000s and nearly tripled the number of contributions in the next decade.

Table 4. Risk metrics in disaster risk management

Discipline	Risk metric
Seismology	• Annual probability of hazard, i.e. ground motion (Cornell, 1968): • Intensity • Frequency of occurrence
Engineering	• Annual probability of collapse of a given structure, i.e. collapse capacity of inventory and fragility (Cornell, 1968)
Economics	• Expected loss of assets at risk, upper loss and probable loss (OECD, 2008); • Disability adjusted life years (Salgado-Gálvez, 2018)
Social Science	• Social vulnerability index (Tate, 2012) • Life expectancy (Gruev-Vintila, 2007) • Psychological cost (Welton-Mitchell et.al, 2018) • Waiting cost (Wang, 2020)

Different risk metrics are normally used in different disciplines. For example, ground motion amplitude and return time are used in seismologic and geologic research; fragility is used in built environment and engineering research; mortality, income and gross domestic product that may be impacted are the most common indicators used by economists; risk perception, demographical and psychological aspects are addressed by social scientists. Table 4 summarizes the main findings.

According to the extant body of knowledge, seismic risk quantification has a strong engineering, financial and demographic focus, targeting direct damages, in particular fatalities, built environment damage or loss, and losses per average income. However, economic consequences of business and operations disruptions - such as impacts on market demand for certain goods or services, or productivity - are generally neglected. Only very few studies (e.g.Nguyen et.al., 2017) investigated what stakeholders – such as public administration, businesses, and community – might desire and need, and how earthquake impact can be reduced at the operational level. This is a significant limitation, as business interruption and other indirect service losses (e.g. electricity) can be very significant and impactful on communities as observed in the case of the 2011 Japan earthquake and tsunami (Ranghieri and Ishiwatari, 2014), and stock market (Tao et.al, 2019).

Other limitation comes out from the way risk metrics are used in the analytical tools (Kilanitis et.al. 2019). During phases of disaster management cycle, decision makers evaluate the level of risk before disaster, and the recovery progress after disaster. To this end, Beccari (2016) found a small number of variables (12% of the total number of variables in each index) that make the composite risk index to contribute for "measuring action to mitigate or prepare for disaster" and, therefore, it poses limitation for decision making. In sum, scholars (Newman et.al., 2017) acknowledge that analytical systems have limitations in helping decision makers to proactively reduce disaster risk. It happened mainly because, firstly, display information of an application is not intuitive clear for end users, and secondly, few cases provided evidences whether stakeholders participated in the development and their needs were met in the development of the decision support system.

To this end, early warning system (EEW) for 10-40 sec detection of earthquakes is considered (Strauss et.al, 2016) as a possible engineering solution to tackle seismic hazard uncertainty and decrease the earthquake losses. However, the use of EEW is limited to use in controlled environments, while, the fundamental limitation on EEW is the physics of seismic wave propagation (Minson, 2019). Large earthquake is not covered by EEW system, because warning propagation time between damaging ground motion and user location is too small. In overall, due to a lack of time that EEW can give, business interruption still has not been covered by this type of EEW.

These limitations illustrate the relevance of exploring Cosmetecor capabilities and raise awareness among stakeholders. When exploring fit of available timing of stakeholders responses to seismic event and resilience at the stakeholders level of analysis, researchers argue that stakeholders' expectations need to be asses, as scholars demonstrate in the case of earthquake early warning system (EEW) in USA (Dunn et.al, 2016, Minson et.al. 2019) and Mexico (Santos-Reyes, 2019).

Inspired by these studies and Cosmetecor precedent in disaster management, we argue that we shall consider awareness of near future earthquake as a building block of the framework that make stakeholders responses to seismic event faster and effectively.

4. Stakeholders' needs analysis via semi-structured interviews

To achieve a more in-depth examination of the needs and priorities of stakeholder groups, a semi-structured interview protocol was designed enabling further insights on the "how" and "why" questions (Yin, 2013; Bryman and Bell, 2015) about seismic risk management strategies and practices. The empirical setting for the study was centred on strategies and practices adopted in Italy by different organisations representative of different stakeholder groups. Interviews took place over a period of six months, between April 2019 and September 2019. Beside interview transcript, the study gathered additional information from secondary sources of evidences to allow for data triangulation (e.g. internal documentation or official reports). Two investigators analysed the data separately.

We selected 8 board level managers of key stakeholders which is enough for theoretical saturation at the current level of analysis. Total duration of transcripts of 8 interviews is 335 minutes, as outlined in Table 5. The key research questions were formulated for the interviews and adapted for each stakeholder group. The questions addressed in use practices and solutions, such as: "In which way you identify priorities for reducing seismic risk? Do you use any specific risk metric?"; "What is the value of the selected metrics when compared to available alternatives? (the list reported in Table 4 was used to bring examples); "What are the main practical constraints in meeting priorities?"; "Do you envisage any benefit in using Cosmetecor EEW?"; "What are the actors (other stakeholder groups) you are more dependent on when building earthquake resilience?"

Table 5. Stakeholder groups and number of informants.

Stakeholder group	Total informants	Total time [mins]
Insurance (national market player)	2	55
Re-Insurance (global market player)	1	40
Manufacturer (Automaker supplier)	1	30
Civil Protection (Regional agency)	2	90
International Disaster Management Professional Association	1	90
International Association on Critical Infrastructure Protection	1	30
Total Informants	**8**	**335**

4.1 *Data analysis*

An analytical framework (Yin, 2013) was set for analysing and interpreting data; it comprises three stages: breaking the text down into meaning units, developing a category system and grouping together ideas of a similar sort. First, authors worked independently through the transcripts of interviews and coded it. On the second and third stages, all the two investigators inductively categorized interview data looking for patterns. Finally, theoretical thinking was used to offer explanation of the identified patterns and their relationships in the view of building societal resilience against earthquake.

4.2 *Main findings from interviews*

Drawing from the interviews and the review of the literature we unpack the main stakeholders' roles in seismic risk management.

Figure 2 represents the social world, current configuration is occupied by stakeholders involved in earthquake risk mitigation decisions such as government bodies and first responders, critical service providers, managers of business enterprises, managers of insurance and reinsurance institutions, academia professionals and disaster managers, community, donor agencies and societies.

The business owner among these stakeholders is central to our analysis. We draw particular attention to the relationships between businesses, critical service providers, financial institutions, first responders, with a focus on two dimensions of these relationships: the motives that lead to adoption of anti-seismic risk practices, followed by the value creation structuring this adoption and exchange between stakeholders.

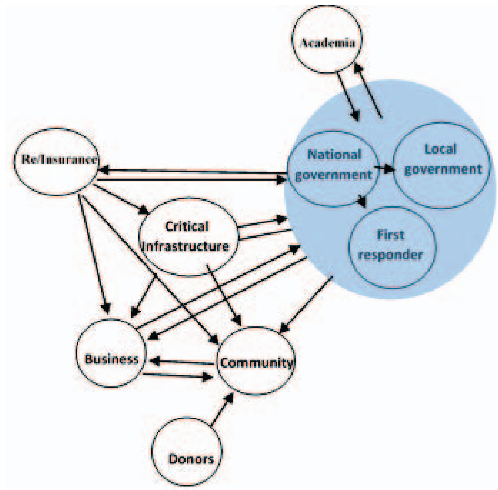

Fig. 2. Stakeholders involved in seismic risk management.

4.2.1. *Regulatory framework*

The stakeholders within the government bodies such as national councils and first responders have a legal responsibility to intervene with policies and guidelines that dictate community's safety and can significant impact on other stakeholders' earthquake mitigation decisions (Keefer P. et.al, 2011). Firstly, Italian State provides specific regulations for the design of buildings in seismic areas. Italian territory has been classified accordingly to the probability of the earthquake in 50 years, each region has been assigned to the four seismic zones, where zone 1 has the highest seismic risk. Secondly, nationwide Casa Italia program (http://www.casaitalia.governo.it/) that gives the right to tax deductions (sisma-bonus) for those owners who carry out renovations of vulnerable buildings.

Main practices arise from the regulatory framework: 1) increasing the awareness among population and public-private institutions by disseminating information about seismic risk, 2) fostering knowledge about earthquake readiness actions.

Following the interviews' analysis, two challenging aspects were revealed. First one, stakeholders both in public and private sector expressed their disbelief that an earthquake is a predictable event. Second aspect represents barrier on how scientists alert the community on issues related to seismic risk information. Public-private sector has difficulties in understanding issues of probability and uncertainty. As a result, businesses may take only selective preparedness actions on the organizational level such as store emergency equipment, first aid kits or strapping mechanism (Mileti, 1999).

Insights from interviews suggest that more accurate timing of near future earthquake will allows stakeholders to know earlier and take actions faster to minimize the impact that seismic event can have on business operations, delivery time and costs.

4.2.2. Insurance and Business continuity planning

The study's findings show that transferring the financial risk to the insurance is the mitigation strategy that may guarantee business continuity and cover earthquake disruptions. Businesses use it in order to avoid a decrease in revenues or losing customers. Considering the following examples from businesses located in Emilia-Romagna and Abruzzo regions, challenging aspects were revealed from interviews. Firstly, businesses were not able to obtain all compensations from insurance just after seismic events that occurred in those regions. Secondly, only part of industrial and commercial entities in the regions had an insurance that covered earthquake disruption. Both aspects are to be fundamental for businesses' economic development and competitiveness in the aftermath of seismic events.

Similar results are relating to the adoption of the business continuity plans. Development of business continuity plan was addresses directly by customers rather than directly by received written information from the Civil Protection Department. The companies explained that they did not have the possibility for developing any practices at operational level from previous experience. However, the excerpt from interviews suggest that manufacturing companies undertook a study for a creating outsourcing strategy of safety stock and list of alternative suppliers in the region. Finally, companies confirmed the influence of the timing of near future earthquake warning on their operations, because anticipating time of ground motion arrival must be aligned with their capacities to implement pre-impact mitigation strategy.

4.2.3. Damage mitigation

The qualitative findings indicate that the businesses undertake ex ante preventive measures to implement earthquake-proof in a presence of incentives. In particular, nationwide Casa Italia program (http://www.casaitalia.governo.it/) targets owners of the vulnerable buildings. In words of participant: *we are trying to get the "sisma-bonus" since we follow the provisions of the legislation.*

5. Discussion

Drawing from the literature review and the semi-structured interviews, we found that the business owner focuses mostly on reactive risk mitigation measures, aiming at reducing earthquake impact and fulfil the core needs of the community. However, collected evidence emphasizes the importance of near future warning, since emergency response protocols and business continuity plans can be effective only when there is sufficient time.

A set of propositions were set forth linking the change in risk mitigation strategies and practices implemented by businesses and the achievable level of earthquake resilience (Figure 3). A new framework highlights the potential benefits for critical services providers. Advanced warning enables to know earlier and take actions faster for restoring critical services to the community. This leads to our first proposition:

Proposition 1. *Companies are likely to adopt more effective proactive measures after integrating Cosmetecor capabilities into risk management practices against earthquake disaster.*

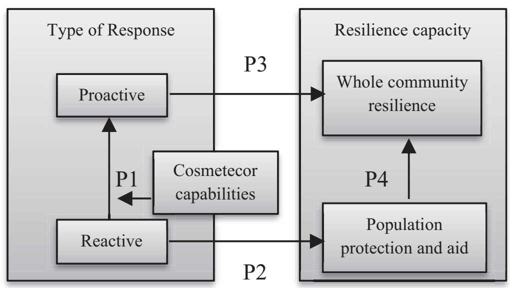

Fig. 3. Reactive and proactive responses and resilience capacity building.

Stakeholders adopting a reactive strategy rely on fast recovering from an earthquake event. Typically, public-sector emergency services coordinate post-disaster operations for civil protection and first aid to the affected population also handling donations from charitable organizations. Companies exhibit capabilities to safeguard own operations, operations of key supply chain partners, to deliver products and services for citizens.

They may have instrumental and normative aims considering benefits that accumulate from interacting with community stakeholders. However, the case of the 2011 Japan earthquake provides an example of losing production efficiency that results in shaping the macroeconomic impact of the earthquake and its aftermaths (Carvalho et.al., 2016).

Proposition 2. *In case of limited preparedness or short alerting time, adopted reactive measures are limited to protect or support the population disregarding indirect and long-term socio-economic effects.*

Scholars agree on the fact that building capacities in community members for anticipatory response (Boin & McConnell 2007) is a matter of what enabling conditions (social capital, competences), and of what key interdependences (economic importance) are supported for whole community resilience (Tierney, 2007). In the time of disaster, investment in preventing breakdowns may exceed the capacity of local economies (Chen, 2013), while poor resilience of companies may negatively impact income growth (Hsiang & Jina, 2014). Higher rates of business failures (Webb, 2002) expose the affected community to long-term income depression before achieving a full recovery to the initial stage. Thus businesses which adopt anticipatory response based on Cosmetecor NFW tend to improve community economic capital; they strengthen the local economy and help employees get back to work.

Proposition 3. *Companies adopting advanced Cosmetecor EEW are likely to improve community-wide resilience to an earthquake.*

Enhancement of citizen's competences improves community resilience contributing to the capacity of a whole community the same way as government coordinates response and reconstruction activities. Resilient citizens may benefit from the anticipatory responses that companies will initiate in the face of challenge due to dislocation of customers and employees.

Proposition 4. *The wide adoption of Cosmetecor NFW by different stakeholders contributes to higher societal resilience.*

6. Conclusions

The case of risk management practices within businesses has three managerial implications related to the usage of a new framework of risk metrics. First, businesses must attempt to recognize the measure factors in their environment and to identify, which measure could contribute to the business capacity ensuring business continuity in the face of earthquake disruption. Following this identification, stakeholders will approach the potential alignment between Cosmetecor risk metrics and the measure of their business resilience. This is the first step to find suitability of a given risk metrics to applied to a given business.

Second, we should acknowledge that the stakeholder groups have varying needs and priorities that shape mitigation practices and solutions against earthquake disruption. Consequently, collecting and analysing the information provided by stakeholders is essential for producing efficient Cosmetecor risk metrics. These Cosmetecor risk indicators may change the expression of stakeholders' needs and priorities and their practices. This can be done by integrating new solution through key resilience indicators. In turn, we will be able to measure enhancement as the best compromise between event warnings with sufficient accuracy and countermeasure mitigation costs. Third, private sector is core providers of products, services, and infrastructure to a community in the aftermath of a disaster. As these exchanges of services and products appears in a seismic disaster context, changes in stakeholders' practices will enhance community resilience. Consequently, this will lead stakeholders to rearrange their practices in the process of building resilient community, with several personal implications.

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