Integrating earthquake early warnings into business continuity and organisational resilience: lessons learned from Mexico City

Gianluca Pescaroli, Omar Velazquez, Irasema Alcántara-Ayala and Carmine Galasso

Abstract

Earthquake early warning (EEW) is becoming a popular tool for mitigating earthquake-induced losses. However, the current literature separates the EEW's technical components and their operational and behavioural implications.

This paper investigates how EEW can be integrated into business continuity practices, organisational resilience, and disaster risk reduction. We use a mixed-method approach to analyse EEW perceptions in the case study of Mexico City (Mexico), a city characterised by high seismic hazard, and social and physical exposure/vulnerability. Our dataset includes evidence from 15 semi-structured interviews with representatives of the public and private sectors (e.g., governments, enterprises) and 78 valid questionnaires compiled by local organisations, including civil protection, education institutions, and enterprises.

Our results reveal inconsistencies between technical EEW methodologies and their integration in three core domains of organisational practices: accountability, governance, and jurisdiction; standardisation of plans and procedures; training and education. Finally, we highlight open challenges for future research.

Keywords: Earthquake early warning; organisational resilience; business continuity; risk perception; mixed methods

1. Introduction

In the last few years, we have seen new complex risk scenarios developing globally. For example, earthquakes and other natural-hazard events have happened concurrently with the COVID-19 pandemic (e.g., Alcántara-Ayala et al., 2021). Some risk-mitigation measures, such as early warning systems, could be used more effectively to "*prevent new and reduce existing disaster risk*", including systemic risks (UNISDR, 2015). According to the United Nation's terminology, early warning systems are "*An integrated system of hazard monitoring, forecasting, disaster risk assessment, communication and preparedness activities processes that enable individuals, communities, governments, businesses and others, to take timely action to reduce disaster risks in advance of hazardous events*" (UNDRR, 2017). Further research is needed at the interface between physical and social sciences (Pescaroli and Alexander, 2018) to influence policy effectively (Cutter et al., 2015). New early warning methodologies could support the management of complex events. Still, they need improved training for end-users and cross-disciplinary research in areas such as hazard/risk modelling, societal behaviours, and their implications for practices (Pescaroli et al., 2018).

Earthquake early warning (EEW) systems have been a fairly limited area of cross-disciplinary investigations until now, with most studies focusing on seismological aspects of EEW. EEW systems

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/disa.12551.

combine real-time seismic instruments, fast telemetry capability, data processing software and methodologies/models/algorithms that can 1) provide real-time seismic-source information (e.g., rupture location and magnitude) and/or the ground-shaking intensity at target sites in the early stage of fault rupture; and 2) issue (based on some decisional rule) real-time warnings to the public or other end users in large urbanised areas before they experience the strong shaking that might cause damage/loss. The technical components of EEW have been widely reviewed and debated by authors such as Allen and Melgar (2019) and Cremen and Galasso (2020). Nevertheless, there is an urgent need to integrate new technology, real-time-seismology methods and engineering modelling/decision making (e.g., Cremen and Galasso, 2021; Cremen et al., 2022), and practices of dissemination of warnings (e.g., Alcántara-Ayala and Oliver-Smith, 2019; Herovic et al., 2019; Velazquez et al., 2020). Different authors investigated people's behaviours and perceptions toward EEW (e.g., Nakayachi et al., 2019; Santos-Reyes, 2019), but some critical fragmentation is still associated with organisational needs, policies, and practices (Velazquez et al., 2020). The lack of studies on how communities and organisations use warnings implies a less efficient use of the advanced technical tools (Alcántara-Ayala and Oliver-Smith, 2017; 2019; Velazquez et al., 2020).

A missed link in the literature is associated with studies in business continuity (BC) and organisational resilience (OR). OR is defined as "*the ability of an organisation to anticipate, prepare for, and respond and adapt to incremental change and sudden disruptions"* (BS 65000:2014). It can achieve different maturity levels depending on the implementation status of the measures adopted in each organisation (BS 65000:2014). One of the essential steps for building OR is developing BC practices, intended as the "*capability of an organisation to continue the delivery of products and services within acceptable time frames at predefined capacity during a disruption"* (ISO 22301:2019). This relies on the implementation of a response structure enabling adequate warning and communications by developing effective BC plans that can be defined as the "*documented information that guides an organisation to respond to a disruption and resume, recover and restore the delivery of products and services consistent with its business continuity objectives*" (ISO 22301:2019). Authors such as Burnard and Bhamra (2019) argued that OR could be seen as a dynamic capability process that needs further research to be understood. A critical point left for scholars is identifying and exploring existing cross-disciplinary gaps, including the analysis of engineering/physical sciences and socio-political systems (Linnenluecke, 2017). Blyth (2009) discussed the role of warnings for BC, but the work did not explore how EEW could be used for orienting organisational processes. Elliot et al. (2010) referred just to the dangers of ignoring an early warning in the general process of continuity management. Studies such as the one by Whitman et al. (2014) analysed OR within the context of specific natural-hazard events but did not include EEW. In Japan, Maruya (2013) analysed the lessons learned from the Great East Japan Earthquake (2011) for BC without mentioning the use of EEW, while earlier studies focused just on the healthcare sector (Horiuchi, 2009). In California, Goltz (2002) first and Johnson et al. (2016) very recently explored EEW benefits for organisations but did not consider aspects of BC or resilience issues. Recent work on the potential for EEW in New Zealand identified the preferences in system attributes (Backer 2020a), recognising the existence of open challenges such as confidence levels and information about appropriate response actions (Backer 2020b).

This paper aims to fill this grey area of literature, investigating gaps and operational criticalities that limit the integration of the technical components of EEW (i.e., seismological/engineering) into

practices of OR, particularly in terms of investigating information and training needs. Our scope is to derive a new theoretical and practical understanding that could be relevant to supporting the more effective use of EEW for limiting organisational disruptions, reducing downtime, and facilitating recovery.

In the following sections, we propose an empirical analysis of the case study of Mexico City (Mexico), bridging the social-science and technical fields. Here, the authorities have developed an operational EEW system that needs to improve its effectiveness (Suárez, 2022; Santos-Reyes, 2019; Suarez et al., 2009). We develop a mixed-method approach to derive qualitative and quantitative evidence discussed within academic literature and practical considerations on the International Organization for Standardization (ISO) standards (ISO 22301:2019).

2. Case study description: Mexico City

Mexico City is the capital of Mexico and one of the main financial hubs of Latin America. It has approximately nine million inhabitants plus the ones of its metropolitan area, all exposed to socio-economic vulnerabilities and natural hazards, including large earthquakes. The M8.1 Michoacán earthquake of 1985 led to the early development of the Mexican EEW system (Cuéllar et al., 2017; Espinosa-Aranda et al., 2009; 2011).

Since the '80s, the Mexican EEW system has evolved, achieving three critical milestones: a) in 2005, the governments of Mexico City and Oaxaca created the Seismic Alert System of Mexico (SASMEX), which can provide warnings up to 120 seconds to Mexico City, depending on the considered rupture (Cuéllar et al., 2018); b) in 2010, the government of Mexico City funded a further extension and update of the system, that counts now 97 stations within SASMEX. Here the warning is publicly disseminated across the city both using permanent speakers and traditional media such as national television and radio broadcasters (Espinosa-Aranda et al., 2009; Santos-Reyes, 2019; Suarez et al., 2009); c) in 2019, the warning thresholds have been updated to include different scenarios that could trigger an alarm, including a magnitude threshold ranging from 5 to 6 (Velazquez et al., 2020). Specifically, more than 12,000 warning speakers and repeating devices have been installed in Mexico City since 2015 to improve the dissemination of alerts (Santos-Reyes, 2019). In addition, the current legislation requires that critical infrastructure, such as hospitals, schools and government buildings, must install EEW infrastructure to receive alerts, integrate them into the emergency procedures, and carry out regular drills (Suárez et al., 2018).

However, there are still shortfalls associated with the organisational, behavioural and societal implementation of EEW in the city. First, the public service remains fragmented as not all the areas of Mexico City are covered with sirens and speakers (Velazquez et al., 2020). Private services are available using receivers that require a paid subscription, but the number of registered users is low (Velazquez et al., 2020). Additional EEW mobile applications represent both an opportunity and a shortfall. Although they increase the accessibility of the service, they also can create conflicting sources of information with the official EEW (Reddy, 2019). Similarly, common gaps in education, training, and governance have been emphasised (Alcántara-Ayala et al., 2020). Although the system is reliable (rarely providing false alarms), the seismic network around Mexico City could be denser, influencing predictions' variability (Tajima and Hayashida, 2018). At the time of the M7.1 event on

the 19th of September 2017, a common belief among the citizens of Mexico City was that - in all cases - they would have had 60 seconds between the warning and the arrival of the ground shaking (Santos-Reyes, 2019). When the EEW system instead provided no warning, this created confusion and affected trust. This circumstance highlighted the challenges involved in warning of an earthquake at close range (Suárez, 2022). Santos-Reyes (2019) argued the critical need for further governance development, particularly in terms of training and procedures to follow before, during and after an earthquake (Santos-Reyes, 2019; Suarez et al., 2009).

3. Methodological approach

This study adopted a mixed-method approach (Creswell, 2014), using semi-structured interviews and questionnaires. A sequential data collection was developed using first qualitative and then quantitative methods (Palinkas et al., 2011). This process maximised the complementarity between the interviews and questionnaires, using qualitative data to provide open-ended/in-depth understandings and quantitative data to perform robust statistical analyses (Palinkas et al. 2010; Creswell 2014). The target group was recruited through a convenience sample and voluntary participation in Mexico City, including representatives of organisations from the local public and private sectors and experts from academia. Convenience sampling was chosen because of resource constraints (see 'Limitations' subsection), but we limited bias by ensuring that different types of organisations were included in the database. Interviewees were contacted directly via local networks using telephone and emails, prioritising larger organisations' representatives (e.g., civil protection). The questionnaires were disseminated within the Institute of Geography network at the Universidad Nacional Autónoma de México (UNAM), and it was supported by ARISE MX (*Alianza del Sector Privado para Sociedades Resilientes ante Desastres en México*). The latter is a private sector national network aiming to support disaster resilience within the aegis of the United Nations Office for Disaster Risk Reduction. Since the main goal is to find general trends among different organisations, collecting data from several organisation categories helped draw conclusions that may apply in general. No personal data about individuals was stored/captured to assure the anonymity of participants.

The central hypothesis of the paper is that *if there are criticalities in how the technical components of EEW are integrated into practices of OR, then results will highlight gaps in aspects such as* a) critical information (e.g., the contents of the warning messages), coordination and dissemination procedures (e.g., who should have access to more complex warning messages, including warning times); b) implementation of BC plans, training, and education strategies; c) attribution of jurisdiction and accountability. Criticality is associated with the existence of an "undesirable state" with diffused gaps, or a "moderately undesirable state" with the presence of some gaps, as reported in the scale by Pescaroli et al. (2020).

A first draft of the semi-structured interviews and online questionnaires was derived in English and then translated into Spanish. Piloting was conducted to assure the accessibility of the questions and to corroborate the rationale. It was developed involving a team of 11 Mexican academics and postgraduate students working or studying in the field of disaster risk reduction at University College London (UCL), UK. The feedback obtained was used to update both instruments and was followed by a second round of pilots.

The final results included 15 semi-structured interviews and 78 valid questionnaires analysed in sequence and then connected in the discussion (Creswell 2014; Palinkas et al. 2010). This can be considered a significant result because the case study was focused on a single city with a limited target group of formal organisations and sectors with EWW compliance. As a reference, the total organisations affiliated with ARISE are approximately 200 in the country. The use of mixed methods also allowed a balance of quantitative and quantitative data and contained possible limitations in the quantitative dataset. Even though we did not have a large sample from some types of organisations, our findings generally agree among all those who responded. The following sections describe the criteria used for developing the data collection and analysis.

3.1 Semi-structured interviews

The methodological process adopted for the semi-structured interviews defined a replicable protocol for data collection and analysis (Harrell and Bradley 2009). The target group included respondents in the following fields: local government, civil protection, private sector, academia, disaster risk reduction governmental agencies, NGOs, and civil societies. The format was such that each interview was expected to last approximately one hour, including four main sections: 1) *how do public and private organisations use EEW?*, including pros and cons of the system and improvements needed; 2) *what information and training are available to integrate EEW in organisational procedures?*; 3) *has the link between BC management, OR and EEW been established and developed?*; 4) other priorities and needs, such as personal comments from the interviewees. The fieldwork took place in January 2020; 13 of 15 interviews were conducted in situ, and two were followed up via videoconference. Each interviewee's anonymity was assured by following a two-step process: the first anonymisation happened at the time of recording, and no specific reference to the names, organisation, or date of interview was associated with the files. Then, the interviews were transcribed, allocating random numeric codes from 0 to 30 during the analysis, which were then reassigned during the answers analysis process (Saunders et al., 2015). A content analysis was developed without the support of software (Weber, 1990). The process aimed at exploring the recurrence of concepts associated with four interacting categories of themes described in the study by Velazquez et al. (2020) and associated with components of OR (BS 65000:2014; Burnard and Bhamra 2019; Linnenluecke, 2017):

- *Operational sphere*, including tactical elements and tools that influence how EEW is developed and disseminated, such as information on lead (i.e., warning) times and expected impacts and the use of devices such as sirens.
- *Political and governance sphere*, including aspects associated with the legal framework in which EEW systems are implemented.
- *Social and behavioural sphere,* associated with aspects such as local culture, local knowledge and experience with the considered hazard, trust in institutions, and community-based resilience.
- *Organisational sphere*, associated with procedures and practices that integrate EEW actions into BC plans and practices.

The preliminary outcome was further divided into two sub-themes for comparison, namely "strengths and opportunities" and "weaknesses and open issues". Deductive analysis was used to

confirm or disprove the previous hypotheses and results. In contrast, inductive analysis was carried out to derive more unknown relationships or issues that emerged from the data gathered from each interview. For the inductive analysis, an unbiased coding and indexing process was carried out following the procedure described by Weber (1990) to identify and classify keywords, phrases and sentences that would determine the most common topics raised during each interview.

3.2 Online questionnaires

Online questionnaires were used complementarily to interviews to support the quantitative assessment of OR maturity and existing gaps in BC. This process resulted in 42 questions, divided into four main sections, a) *Perception of EEW systems;* b) *Current status of planning for mitigating disruptions*; c) *Training needs related to EEW;* d) *Background*. The items are reported in their English version in Appendix A. Most of the answers used a Likert scale-based model for benchmarking operational capacity, OR, and disaster risk reduction developed within this study's same project/framework and introduced in Pescaroli et al. (2020). The items' numerical values varied from 0 to 3, where 0 was associated with an undesirable state, insufficient capacity, and low resilience maturity; and 3 represented a desirable state, comprehensive capacity, and higher resilience maturity (Pescaroli et al. 2020). Qualitative descriptive attributes supported the quantitative values to assure consistency, and the option "don't know" was available to avoid discretionary answers on intermediate values.

The questions were derived from the existing academic literature, considering previous questionnaires or evidence associated with open gaps in EEW implementation, essential criteria for assessing emergency management, continuity planning and resilience strategies; considerations on the role of institutions and training. The researchers used in this process included: Alexander (2000; 2015); Blyth (2009); Elliot et al. (2010); Burnard and Bhamra (2019); Gibson and Tarrant (2010); Hiles (2010) Johnson et al. (2016); Linnenluecke (2017); Nakayachi et al. (2019); Ohara (2012); Porter (2016); Santos-Reyes (2019); Suarez et al. (2009); Velazquez et al. (2020). Moreover, further considerations included the use of resilience indicators considered in the UNDRR City scorecards (UNISDR, 2017) that mention EEW directly, British Standards on OR that includes a checklist on resilience maturity assessment (BS 65000:2014) and the International Standards on Business Continuity (ISO22301:2019).

The online questionnaire was distributed through UCL's Web-Based Survey Tool "Opinio"[1] and ran between mid-February 2020 and March 2020. Approximately 100 questionnaires were collected. A threshold of 50% or more answers was used to consider them valid for analysis, reducing the dataset to 78 questionnaires. The responses to each questionnaire were analysed by performing a non-parametric correlation Spearman's Rho test, using SPSS V. 19 (IBM Corp. Released 2019) and Matlab®. This type of analysis was chosen as the input variables obtained from the questionnaire's answers are of type categorical (discontinuous) and therefore not normally distributed, preventing the adoption of traditional correlation methodologies (e.g., Pearson correlation).

3.3 Limitations

[1] https://www.ucl.ac.uk/isd/services/learning-teaching/e-learning-services-for-staff/e-learning-core-tools/opinio

We recognise the existence of limitations in our study. First, we acknowledge that using a convenience sample for feasibility reasons implied the lack of participation of certain infrastructure providers, such as the water provider network, or the limited access of small and informal enterprises outside the ARISE domain, including the informal sector. The access to some stakeholders was also affected by the increasing concerns associated with the beginning of the COVID-19 pandemic in Mexico. Using an online survey was essential to maintain the feasibility of data collection in terms of resources. Still, it may also have influenced the responses by limiting the target group to more active social media users or in terms of the digital divide. Thus, we may consider this study more indicative than fully representative and make a case for more extended studies. Secondly, our analysis focused on the planning components of OR more than exploring the broader strategic management dimension. Further studies should understand how priorities and needs may vary across organisational sectors and, as we suggested, depending on the maturity level of organisations. This should include a focus on the role of leadership in promoting a culture of OR that has not been analysed in the state-of-the-art. Finally, we focused on specific aspects of BC for a matter of feasibility, including a broader reference to parts of the management process, including recovery. Our questionnaire is the first step in its context but could be more refined in the future, including new items as the literature progresses.

4. Interview results

This section introduces the findings of the interviews, using the categories reported in section 3.1. As a general comment, it is possible to note a general agreement among the respondents on the strength of the EEW system's technological components in contrast with the weakness of some political, social and organisational aspects.

4.1 Operational sphere

All the interviews (15/15) pointed out that the Mexican EEW system had good technical reliability. For example, the respondent (R) 02 highlighted that *"technically, the system works well, and few false alerts have been released since it was launched (1986)".* All respondents agreed that the system is technically reliable, with no significant issues observed. The problems are associated with implementing and translating an EEW into action. As a substantial downfall within the operational sphere, all the respondents noted a lack of geographic coverage due to limited resources. R30 suggested that "*the potential for the (Mexican) EEW system to grow and have broader coverage is huge, but everything relies on the funding from the local, regional and federal government"*. An element connected to this was the lack of speakers deployed across the city, which implied gaps in the public dissemination of the alerts. According to the experience of R21, *"during the January 2020 drill, we did not even hear the simulated EEW"*. Similarly, R03 highlighted that *"many places in Mexico City, where shaking has been quite intense during past events, do not have any speaker. People located in these areas do not have access to the alerts".* All the respondents were concerned about the low number of users that must receive the warnings following the Mexican law, raising the point that the operational and governance/political spheres are interlinked. As R05 highlighted, *"it is unbelievable that not all the schools, hospitals and offices in the city have access to the warning; why not?".*

It was pointed out the need to support organisations' understanding that "false alerts" are a possible outcome of the EEW and could impact the trust in the technical system. R04 pointed out that the need for more transparent information for organisations and individuals should be paramount because "*Even drills are now considered just a nice time to catch up and chat with colleagues; people do not believe in them anymore*". This was complementary to a common perception that lacking a clear strategy to disseminate operational procedures to end-users would reduce the capacity of EEW to influence individual behaviours. All the respondents also agreed that there was potential for operational improvements, in particular by including the warning time between the release of the alert and the arrival of the shaking at a given target location (i.e., the lead time). This was considered an essential piece of information but needs to be supported by the complementary development of training strategies.

4.2 Political and governance sphere

All the respondents agreed about the presence of opportunities for implementing new policies and legislation on EEW in Mexico, with the potential to foster collaborations between academia and practices. In particular, R07 and R11 argued that universities are quite open to partnerships with the government, especially in disaster risk reduction. However, there was concern among all the respondents about the lack of leadership in activating such collaborations.

A common element of criticality was the lack of interaction between governmental bodies and academic institutions. All respondents agreed that during previous governments (before 2018), the Civil Protection Department and similar bodies somehow ignored the advice given by research institutes. According to R11 and R21, it was possible to note some more collaborations after the elections of 2018. However, for another group of respondents, academia still needed some wider involvement to improve disaster management. There was the belief that a lack of adequate funding may have undermined the capacity of civil protection. As pointed out by R04 "*in a country where security is an everyday concern at any governmental scale, focusing funds for disaster risk reduction might not be the priority"*. Similarly, it was highlighted that the fragmentation of rules, scopes, and goals toward disaster risk reductions and mitigation actions between the local, regional, and national administrations could affect civil protection.

All the respondents noted a lack of governance and policies aimed at developing an EEW culture that could foster communication and knowledge transfer of lessons learned and ensure the inclusion of vulnerable categories. R03 and R05 pointed out the potential to inform people about the nature of earthquakes and their impacts, the principles of an EEW system, and disaster risk reduction strategies, which are topics that have generally received little attention from the government. For example, the 2017 earthquake created a window of opportunity to develop some knowledge transfer with the public, but *"2 years have passed…and this was a very badly missed chance"* (R03). In December 2019, three earthquake national drills or exercises were integrated into policies to gather data and improve evacuation protocols. However, most respondents suggested concerns about the actual outcomes due to an approach that limited valuable feedback, mainly due to the inefficient organisation and coordination efforts when the drills were performed. For example, R12 highlighted that *"we have expressed many times that there is a lack of feedback among the drills; we*

are told there will be feedback, but this never happened. This is not a good practice as every single drill is the same as previous ones, and people get bored, not taking seriously future drills".

Finally, it was clear that the warning providers were not in charge of public and organisational training for all the participants. It was also highlighted a lack of consistent governance on accountability, mainly through two aspects that need to be addressed:

1) The "liability" of releasing the warnings. In the interviews, R30 highlighted a critical point: "*this is a system that is likely to fail, this is normal, and everyone needs to understand it. Many uncertainties are involved in the EEW process, and triggering false alerts might not be avoided. However, when false alerts lead to losses, there should be a political body paying for them. This covers individual aspects (like a heart attack/panic) or economic losses due to interruption of business continuity (for organisations)".*

2) Resolving the conflict between public and private EEW systems. All respondents agreed that only the official EEW system should provide alerts, and releasing alerts without the consent of those in charge of the system should be penalised. R04, in particular, stated that *"the number of alerts (false) triggered by private systems sometimes is even dangerous. Once, I was walking in my institution's corridor, and many people were concerned as their private app alerted them about an incoming earthquake. There was no warning, actually, and the official system did not warn anything at all. These private apps just induce panic in the community".* However, private systems were seen very positively as a tool that could add functions to the official system and might be quite helpful for organisations and the public once "synchronised" with the official alerts.

4.3 Social and behavioural sphere

Some widespread issues in the political and governance sphere do not seem to compromise positive aspects from the social and behavioural perspectives. All the respondents pointed out that the population of Mexico City learned from previous experience: *"The population was aware of some of the 'basics' (of EEW) at both individual and collective levels, using surprisingly positively social media for the dissemination of correct information"* (R04). Specifically, R25 showed that *"the use of social media in the aftermath of the 19th of September 2017 earthquake allowed the dissemination of true information (and slightly prevented fake news from being spread). The population accessed more non-governmental media efforts that gained much credibility as the content shared significantly helped in the recovery and response phases of the disaster"*. It was also highlighted the potential for developing good practices at the local level, building on the will to cooperate demonstrated by the population during past events. However, better strategies for communication and education among residents were needed. According to R06, *"governmental bodies talk about a culture of prevention, that is a concept completely unknown by some residents in Mexico City and even by (some of) those bodies that try to teach it".* For all the respondents, there was still some confusion about the behaviours to undertake before, during and after events, for which a better training and education strategy are needed. Similarly, actions are needed to tackle the general idea that false alerts were most beneficial to provide the chances of extra drills without being aware that they could also be the sign of some technical problems (and produce losses) and ultimately distrust in the system. Indeed, R11 highlighted that *"if the system is not working, people need to know it is not working. What the*

public needs to accept is that the system can fail". A critical issue that needs to be addressed is that people are confused about who officially issues warnings, in line with the findings of section 4.2. R06 argued that *"earthquakes is a topic being covered by so many institutions and private companies in Mexico that people are confused about who actually triggers the alerts. People are so confused that they do not even know whom to blame in case of a false alert".* On the positive side, common thinking among the respondents was that there is the potential to introduce some disaster risk reduction education across the country, starting from a young age (6-12) and including training on individual actions toward different warning times. R25 pointed out that volunteers could represent a significant added value for high-magnitude events as "*the community's response and organised civil societies were key factors for the emergency response and recovery after the 2017 earthquake. The government could not deal with the disaster; it was quite clear*".

In conclusion, a critical point for all the respondents was the widespread lack of trust in political bodies, including civil protection, which may even hamper positive efforts in implementing new measures/technical improvements. Unfortunately, this was associated with the common belief that corruption is a critical factor affecting the development of a disaster risk reduction culture in Mexico.

4.4. Organisational sphere

All respondents suggested that public and private organisations could be essential actors in improving the EEW planning and response process: they could build on what they have already achieved, such as sound evacuation plans, to achieve optimal resilience levels. R15 highlighted that *"organisations can benefit from the EEW system; however, there has been minimal information on implementing alerts/actions. I believe there is a great opportunity to start integrating EEW into organisational plans, for instance, by registering and training key organisations. Procedures could be tested with the registered users, and then guidelines could be distributed to the other organisations that did not register*". Similarly, some respondents were sceptical about the guidelines and training provided by government actors, such as civil protection, for the availability of qualified personnel. R08 commented that *she/he "would never allow the Civil Protection'experts' to come and design any protocols within her/his company. I do not trust their technical expertise*". In addition, R09 and R14 raised doubts about the technical and cross-disciplinary knowledge/expertise available within the organisations involved in preparedness and response (e.g., civil protection).

The academic sector had some additional points associated with training and education. First, they noted that the private sector was not well involved in implementing protocols for BC provided by governmental bodies. Therefore, the private sector has to invest in getting their own training and updated protocols (as they have the finance to do it). Second, the expertise and knowledge about procedures to be activated after issuing an EEW are already available in universities. However, it has not been used (see points in sections 4.1, 4.2, and 4.3). In conclusion, an overall lack of consistency in BC planning is clear, which is not included sufficiently in designing and implementing EEW alerts. According to some interviewees, most organisations do not know that they can implement actions. For example, R06 brought the example of *"hospitals, where staff are more concerned about evacuating people and themselves, rather than protecting dangerous items/materials".* Some non-academic respondents also confirmed this. R08 clarified that *"the actions implemented once a*

warning is issued are a consequence of protocols that have been designed without keeping in mind particular EEW aspects and their implications. It is just a coincidence".

Some respondents from the public and private sectors had similar concerns. R01 reinforced the message of a current lack of training for organisations about options of response actions, including basic factors such as the impact of protection/repair works (if possible) before evacuation. R01 believed that *"there should be an emergency protocol to protect pieces in museums. To be honest, I do not understand why we do not have one*". The same respondent also manifested concerns about a general lack of specific organisational procedures that targeted vulnerable societal categories.

The status of things defined by R03 was that *"in schools, during the 2017 earthquakes, the teachers asked kids to run away from buildings during the earthquake (rather than drop, cover and hold on). Not even the educated people know the basic rules to be followed during shaking'.*

In conclusion, the lack of clear accountability between the public/private components of EEW reported in the previous spheres had consequences at the operational and organisational levels. Having various institutions delivering alerts confuse organisations and does not allow the implementation of emergency protocols. R13 suggested tha*t "no single organisation will implement any kind of emergency protocols (following the alert) if they do not know the available time to carry out a particular action. It is extremely dangerous (in terms of economic losses and other consequences) to carry out emergency actions blindfolded; it does not make any sense".*

5. Questionnaire Results

5.1 Background of the respondents

The respondents formed a mixed background of organisations with access or registered to the EEW service (27%). 39% had no access or had not registered, and the remaining one-third did not know the answer. In general, the level of training was inadequate among all respondents. A substantial majority never took part in training sessions or workshops on how to use EEW efficiently in their organisation (64%), nearly one third (24%) received training but not in the last 18 months, and just 12% were trained and updated during the previous 18 months. In addition, the respondents had a very high level of education, as 91% of them had some form of an academic degree. In addition, there was a balance among the gender of the respondents, males and females (both 48%), while the other 4% defined themselves as "others" or preferred not to answer.

5.2 Perceptions of the EEW System

Most people believed that there is a given constant time between the release of the warning and the shaking (overall 69%). In comparison, one third (31%) was aware of the existence of variability. Most of the respondents had a strongly negative perception of false alerts, and they found them unacceptable (61%). Their affiliations included a well-balanced mix of the public and private sectors, with some particular spread among education institutions that could be referred to as both public and private sectors.

Nearly all the respondents (Q1) agreed that EEW is relevant for their organisations (84%). Most respondents (Q2) considered it a useful service that needed improvements (63%). Less than a third recognised it is useful in its current form (22%), and a minority suggested that its development was insufficient (11%). Just 4% (N = 3) argued that the service was not useful at all. 66% of the respondents (Q3) knew what to do in the case of an alert, and 30% suggested that they knew it, but they needed more information/training.

The vast majority of respondents to Q5 suggested that the development of SASMEX considered the integration with organisational needs, such as operational functions. However, approximately 58% highlighted substantial deficiencies, or these needs were insufficiently addressed.

In conclusion, the answers tended to be split, even assessing local policies' status to support the integration of EEW in organisation practices and procedures (Q6). What emerges is that most respondents suggested the existence of a supporting local legal framework (14%), which, however, has deficiencies and gaps in 67% of the cases. Nevertheless, the negative component associated with a total lack of implementation (17%) was stronger than in Q5.

5.3 Current status of planning for mitigating disruptions

The current status of planning is extremely fragmented (Q7). Most of the organisations had some specific plans or procedures to undertake in case of EEW (79%). However, a polarisation was observed between elementary plans (31%) and specifics one (34%).

Similarly, there was a split between organisations that did not have continuity plans updated (Q8) in the last 18 months (37%), organisations that updated them in the previous 18 months (36%), and respondents that did not know the answer (27%). A fragmentation of responses also distinguished the status of how organisations identified and prioritised their critical functions and activities. For example, the responses to Q9 show insufficient levels of identified critical activities (42%) and equivalent levels between entirely positive answers (30%) in which a dominant component of responses was in all cases suggesting the need for updates (28%).

Instead, some organisations (30%) had fully prioritised which critical functions/activities could be protected by using the EEW system's alerts (Q10), though sometimes updates were required (31%). 15% of the organisations could not prioritise the critical functions that can be protected, while 19% recognised they did carry out the prioritisation process but inadequately. However, Q9 and Q10 will require further considerations in the discussion.

The situation was better than expected in identifying internal responsibilities/liabilities for activating procedures and actions associated with an EEW (Q11). Most organisations showed that they are aware of those individuals responsible (and accountable) for activating mitigation actions following an alert (58%). In comparison, 42% could not recognise the people in charge.

The levels of awareness about which official institutions release an EEW in Mexico City (Q12) were fragmented, as 49% of the respondents indicated to be aware, 19% were not aware, and 32% did not know. However, considering that the respondents had the open possibility of writing "who

provides the warnings", we realised that 45% of those who mentioned being aware were actually wrong. For example, some responses indicate "firefighters" or "civil protection" as alert providers that instead are end-users of EEW. These results unequivocally highlight confusion in this regard.

There is no consistent approach for protecting vulnerable categories (Q13), highlighting different maturity levels, with similar percentages in each category, with central values slightly higher, and a clean split between positive and negative values. Despite this, there was a total agreement among the respondents (Q14) about the perceived utility of knowing the warning time before the shaking (90%).

The absence of a clear warning time in the alert message likely induced fragmented responses to Q15, with a thin majority of organisations not identifying mitigation actions likely to be activated for short warnings or long warnings (27%), insufficiently identifying them (22%), while planning had to be updated in 24%, and just 15% of organisations identified the actions consistently; 12% of respondents did not know. Complementary to this point, most respondents (Q16) agreed that it would be helpful to run a beta test for organisations where warnings would include the warning time (87%). There was a clear perception that false alerts could affect business continuity (Q17), creating economic losses. However, more uncertainty was associated with the magnitude of the possible impact, which was unknown (33%) or needed to be re-evaluated (33%). It was clear just for a minority of responses (10%).

Drills were practised mostly once (40%) or three times a year (40%) (Q18). A small minority practised three times a year (12%), and nearly nobody had no drill (8%).

All the measures suggested for improving the use of EEWs in organisations (Q19-Q22) were perceived as very useful, with similar values associated with guidance about good practices, legislations, guidance on what to do according to warning times, and assistance in defining the best continuity strategies. The most useful tool was considered the guidance about good practices and procedures to follow for integrating EEW in the respondents' organisation, followed by guidance on what to do according to the time intervals between the EEW and the arrival of the ground shaking (Q23).

The majority of respondents to Q25 (64%) did not receive enough training to understand the applications of EEW for limiting the disruption of their organisations. To those who did receive training, their training courses did not include the implications of EEW related to preparedness, response, and recovery (37%) (Q26). All the actions were included in 21% of cases, and 8% in some options available. A significant number of respondents chose "I do not know" (34%), which was the suggested option for those who had received no training at all on the subject.

Most of the training options available were judged very positively (Q27-Q32). However, when asked to prioritise from the most useful to least useful (Q33), the respondents prioritised courses to understand how to integrate the EEW into the daily activities of their organisation and the availability of free short courses on how to respond to EEWs in organisations, provided by the local authorities.

This section had some active comments on what the respondents may find more useful. In particular, the following aspects were included: include media for training in organisations, involving tv and radio messages. Most people indicated the need to ban private systems if not coordinated with the central/official EEW system.

5.5 Correlations among responses

This section explores the possible correlations among the questionnaires investigated using the continuous scale by Pescaroli et al. (2020) to understand which survey items could be related together (see Evans, 1996). Table 1 reports those correlations in which *p*-values were less than 0.01. This value (or smaller) rejects the null hypothesis that the pair of items being compared are not related (i.e., their empirical correlation coefficient is not significantly different from zero). Then, the correlation coefficients for each pair of items (with *p*-value<0.01) were computed, selecting those pairs with correlation coefficients closer to -1 or 1 (values close to -1 indicate negative correlations, and values close to 1 indicate positive correlations; coefficients close to 0 express no correlation between the variables tested).

For the specific case of the database used for this analysis, all the correlation coefficients resulted positive. Table 1 enlists the stronger correlations found after the analysis, and the description between such correlations is briefly explained below, then integrated into the discussion:

- The stronger values were between Q30 (guidelines), Q31 (online lessons), Q32 (webinars). This result indicated that the vast majority of the participants require/would like to receive the training listed in Q30, 31 and 32.
- Q9 (identification of critical functions) was positively correlated with Q10 (prioritising critical functions). These correlations suggest that the organisations that identify their critical function are also the ones that are better prioritising them, which could be expected by developing a whole process of business impact analysis (ISO 22301:2019).
- Q13 (identify vulnerable categories) was positively correlated with Q15 (identify mitigation actions for short and long warnings). This highlights that some organisations may be more mature than others because they consider in-depth aspects to be included in planning, procedures and scenarios (BS65000:2014; ISO 22301:2019)
- Q19 (guidance about good practices) was positively correlated with Q21 (guidance on what to do according to possible lead times), highlighting that organisations may need more guidance as a whole, including both general information about good practices and specific information about what to do in case of given lead times.
- Q25 (received enough training) was positively correlated with Q26 (implications of EEW) because training can influence awareness of the available tools (Alexander 2000; 2015) positively.
- Q7 (developed specific plans or procedures) was positively correlated with both Q10 (prioritisation of critical functions) and Q11 (identification of responsibilities). This confirms that those organisations that developed plans and procedures did it by addressing some of the components identified in ISO22301:2019.
- Q10 (prioritised of critical functions) was positively correlated with Q17 (impact of false alerts). A correlation was also observed between Q9 (identification of critical functions) and Q17 (false alerts as sources of disruptions). These two correlations suggest that organisations that

identified and prioritised critical functions may have in place emergency plans/actions that could be activated to facilitate recovery and limit damages. However, in the case of false alerts, those procedures' activation may imply broader impacts.

- The training options had strong values correlated with each other's (Q27-31), and it could be argued that there is a general need for increased training more than specific needs on a pre-determined tool.
- The development of specific plans or procedures to undertake in the case of EEW (Q7) was strongly correlated with many other variables. This confirms the role of advanced emergency planning in increasing the awareness of other organisational processes as it would be expected following the existing standards (ISO 22301:2019; BS65000:2014).
- Q12 (awareness of the official institutions) was also positively correlated with Q30 (participation in training sessions and workshops), in line with the concept that training can have a useful role in influencing individual and organisational behaviours in disaster risk reduction at large (Alexander, 2000)
- Finally, there is a strong correlation between Q11 (identification of internal responsibilities) and Q16 (beta testing in organisations). Organisations that are clear about who is doing what are keener to activate new practices and procedures.

Table 1. Stronger correlations among the answers of the questionnaire

#Q	**#Q**	***p*-value**	**Correlation Coefficient**
30	31	0.0000	0.754
31	32	0.0000	0.750
9	10	0.0000	0.692
13	15	0.0000	0.645
19	21	0.0000	0.606
25	26	0.0000	0.594
7	10	0.0000	0.553
7	11	0.0000	0.549
10	17	0.0000	0.494
9	17	0.0003	0.43
27	31	0.0010	0.394
12	30	0.0017	0.376
11	16	0.0079	0.322

Surprisingly, there were no significant correlations between the various responses with gender and education that often influence the levels of risk perceptions. Moreover, we did not find any strong correlation between the size of the organisations. At the same time, we may have argued that larger organisations had higher maturity levels regarding BC and resilience plans/procedures. Affiliation categories were also not significant, while we were expecting some differences between sectors. Considering that the respondents with educational affiliations are the majority, we verified that the responses from different sectors do not differ from those from educational institutions; this fact might suggest that more respondents would have possibly followed the tendencies we have found.

Further considerations derived from the observed correlations will be integrated into the discussion available in the next section.

6 Discussion

Our data suggested that EEW can be essential in ensuring effective emergency response and facilitating recovery. However, we noted a limited integration of the technical components of EEW into practices of BC and OR, and this could undermine the achievement of higher levels of functionality/effectiveness of the system maturity. The following subsections analyse *three overlapping gaps* that emerge when considering our analysis.

6.1 Accountability, governance, and jurisdiction

Our data showed that the complementarities between the public and private EEW systems in Mexico City are undermined by a lack of clear accountability and liability. In other words, there is a lack of accountability in terms of who manages the various components of the EEW system and the implications in terms of risk ownership.

At the societal level, this reveals systemic challenges in how disaster risk reduction is approached (e.g., Alexander, 2000; Twigg, 2003; Alcántara-Ayala, 2019) and practical issues of operational capacity and coordination (e.g., Alexander, 2015; Alcántara-Ayala, 2019; Santos-Reyes, 2019). At the organisational level, it is translated into challenges for strategic asset management (Burnard and Brahma, 2019). The definition of “interested parties” and legal and “regulatory requirements” are among the first steps needed for understanding an organisation for BC purposes (ISO 22301:2019). Effective governance is essential to encourage innovations and investments, while legal and regulatory constraints address strategies and actions (e.g., Elliot et al., 2020; BS 65000:2014).

The Japanese experience has highlighted the need to enforce the process of accountability across sectors, integrating bottom-up and top-down perspectives (e.g., Maruya, 2013; Velazquez et al., 2020). According to Maruya (2013): “public and private organisations should advance simultaneously to strengthen their BC ability”. Better involvement of scientific and academic actors may represent a further potential for many interviewees, in line with the recommendations of the 2015-2030 *Sendai Framework for Disaster risk reduction* (UNISDR, 2015).

Interestingly, all the interview respondents pointed out that the population suffered from a lack of trust in political bodies, including recurrent challenges such as corruption and management. This has been argued in many theories (e.g., Alexander 2000). Still, our dataset is one of the few that provides clear evidence on the subject and further point out that organisations’ resilience is context-dependent.

6.2 Standardisation of plans and procedures

Our evidence pictured a fragmented scenario of how EEW is integrated into planning and procedures. The dataset showed high polarisation between responses, a lack of frequent updated/practised plans, and the common need for better support by policies. It is possible that some aspects of the BC could have been misunderstood, and in the implementation phase, some generic protocols could have been designed without considering the implications of EEW.

The gaps in the standardisation of plans and procedures imply that new actions should bring coherence in prioritising operational activities, ensuring clear internal and external communication procedures, and establishing good practices on review/exercise (BS 65000:2014; ISO 22301:21019). Indeed, developing a solid prioritisation can affect how critical risk is recognised, influencing the capacity to adapt to uncertainties (BS65000:2014). Warnings, including EEW, can focus on what action needs to be activated first and must be translated into procedures that include communicating internally and externally and coordinating with stakeholders and other interested parties (ISO 223019:2019). According to Blyth (2009), the drills and exercises have an essential role. The limited notice time available implies that the "initial response to a warning must therefore be well practised and proven to be effective" (Blyth, 2009). Basic guidelines could be released by local authorities or associations such as ARISE.

Our data suggest that more information about the warning lead time is desired because it could orient the capacity to identify mitigation actions, including those for vulnerable categories. On the one hand, this confirms that organisations' perceived need for knowing the available time is similar to the one of the general public (Santos-Reyes 2019; Velazquez et al. 2020). On the other hand, our evidence suggests that the use of lead time may depend on the maturity levels of each organisation. The analysis showed a correlation between identifying internal responsibilities and the option of beta testing, suggesting that organisations that could be considered more mature could also better use additional information (available lead time). Similarly, the correlation between identifying critical functions and the view on false alerts (including their consequences) highlights that more mature organisations in the resilience scale find false alerts as sources of disturbance rather than useful (i.e., as unplanned/unexpected drills). This result is divergent from the literature focusing on the general population, where it is suggested that the tendency to accept and tolerate false alarms (Allen et al., 2017, 2018; Goltz, 2002; Herovic et al., 2019; Reddy, 2019). This is a critical remark because it points out the existence of different needs that need to be considered for targeting strategies and policies, such as liability and training. Following Johnson et al. (2016), any actions aimed at improving OR should consider/assess different groups and tailor solutions as much as possible.

In conclusion, the integration of vulnerable categories remains a neglected topic, in line with other evidence in emergency planning (Alexander, 2015). However, our analysis shows that actions in this domain could be associated with higher organisational maturity levels and improved scenario building.

6.3 Training and education

The interviews highlighted a critical aspect that we verified by looking carefully at the statistics: a substantial majority of the respondents stated they knew what to do in case of an alert, while the data revealed that they also wrongly believed in a given fixed/constant time between the issuance of the warning and the arrival of the shaking. Just one-third of the respondents were aware of variability, which is in line with the number of people who participated in training sections on how to use EEW efficiently in their organisations. Similarly, the awareness of official institutions towards EEW, in which a consistent percentage of the answers was wrong, was correlated with participation in training sessions and workshops. The drills and exercises evidenced in the questionnaires seem quite frequent, though it could be simply associated with the yearly drill promoted by the national government. The semi-structured responses pointed out a problem of quality more than quantity, as drills become routine and not used adequately to define gaps in practices. Finally, our case study seems characterised by a wrong perception of reaction capacities, associated with the combination of inadequate protocols, improper use of drills, and training.

Training, education and exercising are the pillars of effective BC and OR, and without adequate processes and strategies in place, also the other measures lose effectiveness (e.g., Blyth, 2009; Gibson and Tarrant, 2010; ISO22301:2019). They are essential for enabling response flexibility (BS 65000:2019), while the use of drills and exercise (both simulations, tabletop, and integrated) could make the difference in testing BC strategies (e.g., Blyth, 2009; Elliot et al. 2010; Maruya, 2013; Alexander, 2015). Johnson et al. (2016) argued that the EEW system's implementation must be supported by training strategies and practices that are not self-standing but must be adequately explained and understood, assuring communication and information sharing between the companies and first responders. Practical actions to improve training include giving priority to guidelines, online lectures, and webinars that may highlight the preference for flexible learning, structured to reinforce and consolidate the existing capacity. However, these may be insufficient on their own if not supported by measures in the accountability and governance sphere that could introduce compliance. This is a critical challenge where scientific expertise can support the development of a more comprehensive collaborative approach between the public and private sectors (e.g., Alexander, 2000; 2015; Blyth 2009).

7 Conclusions

Our analysis and discussion highlighted that integrating EEW into OR and BC practice implies new considerations on both internal and external resilience drivers. We provide evidence that such integration may be context-dependent and, if not achieved adequately, can undermine effective and mature technological tools.

Our case study suggests the existence of gaps in three critical domains: 1) Governance, accountability and liability; 2) Standardisation of plans and procedures; 3) Training and education. These can be considered overlapping areas between the field of OR and disaster risk reduction, where criticalities have to be addressed with practical actions in the social, political, behavioural, and operational context of reference (e.g., Alexander, 2000, 2015; Annarelli and Nonino, 2016; Elliot et al.2010; Linnenluecke, 2017; Burnard and Brahma, 2019; Pescaroli and Alexander, 2018).

Although our results must be considered context-depended, integrating standards on BC and OR gives the basis for further generalisations and replicability on other case studies. This paper does not pretend to be exhaustive. However, it aims to provide the first step to fill an existing research gap on integrating EEW into BC and OC. We would argue that new studies focused on EEW and their applicability in complex scenarios should be conducted systematically to better understand possible differences between institutional and cultural contexts, supporting the creation of safer societies.

Correspondence
Gianluca Pescaroli Institute for Risk and Disaster Reduction, University College London (UCL), Gower Street, London, UK. Email: g.pescaroli@ucl.ac.uk

Author affiliations
Gianluca Pescaroli Institute for Risk and Disaster Reduction, UCL, UK.
Omar Velazquez Institute for Risk and Disaster Reduction, UCL, UK.
Irasema Alcántara-Ayala Institute of Geography, National Autonomous University of Mexico (UNAM), Mexico.
Carmine Galasso Department of Civil, Environmental and Geomatic Engineering, UCL, UK; and Scuola Universitaria Superiore (IUSS), Italy.

Acknowledgements
This short article was made possible thanks to the experience matured in different projects awarded by our funders: BA/Leverhulme Small Research Grant Award 2019 supported by the United Kingdom's Department for Business, Energy and Industrial Strategy (Grant Reference: SRG19/191797); the Earthquake Engineering Field Investigation Team Award 2019 by the Institution of Structural Engineers in the UK; the Mexican Consejo Nacional de Ciencia y Tecnología (Grant Reference: 398485); the European Union's Horizon 2020 Research and Innovation Programme (Grant Agreement: 821046), and the TURNkey (Towards more Earthquake- resilient Urban Societies through a Multi-sensor-based Information System enabling Earthquake Forecasting, Early Warning and Rapid Response actions) Project.

Data Availability Statement
The SPSS file used for the statistical analysis of this paper is open access and available through University College London's data repository. To access the item, go to https://doi.org/10.5522/04/14036552.v1
The qualitative dataset is available from the corresponding author upon reasonable request.

References
Alcántara-Ayala, I. (2019) 'Desastres en México: mapas y apuntes sobre una historia inconclusa' (Disasters in Mexico: maps and notes on an unfinished history). *Investigaciones Geográficas, Boletín del Instituto de Geografía*, UNAM 100. pp/ 1-17.

Alcántara-Ayala, I. and A. Oliver-Smith (2017) 'The necessity of Early Warning Articulated Systems (EWASs): Critical Issues Beyond Response'. In Sudmeier-Rieux, K. Fernandez, M., Penna, I., Jaboyedoff, M. and J.C. Gaillard (eds.), *Linking sustainable development, disaster risk reduction, climate change adaptation and migration*, 101-124, Springer.

Alcántara-Ayala, I. and A. Oliver-Smith (2019) 'Early Warning Systems: Lost in Translation or Late by Definition? A FORIN Approach'. *International Journal of Disaster Risk Science.* 10. pp. 317–331

Alcántara-Ayala, I., D. Rodríguez-Velázquez, R.J. Garnica-Peña, and A. Maldonado-Martínez (2020) 'Multi-sectoral reflections and efforts to strengthening partnerships to reduce disaster risk in Mexico: the first MuSe-IDRiM Conference'. *International Journal of Disaster Risk Science*. 11.pp. 686–69.

Alcántara-Ayala I., I. Burton, A. Lavell, E. Mansilla, A. Maskrey, A. Oliver-Smith and F. Ramirez (2021) 'Editorial: Root causes and policy dilemmas of the COVID-19 pandemic global disaster'. *International Journal of Disaster Risk Reduction*. 52. 101892. https://doi.org/10.1016/j.ijdrr.2020.101892

Alexander, D.E. (2015) 'Evaluation of civil protection programmes, with a case study from Mexico'. *Disaster Prev. Manag.* 24. pp. 263–283. doi:10.1108/DPM-12-2014-0268.

Allen, R., E. Cochran, T. Huggins, S. Miles, and D. Otegui (2018) 'Lessons from Mexico's Earthquake Early Warning System. *Eos (Washington. DC).* 99. doi:10.1029/2018eo105095.

Allen, R.M., E.S. Cochran, T. Huggins, S. Miles, and D. Otegui (2017) 'Quake warnings, seismic culture'. *Science. 80 (*358). 1111. doi:10.1126/science.aar4640.

Allen, R.M. and D. Melgar (2019) 'Earthquake early warning: advances, scientific challenges, and societal needs'. *Annu. Rev. Earth Planet. Sci.* 47. doi:10.1146/annurev-earth-053018-060457.

Becker, J.S., S.H. Potter, L.J. Vinnell, K. Nakayachi, S.K. McBride, and D.M. Johnston (2020a) Earthquake early warning in Aotearoa New Zealand: a survey of public perspectives to guide warning system development. *Humanities and Social Sciences Communications*. 7(1), 1-12.

Becker, J.S., S.H. Potter, R. Prasanna, M.L. Tan, B.A. Payne, C. Holden, C., ... and D.M. Johnston (2020b) 'Scoping the potential for Earthquake Early Warning in Aotearoa New Zealand: a sectoral analysis of perceived benefits and challenges'. *International Journal of Disaster Risk Reduction. 51*. 101765.

Blyth, M. (2009) *Business continuity management: building an effective incident management plan*. John Wiley & Sons.

BSI (British Standards Institutions) (2014) *Guidance on organisational resilience BS 6500:2014*. London: BSI Standards Limited.

Burnard, K.J., and R. Bhamra (2019) 'Challenges for organisational resilience'. *Contin. Resil. Rev.* 1(1).pp. 17-25.

Cremen, G. and C. Galasso (2020) 'Earthquake early warning: recent advances and perspectives'. *Earth-Science Review.* 103184.

Cremen, G., Galasso, C. (2021) 'A decision-making methodology for risk-informed earthquake early warnin'. *Computer-aided Civil and Infrastructure Engineering* 36(6). pp. 747– 761. doi:10.1111/mice.12670.

Cremen, G., Bozzoni, F., Pistorio, S., Galasso, C. (2022) 'Developing a risk-informed decision-support system for earthquake early warning at a critical seaport'. *Reliability Engineering & System Safety* 218(A), 108035. doi:10.1016/j.ress.2021.108035.

Creswell, J.W. (2014) *A concise introduction to mixed methods research*. Sage, New York, NY.

Cuéllar, A., G. Suárez, and J.M. Espinosa-Aranda (2018) 'A fast earthquake early warning algorithm based on the first 3 s of the P-Wave Coda. *Bull. Seismol. Soc. Am.* 108. pp. 2068–2079. doi:10.1785/0120180079.

Cuéllar, A., G. Suárez, and J.M. Espinosa Aranda (2017) 'Performance evaluation of the earthquake detection and classification algorithm 2 (tS-tP) of the seismic alert system of Mexico (SASMEX)'. *Bull. Seismol. Soc. Am.* 107. pp. 1451–1463. doi:10.1785/0120150330.

Cutter, S., A. Ismail-Zadeh, I. Alcántara-Ayala et al. (2015) 'Global risks: Pool knowledge to stem

losses from disasters'. *Nature.* 522. pp. 277–279. https://doi.org/10.1038/522277a

Elliott, D., E. Swartz, and B. Herbane (2010) *Business continuity management: A crisis management approach*. Routledge, London

Espinosa-Aranda, J., A. Cuellar, A. Garcia, G. Ibarrola, R. Islas, S. Maldonado et al. (2009) 'Evolution of the Mexican Seismic Alert System (SASMEX)'. *Seismol. Res. Lett.* 80. p. 694. doi:10.1785/gssrl.80.5.694.

Espinosa-Aranda, J.M., A. Cuéllar, F.H. Rodríguez, B. Frontana, G. Ibarrola, R. Islas et al. (2011) 'The seismic alert system of Mexico (SASMEX): Progress and its current applications'. *Soil Dyn. Earthq. Eng.* 31. pp. 154–162. doi:10.1016/j.soildyn.2010.09.011.

Evans, J.D. (1996). *Straightforward statistics for the behavioural sciences*. Brooks/Cole Publishing, Pacific Grove, CA.

Gibson, C.A. and M. Tarrant (2010) 'A "conceptual models" approach to organisational resilience'. *Aust. J. Emerg. Manag.* 25(2). pp. 1-7.

Goltz, J.D. (2002) *Introducing earthquake early warning in California: A summary of social science and public policy issues.* Governor's Office for Emergency Service, Pasadena, CA, US. http://www.cisn.org/docs/Goltz.TaskI-IV.Report.doc

Harrell, M.C., and M.A. Bradley (2009) *Data collection methods. Semi-structured interviews and focus groups.* Rand National Defense Research Inst, Santa Monica.

Herovic, E., T.L. Sellnow, and D.D. Sellnow (2019) 'Challenges and opportunities for pre-crisis emergency risk communication: lessons learned from the earthquake community'. *J. Risk Res.* pp. 1–16. doi:10.1080/13669877.2019.1569097.

Horiuchi, Y. (2009) Earthquake early warning hospital applications'. *Spec. Issue Early Warn. Nat. disaster mitigation.* 4.pp. 237–241.

ISO (International Organization for Standarization) (2019) *ISO 22301:2019. Security and resilience - Business continuity management systems - Requirements.* Geneva: ISO.

Johnson, L.A., S. Rabinovici, G.S. Kang, S.A. Mahin, C. Curry, R. Arba et al. (2016) 'California Earthquake Early Warning System Benefit Study'. *CSSC Publ.*pp. 16–04.

Linnenluecke, M.K. (2017) 'Resilience in business and management research: A review of influential publications and a research agenda'. *Int. J. Manag. Review.* 19. pp. 4–30.

Maruya, H. (2013) 'Proposal for improvement of business continuity management (BCM) based on lessons from the Great East Japan Earthquake'. *J. JSCE.* 1. pp. 12–21.

Nakayachi, K., J.S. Becker, S.H. Potter, and M. Dixon (2019) 'Residents' reactions to earthquake early warnings in Japan'. *Risk Anal.* doi:10.1111/risa.13306.

Ohara, M. (2012) 'A study on people's awareness of earthquake early warning before and after the 2011 off the Pacific Coast of Tohoku Earthquake, Japan'. in *15th World Conference on Earthquake Engineering (15WCEE)* (Lisboa).

Palinkas, L.A., G.A. Aarons, S. Horwitz, P. Chamberlain, M. Hurlburt, and J. Landsverk (2011) 'Mixed method designs in implementation research'. *Adm. Policy Ment. Heal. Ment. Heal. Serv. Res.* 38. pp. 44–53.

Pescaroli, G. and D. Alexander (2018) 'Understanding dompound, interconnected, interacting, and cascading risks: a holistic framework'. *Risk Analysis.* 38. pp. 2245–2257. doi:10.1111/risa.13128.

Pescaroli, G., M. Nones, L. Galbusera, and D. Alexander (2018) 'Understanding and mitigating cascading crises in the global interconnected system'. *Int. J. Disaster Risk Reduction.* 30. pp. 159–163. doi:10.1016/J.IJDRR.2018.07.004.

Pescaroli, G., O. Velazquez, I. Alcántara-Ayala, C. Galasso, P. Kostkova, & D. Alexander (2020) 'A Likert Scale-based model for benchmarking operational capacity, organisational resilience, and Disaster Risk Reduction. *International Journal of Disaster Risk Science. 11. pp. 404-409.*

Porter, K.A. (2016) 'How many injuries can be avoided through earthquake early warning and drop, cover, and hold on?'. *Structural engineering and structural mechanics program, Boulder, CO*.

Reddy, E. (2019) 'Crying "crying wolf": how misfires and Mexican engineering expertise are made meaningful'. *Ethnos.* 1844. doi:10.1080/00141844.2018.1561489.

Santos-Reyes, J. (2019) 'How useful are earthquake early warnings? The case of the 2017 earthquakes in Mexico city.' *Int. J. Disaster Risk Reduct.* 40. 101148. doi:10.1016/j.ijdrr.2019.101148.

Saunders, B., J. Kitzinger, and C. Kitzinger (2015) 'Anonymising interview data: Challenges and compromise in practice'. *Qual. Res.* 15. pp. 616–632.

Suárez, G., D. Novelo, and E. Mansilla (2009) 'Performance evaluation of the Seismic Alert System (SAS) in Mexico City: a seismological and a social perspective'. *Seismol. Res. Lett.* 80. pp. 707–716. doi:10.1785/gssrl.80.5.707.

Suárez, G., J.M. Espinosa-Aranda, A. Cuéllar, G. Ibarrola, A. García, M. Zavala et al. (2018) 'A dedicated seismic early warning network: the Mexican Seismic Alert System (SASMEX)'. *Seismol. Res. Lett.* 89. pp. 382–391. doi:10.1785/0220170184.

Suárez, G. (2022) The Seismic Early Warning System of Mexico (SASMEX): A Retrospective View and Future Challenges. *Frontiers in Earth Science*. 10. 10.3389/feart.2022.827236.

Tajima, F. and T. Hayashida (2018) 'Earthquake early warning: what does "seconds before a strong hit" mean?'. *Prog. Earth Planet. Sci.* 5. doi:10.1186/s40645-018-0221-6.

Twigg, J. (2003) 'The human factor in early warnings: risk perception and appropriate communications'. In J. Zschau and A. Küppers (eds) *Early Warning Systems for Natural Disaster Reduction*. Springer, Berlin, Heidelberg.

UNISDR (2015) *Sendai Framework for Disaster risk reduction 2015 - 2030*. Geneva, Switzerland doi:A/CONF.224/CRP.1.

UNISDR (2017) *Disaster resilience scorecards for cities- Preliminary level assessment.* Geneva, Switzerland Available at: https://www.unisdr.org/files/58158_unisdr2017annualreport.pdf.

UNDRR (2017) Early Warning Systems (the 2nd of February 2017). Available at: https://www.preventionweb.net/terminology/view/478. Accessed Nov. 2020.

Velazquez, O., G. Pescaroli, G. Cremen, and C. Galasso (2020) A review of the technical and socio-organisational components of earthquake early warning (EEW) systems. *Front. Earth Sci. Geohazards Georisks*.

Weber, R.P. (1990) *Basic content analysis*. Sage, New York, NY.

Whitman, Z., J. Stevenson, H. Kachali, E. Seville, J. Vargo, and T. Wilson (2014) 'Organisational resilience following the Darfield earthquake of 2010'. *Disasters.* 38. pp. 148–177.

APPENDIX A. Questions (Q) included in the survey

Section 1. Perception of EEW Systems
Q1. How relevant is EEW for your organisation?
Q2. Do you consider EEW as a useful service when considering its current state of development?
Q3. To what extent do you know what to do in case of an EEW?
Q4. Do you think EEW could be useful to limit the disruption of critical services such as communication and transportation?
Q5. Do you think the current development of EEW takes adequate consideration of how they can be integrated in organisational needs? (e.g., operational functions, day to day activities)
Q6. To what extent do you think that local policies are adequate to support the integration of EEW in your organisation's practices and procedures?
Section 2. Current status of planning for mitigating disruptions
Q7. Does your organisation have developed specific plans or procedures to undertake in case of an EEW? (e.g., stop a production process, empty the cash register, close the gas mains)
Q8. Has the business continuity plan of your organisation been updated in the last 18 months?
Q9. To what extent your organisation identified which critical functions/activities could be protected using EEW?
Q10. To what extent your organisation prioritised which critical functions/activities could be protected using EEW?
Q11. To what extent your organisation identified internal responsibilities/liabilities for activating procedures and actions associated with an EEW?
Q12. Is your organisation aware of the official institutions that provide EEW in Mexico City?
Q13. To what extent your organisation identified possible vulnerable categories that could be better protected by activating specific procedures following an EEW?
Q14. Do you consider useful to know the available warning time, before the arrival of the ground shaking at your location? (Specially to activate organisational procedures).
Q15. Assuming the Mexican EEW system includes the available lead time in the warning messages, has your organisation identified the mitigation actions likely to be activated for short warnings (e.g., 10 seconds), or large warnings (e.g., 60 seconds)?
Q16. Do you consider the Mexican EEW system can initiate beta testing in which warnings include the available warning time? The beta testing would only include those organisations with appropriate structures and capacity to deal with such warnings.
Q17. Do you consider that false alerts can trigger interruption of business continuity, and therefore create economic losses, within your organisation?
Q18. How often your organisation practice drills for both short and long warnings?
How helpful do you think the following tools could be to improve the use of EEW for your organisation?
Q19. Guidance about good practices and procedures to follow for integrating EEW in your organisation
Q20. Legislations that clarify responsibilities associated with actions to undertake when an EEW is released
Q21. Guidance on what to do according to the possible time intervals between an EEW and the arrival of the ground shaking at your location (e.g., distinguishing between short warning, long warning and

common actions)
Q22. Assistance in defining the best continuity strategies for your organisation in case of an EEW
Q23. Please rate the tools enlisted in Qs 19-22, from less useful to more useful, according to their relevance in your organisation.
Q24. Is there anything else that has not been mentioned above that you may find useful?
Section 3. Training needs related to EEW
Q25. Have you received enough training to understand the applications of EEW for limiting the disruptions/ helping the continuity of your organisation?
Q26. Did your training (if any) include the implications of EEW for preparedness, response, and recovery?
How useful do you think the following training might be?
Q27. Courses to understand how to integrate the EEW into the daily activities of your organisation
Q28. A free short course provided by local authorities on how to respond to an EEW in organisations
Q29. Roundtable events or tabletop exercises held in the local authorities/community or business organisations
Q30. Freely available guidelines
Q31. Online free lessons
Q32. Webinars and online videos with basic instructions to undertake in the case of an EEW
Q33. Please rate the training enlisted in Qs 27-32, from less useful to more useful, according to their relevance in your organisation.
Q34. Is there anything else that has not been mentioned that you may find useful to support training on EEW?
Section 4. Background
Q35. Does your organisation have access/is registered to EEW?
Q36. Have you ever participated in training sessions or workshops on how to use an EEW efficiently in your organisation?
Q37. Are you aware of how long the warning time in case of an EEW is?
Q38. What is your opinion about false alerts?
Q39. What is your level of education?
Q40. What is your affiliation?
Q41. What is your gender?
Q42. Do you have any other comments?