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Understanding the decision-making process in disaster risk monitoring and early-warning: A case study within a control room in Brazil

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ABSTRACT

The tasks of disaster risk monitoring and early warning are an important means of improving the efficiency of disaster response and preparedness. However, although the current works in this area have sought to provide a more accurate and better technological infrastructure of systems to support these tasks, they have failed to examine key features that may affect the decision-making. In light of this, this paper aims to provide an understanding of the decision-making process in control rooms for disaster risk monitoring and early warning. This understanding is underpinned by a conceptual framework, which has been developed in this work and describes factors that influence the decision-making. For doing so, data were collected through a series of semi-structured interviews and participatory observations and later evaluated with members of the control room of the Brazilian Center for Monitoring and Early Warning of Natural Disasters (Cemaden). The study findings provided a solid basis for designing the conceptual framework of the essential factors required by the decision-makers. These factors are separated into two groups: 1) the "dimensions" of decision-making (i.e., the type of hazard, the phase of the disaster risk, the location, and area of expertise of the operators) and the "pillars" of decision-making (i.e., the tasks, their required information, useful data sources, and the decision rule). Finally, the contributions achieved in this study may help operators to understand and propose proactive measures that could improve their decision-making, overcome uncertainties, standardize the team's decision-making, and put less pressure on operators.

1. Introduction

Communities from different countries all over the world have been affected by the growing occurrence of disasters, which in 2015, incurred financial losses close to US$100 billion worldwide and caused 23,000 fatalities [38]. These disasters are a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation [33,24,18]. A disaster is thus triggered by natural hazards, which can be natural (geological, hydrometeorological and biological) or induced by human processes (environmental degradation and technological hazards) [18]. Geographically, different locations are more or less exposed to these different types of hazards. Hazard and exposure are well known and the concepts that are easy to understand. By contrast, vulnerability is a complex concept, and disciplines have several ways of defining, measuring and assessing it. The concept involves the characteristics of people and groups that expose them to harm and limit their ability to anticipate, cope with and recover from harm [62]. Disaster risk is determined probabilistically as a function of hazard, exposure, vulnerability and capacity. It is the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, a society or a community in a specific period [18].

In this manner, early warning systems (EWS) have been established to protect people by enabling action in advance to reduce risks and impacts [6]. Together with a technological infrastructure for data collection and analysis like decision support systems [27,44,37], as well as decision analysis models [26,15], EWS also denotes a social process that occurs at different spatial scales and involves decision-making [25]. There are some chains with several types of data, information,

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knowledge, experts, stakeholders, practitioners, policymakers, citizens involved in this social process. Monitoring available information[1] and making a decision to issue warnings about potential disaster risks are often carried out in a control room, which is staffed by operators for analyzing environmental variables, identifying potential hazards and vulnerabilities, and communicating warnings with an emergency response team [36,49]. These control rooms have been established not only for disaster risk management, but also areas of interest, such as nuclear power plants [30,11,63,31], mineral processing plants [28,29], and oil refineries [48].

Since social aspects of a control room impact the way how decisions taken, they have been examined in research works existing in the literature [30,11,63,31]. However, although these works have resulted in a better understanding of the procedural, cultural, and social aspects of control rooms in different scenarios, the challenge now is to recognize how those factors can influence decision-making in control rooms for disaster risk monitoring. This is particularly important once activities carried out by operators are often affected not only by the cognitive skills of each operator [3,14,29] but also by communication and collaboration between them [32,14,3]. As stated by Reed [45], decision-making preferences in organizations are often inconsistent, unstable, and externally driven; the linkages between decisions and actions are loosely-coupled and interactive rather than linear.

On the basis of this challenge, this study investigates the following research question: *what are the factors that influence the decision-making process in a control room for disaster risk monitoring and early warning?* The first stage in answering this question was achieved in our previous work when a preliminary version of the decision-making process was modeled by means of a standard modeling notation [21]. This version was later extended and refined in another work [19], which also sought to link the tasks of the decision-makers with existing data sources. This paper goes beyond the modeling and development of diagrams that described the decision-making process by interpreting the factors that could influence it. The interpretation is supported by a conceptual framework that was based on a case study that was conducted within the control room of Cemaden. Hence, this work not only consolidates and extends our previous works but also provides the following new contributions:

- **Conceptual framework**: A framework is proposed for conceptualizing the relationship between the factors that influence the decision-making process. These factors can be described as “dimensions” (i.e., the type of hazard, the warning phase of the disaster, the location, and area of expertise of the operators) and “pillars” (i.e., the tasks, their required information, useful data sources, and the decision rule) of the decision-making process in the control room.
- **Case study**: Lessons were learned from the case study within the control room of Cemaden and formed the basis of the conceptual framework.

This paper is structured as follows. Section 2 first outlines the conceptual basis of this work. Following this, Section 3 describes the research method employed for conducting this work, as well as the study settings, i.e., Cemaden, its control room, and existing monitoring systems. On the basis of this, Section 4 describes the findings of the study, which are discussed in Section 5. Eventually, Section 6 reaches some conclusions and makes suggestions for future work and research lines.

2. Background

2.1. Disaster management and early warning systems

Disaster management presents as an important alternative to achieve this resilience and, as a consequence, avoid or, at least, reduce the impacts caused by natural disasters [5]. It follows a continuous process, which consists of activities that are executed before, during and after a disaster. These activities in turn are separated into four main phases (mitigation, preparedness, response, and recovery). The monitoring of different variables (e.g., structural, environmental, and social), as well as decisions of issue warnings are defined in the preparedness phase, which aims to reduce potential damages caused by a disaster [43,57]. Early warning systems (EWS) indeed play a critical role for supporting these tasks, and because of this, enhancing EWS is one of the seven targets of Sendai Framework for Disaster Risk Reduction to minimize disaster risks and save lives [52].

EWS are defined as a “set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act and in sufficient time to reduce the possibility of harm or loss” [54] For doing so, they consist of four interrelated elements [27,6,56]. To start with, the first element is risk knowledge which requires a systematic collection and analysis of data and should include a dynamic assessment of hazards and physical, social, economic, and environmental vulnerabilities. The second element is monitoring and warning that should have a good scientific basis for predicting and forecasting hazards and a warning system that operates 24/7. While the third interrelated element focus in the communication and dissemination of warnings that contain clear messages and useful information to enable proper responses. Last but not least, the response capability element is essential to ensure effectiveness of EWS, i.e. people should understand their risks and know how to react [53].

2.2. Control rooms

Effectiveness EWS requires a proper monitoring of variables of interesting in order to ensure that accurate warnings of potential events are issued in time. Control rooms are particularly important to support these tasks. This is because they are staffed by operators that are responsible for analyzing environmental variables, identifying potential hazards and vulnerabilities, and communicating warnings with a response team [36]. Consequently, they are a core element in different levels of chains at spatial locations from national to local organizations.

In the same manner of any other organization, control rooms can be also characterized by “a series of interlocking routines, habituated action patterns that bring the same people together around the same activities in the same time and places” [61]. These however can be located within an organization, or as an organization itself. Their activities are thus often affected by factors that can be the complexity and variety of several data collection tools, as well as the variety of external and internal factors that affect control room operators [49]. Example of external factors are a broken rainfall gauge, or the restrictive national laws, and on the other hand, an internal factor may be organizational policies for communication among operators.

Control rooms can be found in nuclear power plants [30,11,31], mineral processing plants [28,29], oil refineries [48], emergency warning systems [36,23,3,49]. Although these existing works investigate the physical design of a room and its technological tools, only few of them are focused on analyzing organizational theory and issues [9,60,50]. Yang et al. [63] studied the effects of computer-based procedures on the performance of operators in nuclear power plants, including factors, such as mental workload and situational awareness. Li et al. [29] examined human factors in the complex and dynamic environment of mineral processing plants. Furthermore, Weick [59] investigated an air control system incident with the aim of identifying its

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[1] We understand “data” as a single and unorganized raw value that is provided by a specific source. It requires a processing in order to obtain its meaning. While, the term “information” allows us to expand our knowledge about a specific data by means of organizing and structuring it, which in turn provide a meaning of such raw value. Therefore, a required information may consists of a single element or a complex structure of data.

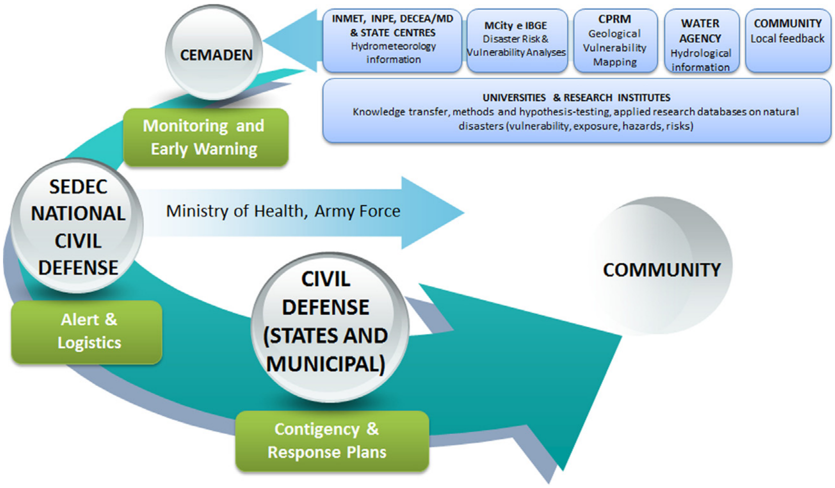

Fig. 1. Scenario of disaster monitoring and early-warning in Brazil: overall institutions and information flow.

failure issues. Results of this work showed that interruption of routines (e.g., loss of communication among operators) when combined may incur into a small errors, and, thus, an overall event.

2.3. Decision-making process in control rooms

Decisions are intrinsic in the daily activities within control rooms; for example, if a traffic engineer requires data about the condition of the roads when deciding on what is the appropriate traffic flow [36]. Both tangible and intangible factors affect the success or failure of a decision but a decision-maker still requires suitable data when making decisions. Otherwise, he/she might simply have to depend on his/er own experience and this might result in a wrong decision and raise questions about his reliability and efficiency [51,45].

In the case of disasters, before control room operators can make informed decisions and issue accurate and useful warnings, they usually analyze information from different types of variables (e.g., the water level inside the riverbeds and volume of rainfall) in a short period of time. For this reason, attempts have been made in both the literature and common practices to develop decision support systems [27,58,44,37] that would be able to support decision-making. For example, Picozzi et al. [42] devised an early warning tool for earthquakes which provides alert messages within about 5–10 s for seismic hazard zones, while Alfieri et al. [2] analyzed a European operational warning tool for water-related disasters. Another line of works are focused on developing decision analytical models that provide a better understanding of how to use required variables, and thus improve decision-making [40,15,12]. Within this group, Kou and Wu [26] proposed a multi-criteria-based decision model that could be employed for analyzing existing medical resources and providing their optimal allocation. Furthermore, Comes et al. [13] presented an approach that supports decision-makers under fundamental uncertainty by suggesting potential developments scenarios.

Although these works provided relevant contributions to improve decision-making in disaster management, none of them investigated these decisions as an organizational process within control rooms. Here, it is worthwhile to mention the work of While Weick [59] that examined an air control system and indicated the interruption of important routines, together with a broken communication chain among operators, as two factors that may trigger small errors into major disasters. This study is closely related to this work; however, we are focused on modeling the decision-making process, and then examined the influencing factors. In other words, a process can be modeled as a set of connected activities using information and communication technologies, which lead to a closed outcome providing a measurable benefit for a customer” [41]. On the basis of a modeled decision-making process, operators and coordinators are able to analyze and define proper decision models, which may fit to the goal of activities. Thus, decision analytical model should be recognized as beyond the scope of this work.

3. Method

3.1. Study settings: The Cemaden

In Brazil, preventive countermeasures have been taken to mitigate loss and damage, as well as to improve the coping strategies employed by communities against floods, droughts, and landslides. One of these countermeasures was to set up Cemaden (in 2011), which is a branch of the Brazilian Ministry of Science, Technology, Innovation, and Communications (MCTIC, in Portuguese). Since the establishment of Cemaden, the number of monitored municipalities has grown from 56 in 2011 to almost 1000 in 2016, which represents 17% of all Brazilian municipalities (5570 towns and cities). In parallel, the number of warnings that were issued by the control room of Cemaden has also grown during the last few years, i.e., 1353 (2014), 1762 (2015), 1983 (2016), and a total of almost 6500 issued warnings since 2011 when Cemaden was founded. This growing number of monitored municipalities, combined with the number of issued warnings, illustrates the complexity of the ongoing problem of disaster risk monitoring and issuing early warnings in Brazil.

For dealing with this scenario, Cemaden has been building a monitoring system that consists of more than 4750 rainfall gauges, about 550 humidity and rainfall sensors, nine weather radars, and almost 300 hydrological stations. These sensors provide data on precipitation, calculate the movement of weather systems, and forecast the weather conditions (e.g., rain). In addition, the center also works in collaboration with several institutions such as the National Water Agency (ANA, in Portuguese), the Brazilian Geological Survey (CPRM, in Portuguese), and the National Institute of Meteorology (INMET, in Portuguese) (see Fig. 1). These provide further data about weather conditions, risk maps, and environmental variables, which supplement the existing data of the center.

All these different types of data are monitored and used within a control room for making decisions of whether or not issuing warnings of potential hazards when adverse weather conditions are forecast. This contains a video wall, which displays the data that is drawn on to support the decision-making of a monitoring team (Fig. 2). The monitoring teams work 24 h a day, throughout the entire year, in a continuous monitoring cycle that is divided into six-hour shifts, starting at midnight. They comprise a team of seven to eight members that include

Fig. 2. Video wall in the control room of CEMADEN.

at least one specialist in each of the following areas of expertise: hydrology, meteorology, geology, and disaster management specialist.

In addition to the video wall, each member has a separate working station where they analyze particular information on their own (Fig. 2), e.g., a geologist may want to analyze data provided by geological agencies (e.g., CPRM), while a hydrologist is more interested in data from water resources agencies (e.g., ANA). While working, they can use a decision support system, which integrates data from the monitoring systems and displays integrated data on a geospatial dashboard. These data are also analyzed by the teams to determine what warning level should be adopted; on the basis of this warning level, relief agencies on the ground can decide what kind of action should be taken.

Since previous knowledge and experiences of an area (like its rainfall seasonality) are also essential when deciding whether or not to issue a warning of a potential disaster, this makes decision-making more empirical, although it is also highly subjective. Furthermore, the task of issuing a warning and deciding on its level implies a high degree of responsibility and puts pressure on the operators, which makes decision-making more complex.

3.2. Study design and sampling

A case study was carried out as a part of the research methodology, mainly because it is a means of investigating a contemporary phenomenon in its context when the boundary-line between them may be unclear [64,46]. Since the aim of this study is to analyze the decision-making process of a control room for disaster risk monitoring and early warning, the control room operators of Cemaden represent the subject of the study and their daily business processes are the units of analysis (or "case"). A set of analytical variables was employed to assist in the collection and analysis of significant information about the units of analysis [64]. These included Activity, Sequence Flow, and Actor and were derived from our previous work [22].

During the phase of data collection, semi-structured interviews and direct observations were employed to gather qualitative data from control room operators. Purposive sampling was adopted as a technique for selecting participants for the qualitative study, i.e., those operators who were working in the control room on the visiting day were selected as the sample for the study. This method was chosen mainly because control room operators have a very strict work schedule and are unable to spend much time away from their regular activities; in view of this, the best alternative was to approach them informally in their free time, and not during their work shifts. The aim was to recruit as many participants as possible and thus include a comprehensive and appropriate number of individual cases for the study.

Collected data were then used for preparing a diagram that describe the decision-making and reveal influential factors. This diagram was modeled with the aid of Business Process Model and Notation (BPMN) [41], which is a standard model that is used in research for the task of modeling business processes in different application domains. After this diagram has been modeled, it was further evaluated with control room operators. Purposive sampling was also conducted during the free time of the participants (i.e. between their work shifts). It is also worth mentioning that no *a priori* fixed sample size was set in any phase of the case study.

3.3. Data collection

Data were collected during the period January 19th-22nd, 2016 and on February 1st, 2016 at the Cemaden headquarters in São José dos Campos, Brazil. During these periods, 88 warnings were issued from the control room to the National Center for Disaster and Risk Management (CENAD, in Portuguese), at the Nacional Civil Defense (SEDEC, in Portuguese) (see Fig. 1). Direct observation sessions were conducted following a study protocol and with a limited degree of interaction by the researcher (observer) and the subjects. This meant that the observer was only regarded as a researcher and did not interact with the subject or interfere with the subjects' activities [46]. The aim of these sessions was to gather data about the day-to-day activities and interactions of the subjects without interfering with their work.

Individual, face-to-face interviews were also conducted with the aim of obtaining data about the business activities of the participants. Open-ended questions were asked, and these guided the course of the interviews. There were 10 semi-structured interviews with members of the control room comprising two geologists, two hydrologists, two meteorologists, and four disaster analysts and these took place at the workplace of the participants. This represented 30% of all the members that were working in the control room, all of whom have had at least one year's experience there. Since the interviewers were working within strict time constraints, the interviews took no more than 35 min and all of them were audio-recorded.

The data collection was carried out by a Ph.D. Student with a background in business process modeling and information systems. His work was supervised by a Researcher with a background in the sociology of disasters and early warning systems and a Professor with a background in information systems and disaster management. This interdisciplinary teamwork was important since it provided a solid basis for conducting all the phases of the study.

3.4. Data analysis

The audio-recording from the interviews was used for transcribing

Table 1
Summary of the methods of data collection.

#	Method	Subjects	Period (min)	Objective
1	Direct observation	–	120	To analyze activities in the monitoring room
2	Direct observation	–	60	To analyze the shift of a monitoring team and the use of available systems
3	Direct observation	–	150	To analyze the communication in the monitoring room
4	Interview	2 Meteorologist	35/45	To collect data of the subject's daily activities
5	Interview	2 Hydrologist	21/46	
6	Interview	2 Geologist	30/33	
7	Interview	4 Disaster Mgmt Spec	48/22/33/30	

each of them verbatim, i.e., the transcription included every word of the audio-recording and so represented just the way it was said. The analysis and classification were conducted in two distinct phases.

In the first stage, the analytical variables used during the data collection were again employed as a basis for defining a coding technique for the classification and analysis of the data. Coding is "a method that enables you to organize and group similarly coded data into categories or "families" because they share some common characteristics" [47]. The coding scheme was then employed to classify the content of each transcription. This analysis relied on the NVivo Data Analysis Software.[2] The second phase was based on the coded data, and consisted of modeling the decision-making process, by means of BPMN. This modeling centered on the business process that covers the analysis of all the coded data assigned to the "Activity" and "Sequence Flow" categories of the coding scheme (see Supplementary materials). Signavio Modeling Platform[3] was used for supporting in this task (Table 1).

3.5. Data evaluation

Focus group sessions were held with the aim of obtaining practical feedback on the model diagram, as well as assessing recommendations for improvements and/or discovering new ideas. Focus groups can be regarded as a social research method that allows a group of people (4 – 8) to provide data about a specific topic by means of informal group interaction [39]. A protocol was created to guide the work during the sessions, which consisted of unstructured and open-ended questions. Two focus group sessions were held on August 23rd, 2016 at the control room of Cemaden with teams that were working in shifts (as summarized in Table 2). Six people attended the first session - one meteorologist (M), one disaster analyst (D), two hydrologists (H), and two geologists (G) - while the second session consisted of seven people - two geologists (G), one hydrologist (H), two disaster recovery analysts (D), and two meteorologists (M).

The focus group sessions were conducted by the Ph.D. Student under the supervision of the Researcher and Professor. The participants of the focus group session were the only people present in the room.

3.6. Ethical statement

This study fully complied with the ethical and legal principles governing scientific research with human beings, drawn up by the School of Arts, Sciences and Humanities of the University of So Paulo and took into account the requirements laid down by the Brazilian National Board of Health. All the participants signed the Informed Consent Form. The interviews and focus group sessions were conducted in Portuguese because it was the native spoken language of the participants. They were also audio-recorded by means of a smartphone. The subjects were not paid anything for their participation in the sessions. Moreover, the participants were not given immediate feedback after the interviews and focus group sessions, although the ideas and results obtained in this study will eventually be shared with the CEMADEN community during a workshop at the center.

Table 2
Summary of focus group sessions.

#	Participants	Period	Objective
1	6 people (1 M, 1 D, 2 H, 2 G)	60 min	Evaluate the generated model diagrams
2	7 people (2 G, 1 H, 2 D, 2 M)	60 min	

4. Findings

When examining the feedback of the control room operators on the decision-making process, the focus group data was divided into two key areas: the "pillars" of the decision-making process and the "dimensions" of the control room for disaster risk monitoring and early-warning.

4.1. The pillars of decision-making process

The results of the focus group sessions provide qualitative data that decision-making in the control room is linked to four areas: 1) tasks; 2) required information for informed decision-making; 3) decision rules that make sense of the available data; and 4) accurate data sources.

Interestingly, during the phase of data collection at Cemaden, control room operators were reticent in regarding of the decision-making process. This was mainly because they did not know how this process would be and why it could be important for their work. However, during the phase of data evaluation, we could understand that operators have a tacit knowledge about their daily activities, which turned to be useful in their own opinion, as one of the meteorologists stated:

> "*It [the decision-making process] helps the operator. For example, I followed all the predetermined tasks; if something unexpected happened it was because it was not covered by the process.*"

The participants also thought that the decision-making could be speeded up once they know what their activities are and what data and information they have to look for. This is consistent with a previous analysis of the work in the control room [36], which found there were disruptions in information flow and a work overload among the control room operators when there was a lack of appropriate tools and action protocols. However, Militello et al. [36] only analyzed the information flow between different control rooms, whereas this paper is concerned with analyzing the decision-making process.

Furthermore, control room operators believe that training can capacity them to making better decisions or even improving them. It is worthwhile to mention that the operators did not have any training and/or drills since Cemaden's creation in July 2011. Indirectly, they recognized that their decisions have uncertainties and they want to reduce this vulnerability. As a geologist stated:

> "*Decision-makers will be trained to know how the existing processes and decisions should be carried out, and thus be prepared for making better decisions or even improving them.*"

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[2] http://www.qsrinternational.com/what-is-nvivo.

[3] http://www.signavio.com/.

A clear understanding of the decision-making process also provides a basis for understanding the interactions and relationships among the operators. This can not only help them to analyze any inconsistencies and avoid misunderstandings but also manage conflicts within the teams during the daily activities (e.g., the power inequalities among experts in relation to the unrecognized expertise of disaster management analyst, or the pressure to issuing early warning for several cities when emergency situations appear [60]). An example of this devalued expertise of disaster analyst is expressed by the obligation to perform administrative tasks when the other experts are performing scientific analysis of hazard monitoring using meteorology, hydrology and geology knowledges. Disaster experts expressed their vulnerability in the organization trying to highlight some information regarding people exposed to floods and landslides and/or physical vulnerability of buildings in these risk-prone areas:

> "*My job is not restricted to administrative tasks (e.g., filling in forms or issuing warnings). I am also responsible for providing data to the other members about the vulnerable community (e.g., the number of buildings located in an area at risk).*"

Furthermore, the results from the focus group sessions also provided evidence that decision-making is closely related to an understanding of what information is available and how it can be combined to detect a potential disaster through a decision rule. For example, a hydrologist requires data about the volume of rainfall and water level of riverbeds in order to predict the risk of flooding.

This required information is affected by the quality of the shared data, and location of the available data sources, such as hydrological stations and rainfall gauges. The uncertainties caused by the huge volume of available data or the condition of the data collection tools, should be also taken into account when making decisions. As one meteorologist pointed out:

> "*The forecasting of rainfall depends on having available tools, and effective meteorological stations; it also requires data that are updated and reliable because the rainfall gauges might not be properly calibrated. Unfortunately, some municipalities do not have any available tools, which means one is monitoring 'in the dark'.*"

Indeed, forging a relationship between tasks, required information, decision rules, and data sources is a crucial issue. With regard to this, a geologist made the following comment:

> "*You know how things should work and are thus suitably prepared to make a decision or even improve the decision-making process.*"

A meteorologist echoed the geologist's comment on the importance of understanding the basic principles of decision-making which he supplemented by pointing out that "*this could help in the management of the team members; for example, when you have to hire a new member.*"

4.2. Dimensions of the control room for disaster risk monitoring and early-warning

The results of the study showed that the tasks carried out in the control room can often be divided into four key areas: 1) phases of warnings; 2) determining the type of hazard; 3) the location of warned areas, and 3) the expertise of the operators.

With regard to the phase of issuing warnings, according to the participants, the status of a warning could fall into one stage of the following sequence *phases*: (a) Analysis; (b) Opened; (c) Kept; (d) Ceased; and, (e) Under Review.[4] The participants emphasized the fact that the required tasks and their sequence flow may change during these phases and thus there could be evidence of further activities. For example, in the "Under Review" phase, the warning is analyzed with regard to its quality, while in the "Kept" phase, the disaster management specialist could investigate the occurrence of disaster damages and losses reported by the media in an affected area. A different set of tasks, information, and data sources are required to assist in the decision-making.

In the same manner, the decision-making process is also affected by the different types of hazards that might share several common features but could also have idiosyncrasies. For example, the volume of rainfall at a specific city/town and/or region can be used to assist in the forecasting of both floods and landslides; however, the water level in a riverbed that is essential for flood forecasting is hardly useful for forecasting landslides.

The location of data monitoring also affects the decision-making, especially because of the territorial size of Brazil where many different kinds of weather systems can be found. Moreover, each area has its own specific environmental features, e.g., the geological setting of the Mountainous Region of Rio de Janeiro is more susceptible to landslides than that of the Center region of São Paulo. At the same time, urban settings also play a critical role since locations with inhabitants are more hazardous than rural areas. Furthermore, the characteristics and state of buildings are also essential in the decision-making, as pointed out by the meteorologist:

> "*A warning about a landslide in the Mountainous Region of Rio Grande do Sul takes a completely different form from the Mountainous region of Rio de Janeiro because the buildings are stronger than those in the shanty towns.*"

The differences between the environmental, urban, and residential settings mean that the decision rules and required information change from one location to another, e.g., a decision rule may determine that the rainfall threshold of the volume of rainfall of the Metropolitan Region of São Paulo is 60 mm in 24 h, while, the threshold for the landslide-prone areas between Jaboato dos Guararapes and Recife cities could change to 40 mm.

Furthermore, the results of the focus group sessions showed that the decision-making process is also affected by the expertise of each member of the monitoring team, as well as how these members should interact in their teams. This was made evident when a geologist explained the role of the disaster analysts, although the geologist did not identify the role of disaster analyst in the risk analysis cycle:

> "*For example, it could be raining in a region. The geologist predicts the risk of several landslides; however, none of them will occur in an urban area. Here, the disaster analyst can help me as well [to identify what is the vulnerability].*"

The role of meteorologists in the decision-making process also demonstrated the level of expertise among the members of the control room. The interactions among the diverse experts of the team is different. Further information often required to meteorologists, which sometimes did not have their competences well defined. The concept of disasters, in the most parts of interviews, is attached to the idea that disasters are caused by rains. As a geologist stated:

> "*I have often asked the meteorologist: 'Is it going to rain? Is it a high-risk potentially critical situation? Is it likely going to cause a disaster critical event?'.*"

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[4] The first stage of a warning is "Opened", i.e., an adverse condition has confirmed by the operators and a warning should be sent to the National Civil Defense (SEDEC). After a warning is opened, the operators continuously monitor the area until the adverse condition is ceased. So, the warning moves to the stage "Ceased". In case of the operators identify that the adverse condition will remain, they move the warning to the stage "Updated". When a warning is updated, the operators can keep the warning level, increase (e.g., from moderate to high), or decrease (e.g., from very high to moderate). Finally, the last stage of a warning is called "Under Review" and it indicates that an operator is examining disaster data collected about the warning for establishing a timeline of the event and evaluating the effectiveness of the warning. This is also used as historical data for learning process.

A kind of decision-making that is only centered on the analysis of meteorologists increases the uncertainties of the process. In contrary, when a decision is made on the basis of risk modeling and events forecasting, it is able to standardize the team's decision-making, as well as overcome uncertainties, by allowing the specialists to share their responsibilities and putting less pressure on them. Apart from this, a decision-making that relies only on the analysis of meteorologists overloads the work of these specialists, and hence makes their decision-making more vulnerable and prone to human errors. Moreover, during emergency situations, sensors and meteorological reports are subject to failures and real-time decision-making can no longer be based on dynamic data.

4.3. Conceptual framework of factors that influence decision-making in control rooms for disaster risk monitoring and early-warning

On the basis of the two key areas presented in the previous sections, a conceptual framework is proposed here as a way of describing factors that influence decision-making in control rooms for disaster risk monitoring and early-warning. This framework then consists of two essential groups of elements, as displayed in Fig. 3: 1) the "pillars" of decision-making that is illustrated as a triangle; and 2) the "dimensions" of decision-making represented by the ellipses.

The performance of monitoring teams is closely related to the "pillars" of decision-making, the operators of the control room feel more confident when they are following a defined process. In turn, this process may be centered by a decision rule, which draws the relationship between a) the tasks of the decision-making process, b) their required information, and c) useful data sources. By understanding this process, when the decisions are speeded up, every member can understand their role in the process (e.g., what their tasks are, what information is required, and what data sources are analyzed). This kind of understanding also makes the operators more confident about making decisions. There are two reasons for this: 1) they are following a predetermined protocol and 2) they can be trained to be more specialized in the activities that they have to carry out.

On the other hand, the results of this study also suggested that the "pillars" of the decision-making process should be adapted and driven by not only the traditional elements of the risk framework for broad structural policies (Vulnerability + Hazard + Exposure) [16], but also by a supplementary element named Temporality (i.e., the warning phase of disaster). Table 3 details each element of the framework. Together, these elements constitute what we named as the "dimensions" of decision-making, i.e., the type of hazard, the warning phase of the disaster, the location of hazardous-prone areas, and area of expertise of the operators. Understanding the links between two essential groups of elements is particularly valuable as it highlights areas of improvement in the overall decision-making process. This is because an action protocol should provide a guideline of essential activities but not constrain the monitoring team which is liable to happen because of the inherent dynamics of disaster management.

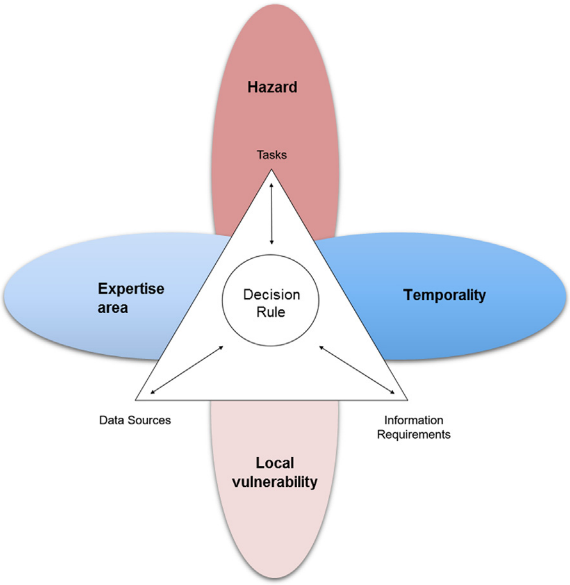

Fig. 3. Conceptual framework of factors that influence decision-making in control rooms for disaster risk monitoring and early-warning.

5. Discussions and implications

Control rooms are indeed an essential feature of early warning systems (EWS) and, thus, disaster management, largely because they trigger countermeasures and responsive actions if there is a hazardous situation, e.g., the imminence of a disaster. Therefore, this work provided lessons that were learned from a case study within Cemaden.

Firstly, the establishment of an action protocol could provide guidelines for monitoring teams, by reducing the need to depend on their own experience, assessing the workload of the operators, improving the reliability of the decision-makers, and making it possible to track the information required for decisions. The findings of this study provided empirical evidence that professional Bourdieu's *habitus* arises when no process is established. In other works, this behavior indicates the tendency of people to maneuver their body in certain ways that they are used to, e.g., posture and more abstract mental habits, modes of perception, classification, appreciation, and feeling [8]. As a turn, more complex multidisciplinary discussions have emerged.

Secondly, given the importance of decision-making, a proper method for designing action protocols should be tailored by influencing "factors" and "dimensions" (Fig. 3). These factors corroborate the results of the analysis conducted by Altamura et al. [3] on the social and legal significance of the concept of "uncertainty" in an early warning insofar as they enforce the need for an analysis when for an analysis a decision-making process for control rooms. In line with past works that investigated failure chain of control rooms [9,59,60], this work enlarges the importance of a decision-making process for control rooms as a means of reducing possible errors. This also supplements other research that is focused on investigating the uncertainties that face the decision-makers for disaster management [35,14,10]. As participants mentioned during th e focus group sessions, operators feel more convincing when they recognize the full scope of their activities (i.e., the required information, data sources, and decision rules).

Thirdly, available systems and decision models should be aligned with the decision-making process; otherwise, they might become useless, by making the tasks complex and delaying the decisions. As a result, both cosmology episode [60] and *habitus* [8] may come back into the spotlight, and thus wrong decisions could be taken. This study finding supplements previous research works on the development of decision analytical models for disaster management and control rooms [40,26,15] insofar it approaches the problem from another perspective, i.e., the decision-making process itself as a sequence of tasks, required information, actors, and data sources. This result is consistent with other studies in the literature that analyze key aspects of decision-making for disaster management [28,29,55]. Our study adds to these previous works by offering a conceptual framework (Fig. 3), which refines the factors that help to define the way decision-making is carried out in the control rooms for disaster risk monitoring and early warning. This framework is also particularly valuable for a better understanding of how computer-based procedures (e.g., decision support systems and decision models) can be implemented in the main control room.

Forth, when traditional data sources are damaged, inexistent, or not well calibrated, crowdsourcing and volunteered information may be

Table 3
Elements of the conceptual framework.

Group	Element	Description
Dimensions	Hazard	This indicates the type of hazard, e.g., earthquake, flood, or storm.
	Temporality	This element is associated with the phase of a disaster, e.g., preparedness, or response. However, it could be also adopted for indicating periods within a specific phase, e.g., 24 h before the event, or 72 h after.
	Local vulnerability	Location and characteristics that make it an area susceptive to a disaster.
	Expertise area	The expertise area of control room operators, e.g., hydrologists, traffic control, or physicist.
Pillars	Tasks	Tasks that are performed by control room operators and also constitute a decision-making process.
	Information requirements	A set of information required for performing tasks. It can be represent by either a simple data item or complex data structures but rather than a data source.
	Decision rules	The functions or rules that can be used for supporting the tasks. This could be a decision table, or an analytic model (e.g., hydrology model).
	Data sources	Data source is associated with all resources that could used for providing a specific data value, e.g. a report, an institution, or an information system. In other words, this represents the source of data rather than the data (or information) itself.

adopted as a supplementary source. Results obtained in this study also suggest that the condition of data collection tools implicates decision-making in control rooms, as it was mentioned by participants during interviews and focus group sessions. Since control room operators are making decisions far away of a vulnerable region, their judgments rely on data provided by existing monitoring equipment. Therefore, when a data collection equipment is not proper working, operators could decide "in the dark" without knowing the "real" situation in the area; this occasionally may lead to devastating consequences due to a wrong decision. This conclusion is in line with previous works that investigated decision-making and human factors in different control rooms [9,29]. For overcoming this challenge, common people can provide reliable and accurate volunteered geographic information from vulnerable areas [17], which thus supplements traditional data collection tools and enhances decision-making in control rooms [20,1,34,19]. Findings of this work however show that as any other information, this should reflect the decision-makers' requirements, otherwise it may be useless or even misused.

In summary, these lessons that were learned from the case study, together with the conceptual framework, provide contributions that are useful not only for operators but also coordinators in guiding the establishment of a control room in different application areas. Although we believe these results are of great significance for research and practice, there are limitations to our study which should be recognized. The conceptual framework could be useful in several other application domains for understanding their decision-making process; for example, control rooms of nuclear power plants, air traffic control, oil factories. However, while these examples demonstrate the potential of the framework, its rigorous evaluation through the systematic application in several other scenarios is still required to establish the generality of the framework, which is beyond the scope of this work.

6. Conclusion and future works

The aim of this paper has been to understand the factors that affect decision-making in the control room for disaster risk monitoring and early warning. Semi-structured interviews and participatory observations were conducted in a qualitative analysis project, which was conducted in the control room of Cemaden. The results obtained in this analysis showed that members of the control room tend to draw on their previous experiences and knowledge in their decision-making when there is a lack of a clear strategy. As a result, control room operators become more concerned and worried about the way they are making decisions. At the same time, this increases uncertainty in decision-making since operators do not know what activities they are supposed to carry out which kind of information can be regarded as "additional information", and what data sources should be analyzed.

On the basis of these concerns, our framework describes the essential features (the "pillars") of a decision-making process, i.e., a) the tasks involved, b) the required information, c) the decision rules that are designed to make sense of the information, and d) the required data sources. The results of the study showed that these are the essential components of the decision-making processes that assist in carrying out the activities of control rooms for disaster risk monitoring and early warning. Furthermore, the framework provides a set of "dimensions" that characterize the decisions made in the control room, such as the expertise of the members, the warning phase, types of disasters, and geographic location. The results provided evidence that there is a strong relationship between the essential features of decision-making and these dimensions. In other words, the dimensions influence the way that the tasks are carried out by monitoring teams, e.g., control room operators will not analyze the water level of a riverbed (the task) when making decisions related to landslides (the type of hazard). This also affects the required information, decision rules, and analyzed data sources. For example, a hydrologist will not analyze weather forecasting (task), since it is assigned to a meteorologist (expertise area).

Future lines of research should also be noted. Given the nature of the findings of this study, there is still a need to conduct further case studies in different organizational settings, which could support the generalization of the contributions achieved in this study. In addition, more participatory observations should be conducted in the control room to extend the acquired knowledge basis, especially during a disaster situation such as that occurred in the Mountainous Region of Rio de Janeiro in 2011, before the Cemaden creation. The conceptual framework should be also applied and evaluated in other applications domains; for example, control rooms that aim at monitoring and issuing warnings of tornadoes or earthquakes, as well as control rooms of a nuclear power plant, which has distinct requirements of a control room for disaster management. These further evaluations have the potential to provide a new understanding or improve the body of knowledge on factors that influence decision-making in control rooms.

Moreover, although a sequential process is useful for supporting decision-making, in some cases it may become pointless due to the uncertainty of resources or existing information. For example, an action protocol may determine that a control room operator must issue an alert using data from rainfall gauges; however, in one particular case, he/she does not found an equipment installed at the location. In this context, there is an emerging trend to adopt reference task models to assist in disaster management [7,4], which is a definition of universal elements that can be employed by organization developers to solve a specific task at a given time. As a result, this could meet the need for a more flexible decision-making process and more resilient during disaster situations [60].

Data access statement

Due to ethical concerns, supporting data cannot be made openly available. Further information about the data and conditions for access are available at the University of Warwick data archive: http://wrap.warwick.ac.uk/87038.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.ijdrr.2018.01.034.

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