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REVIEW ARTICLE

From solitary to an adaptive continuum process: Toward a new framework of natural disaster emergency decision-making

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Abstract Major studies in emergency decisions are focusing on how techno-rational approaches applied in early warning systems to produce an output; rarely explore its opponent, the naturalistic intervention, or how both paradigms function in a crisis decision process. This research aims to identify the actual process of emergency decision making in the context of natural hazard studies, whether it employs the techno-rational or purely naturalistic approach. A systematic review is adopted to assess papers in the period 2000 -2018 within the "emergency decision making" AND "natural disaster" keywords. Research finds a non-techno-rational paradigm that contributes to producing a decision outcome. Instead of categorizing it the naturalistic paradigm as named by the scholars, we labelled it a non-technological paradigm. It consists of two main instruments: individual and institutional interventions, that together with the techno-rational instrument develop an adaptive continuum behavior while operating in uncertainty condition in order to generate an effective evacuation order for vulnerable people.

1. Introduction

The global disaster trend has increased throughout the years. The number of natural hazards occurred in the first decade of 20th century was 73, then soared dramatically around 39 times during 2000 to 2005 (Kusumasari, Alam, & Siddiqui, 2010). The Centre for Research on the Epidemiology of Disasters/CRED (2017) identifies geophysical hazards mainly earthquakes as the most killer factor in natural disaster in the past 20 years, especially those followed by tsunamis, i.e. 2004 Indian Ocean and 2011 Great East Japan tsunamis. Similarly, scopes and consequences of man-made calamity are also broader despite that the frequency cannot be calculated exactly (Harding, 2007). SwissRe (2018) figures out 118 cases of man -made disasters in 2017 alone were dominated by major fires and explosion incidents. Effects of all types of disaster are negative (Halkos, Managi, & Tzeremes, 2015), nevertheless, natural hazards have caused more fatalities than man-made disasters (Coleman, 2006). EM-DAT released that the 10 deadliest disaster events in 2018 were natural hazards (Centre for Research on the Epidemology of Disaster CRED, 2019).

Natural disasters are filled with uncertain factors. Unknown impending events and their consequences force disaster stakeholders to think and behave rapidly. They are demanded to be a rational actor who analyze comprehensive data and verify each alternative to find best solution for implementing a concrete action. Nevertheless, time limitation becomes constrained for the actors to adhere it in that rational way since triggers actor's vulnerable cognitive, emotional and behavioral abilities (Hadley, Pittinsky, Sommer, & Zhu, 2011) when setting responsive strategy. Simon (2000) examines it as bounded rationality. Scholars have developed an approach to deal with human bounded rationality in emergency decision.

Studies on artificial intelligence design tools are expected to take over human cognitive ability while dealing with uncertainty. Unfortunately, as its termed as the act of God, several types of natural hazards cannot be accurately predicted because of unmeasured data, model, and scenario features (de Kort & Booij, 2007). What science has been doing is developing warning systems to predict impending catastrophes through forecasting applications (Shaluf, 2007; Sobradelo, Martí, Kilburn, & López, 2015; Su & Tung, 2014). Still, consecutive calamities, i.e. The Haiti earthquake, Mentawai tsunami, Hurricane Sandy and Oklahoma tornadoes, disrupted the sophisticated picture of techno-rational based decision making. These depict that decision making during crises have gaps from rationality process, even though there were technological intervention (Dionne, Gooty, Yammarino, & Sayama, 2018).

Researchers from naturalistic decision making (NDM) argue the techno-rational models that have been produced are majority unhelpful and irrelevant to the real situation (Tuckett et al., 2015). Rather than following procedural and rigid step, the naturalistic paradigm asks the decision actor relies on their recognition of prior knowledge and intuition. By assessing current situation based on relevant experience and knowledge of decision maker to create situation-action matching decision rules is considered to be an appropriate strategy in emergency situation (Lipshitz, Klein, Orasanu, &

Salas, 2001).

Referring to the background, this paper aims to answer how the paradigms serve emergency decision making in contextual case. To that, there are two objectives of this study: 1) identifying components of techno-rational in emergency decision process and how it function; 2) investigating whether the techno-rational work independently or collaboratively with other paradigm(s) when generating an effective decision outcome. To that end, this paper is structured into three parts: techno-rational paradigm and its instruments, the existence of non-techno-rational paradigm, and a shifted framework in natural disaster emergency decision making.

2. The Methods

The research conducted through a systematic review that refers to a repeatable process applied into available documents relevant to studies or topic areas (Balaid, Abd Rozan, Hikmi, & Memon, 2016). There are rationales behind applying the method into this study: 1) to summarize research related to decision making in natural disaster emergency; 2) to pinpoint a mode of real context of emergency decision making. This is performed by looking up seven databases: JSTOR, ABI/Inform (ProQuest), Sage Journals Online, SCOPUS, ScienceDirect, SpringerLink, and Taylor Francis. The term used on the search engine is "emergency decision making" AND "natural disaster."

Duplicated papers were removed during the identification phase through title scanning. Relevant papers must fulfill criteria: 1) published during 2000-2018; 2) written in English. The reason behind the first criterion is episodic evolution of the second two decades disaster publication trend (Alexander, 1997), besides consideration about time occurrence of some memorable natural disasters in the beginning of this millennium, i.e. 2001 earthquake in Peru, 2004 Indian Ocean tsunami and 2005 Hurricane Katrina (Galindo & Batta, 2013). While reason for the second criteria due to its scientific predominance (Bocanegra-Valle, 2014). Furthermore, authors exclude reviewed-papers and papers that are published in conference proceedings or in an editorial section. Table 1 summarizes the systematic review process.

The extraction and synthesis process of papers were performed by reading each of them and looking for essential data in term of decision process. There were resulted in 5 main papers that all describe case studies. These papers then arranged onto a MS Word tabulation consists of study ID and study contents. The study ID describes authorship, title of study and publication sources while the study content elaborates major findings, methods, focus coverage, strength, and weakness of each research. The tables help the author simplify the information retrieving process.

3. Result and Discussion

Technology: Its role is stalled when the decision process reaches the output

Making an emergency decision becomes so challenging since decision actors must overcome numbers of obstacles whilst collecting and processing information. Curiosity about upcoming events induces people to gather more information which are assumed to reduce uncertainty (van Dijk & Zeelenberg, 2007). When information is provided, further steps are begun through developing models to simplify human cognitive work during a specific task, as well as deliver decision output. Table 2 figures out literature findings on technological instruments for managing uncertainty during catastrophic.

Despite their study focusing on a distinct activity on pre-disaster phase with its specific instrument, those authors agree on a main set of techno-rational paradigm: observation, modeling and predicting, alert and communication. Relating to their study about modeling, Sobradelo et al. (2015) believe an impending crisis detects from pre and unrest stage. Parameters of a modeling scenario come from those two stages either by doing field monitoring or looking up historical records. The probabilistic combination of an upcoming hazard resulting from the model simulations and cost function forecasts helps the decision actor calculate total damage caused by a warning to be issued (Reggiani & Weerts, 2008). The study by Horita et al (2018) complements the finding by stating that both proper monitoring activities and competent staff support an effective warning system.

The techno-rational instruments are working to replace human physical and cognitive activities while collecting and processing data in order to produce a decision output during crises. Monitoring and observing fluctuation of rainfalls, sea levels, or volcanic behaviors are no longer handled manually. Gauges, radars, and sensors are set to periodically record data which is then processed using decision-support models. The decision models such as Bayesian are evolved to simplify human cognitive tasks when designing alternatives and selecting options. Finally, the warning system supported by advanced technology abridges communication gap whilst disseminating an alert massively and efficiently. The simplified sketch of the techno-rational decision making during natural hazard emergencies is depicted in Figure 1.

The five study cases describe by those scholars show us

Table 1. Criterion for selection papers for systematic review on emergency decision making in natural disasters

Criterion	Inclusion	Exclusion
Type of document	Peer-reviewed	Reviewed papers, conference papers, editorial
Databases	JSTOR, ABI/Inform (ProQuest), Sage Journals Online, SCOPUS, ScienceDirect, SpringerLink, and Taylor Francis	Other databases
Language	English	Other languages
Research object	Government actor(s)/agency	Personal, group of citizens
Unit analysis	Decision process	Others than process

that the emergency decision making during natural disaster events from the perspective of techno-rational runs like a decision process in a normal situation: starting by collection of relevant data, which it then analyzed using specific algorithm, ended up with a particular alert as its output. It is the way it works when successfully estimating River Rhine flood (Reggiani & Weerts, 2008). However, Sobradelo et al. (2015), Soulé (2014), and Fearnley (2013) note that techno-rational instruments alone are not sufficient to produce either an effective natural disaster early warning or evacuation order.

Non-technological paradigm: a puzzle piece to accomplish the emergency decision-making processes

Considering that emergency decision making cannot be automatically replicated through simplifying hazard characters, scholars introduced the naturalistic paradigm, also called intuitive. This paradigm presents the decision making process in real world perspectives (Sinclair, Doyle, Johnston, & Paton, 2012) which is positioning human judgment (Leonard et al., 2008) and situational awareness as determinants of effective decision making (Endsley, 1995).

Four of the five case studies are presented in this paper literally focused on the techno-rational decision making in the context of natural disaster emergency. A further exploration involving intensive reading strategy recognizes non-techno-rational intervention during formulating emergency decision as simply described in Table 3. Instead of calling it a naturalistic or intuitive paradigm, labeling it a non-technological paradigm may be more suitable. The techno-rational instruments have stopped its function when it reaches the decision output. They provide disaster alerts for the decision actor. However, vulnerable communities need an operational decision guiding them into specific actions: a clear rescue order e.g., to do an evacuation or stay at home. Hence, the actor must interpret the decision output into an outcome which inevitably requires non-technological mediation.

Intervention of non-technological instruments is present in every phase of the emergency decision-making process. A malfunction of technological device may hinder field monitoring. These require the operator's tactics to manually collect data by employing field assistant. During data processing phase, communication developed between various experts often contributes to minimizing potential risk. Besides its benefaction, few cases revealed that human intervention might disrupt decision protocol as worst as generate a harmful decision. The past incidents explained the ignoring or misinterpreting crucial tsunami parameters by the authority had ended up in a false alarm that cause death toll.

Table 2. Key elements of the techno-rational decision process

Author(s)	Highlighted techno-rational instruments
Horita, de Albuquerque, & Marchezini (2018)	Monitoring and warning systems
Sobradelo et al.(2015)	Modelling scenario
Soulé (2014)	Alert chain
Fearnley (2013)	Communicating warning information
Reggiani & Weerts (2008)	Forecasting system

Source: primary data processing

Despite their differentiations, those studies show the intervention of the non-technological aspect in the emergency decision processes which is being classified into individual and institutional intervention. The individual intervention points out how personal background, knowledge and experiences impact the actor's capability handling the crisis decision phase. The control room operator whose apply his tacit knowledge to solve a routine problem, the expert past experiences with hazardous event help her deciding a better option, or an unlearning actor whose repeat his mistake when interpreting information imply that individual physics, psychology, and cognitive activities may contribute to demoting or improving the decision performance.

Meanwhile, institutional intervention mentions that organizational values, beliefs, and norms rule the emergency decision-making. Disharmony coloring work relationships among the emergency agents or political intervention that degrades the decision outcome demonstrates how a particular circle standard dominates the emergency decision-process above the rational side. Soulé's (2014) study talks more about these negative forms of institutional intervention. Nevertheless, like the individual intervene, the institutional can run a mediation role during decision making by initiating either collaborative works to interpret disaster scenarios or an expert network to communicate a decision opts.

An actual context of emergency decision making: an adaptive process; not a solitary

Despite the superiority claim from each paradigm proponents, the five studies indicate the interactive process of both paradigms prepare actor with a better performances as well as effective decision outcomes. Figure 2 illustrates the execution of the techno-rational and non-technological paradigm in emergency decision making in natural hazards.

Emergency decision making is an adaptive continuum process between techno-rational and non-technological perspectives. The findings show that techno-rational instruments are at the forefront in every decision phase. It initiates data collection through technology-based

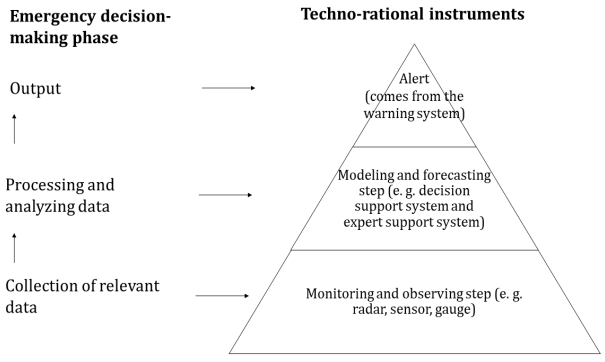

Figure 1. A simple mode of the techno-rational decision making during natural disaster emergency

Table 3. Identifying the intervention of non-technological instruments during emergency decision making

Author(s)	Description of non-technological instruments intervention in emergency decision-making
Horita, de Albuquerque, & Marchezini (2018)	Operators employs their tacit knowledge to overcome daily problems such as lack of tools, inequalities task among experts, data limitation, etc. Past experience and knowledge of the decision actor about real condition of a certain area and its potency to hit by a catastrophe.
Sobradelo et al.(2015)	Direct communication between experts during observation activities Political intervention while choosing 'no action' opt.
Soulé (2014)	Actor unlearning of prior tsunami evidences; Inaccuracy of raw data interpretation; Operator ignores parameters and warning messages delivered by external institution Having no tsunami expert in the National Emergency Office Disharmony relationship amidst the national emergency institutions Intermittent communication between scientists and authorities The absence of official warning The national authorities failed to follow the crisis procedure
Fearnley (2013)	The experts interdisciplinary group discusses field data Using limited statistical modeling to formulate the final decision Examining risk factor manually while set the alert;
Reggiani & Weerts (2008)	Institutional interpretation of outputs provided by forecasting instruments

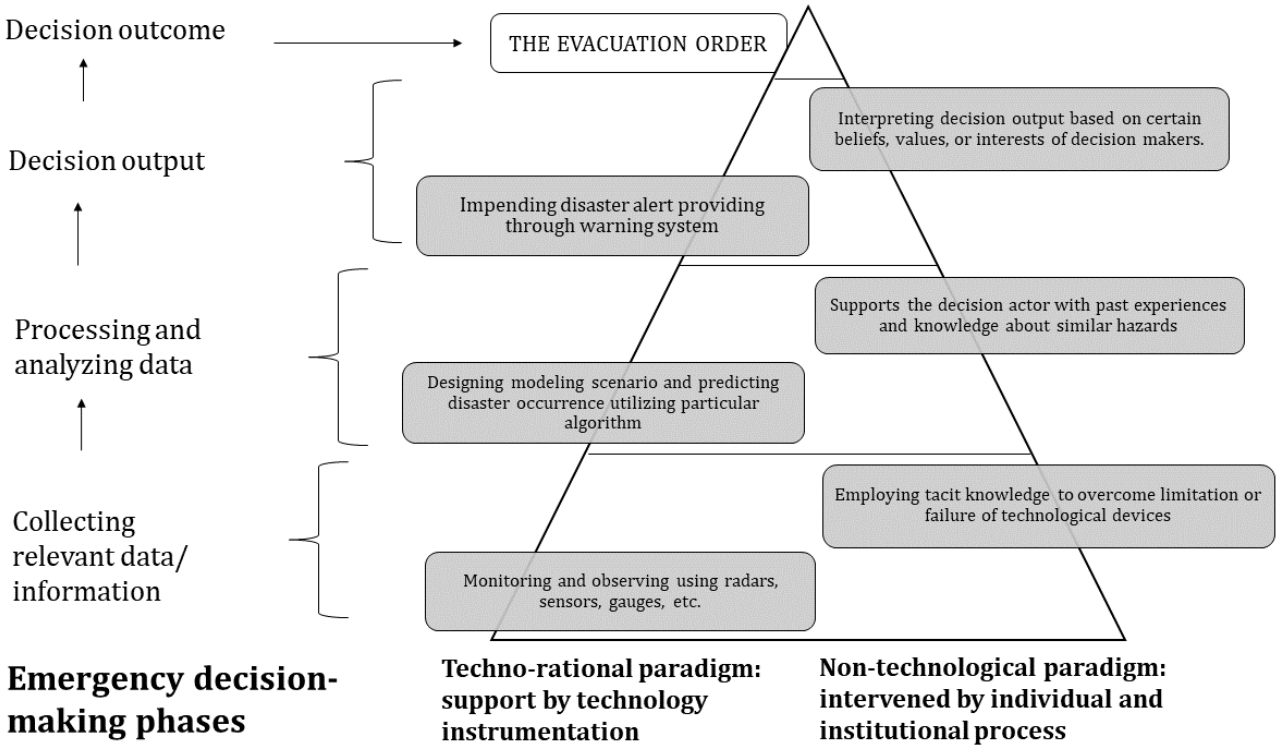

Figure 2. The adaptive pattern of emergency decision-making processes

observation tools although its performance is sometimes supplemented by manual devices. Damage or dysfunction of the technical equipment is often becoming the reason for calling back the function of field observer. In data processing and analysis phase, the main role is still carried out by technological instruments that represent the work of human brain in a simplified form. The decision support system (DSS) and Expert Support System (ESS) tools are the manifestation. However, the interpretation of DSS and ESS outputs is a non-technical domain; it is influenced by the interpreter's knowledge or past experiences.

This finding also presents a different point of view for the scholars who claim the dominance of one paradigm over another. Simon (2000), Ben-Haim & Demertzis (2016), Faraji -Rad & Pham (2017) believe that technological support is the most efficient while generating decision output during time pressure and uncertainty situation while others (e.g. Lipshitz et al., 2001; Sinclair et al., 2012) state naturalistic approach is the most important and necessary ingredient when dealing with emergency situations.

Although this study neither find a certain structured pattern of the adaptive interaction between the techno-rational and non-technological nor contribution intensity of each paradigm in the crisis decision making; it deduces that the adaptation process may be determined by the disaster situational context, the type of disaster and the degree of risk. Empirical research may be able to portray the contribution of both paradigms in producing effective decisions under time pressure and uncertainty.

4. Conclusion

Hammond (Dhami & Mumpower, 2018) and Goldstein & Gigerenzer (2002) abridge a conventional dichotomy between techno-rational and naturalistic paradigm by providing theoretical construction stated that the decision process in the crisis situation takes place in a quasi-rational scheme. Nevertheless, there is a tendency that the developed construct is skewed towards one of the paradigms: Hammond stands for his cognitive pattern whilst Goldstein & Gigerenzer prioritizes the existence of heuristics. The findings of this study may explicitly agree with Hammond and Goldstein & Gigerenzer ideal type. However, there are two crucial differences.

First, we do not use naturalistic or intuitive terminology as opposed to techno-rational or analytic paradigm as many scholars mentioned. This systematic review shows that apart from the techno-rational instrument, it is the non-technological component that takes a delicate role in emergency decision making. It is called non-technological because not only contains of the character inherent to human, such as situational awareness, recognition, emotion, etc., it is also involving elements of values, norms, and beliefs adhered to the organizations or institutions. It implies the existence of institutional domain in crisis decision setting.

Secondly, Hammond uses quantitative calculations to show both human cognitive activity and task indexes, while this research is limited to identifying instruments and simple modes of interaction between techno-rational and non-technological components. Therefore, it is considered necessary to initiate empirical investigations to understand how each component in both paradigms performs adaptive interactions in risky and uncertain environments.

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