Overview of disaster economic assessment methods

Daniel Eckhardt (eckhardt@aluno.puc-rio.br)
Industrial Engineering Department, Pontifícia Universidade Católica do Rio de Janeiro

Adriana Leiras
Industrial Engineering Department, Pontifícia Universidade Católica do Rio de Janeiro

Antonio Marcio Tavares Thomé
Industrial Engineering Department, Pontifícia Universidade Católica do Rio de Janeiro

Abstract

This article seeks to perform an analysis of the existing methods of disaster economic assessment, regardless of their type (long duration or sudden), describing their objectives and evolutionary process through references found in the literature. The inclusion of new methods (crowdsourcing; epidemiological models; augmented reality; cloud; neural networks) ends up bringing possible improvements (execution time, prioritisation and operations planning) to disaster economic assessments.

Keywords: economic assessment, methods, disaster

Introduction

Disasters are natural or man-made events, with a significant degree of uncertainty, in a harsh, dynamic network, with extreme resource constraints (human and material), in environments in which the information may not be very reliable, even when available (Çelik et al., 2012). In 2016, the number of people reported affected by natural disasters (564.4 million) was the highest since 2006, amounting to 1.5 times the annual average (224 million) of the period. The estimates of economic damages (US$ 154 billion) in 2016 was the fifth costliest since 2006, 12% above the 2006-2015 annual average (Guha-Sapir et al., 2016). It is worth noticing that the characteristics of disasters have changed with the proportional reduction in the number of deaths and more significant impacts on infrastructure, assets and economic assets in recent years. According to Guha-Sapir (2016), in 2016, the number of deaths caused by natural disasters (8,733) was the second lowest since 2006, largely below the 2006-2015 annual average (69,827).

The size of the impacts of such events has forced governments and societies to take more active measures throughout the life cycle of the disaster. Altay and Green (2006) defined the phases of disaster as composed by mitigation, preparedness, response, and reconstruction. According to Heaslip (2013), the service operations of the logistic function starts well before a disaster and continues past the occurrence of the crisis and the direct response to it. Therefore, one important measure is the economic assessment of a disaster that aims to provide pertinent information that can support the response and reconstruction phases but may also allow investment in mitigation and preparedness phases.

According to Meyer et al. (2013), to synthesise current cost assessment methods and identify current best practices are the first step to support and guide decision-makers in natural hazards management, risk mitigation, and planning. To improve economic assessments, Meyer et al. (2013) proposed to divide the economic costs in five types, making possible the usage of different assessment methods: (i) direct costs (damages to property due to direct physical contact with the hazard); (ii) business interruption costs that occur in areas directly affected by the hazard; (iii) indirect costs (losses that can occur inside or outside of the hazard area and often with a time lag); (iv) intangible costs (refer to damages to goods and services which are not measurable in monetary terms); and (v) risk mitigation costs (refer to risk reduction).

This article seeks to perform an analysis of the existing methods of disaster economic assessment, regardless of their type (long duration or sudden), describing their objectives and their evolutionary process, through a Systematic Literature Review (SLR). The inclusion of new methods, naturally not mentioned by Meyer et al. (2013) due to the recent technological and scientific evolution, ends up bringing possible alternatives to assessments, such as the use of social media during the first hours of a disaster.

This paper is organised as follows. After this Introduction, Section 2 presents the research methodology. The third section gives an overview of the existing methods. The fourth section has the authors' main conclusions.

Research Methodology

Thomé et al. (2016) describe the SLR as a method including eight steps: (i) formulation of the research problem; (ii) literature search; (iii) data gathering; (iv) quality evaluation; (v) data analysis and synthesis; (vi) interpretation; (vii) presentation of the results; and (viii) updating of the review.

After formulating the research problem, as detailed in the Introduction, the literature search was performed (second step of the SLR). Scopus and Web of Science (WoS) databases were selected. According to Mongeon and Paul-Hus (2016), WoS and Scopus are the primary sources for citation data in natural sciences and engineering. Together, they make the research wider and reduce the possibility of bias related to journals indexed exclusively in one of the databases alone.

Following Cooper (2010), the research was based on three groups of keywords. The keywords were chosen to be sufficiently ample to avoid any artificial limitation on the studies retrieved and strict enough to provide limits to exclude undesirable results. The keywords were applied to titles, abstract and keywords in Scopus and topics in WoS, with no time limitation.

- **Keywords 1** were defined based on keywords used by Leiras *et al.* (2014) to gather the scenario of the event: “disaster*”, “relief” and "humanitar*"
- **Keywords 2** were defined based on the main issue of the discipline: “method*", "guideline" and "model*"
- **Keywords 3** were defined based on the words related to the results of the disaster: “damage assessment*”, “loss assessment*”, “economic* assessment*”, “social assessment”, “economic evaluation*”, “social evaluation”, “damage evaluation”, “loss evaluation”, “economic* loss*”, “material* loss*”, “economic* damage*”, “material* damage*”, “economic disruption” and “social disruption”.

At least two specialists reviewed the titles and abstracts of the selected papers. The following exclusion criteria were adopted: language other than English, documents not linked to the research (for instance, social vulnerability, risk reduction, simulation, subject – medicine, biology etc.), full-text documents unavailable and inductive analysis derived from the material under scrutiny itself, as per Seuring and Gold (2012).

The data-gathering step was supported by a unified spreadsheet. The grey literature documents found in the selected databases were also included in this study, in an attempt to restrict publication bias.

The fifth and sixth steps of the SLR (data analysis, synthesis and interpretation) were performed, through the selection and description of the target methods described in the next section, *Review of methods and models*. The conclusion section complements the results of the research. Updating of the review (step 8 of the SLR) was provided, resulting in the identification of new methods not published in previous review papers. Figure 1 summarises the steps carried out into the SLR.

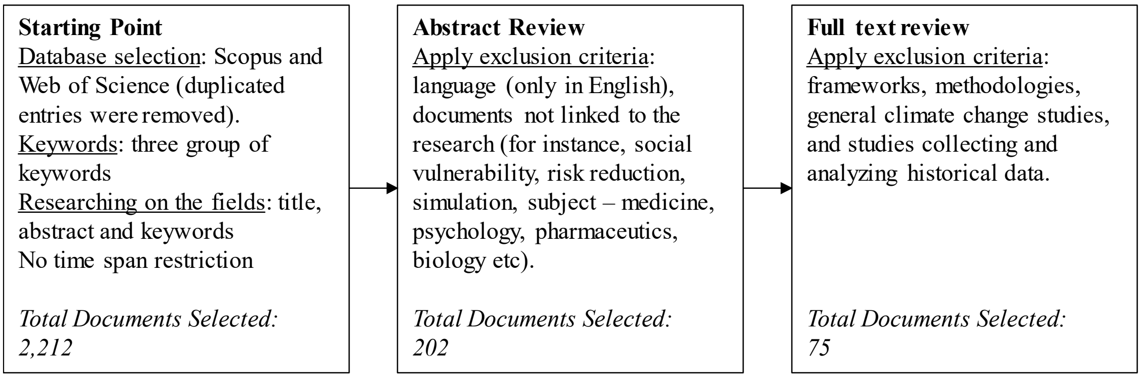

Figure 1 – SLR steps

Review of methods and models

Figure 2 shows the timeframe of the evolution of the publications containing economic assessment methods. The first method applied to disasters was proposed in 1983. The topic gained importance in 2012, mainly linked to high-impact disasters as Haiti earthquake (2010); Japan earthquake and tsunami (2011); and United States Sandy storm (2012).

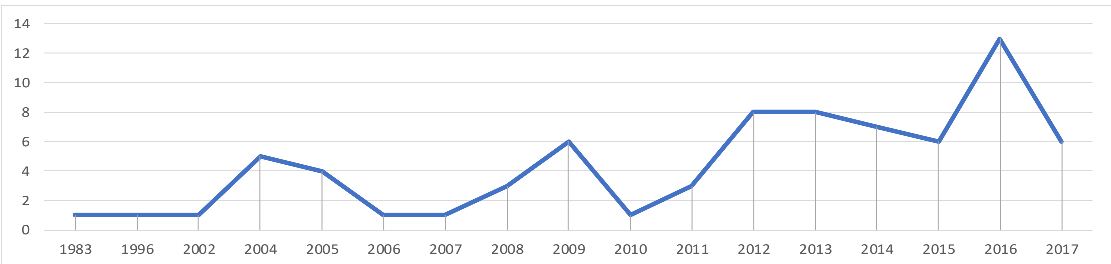

Figure 2 – Evolution of publications

Table 1 presents the main journals and the number of papers published in each journal, only for peer-reviewed documents. Natural Hazards appears on top of the list with ten publications.

Table 1 – Journals with more than two publications

Journals	**Total**
Natural Hazards	10
Natural Hazards and Earth System Sciences	3
Economic Systems Research	2
Disaster Prevention and Management	2
Earthquake Spectra	2
Risk Analysis	2

The SLR output resulted in several methods, usually applied to make an economic assessment for one type of costs. As shown in Table 1, Hybrid methods, followed by GIS (Geographic Information System), SDC (Stage-damage curves), CGE (Computable General Equilibrium) and IO (Input-Output) are the most studied ones. Some of the related methods were already cited by Meyer et al. (2013): IO, Hybrid, CGE, SAM (Social Accounting Matrix), Econometric Models, SDC, GIS, Hedonic Pricing, Linear Programming, Intangible Losses, and Surveys.

Table 2 – Total number of references per method

Methods	Total
Hybrid	13
GIS	12
SDC	11
CGE, SCGE	10
IO	6
Econometric	5
Survey	4
Neural Network	4
Intangible	2
Social Media	2
Crowdsourcing	1
Augmented Reality	1
Epidemiological	1
Linear Programming	1
Hedonic Pricing	1
Cloud	1

The most commonly used method is the Input-Output (IO) model (e.g., Santos et al., 2013; Koks et al.,2015; Hallegatte, 2008; Okuyama and Santos, 2014). This method focuses on building a relationship between sectors, specifying how output from a specific economic sector may impact (as input) in another economic sector. As described by Koks et al. (2015) and Rose (2004), the pure IO method has several gaps: (i) it often overestimates the impacts of a disaster due to its linearity and inability to include effects of resilience measures; (ii) it does not replace products and production factors between regions and producers; (iii) it usually does not deal with supply constraints, but builds a supply disruption through an artificial demand reduction, (iv) it lacks response to price changes.

Hybrids Methods seems to lead studies in this field when merging different methods to improve the overall results of the assessment regarding accuracy, time and range.

Proposed by Hallegatte (2008), the hybrid Adaptive Regional Input-Output (ARIO) model takes into account changes in production capacity due to the productive capital losses and adaptive behaviour in the disaster aftermaths, consequently, making it possible to evaluate the "ripple effects" (indirect damages) caused by a disaster. Santos et al. (2013) propose the Inoperability Input-Output Model (IIM). The two main categories of consequences provided by IIM are the inoperability, which measures the percentage decrease concerning the total output of the sector, and economic loss, corresponding to the reduction in the value of economic output due to the productivity disruptions. The improved IIM, also described by Santos et al. (2013), such as the Dynamic Inoperability IO Model (DIIM) considers the economic resilience of each sector affecting the pace of recovery of the interdependent sectors in the aftermath of a disaster. It connects the concepts of economic resilience with disaster recovery. Other derivations of the IO models can be found in IMPLAN (I/O model from the Minnesota) implemented by Pan (2015), in RIMS2 (Regional Input-Output Modeling System) developed by Taleghani and Tyagi (2017), in NIEMO (National Interstate Economic Model) described by Parks et al. (2012) and in IRRE (Inter-regional ripple effect) by Zhang et al. (2017). Koks and Thissen (2016) proposed the European Regional Impact Assessment (ERIA), a hybrid, dynamic, interregional, IO model. ERIA mixes non-linear programming and IO modelling to make possible finding (i) the production losses in the regions directly affected and in other European regions, (ii) the required production in other regions necessary to take over the lost production in the regions affected and (iii) the required production in Europe to meet the reconstruction demands from the regions affected. Wang et al. (2017) used an econometric model for predicting the relative figures of the input-output table, facilitating the forecast of the damages and losses caused by typhoon disasters.

After IO, the second method most cited is the CGE (e.g., Tatano and Tsuchiya, 2008; Tirasirichai and Enke, 2007; Xie and Li, 2014; Wang et al., 2015; Cochrane, 2004). This method aims to build a relationship between each economic sector based on a set of specific equations using a very detailed database. According to Koks et al. (2016), the general balance approach stands for a closed economic system where not only all products are used elsewhere but also all earnings are spent on different products (possibly through savings on investments), describing the economy, accounting all monetary and non-monetary flows. For Cochrane (2004), flexibility (both price and replacements) is the unique feature of the CGE models, yet when one looks at the actual events, the relative price changes are conspicuously absent. The CGE is also considered as a model that underestimates the impacts, given the price and quantity changes (ROSE, 2004). When extended to a multiregional framework, the CGE model is called a Spatial CGE (SCGE) model, which is more potent since it provides spatial information on the extension of the losses in each region due to the intra-regional and inter-regional trading disruption after the disaster (Tatano and Tsuchiya, 2008)

According to Tirasirichai and Enke (2007), SAM is an expanded version of the traditional IO table, and it is required as an input for developing the CGE model. For Okuyama and Santos (2014), the two main advances of SAM are: (i) it has been used to evaluate the more significant effects in different networks of social and economic agents, activities, and factors and (ii) it is used to generate the damage and loss assessment in the Damage and Loss Assessment (DaLA) methodology. The SAM models are, however, rarely applied since they are not often constructed by national bureaus of statistics; and, if created, they are built explicitly for CGE models for which they are a prerequisite (Koks et al., 2016).

Derived from statistics, the Econometric Models applied in disasters assessments helps in the forecasting. They reflect historical trading patterns that are unlikely to capture the nature of supply impacts; such models reflect the economies balanced and free of distortions (COCHRANE, 2004). The weakness of this method, as described by Rose (2004), is the statistical rigour that requires time-series data with at least ten observations (typically years) and preferably many more – usually not available in a disaster. Examples related to the Econometric Models applied to the economic assessment after a disaster were found in this SLR: tourism trends after the typhoon in Taiwan (Liu, 2014); and disruption of the population and the local economy in the San Francisco Bay Area after an earthquake (Munroe and Ballard, 1983).

The economic damages (direct impact) resulting from a disaster are measured by stage-damage curves (SDC), that is, an asset damage factor is set based on a particular index (for instance, water depth, duration). It is important to highlight that SDCs are not able to establish the economic losses of a disaster. SDCs are either empirically determined from observed damages or inferred from bibliographic sources (Amadio et al., 2016). Studies of Baró et al. (2007) and Amadio et al. (2016) show the importance of having different SDC per affected region (industrial, rural, urban, etc.) to improve the damage estimate based on the actual costs of the affected area.

Somehow associated and following the same logic of SDCs, another conventional method to measure the direct impacts is the Geographical Information System (GIS), comparing image maps (builds in general) of the area before and after the disaster and combining with the related costs to repair/rebuild. According to Ghosh et al. (2011), due to the lack of institutional capacity and the unavailability of qualified professionals on the field to carry out the damage and risk assessments of several buildings, the remote-based evaluation appears to be the only viable option in the early months after a disaster.

Considering the hypothesis that the economic damages caused by a natural disaster can be explained by the magnitude and frequency of the occurrence of the hazard and social vulnerability factors, Hayashi (2012) proposed an epidemiological model applied to ongoing emergency situations. It only requires the necessary and minimum amount of information on variables that are posted daily in many cases. The result showed that there is more substantial economic damage when there are more human casualties, more house destructions, and more emergency headquarters setups. The author recommends using these three variables are proper indexes for the hazard factor.

The hedonic approach is usually applied to the housing markets, that is, the hedonic pricing model is used to estimate the extent to which each factor affects the price. Tanaka and Managi (2016) used the Hedonic Pricing Method to assess the economic damage caused by the radioactive contamination from a nuclear plant disaster. Their study showed a direct relationship between the radiation level and the house prices and revealed that the radiation effects differ by types of use of the land (commercial and business areas are more sensitive to the radiation than the residential areas).

According to Cochrane (2004), the Linear programming may provide guidance on the optimal (maximum value added) allocation of scarce production capacity after the event. However, it is questionable if the linear program’s solutions are feasible, either politically or economically.

For Deng et al. (2016), the Social Media is beneficial to spread information, situation awareness, early warning, risk assessment, damage evaluation, command and control during the crisis. Since the affected people use Twitter, Facebook, Microblog to describe the situation and keep in touch with others – each user acts as a moving sensor. Different from the traditional media, these platforms enable the collection of data on an unprecedented scale, documenting the public's reaction to events unfolding both in the virtual and physical worlds (Kryvasheyeu et al. 2016). Based on the social media data, Deng et al. (2016) developed an index system with three outlooks: description of the disaster, public's demands, and mitigation measures – an evaluation formula quickly estimated the degree of damage. Using Twitter information during large-scale natural disasters, Kryvasheyeu et al. (2016) established a correlation between the damage and the social media activity. It was confirmed that the social media activity decreases as the distance from the disaster increases. The authors showed that the per-capita number of Twitter messages corresponds directly to disaster-inflicted monetary damage – making social media (when available) a platform for a fast, preliminary assessment of the damage.

The assessment of intangible losses is still challenging, based on Penning-Rowsell et al. (2005) method. The method takes into account the likelihood of a flood, if people will be exposed to it, and if those exposed to the flood will be killed or seriously injured. Dassanayake et al. (2015) developed an assessment method for intangible losses to measure casualties and injuries, cultural losses and environmental losses. Due to the complexity, only the monetary losses of fatalities and injuries were presented in the study, based on the life quality index (LQI) method, adapted to account for deaths.

The base of all methods and methodologies is the survey. The stored data is used in almost all methods and models based on surveys. Only with quality information, an adequate assessment of the damage and loss can be done. SLR revealed five studies on assessment of damage and loss linked to survey data (Molinari et al., 2014; Petrucci et al., 2010; Petrucci and Gullà, 2009; Suriya et al., 2012). According to Molinari et al. (2014) defining, feeding and storing regional and national databases for information needed on direct and indirect losses would facilitate the preliminary assessments. However, pure survey assessments thrive on capturing individual decisions but are weak regarding integration (Cochrane, 2004).

Ganz et al. (2014) show the use of augmented reality applied at disaster response. They present a mobile user interface that enables the responders to find patients to be evacuated. The interface gives to the responders the ability to see their patients from far away and through obstacles (trees, walls, vehicles). This kind of study is still not launched into production, but during pilots, according to Ganz et al. (2014), it showed a significant evacuation time reduction by up to 43% when compared to paper-based triage systems.

Another type of methods, such as Cloud (Tao and Kun, 2009) and Neural Networks (Lou et al., 2012) rarely appeared in this SLR.

Conclusion

This article fulfilled its primary objective by conducting a systematic literature review to identify the existing methods to carry out an economic evaluation after the occurrence of disasters. The inclusion of new methods not previously identified in other reviews (Meyer et al., 2013; Merz et al., 2010), ends up bringing possible improvements to economic assessments. Examples of newly reported methods are the usage of social media, mobilisation of people through crowdsourcing, epidemiological models, augmented reality, cloud, and neural networks.

Two methods draw attention to their ability to improve the response: social media and crowdsourcing. The use of Social Media would be restricted to limited sectors, direct losses (per message content) and less useful in case of problems in the telecommunication environment. Its main two advantages are the low costs and the speed. Crowdsourcing is an essential mechanism for obtaining data in near real time, but in-depth studies are still needed to improve its quality. For instance, using crowdsourcing and GIS, Ghosh et al. (2011) showed the confidence of approximately 74% when compared with a field survey. It is also important to highlight that crowdsourcing is not about replacing models or methods, but it shows the potential value of mobilising resources (usually specific resources) capable of executing a particular task, that together, will deliver a unified work package.

The classical economic models (for instance IO, CGE, Econometrics) are the more comprehensive methods that usually results in a multi-sector analysis. However, they are dependent on information difficult to access (or unavailable) and demands considerable efforts (resources and time) to be concluded – which sometimes is too late to support the operations and response to a disaster. It is necessary to provide a better understating of how the new methods (such as social media, cloud, augmented reality) could benefit the traditional ones.

Finally, it is suggested to apply the SLR with a broader scope, using new sources of information such as grey literature search on the Internet. Also, new surveys could provide additional evidence about the usage of the methods described herein and try to identify new methods to support the operations management of disasters.

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