Proceedings of the 33rd European Safety and Reliability Conference (ESREL 2023)
Edited by Mário P. Brito, Terje Aven, Piero Baraldi, Marko Čepin and Enrico Zio
©2023 ESREL2023 Organizers. *Published by* Research Publishing, Singapore.
doi: 10.3850/978-981-18-8071-1_P032-cd

Natural disasters management support models: a hybrid approach focused on humanitarian logistics

Nicolas Lennick Bomfim de Albuquerque[1], Lucas Borges Leal da Silva[1,2], Marcelo Hazin Alencar[1], Rodrigo José Pires Ferreira[1], Adiel Teixeira de Almeida[3], and Daniele Costa Morais[3]

[1]Research Group on Risk Assessment and Modeling in Environment, Assets, Safety, Operations and Nature (REASON), Universidade Federal de Pernambuco – Recife, Pernambuco, Brazil.
[2]Management Engineering Department, Universidade Federal do Rio Grande do Norte – Natal, Rio Grande do Norte, Brazil.
[3]Center for Decision Systems and Information Development (CDSID), Universidade Federal de Pernambuco – Recife, Pernambuco, Brazil.
E-mails: nicolas.b.albuquerque@gmail.com, borgesleal.lucas@gmail.com, marcelohazin@gmail.com, rodrigo@insid.org.br, almeida@cdsid.org.br, dcmorais@insid.org.br

Natural disasters worldwide have highlighted the need for special logistical treatment, called humanitarian logistics. It is known, however, that there are significant challenges in implementing systematized logistics processes, especially those related to the infrastructure and location of humanitarian assistance centers and coordination of emergency processes, including the location of temporary shelters. This paper proposes a hybrid approach of a mathematical multicriteria model based on utility theory and FITradeoff for portfolio problems to assist the management of emergency coping strategies for disaster risks caused by urban flooding. Focusing on the principles of humanitarian logistics for prioritizing the spatial location of temporary shelters. By addressing objectives that require a global and comprehensive view, the multicriteria methods are effective in risk management due to their main characteristic of recognizing subjectivity as an intrinsic part of decision problems. Therefore, four criteria were raised to evaluate the order of prioritization for the deployment of temporary emergency shelters. Therefore, complex situations such as flooding, which require contingency planning over large areas and managing logistical activities, are difficult and complex tasks. As a result, therefore, a subset of locations to be considered as community or collective temporary shelters was established, as well as the computational vision and the logistic operations mode needed to operate these shelters and save lives, which constitutes a helpful decision support tool regarding the selection and location of temporary shelters capable of assisting in the construction of the Emergency Plan in response to floods, at the strategic or operational level of logistical decisions.
Keywords: Disaster risk management, Natural Disasters, Temporary Shelters, MCDA, Utility Theory, FITradeoff.

1. Introduction

Globally, the incidence of natural occurrences has increased the frequency and size of natural catastrophes in metropolitan areas during the previous two decades. Mostly because of variables related to climate change, population increase, and subsequent ill-conceived development, which exacerbates the socioeconomic effects. Current studies highlight issues in urban management, such as flooding, which is one of the natural dangers that have the potential to cause significant financial losses throughout the world, affecting millions of people each year (CRED 2021). According to United Nations (UN) predictions, the Earth's population will reach 11 billion by the end of this century, with metropolitan regions housing nearly 75% of the world's population in 2050 (CRED-UNISDR 2015).

Additionally, the amount of tragedies caused by flooding in metropolitan areas is expected to rise in the future as precipitation increases owing to natural failures caused by climate change. This increases the need of developing an urban flood risk management strategy to decrease the loss of life and property damage, identify the risk and extent of catastrophe effects, and define priorities for disaster risk reduction action (IPCC 2018)

Disaster management strives to minimize or eliminate potential losses caused by risks, provide early and appropriate aid to catastrophe victims, and achieve speedy and successful recovery. The catastrophe management cycle is divided into four stages: (i) Mitigation - the preventive phase in which the goal is to identify the risks in order to lessen the impact of the disaster. (ii) Preparation - this is where you plan how you will reply. (iii) Response - the emergency phase in which steps are taken and efforts are made to limit dangers; and (iv) Recovery - the phase in which the infrastructure is recovered and returned to normal.

More specifically, during the planning and reaction phase of the disaster emergency management plan, when it is required to determine the optimal geolocations for establishing temporary emergency shelters and the best manner to distribute emergency resources during extreme occurrences (Anhorn and Khazai 2015). However, these tasks are not easy, since they involve multiple criteria and conflicting values. To do so, methods and approaches that can contribute to the decision-making process of resource management and emergency actions are required for this (da Silva et al. 2020).

Considering this, multicriteria decision-making methods (MCDM/A) can be advantageous since they allow for the consideration of various stakeholders' perspectives, each with its own set of tradeoffs, feasible alternatives, and criteria. (Adiel T. de Almeida et al. 2015).

Thus, this study aims to structure and describe a flood risk assessment conceptual model with a multicriteria perspective based on Utility Theory to categorize risk using ALARP (As low as reasonably practicable), and, as a result, use a benefit-to-cost ratio (BCR) approach for selecting portfolio with FITradeoff with views to support resource allocation to enhance flood preparedness.

This paper is structured as follows: section 2 draws up a brief literature review in order to justify the innovative approach proposed by this work. Section 3 describes the modeling proposal, sharing insights for real-life applications. Finally, section 4 states some final remarks and highlights important issues to be addressed in future research.

2. A theoretical background on flood disaster preparedness with MCDM/A

The location of emergency shelters in flood-prone areas is a critical issue to ensure the safety of the population in the event of natural disasters (Tran 2015). The selection and implementation of suitable locations for emergency shelters should consider various criteria, such as accessibility, shelter capacity, and proximity to medical facilities, among others. In this regard, multicriteria models are a useful tool to aid decision-making concerning the location of emergency shelters (Mejia-Argueta et al. 2018).

It is possible to identify in the literature a trend of research proposing risk assessment and scenario models before the occurrence of extreme events, with the objective of identifying and mapping hazardous areas, as already evidenced in systematic literature reviews (da Silva, Alencar, and de Almeida 2020; de Brito and Evers 2016; Abdullah, Siraj, and Hodgett 2021).

However, multicriteria models are also useful to assist decision-making during the preparedness and response phase. Given this backdrop, recent studies try to enhance, in the light of MCDM/A, decision models for selecting suitable locations for the installation of temporary emergency shelters in flood-prone areas. Among the multicriteria methods used in these papers, we can cite PROMETHEE, AHP, TOPSIS, etc. (Alam, Habib, and Pothier 2021; Doorga et al. 2022; Mohammadnazari et al. 2022).

The popularity of approaches that are unsuitable for application in the context of floods has been justified by the fact that they are an MCDM/A method commonly utilized in the literature. Ignoring the importance of dealing with the uncertainties involved with this topic.

Therefore, authors such as Kousky et al. (2021), da Silva et al. (2020), and da Silva, Alencar, and de Almeida (2022) have discussed the potential damages of flooding in urban areas, especially during periods of severe rainfall. Likewise, these researchers have warned of the need for tools that can help decision-making during emergency situations caused by natural disasters, which, despite the low probability of occurrence, have a high magnitude of consequences in terms of damages and losses.

Consequently, given the stochastic and unpredictable environment of flood risk management, the utility theory represents a useful approach to deal with this aspect, as mentioned by Keeney and Raiffa (1976). MCDM/A decision models using MAUT and its methodological advances, for example, extend the Expected Utility (EU) theory in a multidimensional perspective, supported by a substantial axiomatic structure to deal with tradeoffs between conflicting objectives under a probabilistic perspective.

However, public administrations usually face complex decisions regarding resource allocation to combat and reduce flood risks, once they have scarce resources, whether in financial, infrastructure, or human terms (Engwall and Jerbrant 2003). This way, the portfolio problem under an MCDM/A approach can be helpful to support these decisions. In practical terms, these problems seek to select, from the set of alternatives, a subset that meets the objectives, such as raising and obtaining the best-expected outcomes, on considering budgetary constraints and other types of limitations.

That is why portfolio oriented MCDM/A methods can support resource allocation in the context of enhancing humanitarian logistics in the urban space.

From this perspective, it must be noticed that the project portfolio selection (PPS) can be faced by multicriteria methods in different manners. Traditional methods are supported by some typical issues from Operations Research so that the portfolio is obtained by solving linear programming problems (LPPs), thereby maximizing the portfolio benefits and obeying LPP's constraints – for example, the knapsack problem (Phillips and Bana E Costa 2007).

On the other hand, some papers such as Kleinmuntz (2007) and Phillips and Bana E Costa (2007) highlight an alternative way to achieve this goal: first of all, the alternatives must be ranked using a benefit-to-cost ratio (BCR) approach, and after that, the DM is able to select projects from the highest performances until the budgetary resources are available.

Frej, Ekel, and de Almeida (2021) affirm that the BCR approach is more powerful to PPS, and closer to real-life applications.

In the light of the multicriteria field, this comprises a lack which this paper aims to cover, thereby proposing a hybrid modeling that considers the utility theory, ALARP principle, and FITradeoff for portfolio selection with BCR approach, which their benefits that justifies the conceptual model is presented next.

3. A hybrid multicriteria model for emergency planning

As deeply discussed in the previous section, the main contribution of this paper is centered on the proposition of a conceptual model focused on supporting decisions on humanitarian logistics that deal with a multicriteria approach.

To do so, hybrid modeling with Utility Theory, ALARP principle, and FITradeoff with BCR approach is adopted to enhance the problem of allocating resources for structuring and preparing temporary shelters.

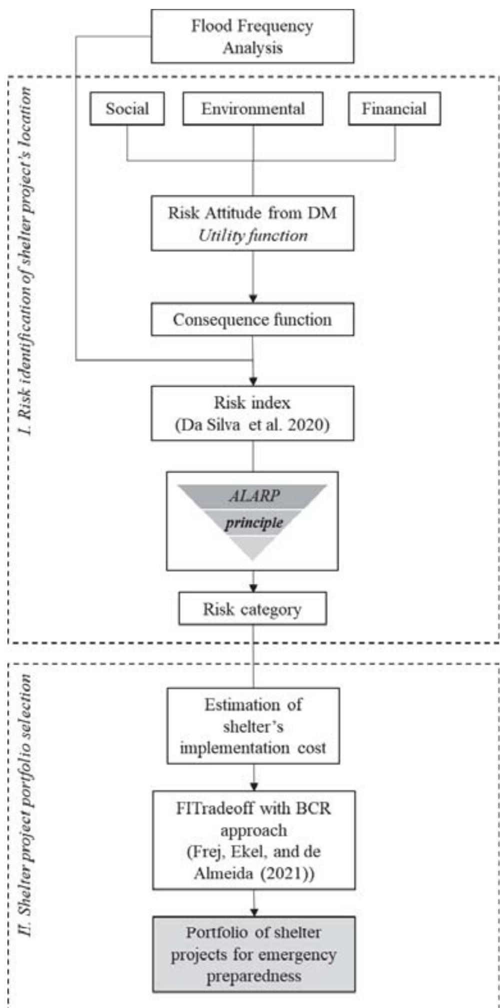

Fig. 1. Flowchart of the conceptual model for selecting shelter projects portfolio for emergency planning and humanitarian logistics Source: The Authors.

Consequently, the proposed model aims to cover some gaps in the literature (see section 2), as well as it aids policymakers in adapting urban areas to flooding events in a preventive perspective. Fig. 1 outlined the step-by-step procedure for portfolio selection of shelter projects.

3.1 *Risk identification on shelter project's location*

First of all, the first stage of the conceptual model is adapted from early findings from da Silva et al. (2020) and their advances (da Silva, Alencar, and de Almeida 2022).

The problem arises in an urban area in which the public administration needs to improve emergency planning of natural disasters in such a way that the decision-maker (DM) – a qualified representant of the public interest – allocates resources, mainly financial ones, to implement structured measures to avoid flood impacts under heavy precipitation, such as the temporary shelter.

In practice, policymakers must prepare these locations in order to make them: (i) more accessible, because human aid should be destinated to the people affected; and (ii) capable to support the public demand, once flooding in critical areas might induce displacements of families.

On the other hand, the limited resources faced by public administrations worldwide should be considered when planning improvements on temporary shelters. For that reason, this paper considers shelter projects (retrofit, expansion, or other structured measures) as the set of alternatives of the problem (a_i).

Besides that, the georeferenced location of the shelter projects are the starting point for structuring the main criteria of the problem. This way, the central point of this stage is to evidence which are the most critical areas, in financial, environmental, and social aspects, that need the implementation of shelter projects for avoiding flood impacts in a risky situation.

Despite this paper establishing generic criteria (*j*), a wide range of contributions suggests risk perspectives which the DM must consider (da Silva, Alencar, and de Almeida 2022; de Brito and Evers 2016; da Silva et al. 2020; da Silva, Alencar, and de Almeida 2020).

Initially, the proposed model uses the risk formulation under the Utility Theory from da Silva et al. (2020) to assess how critical urban areas are to be invested in terms of flood preparedness with shelter projects (see Eq. 1).

$$r_j(a_i) = -\sum_{\theta} \pi_\theta \left[\int_{x_{min}}^{x_{max}} P_j(x_i|\theta) u_j(x_i) dx \right] \quad (1)$$

As observed in Eq. 1, the flood risk index for each criterion represents how the urban location in which the project a_i was designed is critical. So, with the aim to assess flood risks, da Silva et al. (2020) based on the strong protocol from Keeney and Raiffa (1976), assuming that the risk index is obtained by three components:

- Flood frequency analysis (π_θ) – traditional hydrological models, with the aid of statistical analysis, can be used to estimate the probability of occurrence (π_θ) on considering that θ represents the precipitation data. Technically in multicriteria problem, θ means the State of the Nature; broadly speaking, a non-controlled factor by the DM so that its modelling must consider the probabilistic perspective. Da Silva et al. (2020) states that specialists might assist the DM in discretizing θ in flood severity levels, in which probability density functions (PDFs) can be used to calculate π_θ. From this perspective, the Generalized Extreme Value (GEV) distribution is suitable to model extreme events, as observed in Esteves (2013) and Seo et al. (2021);
- Consequence function $(P_j(x_i|\theta))$ – this risk component links the flood phenomena with the potential impacts on the urban functioning. The shelter project location might be complex to support huge effects from floods, so these projects should be better implementer where the impacts are significant. Assuming there is no correlation between the criteria assumed by the DM, it is possible to estimate PDFs with views to model the impacts of this natural disaster. Moreover, public data and a priori knowledge from multidisciplinary

specialists play a key role in estimating this risk component; and

- The DM's preference (risk attitudes) in terms of utilities ($u_j(x_i)$) – the protocol of from Keeney and Raiffa (1976) assumed that the decision-maker can establish personal judgements when dealing with catastrophic consequences (x_i). Questions regarding two hypothetical lotteries guide the DM in thinking about which situation he/she prefer, until the indifference relationship between them leads the elicitation procedure to estimate the utility function (for more detail, see Keeney and Raiffa (1976)). Formally, a best consequence achieved in criterion j, x_{best}, implies $u_j(x_{best}) = 1$, while $u_j(x_{worst}) = 0$. This way, the interval scale of utilities represents the risk attitudes from the DM, which means if he/she is prone-to-risk, risk neutral, or even risk averse.

Altogether, the risk components are calculated according to Eq. 1, and the negative signal is justified by early findings of Berger (1985). The author highlights the need of inverting the interval scale in order to prioritize the most adverse situation that needs public intervention such as the implementation of shelter projects.

Consequently, the risk evaluation for each criterion j and alternative i is subject to a sorting procedure guided by the use of the ALARP principle (French, Bedford, and Atherton 2005). This is commonly used in systems supervision and management. The principle assumes that residual risk should be reduced as much as possible, if reasonably feasible (Jones-Lee and Aven 2011). Fig. 2 illustrates how ALARP classes share important insights for sorting flood risks calculated with Eq. 1.

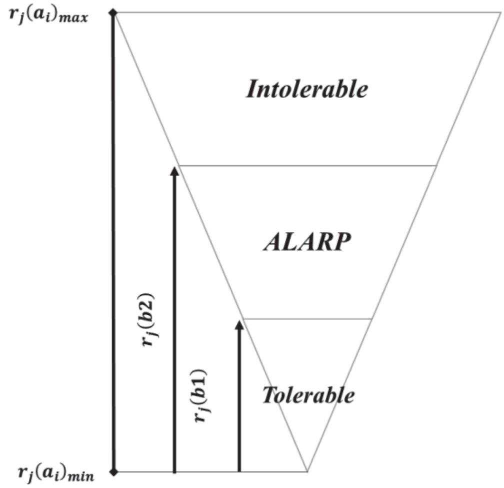

Fig. 2. Risk categorization scheme with the Utility Theory and ALARP principle. Source: The Authors.

This proposed model uses the main tolerability levels adopted in the ALARP principle to establish three risk categories, namely tolerable (C1), ALARP (C2), and intolerable risk (C3).

As insight for decision-making, the DM can define some boundaries on the range of consequences (for each criterion), so that $x_{worst} < b_1 < b_2 < x_{best}$. They represent the thresholds between adjacent categories.

As a result of this parametrization, the risk values associated to b_1 and b_2 suggests allocating a_i into class $C_j(a_i)$, namely:

- C1, if $r_j(a_i) < r_j(b_1)$;
- C2, if$r_j(b_1) < r_j(a_i) < r_j(b_2)$;
- C3, otherwise.

As mentioned by da Silva et al. (2020), the scale of $r_j(a_i)$ might be difficult to understand, in terms of relative magnitude, so the risk categorization meets the real-life applications and works as the starting point for the PPS of shelter projects, as described next.

3.2 *Shelter project portfolio selection*

The second stage of the conceptual model uses the benefits from FITradeoff for modelling multicriteria problems in an interactive and flexible way. Da Silva et al. (2022) already made an in-depth analysis of additive models and highlights a wide range of FITradeoff applicability because the method reduces DM's inconsistencies from the classical tradeoff procedure.

By using partial information, the less cognitive effort demanded from the DM during the elicitation process accredits the FITradeoff methos to be easily replicated in many problems, such as choice (de Almeida et al. 2016), ranking (Frej, de Almeida, and Costa 2019), sorting (Kang, Frej, and de Almeida 2020), and portfolio (Marques, Frej, and de Almeida 2022; Frej, Ekel, and de Almeida 2021).

From the need of selecting portfolio of shelter projects, and considering the benefits of the BCR approach, the risk categorization obtained in the last stage is the input for FITradeoff with BCR approach. In summary, this method aims to aggregate the multiple risk perspectives into a global value function that meets the DM's needs, under a space of weights, as schemed in Eq. 2.

$$V(a_i) = \sum k_j \, v_j \left(C_j(a_i)\right)$$

$$s.t \qquad k_1 + k_2 + \cdots + k_j = 1; \qquad (2)$$

$$\varphi = \begin{cases} k_{1_{min}} < k_1 < k_{1_{max}}; \\ k_{2_{min}} < k_2 < k_{2_{max}}; \\ \quad \cdots \\ k_{j_{min}} < k_j < k_{j_{max}}. \end{cases}$$

Linear and non-linear functions can be assumed by the DM to model the unidimensional value function, so the global score value, $V(a_i)$ measured how the project a_i must be implemented to meet the DM's objectives.

However, the BCR approach assumes that, for each a_i project there is a cost of implementation c_i, estimated to calculate the BCR index ($V(a_i)/cost(a_i)$). This means the starting point for selecting the best mix of alternatives for shelter project portfolio thereby obeying the DM' budgetary constraints.

4. Final Remarks

In the light of many academic discussions about the application of MCDM techniques in different fields and areas of knowledge, Aven and Thekdi (2021) states that in the risk preparedness context, the qualitative and quantitative assessments of the factors that make up the flood disaster scenario are subject to uncertainties, that is, multiple criteria, of different natures, need to be satisfactory to find the most suitable alternatives among several viable options, which result in the best compromise solutions.

For that reason, this paper draws up a conceptual model for risk categorization of urban areas with the Utility Theory and ALARP principle, as the starting point for sorting flood risks in urban areas in which shelter projects are designed for. Afterward, the benefits of using FITradeoff with a BCR approach leads the conceptual model to rank and, a posteriori, select, a subset of shelter projects whose benefits are potentialized, i.e., in most critical urban areas, thereby not exceeding the amount of resources available to the DM.

In practical terms, this model can be easily applied in many real-life problems, structuring the criteria and alternatives properly in a collaborative way with specialists, stakeholders and other related professionals. This way, it is expected that this conceptual model guides the resource allocation to support emergency planning and then reduce injuries, displacements, illnesses and even fatalities.

Future research includes extending this approach for a group-based context, as well as applying the proposed model in flood-prone areas with views to establish a consolidated decision-making process for FRM-related professionals.

Acknowledgement

This paper is part of a research study supported by the National Council for Scientific and Technological Development – CNPq, the Brazilian Council for Improving Higher Education (CAPES), the Fundação de Amparo a Ciência e Tecnologia do Estado de Pernambuco (grant number APQ-0952-3.08/22), the Municipal Secretariar of Civil Defense and Protection of Recife (SEDEC) and the Pernambuco Water and Climate Agency (APAC) for which the authors are grateful.

References

Abdullah, Mohammad Fikry, Sajid Siraj, and Richard E. Hodgett. 2021. "An Overview of Multi-Criteria Decision Analysis (Mcda) Application in Managing Water-Related Disaster Events: Analyzing 20 Years of Literature for Flood and Drought Events." *Water (Switzerland)* 13 (10). https://doi.org/10.3390/w13101358.

Alam, M D Jahedul, Muhammad Ahsanul Habib, and Emilie Pothier. 2021. "Shelter Locations in Evacuation: A Multiple Criteria Evaluation Combined with Flood Risk and Traffic Microsimulation Modeling." *International*

Journal of Disaster Risk Reduction 53: 102016. https://doi.org/https://doi.org/10.1016/j.ijdrr.2020.102016.

Anhorn, J., and B. Khazai. 2015. "Open Space Suitability Analysis for Emergency Shelter after an Earthquake." *Natural Hazards and Earth System Sciences* 15 (4): 789–803. https://doi.org/10.5194/nhess-15-789-2015.

Aven, Terje, and Shital Thekdi. 2021. *Risk Science: An Introduction*. 1st ed. London: Routledge. https://doi.org/10.4324/9781003156864.

Berger, James O. 1985. *Statistical Decision Theory and Bayesian Analysis*. Edited by Springer-Verlag. New York: Springer-Verlag. https://doi.org/10.1007/978-1-4757-4286-2.

Brito, Mariana Madruga de, and Mariele Evers. 2016. "Multi-Criteria Decision-Making for Flood Risk Management: A Survey of the Current State of the Art." *Natural Hazards and Earth System Sciences* 16 (4): 1019–33. https://doi.org/10.5194/nhess-16-1019-2016.

CRED-UNISDR. 2015. "The Human Cost of Weather Related Disasters: 1995-2015." Brussels.

CRED. 2021. "Emergency Events Database (EM-DAT)." 2021. https://public.emdat.be/.

Da Silva, L. B. L., Marcelo Hazin Alencar, and Adiel Teixeira de Almeida. 2020. "Multidimensional Flood Risk Management under Climate Changes: Bibliometric Analysis, Trends and Strategic Guidelines for Decision-Making in Urban Dynamics." *International Journal of Disaster Risk Reduction* 50: 101865. https://doi.org/https://doi.org/10.1016/j.ijdrr.2020.101865.

Da Silva, L. B. L., J.S. Humberto, M.H. Alencar, R.J.P. Ferreira, and A.T. de Almeida. 2020. "GIS-Based Multidimensional Decision Model for Enhancing Flood Risk Prioritization in Urban Areas." *International Journal of Disaster Risk Reduction* 48. https://doi.org/10.1016/j.ijdrr.2020.101582.

Da Silva, L. B. L., Marcelo Hazin Alencar, and Adiel Teixeira de Almeida. 2022. "A Novel Spatiotemporal Multi-Attribute Method for Assessing Flood Risks in Urban Spaces under Climate Change and Demographic Scenarios." *Sustainable Cities and Society* 76: 103501. https://doi.org/https://doi.org/10.1016/j.scs.2021.103501.

Da Silva, L. B. L., Eduarda Asfora Frej, Adiel Teixeira De Almeida, Rodrigo José Pires Ferreira, and Danielle Costa Morais. 2022. "A Review of Partial Information in Additive Multicriteria Methods." *IMA Journal of Management Mathematics*, February, 1–37. https://doi.org/10.1093/imaman/dpab046.

Tran, Tuan Anh. 2015. "Post-Disaster Housing Reconstruction as a Significant Opportunity to Building Disaster Resilience: A Case in Vietnam." *Natural Hazards*. https://doi.org/10.1007/s11069-015-1826-3.

De Almeida, Adiel T. de, Cristiano A. V. Cavalcante, Marcelo H. Alencar, Rodrigo J. P. Ferreira, Adiel T. De Almeida-Filho, and Thalles V. Garcez. 2015. *Multicriteria and Multiobjective Models for Risk , Reliability and Maintenance Decision Analysis*. New York: Springer. https://doi.org/10.1007/978-3-319-17969-8.

De Almeida, Adiel Teixeira de, Jonatas Araujo de Almeida, Ana Paula Cabral Seixas Costa, and Adiel Teixeira de Almeida-Filho. 2016. "A New Method for Elicitation of Criteria Weights in Additive Models: Flexible and Interactive Tradeoff." *European Journal of Operational Research* 250 (1): 179–91. https://doi.org/10.1016/J.EJOR.2015.08.058.

Doorga, Jay R S, Leonard Magerl, Priyal Bunwaree, Jiaxin Zhao, Sophia Watkins, Caroline G Staub, Soonil D D V Rughooputh, Tyagaraja S M Cunden, Roddy Lollchund, and Ravindra Boojhawon. 2022. "GIS-Based Multi-Criteria Modelling of Flood Risk Susceptibility in Port Louis, Mauritius: Towards Resilient Flood Management." *International Journal of Disaster Risk Reduction* 67: 102683. https://doi.org/https://doi.org/10.1016/j.ijdrr.2021.102683.

Engwall, Mats, and Anna Jerbrant. 2003. "The Resource Allocation Syndrome: The Prime Challenge of Multi-Project Management?" *International Journal of Project Management* 21 (6): 403–9. https://doi.org/10.1016/S0263-7863(02)00113-8.

Esteves, Luciana S. 2013. "Consequences to Flood Management of Using Different Probability Distributions to Estimate Extreme Rainfall." *Journal of Environmental Management* 115: 98–105. https://doi.org/10.1016/j.jenvman.2012.11.013.

Frej, Eduarda Asfora, Adiel Teixeira de Almeida, and Ana Paula Cabral Seixas Costa. 2019. "Using Data Visualization for Ranking Alternatives with Partial Information and Interactive Tradeoff Elicitation." *Operational Research* 19 (4): 909–31. https://doi.org/10.1007/s12351-018-00444-2.

Frej, Eduarda Asfora, Petr Ekel, and Adiel Teixeira de Almeida. 2021. "A Benefit-to-Cost Ratio Based Approach for Portfolio Selection under Multiple Criteria with Incomplete Preference Information." *Information Sciences* 545: 487–98. https://doi.org/https://doi.org/10.1016/j.ins.2020.08.119.

French, Simon, Tim Bedford, and Elizabeth Atherton. 2005. "Supporting ALARP Decision Making by Cost Benefit Analysis and Multiattribute Utility Theory." *Journal of Risk Research* 8 (3): 207–23. https://doi.org/10.1080/1366987042000192408.

IPCC. 2018. *Global Warming of 1.5 °C - SR15*. *Ipcc - Sr15*.

Jones-Lee, M, and T Aven. 2011. "ALARP—What Does It Really Mean?" *Reliability Engineering & System Safety* 96 (8): 877–82. https://doi.org/https://doi.org/10.1016/j.ress.2011.02.006.

Kang, Takanni Hannaka Abreu, Eduarda Asfora Frej, and Adiel Teixeira de Almeida. 2020. "Flexible and Interactive Tradeoff Elicitation for Multicriteria Sorting Problems." *Asia-Pacific Journal of Operational Research* 37 (5): 1–22. https://doi.org/10.1142/S0217595920500207.

Keeney, R. L., and H. Raiffa. 1976. *Decision with Multiple Objectives: Preferences and Value Trade-Offs*. John Wiley & Sons.

Kleinmuntz, Don N. 2007. "Resource Allocation Decisions." In *Advances in Decision Analysis: From Foundations to Applications*, edited by Ward Edwards, Ralph F Miles Jr., and DetlofEditors von Winterfeldt, 400–418. Cambridge University Press. https://doi.org/10.1017/CBO9780511611308.021.

Kousky, Carolyn, Howard Kunreuther, Siyuan Xian, and Ning Lin. 2021. "Adapting Our Flood Risk Policies to Changing Conditions." *Risk Analysis : An Official Publication of the Society for Risk Analysis* 41 (10): 1739–43. https://doi.org/10.1111/risa.13692.

Marques, Adriana Cavalcante, Eduarda Asfora Frej, and Adiel Teixeira de Almeida. 2022. "Multicriteria Decision Support for Project Portfolio Selection with the FITradeoff Method." *Omega* 111 (September): 102661. https://doi.org/10.1016/j.omega.2022.102661.

Mejia-Argueta, Christopher, Juan Gaytán, Rafael Caballero, Julián Molina, and Begoña Vitoriano. 2018. "Multicriteria Optimization Approach to Deploy Humanitarian Logistic Operations Integrally during Floods." *International Transactions in Operational Research* 25 (3): 1053–79. https://doi.org/https://doi.org/10.1111/itor.12508.

Mohammadnazari, Zahra, Mobina Mousapour Mamoudan, Mohammad Alipour-Vaezi, Amir Aghsami, Fariborz Jolai, and Maziar Yazdani. 2022. "Prioritizing Post-Disaster Reconstruction Projects Using an Integrated Multi-Criteria Decision-Making Approach: A Case Study." *Buildings* 12 (2): 1–26. https://doi.org/10.3390/buildings12020136.

Phillips, Lawrence D., and Carlos A. Bana E Costa. 2007. "Transparent Prioritisation, Budgeting and Resource Allocation with Multi-Criteria Decision Analysis and Decision Conferencing." *Annals of Operations Research* 154 (1): 51–68. https://doi.org/10.1007/s10479-007-0183-3.

Seo, Jiyu, Jeongeun Won, Jeonghyeon Choi, Jungmin Lee, Suhyung Jang, Okjeong Lee, and Sangdan Kim. 2021. "Uncertainty of Rate of Change in Korean Future Rainfall Extremes Using Non-Stationary GEV Model." *Atmosphere* 12 (2). https://doi.org/10.3390/atmos12020227.