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Review

Humanitarian logistics optimization models: An investigation of decision-maker involvement and directions to promote implementation

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ABSTRACT

Reports of successful implementation of humanitarian optimization models in the field are scarce. Incorporating real conditions and the perspective of decision-makers in the analysis is crucial to enhance the practical value and managerial implications. Although it is known that implementation can be hindered by the lack of practitioner input in the structure of the model, its priorities, and the practicality of solution times, the way these aspects have been introduced in humanitarian optimization models has not been investigated. This study looks at the way research has involved practitioners in different aspects of the design of optimization models to promote implementation. It investigates the aspects affecting the implementation of the models and opportunities to guide future optimization contributions. The article introduces a systematic literature review of 105 articles to answer the research questions. The results are contrasted with a multi-criteria decision analysis using responses from Mexican practitioners. The study found that only 10% of the articles involved practitioners for modelling decisions, which was confirmed by a major gap between the objectives used in the literature and the priorities of Mexican practitioners. In terms of swift decision-making, fewer than 22% of the articles surveyed introduced new solution methods to deliver results in a sensible time. The study also identified very limited inclusion of environmental concerns in the objective functions even though these are a priority in the global agenda. These findings are discussed to propose research directions and suggest best practices for future contributions to promote the implementation of humanitarian logistics models.

1. Introduction

The massive impact of the COVID-19 pandemic has put crisis and disaster management in the spotlight [1]. During 2020, the number of disasters and economic losses was higher than the average of the previous two decades [2]. Although the number of people affected was lower because of the absence of mass casualty events, the increasing number of disasters combined with population growth and higher levels of vulnerability represented a major risk for the future [3–5]. As a result, the field of disaster management has attracted the attention of numerous researchers over the years [6] considering the key role of preparedness and readiness to support affected communities [7]. Disasters cause extraordinary situations that require significant logistical deployment to provide basic services to disaster victims [8,9]. It involves multiple participants [10] and it can represent up to 80% of the total cost for aid agencies [11].

The growth of humanitarian logistics in recent years has led to a large number of publications in different recognized journals [12], the creation of the journal *Humanitarian Logistics and Supply Chain Management* [13] and numerous special issues (see Refs. [14–17]. Operations Research (OR) in particular has proven to be very resourceful in balancing the importance of saving lives and resources while maintaining standards of humanitarianism and fairness [18]. There have been some reviews over the years looking into OR for disaster management and humanitarian operations [19–23] and some articles looking into the characteristics of optimization models [12,24–26].

Humanitarian logistics is a valuable research area to inform practice, given the complex and chaotic conditions faced in humanitarian

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operations [27]. Nevertheless, recent accounts of disaster management have shown that several challenges for planning and executing operations globally still remain [28], suggesting a limited level of implementation of the advances in humanitarian logistics. That implementation is directly linked to practitioners' trust in the findings [29]. Unfortunately, different barriers have been identified in the literature undermining this trust. The review from Ref. [20] shows the use of some unrealistic assumptions that can affect that trust and widen the gap between research and practice. Reference [29] argue that the complexity of optimization models can lead to the oversimplification of the problem [30]. That complexity is a major barrier for adoption as well, as optimization models can require time-consuming solution methods [31] which are not practical for operations in the field. This means implementation can be hindered by the lack of practitioner input in the structure of the model and its priorities, along with the practicality of solution times. Therefore, implementation relies on the answers to three key questions: What is the fit between the objectives pursued by the models and the objectives from practitioners? How are decision-makers involved in model design? and how quickly can the model be solved? Despite the abundance of models in the area and the valuable contributions from prior literature reviews, there are no articles investigating the answers to these questions. Hence, the link between research and practice remains unexplored, ultimately affecting the implementation of optimization models in disaster management. Understanding these aspects is crucial to incorporate the voices of practitioners to make research relevant [32] and guide new research in the field in a direction that can make it more impactful.

Optimization models represent an opportunity to facilitate the evolution in the field. An aspect that is becoming more prominent in supply chains is the inclusion of sustainability and environmental considerations because of the effect of operations on the environment [33]. With the development of the sustainable development goals (SDGs) [34,35], commercial supply chains are transforming by incorporating these aspects. Similarly, humanitarian supply chains need to evolve, as shown by calls for the introduction of sustainability in humanitarian operations [36] to support practice. Knowledge about these aspects of humanitarian operations is, however, very limited. Previous reviews have focused on traditional objectives in disaster operations. The complexity of humanitarian operations is the reason urgency becomes the main priority over other aspects, such as responsibility [27]. Therefore, an analysis of the fit between the objectives of optimization models in the area and the objectives of practitioners is an opportunity to also investigate the current state of environmentally friendly practices in disaster management. Identifying the ways these have been included and their link with current practices in the field can deliver insights about the next steps to support future operations. Therefore, this article tackles three research questions: RQ1 – How are optimization models for disaster management incorporating realistic conditions? RQ2 – How are environmental concerns included in the design of optimization models for disaster management? RQ3 – What are the approaches used to enhance the applicability of optimization models for disaster management in practice?

This study looks at the characteristics of optimization models in disaster management and the way research has involved practitioners in different aspects to promote implementation. Specifically, the objectives are a) identifying the approaches used in the design, priority setting, and solution time of disaster management models to introduce realistic conditions; b) identifying the way environmental considerations have been embedded in the models; and c) defining approaches to introduce real conditions to promote the implementation of disaster management models. The aim is to investigate how the optimization models proposed in the literature promoted implementation to identify current practices and discuss avenues for research. Hence, the article introduces a systematic literature review using the findings from 105 articles. To look at the fit between the objectives of practitioners and the objectives from the models, the findings are compared with the results from a multi-criteria decision analysis (MCDA) using insights from six practitioners in Mexico to identify their similarities and differences in this context. The contribution of the literature review is threefold: a) it investigates the role and level of engagement of decision-makers in the development of optimization models for disaster management, b) it discusses the approaches undertaken to incorporate real conditions in current optimization models for disaster management to propose avenues for research, and c) it provides an analysis of the inclusion of environmentally friendly considerations for disaster management in current formulations.

The paper is organized as follows: Section 2 is focused on the contributions of previous literature reviews and the differences with the contributions of this paper. Section 3 explains the methodology used in the study. The general results of the review are presented in Section 4, including the descriptive analysis and themes investigated. Section 5 introduces the MCDA analysis and results, while Section 6 introduces a discussion of the overall results and provides a set of research directions based on the findings of the analysis. Section 7 provides the conclusions of the article.

2. Literature review

2.1. Previous reviews

The area of humanitarian logistics and disaster management has grown significantly in recent years. Evidence of that is found in the number of literature reviews looking at the field, as shown in Table A.1 in the appendix. Initially, the field was closely related to the management of emergencies. For instance, Ref. [23] reviewed OR papers for homeland security (manmade disasters, emergencies, and natural disasters) focusing on preparedness and response to describe the different trends for emergency management, whereas [22] looked at articles for emergency response (including common emergencies and disasters) to analyses trends in volume, focus, or outlet.

Most recent contributions, however, have been looking specifically at disaster management and humanitarian logistics. Reference [19] provided a systematic literature review with a strong focus on the nature of disaster management and the characteristics of contributions in the field of OR and management science (MS), including operational stages, disaster types, methodology, and research contribution. This overview of the field is complemented by Ref. [27] and their analysis focusing specifically on humanitarian logistics. They provide a comprehensive account of the characteristics of these operations and analyze the activities at the preparation, immediate response, and reconstruction stages. They also look at the stakeholders involved in humanitarian logistics and the methodologies commonly used in the area, and use the findings to provide a framework for disaster relief logistics. The evolution of the contributions in the area led [6] to undertake a meta-analysis using content analysis to analyze the literature on humanitarian logistics. Their study looked at the context of operation, speed of the disaster, cause of the disaster, disaster management phase, and research methodology, and they proposed a category based on situational factors as a relevant dimension for the articles in the area. Later on, Ref. [20] provided an update of [19] in the OR/MS field, elaborating on the assumptions of the papers and their research contributions. On the other hand, Ref. [37] provided a systematic review looking into the various stakeholders in humanitarian logistics and the way it affects decisions and coordination at different levels during operations. These stakeholders are essential, as noted by Ref. [38]; focusing on the organizational dimension. Reference [38] looked at the internal issues and challenges in the humanitarian operations of an organization, the core competencies and capabilities required, and performance indicators and readiness metrics from the organization. Beyond the traditional categories identified in the field, Ref. [39] used the literature to classify humanitarian supply chain research into different themes to analyze trends and future directions. They argued the presence of a shift from studies focused on disaster and relief management to the analysis of humanitarian supply chains, and they identified themes related to humanitarian logistics, resilience, IT, mathematical models, theoretical approaches and case studies, performance evaluation, and big data analytics.

The evolution of the field has also allowed the development of reviews focused on specific areas of humanitarian operations. Reference [40] categorized performance measurement indicators in the five supply chain phases to identify current status and challenges, and proposed a performance measurement framework for the field. Contributions focused on the refugee context were reviewed by Ref. [41]. They used structured content analysis to look at performance measurement, logistics and operations, public health, and human rights and refugee protection. The value of systematic literature reviews for the analysis of performance measurement and critical success factors was presented by Ref. [42]. Reference [43] proposed a new classification for the tasks involved in casualty management after the occurrence of disasters to look at the micro level to explore the characteristics of the solutions developed. Reference [44] categorized articles based on coverage of spend analysis, sourcing strategy, supplier selection, and contract design to analyses procurement in humanitarian supply chains.

The interest from previous reviews on OR has led to a focus on optimization models, which has grown considerably since the work of [12]. They used content analysis to look at optimization for preparedness and response in emergency logistics. A major contribution from their analysis included proposing a taxonomy of articles by objective, constraints, and type of model. Their interest in looking at the characteristics of the models is based on the importance of understanding the evolution of formulations in this area. Reference [21] analyzed articles using OR/MS for stock prepositioning in humanitarian operations. They looked at prepositioning articles in general and provided a subsection detailing the assumptions, objectives, constraints, and solution methods employed for optimization models. Reference [24] looked at the different sources of uncertainty and how these have been implemented in optimization models for facility location. Their work provided details about the objectives, sources of uncertainty, approaches for uncertainty, and solution methods employed in these formulations. Reference [26] analyzed several contributions in the area to undertake an exploratory and descriptive study, which was then extended to a correlational study. The analysis was focused on social and behavioral aspects, material convergence, and uncertainty. It also provides details about the objectives pursued and the solution methods employed. Because of the use of objective functions in optimization models, there has been a focus not only on the type of objectives, but also on the number of objectives. Following on from the growth of formulations with more than one objective, Ref. [25] provided an analysis of multi-criteria optimization for disaster management based on the response phase, objectives used, multi-criteria decision-making approach, and type of solution employed. Table 1 provides a summary of the characteristics of the different contributions.

2.2. *Research gap*

The application of OR in general, and optimization in particular, has certainly benefited from authors looking at the nature and characteristics of models to provide support for decision-makers. However, there are different gaps to fill in the current literature.

Several articles have discussed the importance of introducing the "right" objectives into disaster management models [46,47]. That has led to an interest in reviews looking into performance measurement [40,42] and mathematical models [21,24,26]. Reference [25] took this idea even further to incorporate articles using two or more performance measures. Despite these contributions, the limited evidence about the implementation of optimization models in the field questions the value of those objectives to practitioners. Reference [44] acknowledge the importance of incorporating the practitioner's perspective in the analysis of disaster management problems. Following calls for closer relationships between academia and practice, there is an opportunity to promote the involvement of decision-makers in the design of solutions for disaster management and humanitarian operations [37,48]. Little attention has been paid, however, to the fit between optimization objectives and the real priorities of decision-makers. It is important to understand the suitability of current objectives to promote the implementation and value of optimization models for practitioners.

None of the reviews found in the literature provides a current analysis of the involvement of decision-makers in models in the area and the

Table 1
Previous literature reviews in the area.

Author (year)	Articles reviewed	Subject	Objectives and model structure	Solution methods	Experimentation	Environmentally friendly practices	Stakeholders	Review until
[19]	109	Disaster management						2004
[23]	Not specified	Homeland security (Emergencies)						2005
[27]	Not specified	Disaster management					✓	2006
[45]	361	Emergencies						2008
[12]	Not specified	Humanitarian logistics	✓					2011
[6]	174	Humanitarian logistics						2011
[20]	155	Disaster management						2010
[37]	228	Humanitarian logistics					✓	2012
[40]	52	Humanitarian supply chain management	✓					2013
[25]	41	Disaster management	✓	✓				2015
[41]	53	Humanitarian supply chain management						2016
[42]	52	Humanitarian logistics						2016
[39]	362	Humanitarian supply chain management						2017
[38]	Not specified	Disaster management					✓	2018
[21]	83	Prepositioning	✓	✓				2018
[24]	108	Facility location under uncertainty	✓	✓				2019
[43]	88	Casualty Management	✓	✓	✓			2019
[26]	178	Humanitarian logistics	✓	✓				2018
[44]	51	Procurement					✓	2019
This article	105	Humanitarian logistics	✓	✓	✓	✓	✓	2020

nature of that involvement. This gap is extremely important because of concerns about academia's ability to understand the real problems faced in practice [48] and the current calls for fostering the impact of research. Evidence about the use of unrealistic assumptions [20] suggests the need to evaluate the involvement of practitioners to design models that can tackle real and relevant issues.

Environmental considerations are becoming increasingly important in current literature. Although their link to disaster management has been highlighted before [49], limited attention has been given to environmental concerns in the development of disaster management models. It is important to understand the current state of these aspects and their integration into humanitarian operations to support current policy directions.

Data gathering is a well-known challenge for researchers in the field of operations management [50]. There have been claims about the importance of using real-world data or case studies based on real conditions to provide useful insights for practitioners and ensure the applicability of the models designed [29]. Nevertheless, literature reviews in the field, especially those looking into OR and optimization models, have not looked at the experimentation approaches undertaken by published articles. The type of information and experiments presented are relevant for evaluating the potential impact of the conclusions drawn and the confidence of practitioners in the results.

The solution of optimization models can be challenging, especially for large-scale and complex situations, such as the case of disaster management [51]. Some reviews in the area [21,24–26] have provided an account of the solution methods implemented for the models. Nevertheless, the analysis of these has been limited to enumerating the methods. Understanding the types of methods used and the current trends can inform future models to develop more efficient and comprehensive solution tools. This is closely linked to the potential use of models in the field, where there are urgent conditions and time constraints that can limit the use of complex models. Heuristics and metaheuristics represent interesting approaches to shortening solution times and promoting implementation, but little attention has been given to understanding their application in humanitarian operations.

2.3. Contribution of the current review

This study contributes to the literature in different ways: (i) it compares the frequency and use of objective functions in optimization models in humanitarian logistics with real preferences from Mexican practitioners analyzed using MCDA to discuss the differences between literature and practice; (ii) it analyzes the involvement of practitioners in the development of humanitarian optimization models; (iii) it investigates the inclusion of environmental considerations in optimization models for humanitarian logistics, (iv) it discusses the different algorithms used to solve optimization models in sensible time, and (v) it identifies the experimentation approaches used, their current trends, and their effect on the applicability of humanitarian optimization models in practice.

This article combines a systematic literature review with empirical analysis to guide the discussion. It is the first study comparing the findings from the objectives in the literature with empirical results obtained using data from practitioners to discuss the alignment between the objectives of research and practice. That allows identifying the gap between both sides and provide evidence about relevant aspects that need to be included in further optimization models, which is used to inform research directions. That discussion starts by looking at the involvement of stakeholders during the development of optimization models in the area. Reference [27] stress the importance of the multiple stakeholders involved in humanitarian logistics and their priorities whereas [37] discusses the importance of stakeholder's perspectives and coordination. Similarly, Ref. [38] surveys the literature looking at readiness metrics for different stakeholders and [44] explores inter-organizational relationships to gather information from practitioners about barriers for procurement. Those works serve as motivation for this article because they stress the need to consider the preferences of stakeholders to undertake successful operations. This article identifies aspects such as the types of involvement, the proportion of articles including decision-makers in their studies and how have these stakeholders been involved to inform further contributions.

The analysis of the objectives investigates the environmental side, which is currently underexplored in previous reviews. This review is asking: what is the role of sustainability and environmental concerns in humanitarian optimization models? That is the starting point for discussing the inclusion of these dimensions. We have different calls in the literature to include environmental concerns in the analysis, but up to this point there is little knowledge about if/how that has been translated to models in the area. Along with identifying the articles incorporating this aspect, the article compares the results with the priorities of practitioners. In that sense, this article is adding a point of discussion to the agenda regarding the need to develop sustainable objective functions which are currently understudied. Although previous reviews have looked at the different objectives used in optimization models in the area, they often cluster them in groups (e.g. Refs. [12,24–26,40,43]) or look at traditional and innovative objectives (e.g., Ref. [21]. This paper, however, analyses all the different objectives to look at the trends in the area of humanitarian logistics to contrast them with preferences from real practitioners.

The review is not only exploring the appropriateness of the objectives, but also the efforts made to promote implementation of the models given the challenges about tractability and problem size. Previous reviews have listed solution methods [21,24–26,43]. However, this is the first article looking at these solution methods as assets to make the models more applicable to the field, analyzing the different types of heuristics, the trends, and the areas for further development. Additionally, the tractability and application to real situations can affect the implementation of humanitarian logistics models. Although [43] lists the case studies used in articles focused on casualty management, a discussion about the different types of experimentation is still missing in the literature. The way models are evaluated and tested can have a significant impact on their applicability to the field given the importance of providing results that can convince decision-makers about the potential of the models in real situations.

3. Methodology

A systematic literature review approach was selected because it can help identify crucial contributions to a specific field [52]. This type of review is the one most commonly found in previous reviews in the area (Section 2). Systematic literature reviews can ensure the transparency and consistency of the analysis along with the replicability of the results [53]. The steps undertaken in this review were as follows.

3.1. Planning the review

Initially, researchers from the team met online to discuss the objective of the review and the research questions to design the interview protocol. The review aims to provide a thorough understanding of the use of optimization in disaster management. Following a review of the current state of the knowledge and its gaps, descriptive and analytical sections were developed. The study provides an analysis of the main trends in the area, a comprehensive analysis of the objectives used, the type of solution methods introduced, the nature of the involvement of participants, and the inclusion of environmentally friendly considerations.

The target of this review was to look at articles proposing new formulations for disaster management in reputable journals from 2005 to 2020. The search strategy was determined through a keyword search of several databases. The databases included were ScienceDirect, Taylor & Francis, Thompson Reuters, Wiley, Jstor, Springer, Scopus, and EBSCO from September to December 2020. Based on previous literature reviews and focusing on the main areas of emergency logistics, different trials were undertaken to define the set of keywords, as follows.

- disaster OR humanitarian OR catastrophe OR crisis

  AND

- logistics OR relief OR supply chain (if needed facility OR distribution OR inventory OR procurement OR evacuation OR transportation)

  AND

- optimization OR optimization OR model

3.2. Conducting the review

The team initially collected 3271 articles across all databases. A team of two reviewers was appointed to filter the articles by title, abstract, and complete content as part of the screening process. For screening, the inclusion and exclusion criteria were set as follows:

Inclusion criteria:

- Optimization models
- Humanitarian logistics
- Natural disasters
- Papers written in English

Exclusion criteria:

- Conceptual papers
- Daily emergency management
- Manmade disasters
- Literature reviews
- Mitigation and recovery
- Conference proceedings, book chapters, books, working papers, and theses
- Publications prior to 2005
- Articles in journals without an impact factor

Using these criteria as a basis, the titles of the articles obtained were checked to see whether the articles were related to the focus of the research. A total of 2560 articles were excluded based on our review of the titles. Next, the abstracts of the articles were checked to delete articles unrelated to the research questions and eliminate duplicated articles. The result was a total of 285 viable articles. At this point, the publication journal was considered as a filter. Using the Journal Citations Report 2019 from Clarivate, articles in journals focused on Operational Research and Management Science with an impact factor were accepted for the review, whereas articles from other journals were discarded. The purpose was to focus the search on impactful journals in the field with a focus on OR, as done in previous reviews (see Sabbaghtorkan et al., 2020). The remaining 136 articles underwent a full-text review. After checking them and discussing them among the reviewers, 105 articles were retained for analysis. The process can be seen in Fig. 1.

3.3. Data extraction

After the articles were selected, their information was extracted and gathered in a database for analysis. The authors employed EndNote ×8 to manage the articles analyzed during and after the screening process. As suggested by Ref. [52]; the information was prepared to provide a descriptive analysis of the field and a "thematic analysis". The descriptive analysis introduces an overview of the evolution of the optimization models contributing to the area of disaster management, provides a breakdown of the composition of those contributions, and includes the details of the formulations proposed. Next, the thematic analysis provides a synthesis of the findings, looking at the inclusion of environmentally friendly practices measures in disaster management, the involvement of decision-makers in the design of the formulations found, the most widely used objectives in the field, and the different solution methods proposed to obtain solutions. Both analyses are included in the next section.

The information extracted was documented in a template developed by the team of reviewers. The initial data extraction was undertaken by two academics, whereas each theme was allocated to another team of two academics to analyses the data. The findings from the different teams were discussed by the entire team to provide a holistic analysis of the field and to develop a set of research directions.

4. Analysis of results

4.1. Descriptive analysis

This review has shown the evolution of studies in the field using optimization models. Fig. 2 shows an increasing trend in publications in recent years. In fact, publications from 2017 to 2020 represent more than half of the publications included in this review. The rapid growth of the area is one of the factors underpinning the need for this review, with articles not analyzed before.

Among the various journals, the *European Journal of Operational Research* has published most of the works surveyed (18), followed by *Socio-Economic Planning Sciences*, *Transportation Research Part: E, Annals of Operations Research* and the *International Journal of Production Economics*, as shown in Fig. 3. These journals have jointly published 60% of the publications reviewed. From 2016 to 2020, the *European Journal of Operational Research* (14) published most of the optimization models in the area, followed by *Socio-Economic Planning Sciences* (9).

Fig. 4 shows the geographical distribution of the articles according to the affiliation of the first authors. Most of the authors are affiliated with institutions in the USA (28), distantly followed by Iran (13), China (11), and Turkey (10). However, regionally, the formulation of disaster management models seems more developed in Asia, as 46.7% of the first authors are affiliated with Asian institutions, in contrast to the 35.2% of authors based in institutions in the Americas. Devastating events in Asia and the USA have been the triggers for the development of models in these regions. Considering the importance of humanitarian operations in Africa [54], the absence of articles from authors affiliated with African institutions is noteworthy. This can be due to the focus on sudden-onset disasters rather than slow-onset disasters, which are more common in Africa, but it still seems the field needs more development in that region.

Most of the papers have focused on the post-disaster phase (i.e., immediate response and reconstruction – 59%), with only 18% of the articles looking into the combination of pre-disaster and post-disaster disaster activities. Combining both stages integrates the effects of decisions across them. At the same time, these formulations can be more complex and more complicated to solve, often requiring looking at different solution methods used in different formulations.

Fig. 5 introduces the number of articles tackling the activities outlined by Ref. [12]. Relief distribution is the most studied topic in humanitarian logistics, followed by facility location. Additionally, there is an increasing number of contributions combining two or more decisions in the same article, reaching nearly 27% of the articles surveyed.

The following section elaborates on the thematic analysis, looking deeper into the characteristics of the contributions surveyed and focusing on the research questions.

4.2. Analysis

The second part of the review focused on answering the research questions through the analysis of the different formulations surveyed. Table 2 shows an overview of the articles included in this review,

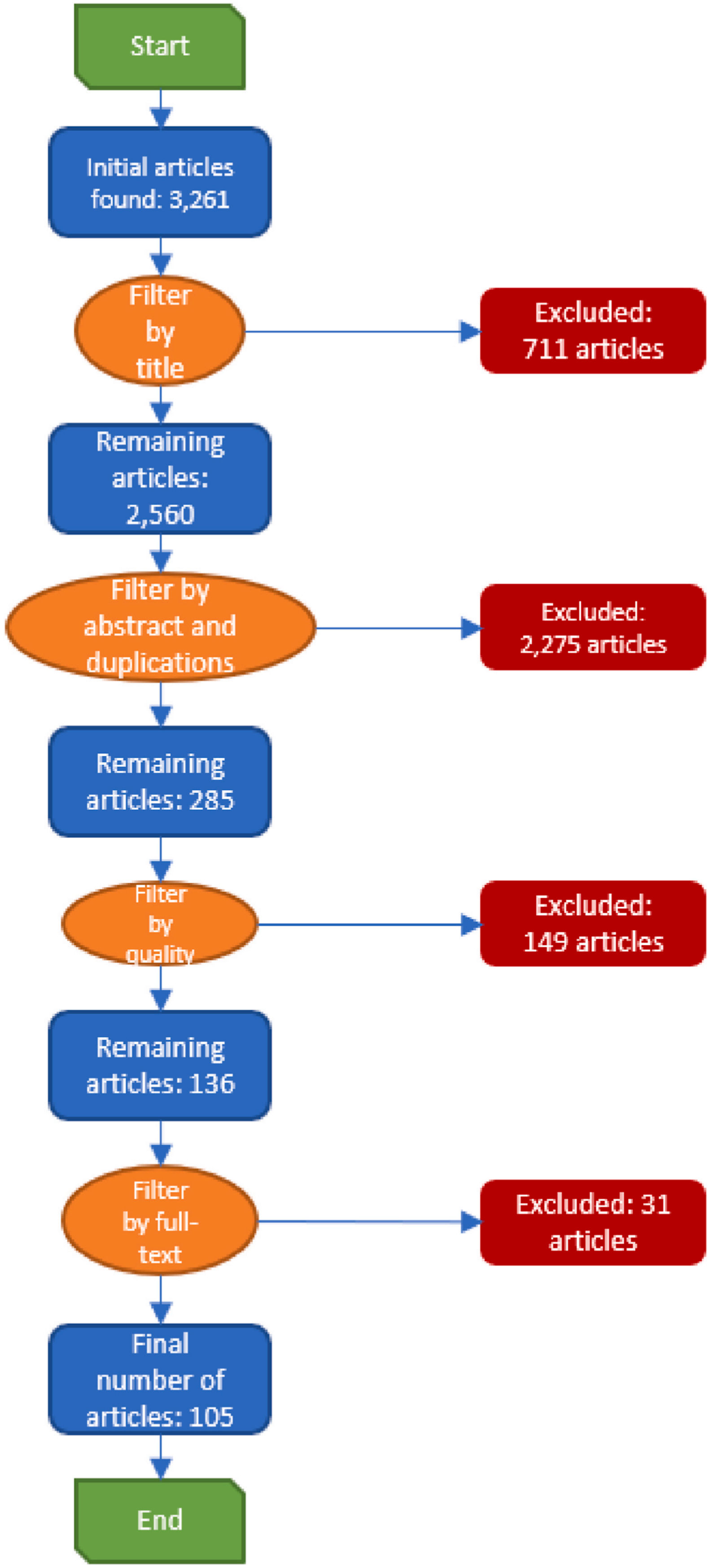

Fig. 1. Filtering process.

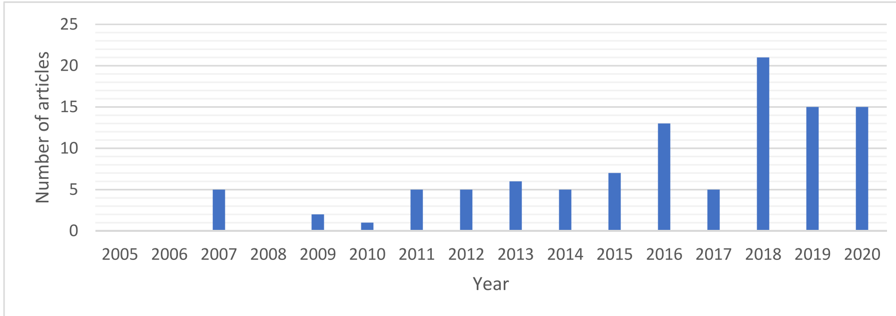

Fig. 2. Publications per year.

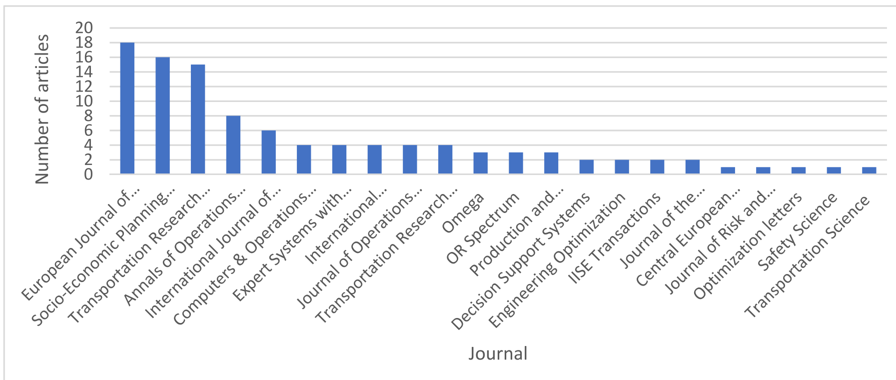

Fig. 3. Publications per journal.

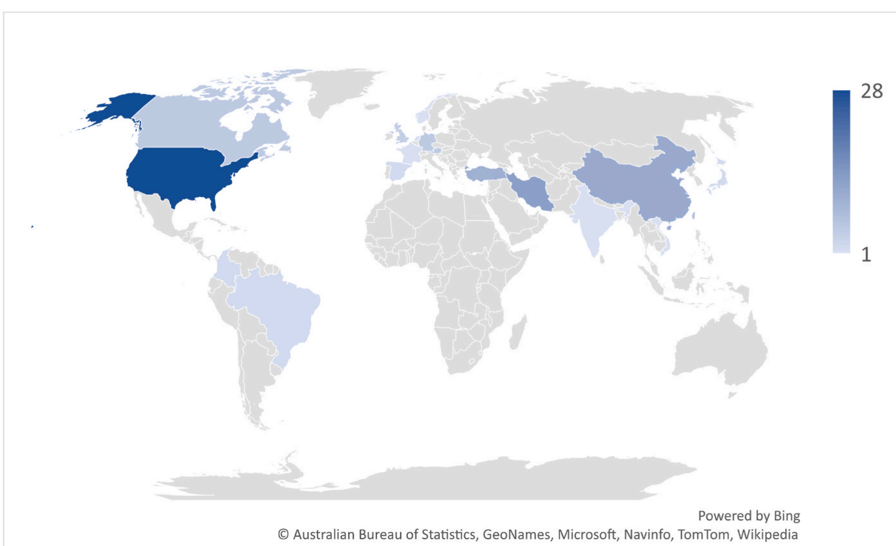

Fig. 4. Publications per affiliation of the first author.

looking at their objective functions, practitioner involvement, and solution approaches used in the different models. Each of these dimensions will be explored in the following sections.

The chaotic circumstances and high level of uncertainty experienced in disaster management have led to increasingly more complex formulations, as shown by the increasing number of multi-objective models, compared to previous reviews.

4.2.1. *Decision-maker involvement*

There has been evidence showing the positive impact optimization models can have in providing solutions for problems faced by decision-makers [117]. These advantages, however, have often been faced with discussions about the way assumptions and modelling decisions can affect the applicability of optimization models in real conditions [29]. The complexity of optimization models can lead to the necessity to simplify some modelling aspects of the problem, especially in settings such as disaster management. That is why the involvement of practitioners at the modelling stage has been seen as an opportunity to ensure these simplifications do not overlook critical aspects of the problem [30]. Their views can make academic contributions more impactful and

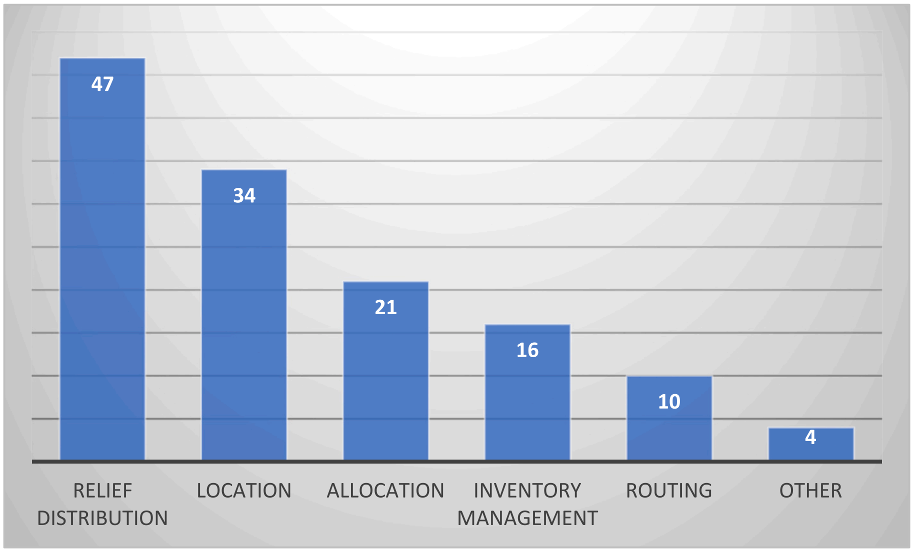

Fig. 5. Problematics addressed by the article.

implementable [29] because they can help identify key challenges, processes, and priorities.

This study examines the level of involvement of decision-makers in the formulation of disaster management models. Our analysis shows that only a little over 16% of the articles had primary involvement from decision-makers as part of the research process, most of them in the last 5 years (Table 3). The involvement of decision-makers is consistently spread between activities to gather their preferences and priorities, the extraction of key information to guide modelling decisions (including assumptions, objectives, and constraints), and data and information gathering for experimentation. From the table, it is possible to see that only 11 articles have included decision-makers for defining priorities or modelling decisions. Although most of the models support their assumptions on a theoretical basis, and some models consider inputs from decision-makers to define critical parameters that affect solutions (e.g. Refs. [63,77,79,95,100,101,108,115,135]), there seems to be a lack of participation of decision-makers at the design stage. That can have steep implications for the suitability of the assumptions underpinning formulations in the area.

The findings suggest a low level of participation of decision-makers in the formulation of optimization models in disaster management. Although the number of articles including the perspective of decision-makers has increased in recent years, the results gathered suggest the presence of a gap between reality and practice. Indeed, although the studies have increased in complexity and have tried to incorporate more features to face the challenges faced in disaster management over time, it is necessary to make sure those improvements are aligned with the needs of practitioners. This study will look further at the implications of the low level of involvement of decision-makers on the way their priorities are reflected in optimization models in the area.

4.2.2. Objective functions

The objective functions in optimization models are essential to ensure that the most relevant priorities are reflected by the solutions of the model [157]. The way the objective functions are defined and formulated heavily influences the type of results obtained. Despite the common focus on single performance measures in commercial logistics [158] there has been a discussion about the most appropriate number of objectives that should be included in models in humanitarian logistics. Our results agree with the findings from Ref. [12] stating that the majority of models in humanitarian logistics use only one objective function, as we found over 73% of papers using single-objective measures in contrast with nearly 15 papers using two objectives, 9 with three objectives, and 4 using four or more objectives.

Fig. 6 shows the balance between single-objective and multi-objective approaches over the years. Despite the advantages of multiple objective optimization [159], single-objective formulations tend to dominate. This can be related to the complexity of these models for a solution. Using more than one performance measure means that there is no single optimal solution, but a set of efficient solutions that can be depicted in the Pareto frontier [157]. Each one of those solutions is the best of its kind because of the trade-off between objectives. Hence, the Pareto frontier adds the step of having to identify the most suitable solution based on the perspective of the decision-maker.

To avoid that extra layer of complexity, there are single-objective formulations suggesting the use of composite objective functions combining different criteria into a single expression (e.g., Refs. [62,67,82,109,117]). Additionally, the need to account for resource and output performance metrics [46] has led to the development of new objective functions, including social cost [47]. Social costs involve the combination of logistics costs from operations along with deprivation costs derived from the suffering of the affected people. There has been a noticeable increase in formulations dealing with these costs over the years, representing the fifth most pursued objective in the models surveyed. That growth, combined with the number of multi-objective formulations and the articles producing composite performance measures, show an increasing interest in addressing the complexity of humanitarian logistics with more than one performance measure.

Table 4 presents the classification of the most common objectives pursued by the models analyzed. The results of this analysis confirm that cost remains the most common objective in disaster management, just as in commercial logistics and supply chain management [158]. That means that resource-oriented metrics [46] still have a prominent role in disaster management. After cost, objectives focused on the fulfilment of demand are frequently sought, followed by the minimization of time. Interestingly, aside from social costs that involve operational and deprivation costs, fulfilment, time, distance, safety, satisfaction, equality, and prioritization are more related to maximizing responsiveness and/or the availability of resources provided. That fits with the output performance metrics [46] with some examples of flexibility, such as minimum response times and mix of relief sent. The remaining metrics are focused on the efficient use of resources such as vehicles, units or facilities, rescue capacity, ranking of facilities, and perishable items. Therefore, there seems to be still a preference for resource-based performance measures, but output- and flexibility-based performance measures are rapidly growing in the area, which is consistent with the

Table 2
Summary of the models surveyed.

Authors	Objectives	Solution	Decision-maker involved	Environmentally friendly practices
[55]	• Minimize cost	Approximation algorithm	No	No
[56]	• Minimize cost	Decomposition method with a commercial solver	No	No
[57]	• Minimize cost	Commercial solver	No	No
[58]	• Minimize the sum of arrival times	Approximation algorithm	No	No
[59]	• Minimize inventory cost	Approximation algorithm	No	No
[60]	• Minimize cost • Maximize coverage	Commercial solver	Yes	Yes
[61]	• Minimize average lead time	Heuristic method	No	No
[62]	• Minimize a combination of the number of facilities, weighted distance travelled and unsatisfied demand	Commercial solver	No	No
[63]	• Maximize the value of an origin-destination route	Heuristic method	No	No
[64]	• Minimize unsatisfied demand	Commercial solver	No	No
[65]	• Minimize unsatisfied demand	Commercial solver	Yes	No
[66]	• Minimize a combination of cost and time	Commercial solver	No	No
[67]	• Minimize a combination of cost and time	Commercial solver and heuristic method	No	No
[68]	• Minimize cost • Maximize ranking score	Commercial solver	No	Yes
[69]	• Maximize coverage • Minimize cost • Minimize time	Approximation algorithm	No	No
[70]	• Minimize cost	Commercial solver	No	No
[71]	• Minimize delay penalty and unsatisfied demand	Heuristic method	No	No
Tuzun Aksu and Ozdamar [72]	• Maximize earliness of path restored	Commercial solver	No	No
[73]	• Minimize opening costs • Minimize operative costs • Maximize covered demand	Commercial solver and heuristic method	No	No
[74]	• Minimize logistics and deprivation costs	Commercial solver	No	No
[75]	• Maximize survival rate	Approximation algorithm	No	No
[76]	• Minimize the weighted sum of injured people • Minimize weighted unserved demand • Minimize the number of vehicles used	Commercial solver	No	No
[77]	• Minimize cost • Minimize the maximum shortage	MO solution using a commercial solver	No	No
[78]	• Minimize cost	Progressive hedging algorithm using a commercial solver	No	No
[79]	• Minimize cost • Maximize coverage	MO solution using commercial solver and heuristic method	No	No
[80]	• Minimize cost	Decomposition method with a commercial solver	Yes	No
[81]	• Maximize the minimum excess coverage (equality)	Heuristic method	No	No
[82]	• Minimize weighted unmet demand and penalties	Commercial solver	No	No
[83]	• Minimize cost	Approximation algorithm using a commercial solver	No	No
[84]	• Minimize cost	Progressive hedging algorithm using a commercial solver	No	No
[85]	• Minimize cost	Commercial solver	No	No
[84]	• Minimize cost	Decomposition method with a commercial solver	No	No
[86]	• Minimize cost • Minimize unsatisfied demand	Approximation algorithm using a commercial solver	No	No
[87]	• Minimize cost	Heuristic method	No	No
[88]	• Minimize cost • Maximize service	Agent-based simulation with optimization	Yes	No
do C [89].	• Minimize cost	Heuristic method	No	No
[90]	• Minimize cost	Decomposition method	No	No
[91]	• Minimize logistics cost • Minimize deprivation cost	Heuristic method	No	No
[92]	• Minimize cost • Minimize fill rate	Approximation algorithm and commercial solver	No	No
[93]	• Minimize the cost of procurement and preparation • Minimize the cost of response • Minimize transportation and loading/unloading times	MO solution using a heuristic method	No	No
[94]	• Minimize logistics and social costs (penalty cost for unmet demand)	Approximation algorithm using a commercial solver	Yes	No
[95]	• Maximize coverage • Minimize cost • Minimize maximum risk	Heuristic method	No	No
[96]	• Minimize the sum of arrival times	Heuristic method	No	No
[97]	• Minimize the weighted sum of unsatisfied demand	Heuristic method	No	No

(*continued on next page*)

Table 2 (*continued*)

Authors	Objectives	Solution	Decision-maker involved	Environmentally friendly practices
[98]	• Minimize cost	Commercial solver	Yes	No
[99]	• Minimize cost • Minimize response time	MO solution using a commercial solver	Yes	No
[100]	• Minimize total exposed hazards • Minimize ratio utilization of the cell - capacity	MO solution using a commercial solver	No	No
[101]	• Maximize coverage • Minimize cost	MO solution using a commercial solver	No	No
[102]	• Maximize total expected rescue efficiency	Commercial solver	Yes	No
[29]	• Minimize cost	Not specified	Yes	No
[103]	• Maximize the ratio of units allocated - response time	Heuristic method	No	No
[104]	• Minimize cost	Commercial solver	Yes	No
[105]	• Minimize cost • Minimize maximum unfulfilllment	MO solution using a commercial solver	No	No
[106]	• Minimize the number of vehicles deployed • Minimize travel time/cost • Minimize total arrival times • Minimize weighted arrival times • Minimize the latest arrival time	Heuristic method	No	No
[107]	• Minimize cost	Approximation algorithm using commercial solver and heuristic method	No	No
[108]	• Minimize cost • Minimize total unfulfillment	MO solution using a commercial solver	No	No
[109]	• Minimize the total weighted flow from the supplier nodes to the demand nodes less the total travel costs and relocation costs of the clearance equipment items	Commercial solver	No	No
[110]	• Minimize cost	Commercial solver	No	No
[111]	• Minimize the average deprivation cost μ and Gini's Mean Absolute Difference of the deprivation costs	Heuristic method	No	No
[112]	• Minimize cost	Commercial solver	No	No
[113]	• Minimize cost	Not specified	No	No
[114]	• Maximize equality • Minimize unsatisfied units • Minimize cost • Minimize deviation from equality • Minimize deviation from dissatisfaction • Minimize deviation from cost	Commercial solver	No	No
[115]	• Minimize unsatisfied demand • Minimize total time • Minimize transportation cost	Heuristic method	No	No
[116]	• Minimize cost	Heuristic method	No	No
[117]	• Maximize the total amount delivered, prioritization by type of item, prioritization by destination, speed, and minimizing cost.	Commercial solver and heuristic method	Yes	No
[118]	• Minimize distance	Heuristic method	No	No
[119]	• Minimize social cost	Commercial solver	No	No
[120]	• Minimize cost	Heuristic method	Yes	No
[121]	• Minimize cost	Approximation algorithm with a commercial solver	No	No
[122]	• Three policies - Minimize distance (2) and minimize maximum regret	Commercial solver	No	No
[123]	• Minimize cost	Approximation algorithm with a commercial solver	No	No
[124]	• Minimize social costs	Commercial solver	No	No
[125]	• Minimize cost	Scenario reduction and commercial solver	No	No
[126]	• Maximize the minimum weight of open shelter areas	Commercial solver	No	No
[127]	• Minimize cost (alternative with deprivation cost)	Commercial solver	No	No
[128]	• Minimize cost (considering fatalities)	Heuristic method	No	No
[54]	• Minimize cost	Commercial solver	Yes	No
[129]	• Minimize total weighted unsatisfied demand	Commercial solver	No	No
[130]	• Maximize lifesaving utility • Minimize delay cost • Minimize the gap between the real and ideal fill rate	Approximation algorithm with heuristic method	No	No
[131]	• Maximize the minimum weight of open shelter areas	Commercial solver	Yes	No
[132]	• Minimize unsatisfied demand • Minimize cost	MO solution using commercial solver and heuristic method	Yes	No
[133]	• Minimize response time	Commercial solver	No	No
[134]	• Minimize the maximum evacuation time • Minimize the maximum distribution time • Minimize total cost of relief operations	Commercial solver	No	No
[135]	• Minimize time • Minimize cost • Maximize equality • Maximize priority • Maximize reliability	Heuristic method	No	No

(*continued on next page*)

Table 2 (*continued*)

Authors	Objectives	Solution	Decision-maker involved	Environmentally friendly practices
	• Maximize security			
[136]	• Minimize total cost • Minimize total travel time • Maximize the minimal satisfaction	Commercial solver	No	No
[137]	• Maximize the total route safety	Commercial solver	No	No
[138]	• Maximize the minimum weight of open shelter areas	MO solution using a commercial solver	No	No
[139]	• Minimize social cost (logistics + deprivation)	Heuristic method	No	No
[140]	• Minimize the cost of relief • Minimize the cost of distribution	MO solution using commercial solver and heuristic method	Yes	No
[141]	• Minimize unmet demand	Commercial solver	No	No
[142]	• Minimize cost	Heuristic method	No	No
[143]	• Minimize social cost (logistics + deprivation cost + placement)	Heuristic method	No	No
[144]	• Maximize accessibility	Heuristic method	No	No
[145]	• Minimize total distance travelled • Minimize total cost • Minimize max travelling time between RCs and DPs • Minimize the number of perished items	Heuristic method and commercial solver	No	No
[146]	• Minimize cost	Commercial solver	No	No
[147]	• Minimize cost	Column generation with a commercial solver	No	No
[148]	• Minimize cost	Decomposition method with a commercial solver	No	No
[149]	• Minimize cost	Approximation method using a commercial solver	No	No
[150]	• Minimize cost	Commercial solver and heuristic method	No	No
[151]	• Minimize total delivery time	Approximation algorithm using a commercial solver	No	No
[152]	• Maximize profit	Not specified	No	Yes
[153]	• Minimize cost	Open-source solver	No	No
[154]	• Minimize cost	Commercial solver	Yes	No
[155]	• Minimize maximum travel time	Heuristic method	No	No
[156]	• Minimize the number of blocked points	Branch and bound method using a commercial solver	No	No

characteristics of disaster management.

Focusing on multi-objective formulations, Table 1 shows that almost all of the articles combine resource-based and output-based measures, except for [68]. The clear preference in the disaster management literature for combining cost and fulfilment (see Ref. [160]) is present in our findings. Although composite measures and social costs have grown recently, the potential of multi-objective formulations to consider the trade-offs between the different objectives to match the priorities of decision-makers can be an asset to reflect their preferences more accurately.

Although this article has confirmed the increasing trend of articles including more complex and complete performance metrics, the question about the appropriateness of these metrics for disaster management from the perspectives of decision-makers remains. Therefore, the findings from this section will be contrasted with the results from an analysis of the priorities of Mexican decision-makers presented in Section 5.

4.2.3. *Environmental concerns*

Sustainability is considered as an emerging trend in all branches and practices in the field of humanitarian logistics, therefore studies on this theme in the past decade has been sparse, but gradually increasing since 2018 [161,162]. The sustainable development goals set by the United Nations mention the importance of developing resilient systems that can cope with climate-related and natural hazards. At the same time, these goals emphasize the importance of developing sustainable communities and taking care of the environment [163]. This has been reflected in the rapid growth of literature about green supply chains [164]. Most companies utilize sustainability as a means of setting themselves apart from competitors, reducing expenses, and improving the quality of their goods and services for customers [41]. By portraying a positive image of their company and conducting business in an environmentally conscious manner, they can attract eco-friendly customers and address demands from both customers and competitors. Unsurprisingly, the importance of both aspects has led to the need to introduce sustainable practices into humanitarian operations [36,165]. The aim is to support governments and aid agencies in undertaking their operations at the same time as they are mindful of the environment.

Humanitarian operations are undertaken in high-pressure situations with uncertain environments [27]. This is the reason urgency takes precedence over any other considerations in these operations, to provide support to disaster victims and mitigate the damage of the hazard as quickly as possible. On the other hand, humanitarian operations have an impact on the environment because of the use of resources, transportation, and operational practices. Moreover, these operations produce waste that often needs to be managed after the impact of the hazard has been controlled [166]. Therefore, it is necessary to account for the impact of humanitarian operations on the environment [152].

Given the importance of prescriptive models that can help decision-makers in chaotic and uncertain situations, it is relevant to analyze the way disaster management models are introducing environmentally friendly practices in their formulations. Beyond the arguments that reducing travelling distances could reduce CO_2 emissions and that the minimization of the number of facilities ultimately reduces the impact of operations, it is surprising to notice the absence of environmental considerations in the models surveyed. Initially, none of the articles explicitly included environmentally friendly considerations in the objective function. It could be argued that efficiency-oriented measures could reduce environmental impact, but that is not always the case. For instance, the use of the cheapest transportation mode does not necessarily reduce the environmental impact of transportation.

Only three articles showed evidence of introducing environmentally friendly practices as part of their formulations. Reference [60] evaluated

Table 3
Involvement of decision-makers in disaster management models.

Category	Approach	Target	Article
Inclusion of preferences and priorities	Evaluation of subjective factors using fuzzy multi-attribute group decision	Decision-makers	[60]
	Group decision-making in the process of determining preferences for inputs and outputs to DEA	Decision-makers	[102]
	Simulation with logisticians to identify their preferences and build the utility function	Participants	[117]
	Interviews with IRCS practitioners to gather priorities and data	Decision-makers	[120]
	Interviews to define the context and gather preferences	Decision-makers	[140]
Modelling decisions	Validation of assumptions and parameters	Decision-makers	[80]
	Interviews with several members of the Federal Emergency Management Agency (FEMA) and state emergency management administrators	Decision-makers	[94]
	Observations and semi-structured interviews with logisticians	Participants	[99]
	Semi-structured interviews with humanitarian organizations	Decision-makers	[29]
	Interviews with UNHRD and the WFP	Decision-makers	[54]
	Interviews with commanders	Decision-makers	[154]
Data collection	Interviews about the flood of 2010 in Colombia	Public and NGO participants	[65]
	Interviews with the Austrian Red Cross	Decision-makers	[88]
	Interviews with IFRC leadership	Decision-makers	[98]
	Collaboration with Iranian authorities	Decision-makers	[104]
	Discussions with experts for data collection	Experts	[131]
	Interviews with members of an NGO to define the context of operations	Decision-makers	[132]

subjective factors such as the availability of open spaces and transportation accessibility for operational sustainability through the use of a fuzzy multi-attribute group decision-making approach. Reference [68] introduced a maximum allowance of CO_2 emissions for electricity generation in disaster operations. Reference [152] focused on the analysis of strategies to reduce carbon emissions, accounting for the influence of the customer carbon sensitivity coefficient and carbon trading price. However, this area needs further development in disaster management. The findings are aligned with statements about the absence of solutions considering sustainability measures in humanitarian operations [167] and claims about the lack of consideration of environmentally friendly practices in mathematical models in the field [152]. This result opens up an avenue of research for future models. Moving forward, disaster management models need to consider the sustainability dimension to support the development of disaster management systems that can support urgent decisions without disregarding the impact on the environment and society.

To understand the importance of involving decision-makers in the development of disaster management models and the current implementation of environmentally friendly practices in the formulations, it is necessary to contrast the findings with responses from practitioners to investigate the suitability of the assumptions underpinning current formulations in the area.

4.2.4. *Encouraging implementation: experimentation and solutions*

The methods used for testing and solving optimization models can have an impact on the value of the practical insights provided for decision-makers. Four different categories of experimental approaches have been identified: numerical analysis of examples, simulation to demonstrate the use of the model, sensitivity analysis on the initial results of the model, and finally, a case study using real data. A summary is presented in Table A.1.

Some of the categories presented could overlap (as shown in Table A.1). For instance, a real-case scenario might also use a sensitivity analysis to develop what-if responses based on real-world data, but also some numerical examples might be used to perform a sensitivity analysis to cover different ranges of responses to potential scenarios that could also use some simulated data in the model. Numerical analysis and real cases do not overlap, since we assume that they either have a numerical example based on assumptions developed by the researchers or are based on real data gathered from a case study. In that sense, the importance of sensitivity analysis in identifying the impact of variation of one variable on the target metric is noticeable, as over 60% of the articles included a sensitivity analysis. Simulation, on the other hand,

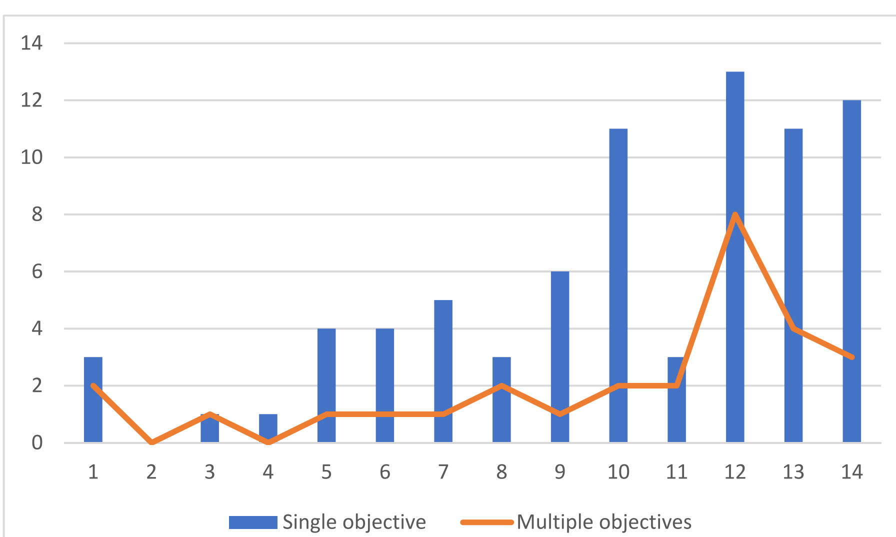

Fig. 6. Distribution of objectives over time.

Table 4
Objectives included in the formulations.

Metric	Definition	Objectives included	Freq
Cost	Involves reducing the monetary cost of operations.	Minimization of logistics costs, operational costs, costs of penalties, inventory costs, opening costs, procurement costs, preparation costs, response costs, travel costs, relocation costs, delay costs, and delivery costs.	67
Coverage	The purpose is to reach as many people as possible.	Maximization of the number of people covered, minimization of the level of shortage, minimization of unsatisfied demand, maximization of fill rate, minimization of unfulfillment, and maximization of the total amount delivered.	25
Time	It focuses on quickly satisfying the beneficiaries.	Minimization of arrival times, minimization of average lead time, minimization of the operation time, minimization of loading/unloading times, minimization of the response time, minimization of travel time, minimization of total time, minimization of the speed of delivery	18
Equality	Ensures all areas are allocated resources equally regardless of the level of impact on each area	Maximization of equality, minimization of excess coverage, minimization of deviation from equality, minimization of the maximum flow time, maximization of the minimum distance between victims and the danger, minimization of the maximum risk, maximization of the minimal satisfaction, maximization of the minimum weight of open shelter areas, minimization of maximum regret based on distance, Gini's Mean Absolute Difference of the deprivation costs	10
Social cost	Involves reducing the combination of the monetary cost of operations and deprivation costs	Minimization of the combination of logistics and deprivation costs, penalties for unmet demand, cost of fatalities, and placement cost	9
Distance	Focuses on reducing the distance travelled.	Minimization of distance travelled to their refuges, the distance between facilities	3
Safety and reliability	Ensures operations are trustworthy considering potential risks and damage, consistent, and continuous.	Minimization of exposure to hazards, maximization of reliability, maximization of security	3
Quality	Aims at achieving the highest level of satisfaction of the victims during operations.	Maximization of the quality of service, maximization of lifesaving utility	2
Priority	Focuses on allocating resources to the most affected areas, channeling more resources to high-priority areas	Maximization of the priority of the relief sent, and maximization of the priority of the destination areas	2
Other		Minimization of the number of facilities, maximization of the ranking score of suppliers, maximization of survival rate, minimization of the number of vehicles, minimization of utilization compared to capacity, maximization of the ratio of units allocated divided by the response time, maximization of expected rescue efficiency, maximization of accessibility, minimization of the number of perished items, minimization of the number of clear edges in the network	14

was the least common type of experimentation found.

Given the importance of planning emergency responses that improve the outcomes for the affected population, it is noteworthy that several works in our survey were developed as numerical analyses (54 articles fall under this category). This type of analysis offers theoretical results that are not based on real data, but provide a result based on some developed scenario used to prove the planning framework or to perform experiments to draw conclusions. This type of experimentation is popular because it allows us to carry out experiments with valuable advances based on theoretical propositions and testing hypotheses.

There are also articles presenting case studies, which are works based on real data using evidence that was usually collected after the fact. These applications are used to estimate the potential benefits that could have been obtained if those models were in place to decide the best response to those situations. The benefit of experimentation using case studies is that it enables testing the models under real conditions to produce insights for decision-makers [108]. These applications are the second highest encountered in the review (43% of all works claim to be case studies). The cases identified commonly focus on prominent situations and allow readers to identify the types of data used and sources, along with a discussion about the performance of the models under scenarios with real magnitudes.

The different experiments developed require efficient solution methods. A common way to find a solution to an optimization problem is to use algorithms that perform an exhaustive search. That is, they go through the entire search space, thereby finding the optimal value. Given that most of the models proposed are either MIPs or SPs, the solution methods used focus on solvers that can handle these types of models, such as CPLEX (50), which is the software with by far the largest share, followed by GAMS, GUROBI, and LINGO. Also worth mentioning are all-purpose software such as Matlab (6) that are used in some non-linear programs with the potential to be used with any of the models presented, similarly to other general-purpose modelling platforms such as C++ (14) AMPL (5) and Java (4). The main problem when solving optimization models arises when the search space is large or continuous. In those cases, it can take hours, days, months, or even longer to find the solution. In addition, this could consume high computational resources, especially when its complexity is exponential, which implies that these algorithms cannot solve problems of a certain size [31]. As it is not always necessary to obtain the absolute best or optimal solution to a problem in practice, it is possible to obtain a near-optimal solution with less effort. Therefore, an approximation algorithm can be designed to find these types of approximately optimal solutions, especially in time-sensitive instances such as those found in the disaster context. This literature review found that various works (e.g., Ref. [66]); do C. References [63,64,78,80,87,89,114,118,124,140,155] reported that their problems were NP-hard, but even some who did not report it had the same NP-hard nature. Therefore, different heuristics and relaxations were implemented to improve the solution time of the experiments.

This review found that 23 works used metaheuristics to solve optimization problems. From the above list, where the authors reported the NP-hard nature, only [155] used a metaheuristic to solve their problem. The most widely used types of metaheuristics were those based on evolutionary or genetic algorithms (43.48%). The Non-dominated Sorting Genetic Algorithm II (NSGA-II) [168] was used in several articles of this literature review because it has good performance in instances where the number of objectives to optimize is equal to or less than three. Different genetic algorithms have also been combined. Reference [71] designed a genetic algorithm to solve a multi-objective model with three objectives, whereas [115] developed a greedy search based on multi-objective genetic algorithms to deal with a three-objective model as well. Reference [142] presented a hybridization approach that included genetic algorithms, simulated annealing, and the Simplex method. This hybridization solves a hierarchical facility location model under uncertainty. Reference [144] developed a parallel genetic algorithm to tackle a multi-period bi-level programming mathematical model. Other alternatives include Bayesian Optimization Algorithms (BOA), Memetic Algorithms (MA) based on genetic algorithms mixed with the Taguchi method, and Differential Evolution (DE) algorithms to solve large instances.

Another type of metaheuristic that is commonly used to solve the models analyzed is Tabú Search (TS). This metaheuristic is a kind of local neighbor search that, to avoid cycling, declares forbidden or tabu those recent solutions explored [169]. Other relevant metaheuristics were variable neighborhood search (VNS) and simulated annealing (SA). Less common metaheuristics found in this review include Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Greedy Randomized Adaptive Search Procedure (GRASP), and Grasshopper Optimization Algorithm (GOA). Table 5 shows a summary of the metaheuristics found in this review.

5. Multi-criteria decision analysis

The small number of articles introducing practitioners in the formulation limits the understanding of their needs and priorities. This article contrasts the findings from the previous section with the views of practitioners using the TOPSIS method with Shannon entropy.

5.1. Technique for order of preference by similarity to ideal solution (TOPSIS) method

The TOPSIS method, introduced in 1981, uses the concepts of "ideal solution" and "similarity to the ideal solution". The solution obtained tries to get close to the ideal solution to maximize performance. To measure the similarity of an objective to an ideal and counter-ideal solution, the distance of that value from the ideal and anti-ideal solutions is measured. The alternatives are then evaluated and ranked based on the ratio of the distance from the counter-ideal solution to the total distance from the ideal and counter-ideal solution [170,171]. To calculate the weight of the attributes, we used a method known as Shannon entropy, and the results were then entered into the TOPSIS method [170]. The steps are given in the appendix.

5.2. Application in the context of objectives for decision-makers in humanitarian operations in Mexico

Climate-related events are faced by an increasing number of vulnerable people in developing countries, who are affected by them and need to rely on constrained resources. It is known that more than two-thirds of all disasters that occur globally take place in low-middle-income countries (LMICs) [172]. Mexico is an LMIC with a high percentage of vulnerable people, and it suffers, on average, four large-scale disasters per year [173].

The state of Sinaloa is a federal entity located in northwestern Mexico with 656 km of coastline along the Pacific Ocean. Sinaloa has 11 rivers and 11 dams [174]. It is divided from north to south by the Sierra Madre Occidental and the Pacific Coastal Plain. The state has a total area of 58,200 square km, which represents 2.9% of the country's surface [175]. Of the 120 hydrometeorological phenomena in Mexico from 2013 to 2018, more than 10% affected the state of Sinaloa, Mexico [176]. This means that authorities in the area are very experienced at handling large-scale disasters, and their insights can benefit the analysis of priorities for optimization modelling.

The steps outlined below have been implemented to rank the real priorities of decision-makers using a sample of practitioners from Sinaloa, Mexico. The study was conducted using information from six decision-makers with the characteristics presented in Table 6.

These practitioners were consulted to rank the nine objective functions thinking about the different attributes, which are based on the

Table 5
Summary of the metaheuristics found in the literature review.

Authors	Evolutionary Algorithms	Tabu Search	Variable Neighborhood Search	Simulated Annealing	Particle Swarm Optimization	Others
[97]						x
[71]	x					
[58]		x				
[155]				x		
[115]	x					
[67]			x			
[142]	x			x		
[61]		x				
[65]				x		
[101]			x			
[132]	x					
[93]	x					
[103]		x				
[111]					x	
[120]	x					
[135]						x
[143]	x					
[95]	x		x		x	
[96]	x					
[106]		x				
[144]	x					
[81]		x				
[145]						x
Total	**10**	**5**	**3**	**3**	**2**	**3**

Table 6
Demographics of the participants.

Participant	Role	Experience
1	Emergency advisor	10–12 years
2	Delegate from the northern area of Sinaloa	19–21 years
3	Civil protection manager	1–3 years
4	Inspection and training department chief of civil protection authorities	Over 21 years
5	Emergency municipality coordinator	Over 21 years
6	Emergency department manager	13–15 years

humanitarian logistics activities suggested by Ref. [12]. The results are analyzed using a sound methodology to score alternatives, define criteria weights, and discover relevant criteria [177]. MCDA allows the user to obtain the direct and indirect preferences of decision-makers to define the structure of models [178]. The purpose of this part is to provide weights and preferences for the different objectives to support the design of optimization models based on those priorities. There are several methods to obtain direct preferences from decision-makers, among which this study uses TOPSIS [178].

5.3. Data collection

The primary-based data was collected directly from the sample presented above. Three general steps were followed to determine the importance of the objectives related to disaster management. They include gathering data from decision-makers through an online survey, using an entropy method to determine the importance of the objectives, and using a multi-criteria method to rank the objectives.

The original intention was to collect data in face-to-face interviews with the decision-makers. However, the COVID-19 pandemic struck at that time, making it impossible to have meetings in person, and authorities were extremely busy managing the contingency. Thus, there was an agreement to prepare a complete briefing, instructions, and a self-applied data collection tool. Given the objectives of the study, the decision-makers were sent the information and a table to fill in with their preferences for analysis. The self-applied table given to the participants can be found in the Appendix. It was used to ask practitioners to set a value from 1 to 10 on eight attributes, where 1 meant the least important and 10 meant the most important. This is a common approach to obtaining the preferences of decision-makers to guide the evaluation of different alternatives [178]. This allows for structuring problems in a practical format [177].

The objectives used were obtained from the literature review presented in Table 3 with the addition of an environmentally-driven objective based on claims about the importance of involving sustainability in humanitarian operations [36]. It involves reducing the implications of humanitarian operations on the surrounding environment. Examples include reducing emissions or reducing the use of water and electricity. The objectives and attributes used are introduced in Table 7.

The collected data included the preferences of the decision-makers, which can be used to determine the priority of each one of the objectives to guide decision-making [177]. In real-world problems, that can be very complex because of the judgement of the decision-makers. In fact, conflicting judgements from decision-makers are a common problem. However, MCDA can deal with this problem using the rough set concept, which elicits having the input of information before the introduction of the decision model [178]. From the MCDA perspective, a prescriptive approach was used with decision-makers to rank a set of nine objectives.

Table 7
List of objectives and attributes.

Objectives	Attributes
Minimize cost	Shelters
Minimize travel distance	Distribution center
Minimize travel time	Evacuation
Maximize demand coverage	Relief distribution
Maximize quality	Procurement
Maximize reliability	Pre-position relief items
Prioritization	Deployment of staff
Maximize equality	Casualty transportation
Minimize environmental impact	

5.4. Entropy method results

Following the results of the Shannon entropy method (Appendix), the weight of the attributes is shown in Fig. 7.

5.5. Results of the TOPSIS method

The decision matrix of this method is the same as the Shannon entropy method decision matrix [179], which was initially normalized using the 3-3 matrix equation. The normal weighted matrix is given after multiplying the weight of the eight attributes into the normal matrix. Next, positive (A+) and negative (A−) ideals must be determined for each attribute. The positive ideal is equal to the largest value of the standard column, and the negative ideal is equal to the smallest value of the standard column [179].

The distance between each objective from the positive ideal (D+) and the negative ideal (D−) can then be calculated. The results are given in Table A.6 in the second and third columns. Finally, the similarity index (CL) was calculated, and the objectives were ranked based on it. The larger the similarity index of an objective, the higher the ranking of that objective [170]. The similarity index is given in Table 8 in the fourth column, and the fifth column details the ranking of objectives.

Interestingly, the most prominent objective found in humanitarian models in the literature was considered the least relevant objective from the perspective of authorities, even below the importance of reducing environmental impact, which has been largely ignored in the literature. Demand fulfilment and time, the other two common objectives employed in disaster management, seem relevant for authorities after maximizing the reliability of the supply, the satisfaction with the service provided, and the prioritization of more affected areas.

The analysis undertaken shows a gap between the priorities stated in the literature on disaster management models and the actual needs of practitioners in Mexico. The result is consistent with findings about the limited inclusion of decision-makers at the model design stage, which highlights the need to close the gap between research and practice to design more impactful solutions.

6. Discussion and research directions

6.1. Discussion

The analysis in the previous section focused on the level and nature of decision-makers' participation in the development of optimization models for disaster management. It considered the characteristics of the models, their objectives, and the fit of the objectives used in optimization models with the priorities of decision-makers in Mexico using an MCDA. Additionally, following the current emphasis on the importance of sustainability in human activities [163], this article has investigated the integration of environmentally friendly practices into disaster management models. Several insights were drawn from the analysis.

6.1.1. Comparison of objectives

The study found a significant gap between the objectives used in the literature and the priorities of decision-makers in Mexico. This gap can be explained by the small number of articles including decision-makers in their studies, with just a little over 10% of the articles incorporating the perspective of decision-makers for modelling decisions or defining

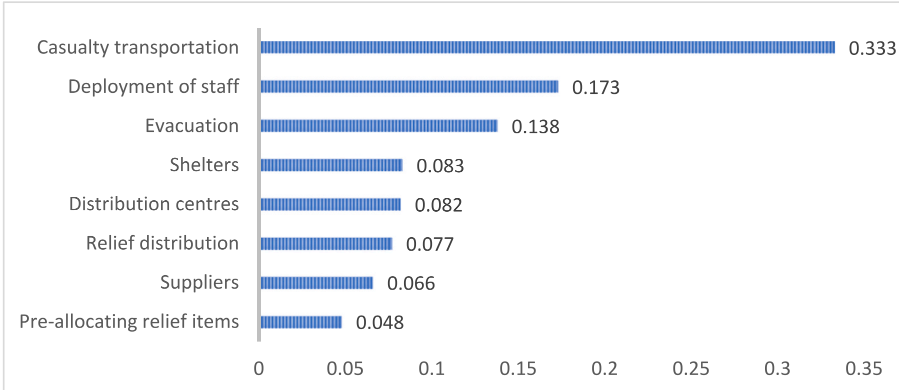

Fig. 7. Weight of attributes.

Table 8
Final ranking of objectives.

	Distance to positive ideal (D +)	Distance to Ideal Negative (D−)	Final score (CL)	Rank
Maximize reliability	0.001	0.086	0.989	1
Maximize quality	0.002	0.086	0.974	2
Prioritization	0.003	0.086	0.968	3
Minimize travel time	0.009	0.084	0.908	4
Maximize demand coverage	0.010	0.084	0.891	5
Maximize equity	0.012	0.075	0.857	6
Minimize travel distance	0.025	0.063	0.717	7
Minimize environmental impact	0.056	0.034	0.376	8
Minimize cost	0.085	0.006	0.064	9

preferences and priorities.

[140] found that decision-makers often have preferences in mind that can help decide the structure of the model and solution methods. The inclusion of decision-maker preferences has been done using interviews to gather key points to develop the objective functions (i.e., a priori) or through the integration of mechanisms to obtain the preferences of decision-makers for analysis (i.e., a posteriori). Interviews with members of the International Red Crescent Society from Ref. [120] point towards the need for responsiveness and cost-efficiency, whereas [117] use five utility functions produced based on the preferences of decision-makers (i.e., the total amount delivered, prioritization by type of item, prioritization by destination, speed of delivery, and cost). Interestingly, both cases broadly support the main objectives found in the literature and agree with the findings of [29] interviewing members of Red Cross, Medecins Sans Frontieres, World Vision International, and Word Food Program. However, these results should be considered carefully. Kovacs and Spens (2007) argue that different stakeholders have different preferences. The findings from those articles are based on interviews with logisticians from humanitarian organizations supporting the main responders (often governments), for which being cost efficient means reaching more victims [29]. Conversely, the MCDA analysis with Mexican civil protection authorities in this article shows less interests on cost, as they have strong funding sources. In comparison, although the model from Ref. [80] validated by experts from the Republic of Turkey Prime Ministry Disaster and Emergency Management Authority focuses on cost, they argue that the real driving force of their model is achieving total satisfaction in a timely manner. This discussion only reinforces the need to have practitioner input in the design of the models to ensure the priorities and structure are aligned to the requirements of the user to promote the use of optimization models in the area, as found by Ref. [99] in their interviews.

There are articles discussing the complexity of encapsulating the preferences of decision-makers in objective functions, and that is necessary to introduce mechanisms to allow them to input their views in less traditional factors. Examples include the use of fuzzy multi-attribute group decision-making to analyze subjective factors for hub location [60] and the implementation of DEA to analyze the preferences of decision-makers to determine of rescue efficiency of an arc for search and rescue activities. These models show the potential of using MCDA approaches to produce more comprehensive decision-support systems accounting for other relevant factors that can be integrated with traditional optimization formulations.

The views of decision-makers and practitioners provide insights that can make research more impactful [44]. The critical aspects of disaster management must be included in formulations and avoid over-simplification [30] because these could lead to problems in the implementation of the models [29].

Another interesting finding of the research stems from the evolution of the metrics used in disaster management. Although cost is the dominant objective measure, there has been a significant increase in models seeking to combine efficiency and effectiveness. The analysis showed that a combination of multi-criteria decision models, models introducing social cost, and formulations with composite objective functions are becoming more frequent. The growth of these approaches shows that, although there is still a heavy focus on cost, researchers are recognizing the need to balance it with measures of effectiveness. These models provide more balanced operations to enhance their usefulness in practice. The inclusion of equality in several metrics based on time, distance, and risk, among others, is also noteworthy. The growth of these types of equitable functions is a distinctive aspect to consider in disaster management models.

6.1.2. Inclusion of realistic conditions

A few models have been validated by decision-makers to promote their use. As a result, these models incorporate some interesting aspects. The interviews with FEMA from Ref. [94] highlight the need for flexibility in the models, Ref. [80] discuss the importance of complete satisfaction in short time, Ref. [99] found that characteristics of the region such as topography should be incorporated along with the characteristics of disaster relief and equity, Ref. [29] found that maximizing coverage is not necessarily a relevant objective for practitioners because of the availability of different vehicles, Ref. [54] found that storage costs were less important in humanitarian operations, and [154] introduce the possibility of simultaneous disasters. Increasing the number of articles validating models with the help from decision-makers will make them more attractive to them, and they will also provide a stronger literature on specific characteristics that can inform further models.

The development of more complex formulations warrants evidence of their applicability in practice. Reference [99] mention that models should be tested and benchmarked against real cases to gain credibility. Charles agrees with this remark arguing that models will only be used if practitioners can trust the results. There was a category of articles incorporating practitioners to support data collection. Interviews were used to collect information about the damage of the disaster and relief items used [65], response activities [88], parameters for the operation of hubs [98], development of scenarios [104], information of the area [131], and operational procedures [132]. These articles reconstruct cases using the information from practitioners. As these cases have more specific and real information about the situation, that approach could be instrumental to develop a set of cases to test and evaluate new formulations. Using real data and situations with large networks can provide an accurate picture of the performance of models for decision-makers. In our analysis, less than half of the articles use case studies, and more than half of them preferred using abstract numerical examples. Although numerical examples can indeed provide valuable insights and underpin useful experiments, case studies and real data instances can be better at convincing decision-makers about the relevance of the models. The use of case studies allows practitioners to identify what data is used, how it can be obtained, and how a model can handle information in formats commonly used by them in real-size instances.

Humanitarian logistics take place under uncertain, chaotic, and time-sensitive conditions [27]. Therefore, swift decision-making is crucial to support disaster victims. The complexity of the models presented, combined with the time pressure of humanitarian operations, are a good fit for the use of heuristic and metaheuristic algorithms. This is especially true with the growth of formulations using social costs, as these functions are non-linear. Articles could benefit from tailored heuristics to solve humanitarian optimization models. Nevertheless, only 23 of the articles surveyed introduced a heuristic algorithm. Tools that can provide good solutions quickly are valuable for the field, so there is a need to have more contributions designing and implementing efficient solution algorithms. We have found that evolutionary algorithms are the most widely used in the area, led by NSGA-II algorithms, and followed by Tabu Search Algorithms. These two types of algorithms have shown very good performance in different experiments, but it is important to leverage advances that can facilitate the use of models in practice in new algorithms. A recent literature review explaining the characteristics of new metaheuristics can be found in Ref. [180].

Despite the increasing complexity of optimization models over the last few years, there is still a disconnect between the pre-disaster and post-disaster stages. The results show that only 18% of the contributions surveyed integrate both stages. These stages are interconnected [27], which means that decisions at one stage can affect the performance of subsequent stages. For instance, facility location is commonly carried out as part of the preparedness activities at the pre-disaster stage, considering the immediate needs of the affected area [181,182], but those locations can become sub-optimal when considering multiple periods for slow-onset emergencies and concurrent disasters. A way to combine both stages is through the use of two-stage approaches with decisions *ex-ante* (before) and *ex-post* (after) the disaster [183]. These two-stage models consider the pre-disaster period as the first stage and the post-disaster period as the second stage [181,184,185].

This research has shown the ways research has involved practitioners in the development of optimization models, given the need to reflect their views to promote implementation [29]. Despite the well-known issues of data gathering, especially in disaster management and humanitarian logistics, it is essential to find ways to ensure that models reflect the real issues faced in practice [30]. Our analysis of the literature and its comparison with the priorities of Mexican practitioners suggest that academic research needs to further promote the involvement of practitioners to become more impactful. This will require looking at and understanding practitioners' perspectives on current approaches to identify areas of opportunity for collaboration.

6.1.3. Environmental concerns

Humanitarian operations have an impact on the environment [152,166], which becomes more evident given the increasing occurrence of disasters globally [186]. Humanitarian operations produce waste, require setting up temporary facilities, and require handling unused/expired items at the recovery stage. Moreover, humanitarian operations are affected by phenomena such as material convergence [187,188], which occurs because of the uncontrolled influx of material into the affected area leading to the delivery of several low-priority items, which can exceed 50% of the relief reaching the affected area [189,190] and can become unused relief leading to waste [187]. The calls for sustainable humanitarian operations [36,165] intend promoting initiatives to mitigate the impact of climate-related hazards [163]. Evidence from the literature shows that including sustainability in different operations can provide various benefits for organizations [33,160]. Humanitarian logistics provide individuals and their families with a level of support that is adequate for their health and overall well-being in the aftermath of a disaster to support sustainable development [34]. By integrating sustainability into humanitarian efforts, the focus is on ensuring that those affected by the disaster receive appropriate living conditions, that donations are utilized effectively, and that the environmental impact of the disaster response operation is minimized [191]. Although there are some interesting examples in the literature, such as reverse logistics for post-disaster debris [192] and models for recycling medical waste [166], there is still a lack of studies in the area of disaster management. Most of the models surveyed did not consider this dimension in their analysis. The few models including environmentally responsible measures looked at subjective factors for operational sustainability or the reduction of CO_2 emissions as part of the constraints, rather than developing objectives addressing environmental concerns.

This is consistent with previous findings in this area [152]. The major barrier to the inclusion of environmental concerns in humanitarian operations is the inherent tension with the urgency and the high stakes faced in these situations. Given the duty of satisfying the pressing needs of victims with limited resources, decision-makers tend to focus on efficiency and effectiveness, leaving aside aspects such as equality and sustainability [193]. This is an interesting point because the negative impact of humanitarian operations on the environment is often overlooked. Reference [194] argued that humanitarian activities should promote supporting development and not harm the environment. From that perspective, humanitarian operations should not be separated from environmental and social aspects. Looking at the social side, one of the main drivers of sustainability in commercial supply chains is the customers [160]. Given the increased awareness of donors, their effect on humanitarian operations is underwhelming [167]. Both the internal and external lack of support for introducing sustainability in disaster management and humanitarian operations can be traced to limited information about its benefits. Aspects such as local procurement to empower society [194], mediation between different goals and actors, long-term thinking [193], improved coordination of carbon reduction [152], and enhanced competitiveness of NGOs [167] represent some of the first steps to create traction behind the benefits of sustainable disaster management systems. This is becoming a relevant research area, as organizations involved in disaster management and the public need to understand the benefits of sustainability for disaster management operations. Increasing that awareness will lead to promoting improvements in current activities. Interestingly, there is an absence of studies that investigate the cost of being mindful of the environment and society. Along with the benefits, it is important to analyze the sacrifice needed to introduce these dimensions in disaster management.

There has been a lot of research on sustainability and environmental considerations in commercial supply chains [33,160], but the differences with disaster management operations [195] make it difficult to extrapolate the findings. The nature of the stakeholders, the involvement of the public, the performance objectives, the level of uncertainty, and the participation of emergent organizations [195,196] call for research specifically looking at sustainability in disaster management operations. The research study shows an absence of articles integrating objective functions with components of environmental concerns. That, aligned with the lack of metrics to promote sustainable performance, is another challenge [197]. The work of [167,193] represent valuable steps towards the definition of those metrics, but this area needs further development. The four areas where humanitarian responses can be more sustainable reducing the impact of environment are: material convergence; co-ordination between humanitarian organizations and industry partnerships; logistics aid transfer; healthcare systems [161]. Each of these areas can benefit from the use of more appropriate metrics and incentives, that will help various supply chain actors to understand the sustainability issues and corresponding implications (business, economic, social, environmental and productivity) [198].

Hence, there is a very interesting opportunity for humanitarian logistics models to catch up with the advances in sustainable operations management to introduce objectives and constraints, allowing them to consider the environment at the same time as disaster victims are delivered a high level of support. Interestingly, the impact of introducing environmental considerations in disaster management, if any, remains unexplored. Rather than disregarding the importance of sustainability because of the urgency of disaster management, there is scope to investigate the possibility of combining both aspects.

6.2. Research implications

The findings of this review show that there have been very limited attempts to introduce the perspectives of practitioners in disaster management models. The lack of their participation at the model design stage, the limited number of solutions promoting quick decision-making, and the gaps between optimization objectives and priorities of Mexican practitioners suggest that current models in the literature are not prioritizing implementation. Researchers in the area need to promote practitioner participation, reflect on practitioner contributions to activities in the field, and enhance their relevance in practice.

The involvement of practitioners in disaster management models is often done through a combination of different methods. The most popular ones are the use of interviews and MCDA. Promoting practitioner involvement to understand the complex environment surrounding decision-making in this context requires new methodologies that allow the combination of prescriptive decision-making with subjective factors.

Sustainable disaster management operations are still an underdeveloped area. There are isolated attempts to include environmental concerns or community factors in some optimization models. However, this area needs to develop further to support SDGs bringing together the social and environmental dimensions with the operational side of disaster management operations.

This research identified different opportunities to promote the adoption of disaster management models. The inclusion of practitioners setting the priorities and modelling design, the development of metaheuristics to promote quick decision-making, and the use of case studies to examine the performance of the models in real networks are the most relevant examples used in the literature. Models combining these three aspects can better encapsulate the benefits of optimization models to convey them to practitioners.

The findings of this study provide an overview of the current state of the field in disaster management models, looking at including practitioners. The following section uses the findings to propose potential avenues for research.

6.3. Research directions

This study introduces a review of optimization models in disaster management. Considering the remarks about the importance of involving decision-makers in humanitarian logistics [30,37,44], this study looks at the way disaster management articles have integrated their perspectives and reflected their aims and objectives. This section introduces a list of research opportunities in this area.

Research opportunity: Design of combined models using MCDA and optimization to promote the use of real priorities – The misalignment between the objectives of practitioners and disaster management models is a barrier to implementation. Using expert preferences can help bridge the gap between research and practice [199]. Sustained collaboration between researchers and practitioners can promote the development of research with a real impact on the field [44]. MCDA is a useful tool to capture insights and preferences from decision-makers, which can be used to inform optimization models in disaster management. This would allow the design of critical objectives and constraints with more applicability to real conditions.

Research opportunity: Studies validating objective functions to promote implementation among decision-makers – The literature has proposed various proxies to resemble the priorities of practitioners [46]. This study showed a large variety of metrics attempting to represent the main composite objectives. However, there is less evidence about the relevance of these metrics for practitioners. There is a need for a stream of research looking into performance measurement in humanitarian logistics to validate these metrics and/or define more appropriate proxies based on practitioner preferences.

Research opportunity: The design of sustainable objective measures – The growth of environmental and social concerns [36] needs to be reflected in disaster management operations. This area is underdeveloped, but different pressures are expected to promote development in forthcoming years [167]. The current nascent area of sustainable humanitarian operations will have to go beyond environmental concerns. The new avenue of research needs to look at comprehensive and integrated objectives and constraints that combine the environmental and social dimensions along with the operational focus on efficiency and effectiveness. These new functions need to be designed in alignment with the views of the decision-maker to align strategy and operations [200] with larger societal aims [194]. Social cost functions [139] and some examples of environmental concerns [152] are the first steps, but new formulations will need to embed these factors in the objectives and constraints of the models, rather than looking at them as additions to current models.

Research opportunity: Analysis of the advantages of sustainability in humanitarian operations to promote adoption – The new area of sustainable humanitarian operations will need the development of studies presenting the lessons learnt in commercial operations. It will explore the benefits and costs of sustainability for humanitarian supply chains to inform users and donors. In particular, empirically investigating the impact of embedding sustainability in disaster management activities will require looking at the needs, the effects, relevant strategies to promote implementation, and the uniqueness compared to commercial supply chains.

Research opportunity: Role of ethics in disaster management models – There has been considerable discussion in the literature about fairness and equality. This study identifies how metrics from both sides have been used in different models. However, with the growth of ethical decision-making [201], it is surprising not to find this dimension in the objectives pursued. This area has significant potential for the future, especially thinking about decision-making at the strategic, tactical, and operational levels. Studies looking at developing decision-support systems with ethical concerns will provide a chance to reflect on and guide activities in the field that consider the complexity of disaster management.

Research opportunity: Use of hybridization heuristics – Enhancing solution times in disaster management models is an area that is still developing. This is reflected in the use of not only off-the-shelf software, but also heuristics. However, increasing speed and managing even larger networks with complex models requires going beyond the algorithms currently proposed. To overcome the limitations of metaheuristics, it could be worth considering the hybridization of different approaches (metaheuristics–heuristics or metaheuristics–metaheuristics) to obtain better solutions in shorter times.

Research opportunity: Development of benchmarking scenarios with real information to facilitate the analysis of new contributions – Following the calls about the need to have benchmark cases to test different contributions, there have been some attempts in the literature to gather databases that can be used for experimentation [202]. However, less data has been prepared for examining disaster management models. There is a need to foster the use of real conditions and information to deliver insightful conclusions for decision-makers and promote the use of the formulations designed in practice. Therefore, there is potential for the development of databases and case studies that are made available to test optimization models under similar conditions to show their advantages.

Research opportunity: Development of integrated models considering the links between stages – The study identified a small proportion of integrated models for disaster management. Considering the impact of decisions in one stage on another, it is important to develop further approaches considering multiple periods at the post-disaster stage and the potential of changing conditions such as demand variation and concurrent disasters, as these can help optimize the use of resources such as employees.

6.4. Practical implications

The first research question addresses the role of optimization models to realistically facilitate decision-making for managing humanitarian logistics across the mitigation, preparedness, response, and recovery phases. The analysis shows that efforts involving decision-makers at the different stages of developing disaster optimization models are not widespread. There is limited participation from decision-makers, and the example with Mexican practitioners shows a significant difference in terms of priorities when compared with current formulations. Humanitarian logistics management needs appropriate frameworks covering variables, methods, inputs, and outputs relevant to practice that vary across disaster types, geographic locations, and perceptions of decision-makers. This requires adjusting to real conditions and providing solutions that can operate in limited timeframes. Therefore, the development of these models should incorporate practitioners at different stages to ensure that the design of the solutions can be impactful in the field.

The second research question deals with the inclusion of environmental aspects in optimization models for humanitarian logistics. Sustainability practices and performances have been emphasized in decision-making across every human endeavor due to climate change and the recent increased awareness of such issues. Although disasters have a huge impact on sustainability, less attention has been paid to including environmental parameters in optimization models. It can be argued that disasters happen due to the lack of a sustainable approach in our economic systems. The inclusion of environmental factors in optimization models for humanitarian logistics management definitely contributes towards achieving higher sustainability. These considerations might have cost implications, but help achieve greater sustainability. Our results show that environmental concerns are not prioritized in either research or practice. It is important to introduce environmentally friendly practices in humanitarian logistics to prevent a cycle where environmental damage produced by these operations contributes to climate change, in turn fostering conditions for further disasters.

The final research question identified opportunities for promoting the inclusion of real conditions in optimization models for disaster management. The analysis shows efforts from some articles to include practitioner views defining the priorities, modelling, and gathering information for experimentation. Additionally, some articles have introduced methods to speed solution times and case studies to provide insights based on real networks. Therefore, there are opportunities to engage practitioners in the design, experimentation, and implementation stages of the models. The accuracy and usefulness of optimization models rely on the inclusion of realistic views from the field. Therefore, our findings can be used to establish mechanisms to facilitate interaction and engagement with practitioners at different stages to promote the implementation of the solutions designed.

7. Conclusions

7.1. Conclusion

Although there have been multiple reviews in the area before, little evidence has been presented about the inclusion of decision-makers in the design of optimization models for disaster management. Moreover, there is scant evidence about the fit of the objectives used in optimization models in disaster management and the real preferences of decision-makers. To fill that gap, this article provides an analysis of the involvement of decision-makers in disaster management models and a comparison between their preferences and the most common objectives used in these. This article has addressed this gap through the combination of a systematic literature review of optimization models in the field of disaster management and an MCDA using TOPSIS with Shannon Entropy. The findings have been used to identify major trends and main gaps and to propose a set of research directions.

Our findings suggest that only a little over 16% of the articles had primary involvement from decision-makers as part of the research process, most of them in the last five years. Looking at that involvement, only 11 articles focused on gathering their preferences and priorities, and extracting key information to guide modelling decisions (including assumptions, objectives, and constraints). The rest of the articles focused on information gathering for experimentation. The effect of that gap between research and practice was shown by the analysis contrasting the objectives used in disaster management with the preferences gathered. The heavy focus on cost from optimization models in the field is misaligned with practitioners' preferences, which consider cost to be the least relevant objective. The outcome of this analysis is that it is critical to encourage the development of studies to ensure that the priorities and goals of decision-makers underpin future models in the area to facilitate the use of models in practice and increase the impact of the most recent research on the field.

This review found that another aspect separating research from practice is the type of experimentation used. Several articles preferred the use of numerical experiments, with less than half of the formulations using databases with real-world information. This is further fueled by the limited number of articles introducing heuristic algorithms to speed up solution times, which can hinder the implementation of the models developed in practice. Finally, the analysis also investigated the importance of environmental sustainability in the area. It is underdeveloped in the field of disaster management in general. Despite the claimed prominence of sustainability, the urgency of disaster management has taken precedence over any other factor, and it has caused the neglect of this dimension both in research and practice. More research is needed to identify how to implement sustainable measures in disaster management models to ensure that this dimension is also addressed in the area. These results have been discussed to provide suggestions for future research that can advance the field of humanitarian operations.

This article has focused on current gaps in the area to contribute to the knowledge and propose relevant research directions. It can be the basis for further research in the area with a broader view and analysis of the field. Following the work of [6]; the development of a meta-analysis to summarize the results of recent studies can provide valuable insights to complement the findings from this study. The application of MCDA in different countries to extract the priorities from practitioners and generalize the findings is another interesting area of future work. In that sense, this article can inform a study looking at the perspective of practitioners about the characteristics of optimization models and the usefulness/effectiveness of the strategies to involve them in model development. Finally, a study looking at the three dimensions of sustainability across the different parts of humanitarian supply chains would provide more information to use the findings from this article.

7.2. Limitations

It is important to be mindful of the limitations of this article. Systematic literature reviews are understood to be very useful for obtaining relevant answers to specific research questions [203]. This targeted approach can be limited when looking for a holistic understanding of a broad field. In this case, the review allowed us to investigate the participation of practitioners in optimization models to discuss the impact on the applicability of the models to reality. However, there are certain limitations to using this approach. Although we followed the guidelines from Ref. [52]; the findings are bounded by the search terms, the databases, and the focus on journals focused on operational research and management science from the Journal Citations Report 2019. Additionally, because of the inclusion and exclusion criteria, this study focused on articles using optimization models to provide tools for decision-makers, but articles considering other methodologies were not included. Although we do not claim to have identified an exhaustive list of references, we believe our results provide an accurate and representative view of the literature. Additionally, conducting filtering and categorization manually can carry a degree of subjectivity [204]. We have addressed this by having teams of two people for these activities and the discussions with the whole team, but there is still a possibility of some subjectivity in the process. Given the limitations of the systematic literature review, there is potential to provide a broader view of the current state of the field using a different approach.

The comparison between the objectives used in research and the objectives of Mexican practitioners must be carefully considered within the context of the study. The purpose was to identify the similarities and differences between objectives in that setting. This information can be used as an indication of the differences between objectives with empirical data from a developing economy prone to disasters. Analyses in similar countries are required to generalize the findings of the comparison. Additionally, data collection was affected by the COVID-19 pandemic. A self-applied questionnaire had to substitute for face-to-face interviews, which could lead to some errors in interpretation from the respondents. We tried to prevent this by sending a full set of instructions along with the briefing of the project, but we cannot fully disregard the possibility of some of these errors in the original dataset.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix

Table A.1
Modelling, Solution Software and Experimentation in Emergency Response

	Software	Solution	Experimentation			
			Case study	Sensitivity Analysis	Numerical case	Simulation
[55]	Matlab	Simulation			X	X
[56]	CPLEX	Bayesian decomposition	X	X		
[57]	LINGO	Optimization				X
[58]	C++	Tabu Heuristic		X	X	
[59]	DSS	Simulation and optimization		X		
[60]	LINGO		X	X		
[61]	DSS	Tabu search				X
[62]	MAXIMAL/GUROBI	Decision engine	X			X
[63]	CPLEX	Decomposition-based heuristic		X	X	
[64]	CPLEX	Optimization/heuristics				X
[65]	JAVA/CPLEX	Decomposition and heuristics	X			
[66]	GAMS/CPLEX	Optimization	X	X		
[67]	CPLEX	Neighborhood search	X			
[68]	MATLAB/CPLEX	Heuristic	X			
[69]	MATLAB	Rule-based interference	X			
[70]	CPLEX	Level crossing		X	X	
[71]	C/CPLEX	GA/decomposition-based algorithm	X			
Tuzun Aksu and Ozdamar (2014)	CPLEX	Optimization			X	
[73]	CPLEX/GA/NS	Heuristic	X		X	
[74]	CPLEX	Optimization	X		X	
[75]	MATLAB	Multi-agent optimization			X	
[76]	CPLEX/GAMS	Hierarchical objectives			X	
[77]	LINGO	Compromise programming	X			
[78]	CPLEX	Progressive hedging	X		X	
[79]	GAMS/CPLEX/ MATLAB	Simulated annealing	X	X		
[80]	CPLEX	Logic-based Benders Decomp.		X	X	
[81]	JAVA	Tabu/constructive heuristic	X	X		
[82]	AMPL/CPLEX	Optimization	X	X		
[83]	CPLEX/GIS	Sample average approximation	X			
[84]	MATLAB	Progressive hedging Lagrangean relax.		X	X	
[85]	AMPL/CPLEX	Optimization	X	X		

(continued on next page)

Table A.1 (*continued*)

	Software	Solution	Experimentation			
			Case study	Sensitivity Analysis	Numerical case	Simulation
[84]	CPLEX/MATLAB	Accelerated Benders decomp.			X	
[86]	CPLEX	Rolling horizon		X	X	
[87]	CPLEX	Heuristic based on Lagrangian relaxation		X	X	
[88]	JAVA	Simulation optimization			X	
do C. [89]	JAVA	Heuristic biased randomized algorit.			X	
[90]	PYTHON/GUROBI	Lagrangian Relaxation		X	X	
[91]	GAMS/CPLEX	Fix- and-optimize, two-step heuristic	X	X		
[92]	C++/LINGO	Clustering-based algorithm			X	
[93]	LINDO/GAMS	NSGA-II			X	
[94]	C++/CPLEX	Rolling horizon value function		X	X	
[95]	LINDOGLOBAL/GAMS	Hybrid Taguchi-NSGA-II			X	
[96]	MATLAB	Memetic Algorithm Taguchi method	X	X		
[97]	C++	Ant Colony heuristic			X	
[98]	C++/CPLEX	Empirical methods				X
[99]	GAMS/CPLEX	Augmented epsilon constraint method	X	X		
[100]	AMPL/CPLEX	Epsilon-Constraint Method algorit.		X	X	
[101]	C++/CPLEX	Adaptive Epsilon-constraint method		X	X	
[102]	LINGO	Data Envelopment Analysis		X	X	
[29]		hierarchical		X	X	
[103]	CPLEX	Tabu Heuristic	X	X		
[104]	GAMS	Optimization	X	X		
[105]	GAMS/CPLEX/GIS	Epsilon-constrained and weighted-sum	X	X		
[109]	CPLEX	Two-stage heuristic extended insertion and tabu search	X			X
[106]	GUROBI	Two-stage heuristic insertion and tabu		X	X	
[107]		two-phase continuous approximation		X	X	
[108]	GAMS/CPLEX	Epsilon-constrained weighted-sum	X	X		
[110]	LINGO			X	X	
[111]	C++/Vstudio	Particle Swarm			X	
[112]	PySP/GUROBI	Progressive hedging			X	
[113]		Min Max Regret		X	X	
[114]	AMPL/CPLEX	Goal Programming			X	
[115]		NSGA-II			X	
[116]	GAMS/CPLEX/MIP	Relax-and-fix heuristics	X	X		
[117]	CPLEX/MIP	Simple practice-heuristics		X	X	
[118]	PYTHON/GUROBI	Sweep heuristic with constant demand rate	X			X
[119]	GAMS/CPLEX	Optimization	X	X		
[120]	CPLEX	Diff Evol Algorithm	X	X		
[121]	C++/CPLEX	Sample Avg Approximation	X	X		
[122]	C/CPLEX	Optimization			X	
[123]	C#/CPLEX	Rolling horizon approach		X	X	
[124]	MINLP software	Optimization		X	X	
[125]	Excel Solver	Scenario reduction heuristics		X	X	
[126]	GUROBI		X	X		
[127]	CPLEX	Benders decomposition	X	X		
[128]		Evolutionary Heuristic				X
[54]	C++/CPLEX	Heuristic prepositioning	X	X		
[129]	CPLEX	Optimization		X	X	
[130]		Rolling horizon with variational inequality		X	X	
[131]	OPL/CPLEX	Approximation		X	X	
[132]	CPLEX	Epsilon-constraint and NSGA-II	X	X		
[133]		Optimization		X	X	
[134]	GAMS/CPLEX	Weighted sum	X	X		
[135]	GRASP	Heuristic				
[136]	LINGO	Hierarchical	X	X		
[137]	LINGO	Optimization		X	X	
[138]	JAVA/CPLEX	Epsilon constraint and goal programming		X	X	
[139]		Heuristic		X	X	
[140]	C/CPLEX	Weighted method tailored heuristic	X			
[141]	LINGO	Optimization	X	X		
[142]	LINGO	Hybridization of GA-SA		X	X	
[143]	C++	Heuristic			X	
[144]		Hybrid steady-state parallel GA	X	X		
[145]	GAMS	Grasshopper metaheuristic	X	X		
[146]	C++/CPLEX		X	X		
[147]	GUROBI	Column-and-constraint generation	X	X		
[148]	LINGO	Parameter-based decomposition		X	X	
[149]	WHAT'S BEST	Percentage of demand scenarios solution	X	X		
[150]	CPLEX	Aggregation heuristic	X	X		
[151]	C++/GUROBI	Rolling horizon			X	
[152]	GUROBI	Rolling horizon			X	
[153]	R	Unspecified		X		X
[154]	C++/CPLEX	Progressive hedging	X	X		
[155]	C++	Heuristic		X	X	
[156]	AMPL/GUROBI	Heuristic based on simulated annealing			X	

Self-applied table of preferences

Participant ID		Attributes (decision variables)							
		Shelters	Distribution centres	Evacuation	Relief distribution	Suppliers	Pre-allocating relief items	Deployment of staff	Casualty transportation
Objectives	Minimize cost								
	Minimize travel distance								
	Minimize travel time								
	Maximize demand coverage								
	Maximize quality								
	Maximize reliability								
	Prioritization								
	Maximize equality								
	Minimize environmental impact								

Entropy method

The entropy method was proposed in 1974 by Shannon and Weaver [179]. Entropy represents the amount of uncertainty in a continuous probability distribution. The basic idea of this method is that the higher the scatter in the values of an index, the more important that index is [179]. In a decision matrix with m objectives and n attributes, the steps of this method are as follows:

Step 1: Form a decision matrix – In the entropy technique, m objectives are evaluated using n attributes. Therefore, each objective is scored based on each attribute. These scores can be based on quantitative and real values or qualitative and theoretical. In either case, a decision matrix $m * n$ must be formed.

Step Two: Determine the P_{ij}.The normalization of the decision matrix is done based on Eq. (1).

$$p_{ij}=\frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \tag{1}$$

Step 3: Determine the entropy of each indicator - In Eq. (2), the value of m is the number of objectives.

$$E_j=-K\sum_{i=1}^{m} p_{ij}\, Ln\left(p_{ij}\right) \qquad K=\frac{1}{Ln\ m} \tag{2}$$

Step 4. Determine the uncertainty or degree of deviation of each indicator (*dj*)

$$d_j=1-E_j \tag{3}$$

Step 5. Determine the weight of each index (*Wj*)

$$W_j=\frac{d_j}{\sum_{i=1}^{n} d_j} \tag{4}$$

Application to the case

The first step in the entropy method is the formation of a decision matrix. The decision matrix of this method includes 9 rows (objectives) and 8 columns (attributes). Each cell evaluates each objective relative to each attribute. These are normalized by dividing the number of each column by the sum of that column [179] and the decision matrix is presented in Table A.2.

Table A.2
Shannon normal entropy matrix

	Shelters	DCs	Evacuation	Relief distribution	Suppliers	Stock pre-positioning	Staff allocation	Casualty transportation
Minimize cost	0.082	0.088	0.086	0.096	0.096	0.106	0.073	0.049
Minimize travel distance	0.107	0.121	0.103	0.117	0.116	0.117	0.103	0.109
Minimize travel time	0.122	0.115	0.126	0.121	0.124	0.106	0.112	0.128
Maximize demand coverage	0.107	0.108	0.111	0.102	0.118	0.110	0.127	0.128
Maximize quality	0.126	0.121	0.122	0.123	0.120	0.119	0.127	0.128
Maximize reliability	0.126	0.126	0.126	0.121	0.120	0.121	0.127	0.128
Prioritization	0.122	0.119	0.124	0.121	0.116	0.117	0.127	0.128
Maximize equity	0.111	0.117	0.124	0.117	0.105	0.119	0.121	0.118
Minimize carbon footprint	0.099	0.086	0.077	0.083	0.085	0.086	0.082	0.083

Table A.3 shows the final weights of the attributes obtained after calculating the entropy of each index and its deviation and the normal weighted matrix is presented on Table A.4.

Table A.3Final weight of attributes

	Shelters	Distribution centers	Evacuation	Relief distribution	Suppliers	Pre-positioning	Deployment of staff	Casualty transp.
Ej	0.996	0.996	0.994	0.997	0.997	0.998	0.992	0.985
dj	0.004	0.004	0.006	0.003	0.003	0.002	0.008	0.015
Wj	0.083	0.082	0.138	0.077	0.066	0.048	0.173	0.333

Results of the TOPSIS method

Table A.4
Normal weighted matrix of TOPSIS

	Shelters	Distribution centers	Evacuation	Relief distribution	Suppliers	Pre-positioning	Deployment of staff	Casualty transportation
Minimize cost	0.020	0.022	0.035	0.022	0.019	0.015	0.037	0.048
Minimize travel distance	0.026	0.030	0.042	0.027	0.023	0.017	0.053	0.106
Minimize travel time	0.030	0.028	0.052	0.028	0.025	0.015	0.057	0.125
Maximize demand coverage	0.026	0.026	0.046	0.023	0.023	0.016	0.065	0.125
Maximize quality	0.031	0.030	0.050	0.028	0.024	0.017	0.065	0.125
Maximize reliability	0.031	0.031	0.052	0.028	0.024	0.017	0.065	0.125
Prioritization	0.030	0.029	0.051	0.028	0.023	0.017	0.065	0.125
Maximize equity	0.027	0.029	0.051	0.027	0.021	0.017	0.062	0.114
Minimize carbon footprint	0.024	0.021	0.032	0.019	0.017	0.012	0.042	0.081

Finally, the positive and negative ideals are presented on Table A.5

Table A.5
Positive and negative ideals

	Shelters	Distribution centers	Evacuation	Relief distribution	Suppliers	Pre-positioning	Deployment of staff	Casualty transportation
ideal+	0.031	0.031	0.052	0.028	0.025	0.017	0.065	0.125
Ideal−	0.020	0.021	0.032	0.019	0.017	0.012	0.037	0.048

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