Humanitarian aid distribution logistics with accessibility constraints: a systematic literature review

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Abstract

Purpose – The purpose of this paper is to review the relevant literature in order to identify trends and suggest some possible directions for future research in the framework of humanitarian aid distribution logistics with accessibility constraints.

Design/methodology/approach – The authors developed a systematic literature review to study the state of the art on distribution logistics considering accessibility constraints. The electronic databases used were Web of science, Scopus, Science Direct, Jstor, Emerald, EBSCO, Scielo and Redalyc. As a result, 49 articles were reviewed in detail.

Findings – This study identified some gaps, as well as some research opportunities. The main conclusions are the need for further studies on the interrelationships and hierarchies of multiple actors, explore intermodality, transshipment options and redistribution relief goods to avoid severe shortages in some nodes and excess inventory in others, studies of the vulnerability of transport networks, correlational analysis of road failures and other future lines.

Research limitations/implications – The bibliography is limited to peer-reviewed academic journals due to their academic relevance, accessibility and ease of searching. Most of the studies included in the review were conducted in high-income countries, which may limit the generalizability of the results to low-income countries. However, the authors focused on databases covering important journals on humanitarian logistics.

Originality/value – This paper contextualises and synthesises research into humanitarian aid distribution logistics with accessibility constrains, highlights key themes and suggests areas for further research.

Keywords Aid distribution, Access restoration, Accessibility constraints, Humanitarian logistics, Systematic literature review

Paper type Literature review

1. Introduction

Humanitarian logistics has managed to position itself as one of the emerging topics in the field of logistics and that is why the academic community has been interested in it since the Asian tsunami occurred in 2004 (Çelik, 2016; Habib *et al.*, 2016; Sakiani *et al.*, 2020). Disasters have affected world's population throughout human history, with terrible consequences for inhabitants and their environment (Çelik, 2016; Habib *et al.*, 2016; Sakiani *et al.*, 2020). Disasters caused by natural phenomena such as earthquakes, floods, landslides, pandemics and others of anthropogenic origin such as wars, forced displacement and terrorism, among others, have become a problem of local and global relevance (Fontainha *et al.*, 2017;

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Klischewski and Elmistikawy, 2017). Similarly, governments and communities are genuinely concerned regarding pre- and post-disaster decisions (Vahdani *et al.*, 2018a). However, to the extent that most disasters occur in the world, several studies have pointed out that there are logistical weaknesses in humanitarian and emergency relief agencies and organizations tasked with preventing and responding to these events (Kim *et al.*, 2018; Lin *et al.*, 2011; Sokat *et al.*, 2018).

Decisions in humanitarian logistics can be divided into four key phases: mitigation, preparedness, response and recovery (Sabbaghtorkan *et al.*, 2020). The pre-disaster stage encompasses the mitigation and preparedness phase. Mitigation includes measures to reduce vulnerability to the impact of the disaster, such as injuries and loss of lives and property, while preparedness includes educating communities on how a disaster may affect them so that they can take a proactive approach. The post-disaster stage encompasses the response and recovery phases. The response phase addresses immediate threats to minimize economic and human losses, while the recovery phase supports the restoration of all damages caused by the disaster (Aksu and Ozdamar, 2014; Çelik, 2016; Habib *et al.*, 2016).

In disaster response, infrastructure networks play an important role in providing humanitarian aid to demand nodes, such as affected areas, shelters, warehouses, centers and distribution points (Iloglu and Albert, 2018; Lu *et al.*, 2016; Maya Duque *et al.*, 2016). These networks help government and non-government agencies establish connectivity to enable mobility of assets and accessibility to critical facilities and resources in times of need (Sakiani *et al.*, 2020).

In the case of events requiring humanitarian aid, such as disasters caused by natural or man-made events, the restoration and recovery of infrastructure networks becomes increasingly important (Maya Duque *et al.*, 2016). In the long term, the restoration and repair of these networks is an important factor for stabilizing the community and restoring at least some level of normalcy after the event (Çelik, 2016; Wu and Wang, 2020). However, in the short term, these networks provide the basis for carrying out response activities such as evacuation, search and rescue, relief distribution and communication between the different stakeholders responding to the event (Çelik, 2016; Sakuraba *et al.*, 2016a, b).

When disasters occur, whose effects or consequences tend to be extended in time, distribution operations may generate the consideration of such different transportation modes such as land, sea, air and river (Rodríguez-Espíndola *et al.*, 2018; Anaya-Arenas *et al.*, 2014). Transportation mode selection depends on the type of disaster, the characteristics of the affected geographical area, the conditions of the infrastructure denoted by road networks, transport terminals, sea and river ports, airports and logistics centers, as well as the duration or transience of the disruptive event (Coco *et al.*, 2020).

However, in the literature, road transport has generally been identified and considered as the first mobility mechanism for immediate humanitarian aid related to the movement of materials and crews (Maya Duque *et al.*, 2016; Shin *et al.*, 2019). It could be broadly determined that distribution logistics taking into account accessibility constraints has typically been addressed in the literature from two main approaches termed as aid distribution (Aksu and Ozdamar, 2014) and access restoration (Çelik, 2016). The former consists in finding clear routes for the population to be reached by relief and rescue teams (Edrissi *et al.*, 2015), and the latter generates a repair program to improve access to target nodes (Çelik, 2016).

Some previous literature reviews were undertaken to address or reveal challenges in humanitarian logistics. For instance, a study by Altay and Green (2006) focuses on the life cycle of disaster operations. They noticed that post-disaster operations entail making decisions about relocating depots and distributing, managing and coordinating the available resources. On the other hand, the pre-disaster studies that they reviewed were mostly focused on assessing and analyzing potential dangers, as well as mitigating possible damages in the event of a disaster. Simpson and Hancock (2009) reviewed the application of operations research techniques in the field of disaster response. Caunhye *et al.* (2012) reviewed optimization models in the field of facility location, relief distribution and casualty transport. Abidi *et al.* (2014) provided the systematic literature review for performance measurement in humanitarian logistics. Anaya-Arenas *et al.* (2014) provided a review of research on relief distribution networks, classifying them according to objective function, model constraints and solution methodology. Özdamar and Ertem (2015) reviewed disaster-response models classified in terms of their vehicle-or-network representation structures and their functionality. Habib *et al.* (2016), for their part, conducted a systematic review of several studies, covering analyses of all disaster phases and various mathematical optimization techniques and algorithms developed to increase the efficiency of humanitarian operations. Grass and Fischer (2016) reviewed the state of the art of the literature regarding the consideration of elements of stochastic nature in aid distribution decisions. Nurmala *et al.* (2017) conducted a systematic review for the state of the art of partnerships between humanitarian organizations and business corporations in humanitarian management.

Additionally, Baykasoğlu *et al.* (2019), revealed that there are deep interactions between fleet planning issues at strategic, tactical and operational levels, so they should be addressed in an integrated manner. Dubey *et al.* (2019) suggested including, in future research, problems associated with coordination and collaboration in the relief network. Hezam and Nayeem (2020) conducted a systematic review on optimization models in the field of humanitarian logistics framed around facility location, relief distribution and mass evacuation. Prakash *et al.* (2020) used a systematic literature review methodology to identify the current status and future direction of organization theory-based study in humanitarian logistics. Sabbaghtorkan *et al.* (2020), in their review article, addressed the problem of humanitarian operations management and concluded that social cost as a performance metrics and elements of uncertainty in resources are key factors in the decision-making process in humanitarian logistics. Based on the development of different literature reviews in the field of humanitarian logistics, these studies explore the framework governing the logistics of humanitarian aid distribution, but those taking accessibility constraints into account are limited. For this reason, the purpose of the present article is to investigate the state of the art of distribution logistics. In order to do this, it considers accessibility constraints and identifies trends, gaps and future research opportunities through a systematic literature review. Moreover, important dimensions such as keyword co-occurrence analysis are considered, as well as the purpose and characteristics of the decision-making models used in this area.

The manuscript is structured as follows. In section 2, the methodology of the systematic literature review is explained. Section 3 presents the results of the review. Section 4 discusses the results of the study. Finally, section 5 presents the conclusions.

2. Method

A systematic review was conducted in order to relate the available research on the topic under study and to collect, analyze and synthesize the results of relevant research (Anaya-Arenas *et al.*, 2014; Habib *et al.*, 2016; Nurmala *et al.*, 2017; Hezam and Nayeem, 2020; Prakash *et al.*, 2020). The systematic review methodology consisted of four steps: study design, search strategy, study selection and inclusion criteria and data extraction and analysis.

2.1 Study design

In this phase, research questions are framed. The research questions that guide this study are:

RQ1. What is the current state of the art in the field of humanitarian aid distribution logistics considering accessibility constraints?

RQ2. What are the research opportunities in the field of humanitarian aid distribution logistics considering accessibility constraints?

2.2 Search strategy

The key terms to collect the research papers related to the field of knowledge of interest were selected based on the research questions. The search of the articles was conducted using electronic databases such as: Web of science, Scopus, Science Direct, Jstor, Emerald, EBSCO, Scielo and Redalyc. To find more accurate research papers, the search was performed using Boolean connectors (AND, OR), on the one hand and the definition of keywords framed in topics, on the other hand. The journal publication time ranged from 2000 to 2020, however, most of the work in the humanitarian supply chain perspective was published after 2004 when the Indian Ocean tsunami hit several countries (Maghsoudi and Pazirandeh, 2016). The basic search strategy is described in Table 1. Based on the analysis of systematic literature reviews conducted in the field of humanitarian logistics, the authors performed the search considering five aspects that generally frame the problem of humanitarian aid distribution logistics considering accessibility constraints: humanitarian logistics, type of zone, type of process that concerns the topic of interest, type of article and time horizon.

2.3 Study selection and inclusion criteria

In this phase, inclusion and exclusion criteria were defined (Table 2).

At the beginning, 356 articles were taken into consideration and 104 articles were identified by eliminating duplicates using bibliographic managers such as Mendeley ® and Endnote ®. After a first review, a total of 65 articles were selected based on the following two criteria: the article's topic is framed in Humanitarian Logistics and the article uses any decision-making model. Eight articles out of the 65 articles were excluded based on the defined inclusion and exclusion criteria. Twelve papers out of the remaining 57 articles provide no quantitative assessment in the analysis and evaluation of policies, management and decision-making models were excluded. Finally, a review of the bibliographic sources of the 45 resulting articles and other databases was conducted. This exercise made it possible to identify other 4 articles. In conclusion, 49 articles were selected since they provided important information on the research questions presented before. Figure 1 illustrates the systematic review process.

2.4 Data extraction and analysis

In the extraction and analysis phase, the selected papers were divided according to important operations in distribution logistics with accessibility constraints. These selected papers are discussed in the *Results* section of this review paper.

Table 1 Terms in search strategy

Topic	Keywords
Humanitarian Logistics	"humanitarian logistics" OR "disaster management" OR "disaster response" OR "emergency response" OR "emergency management" OR "emergency logistics" OR "natural disasters" OR "natural catastrophes" OR "Humanitarian Supply Chain Management" OR "Humanitarian Supply Network Management" OR "Disaster operations management" OR "Disaster relief operations"
AND	
Type of zone	"restricted areas" OR "restricted access routes" OR "restricted routes" OR "damaged roads" OR "damaged roads" OR "restricted access roads" OR "Crew Scheduling" OR "repair crew" OR "Network repair" OR "Road restoration" OR "Relief scheduling" OR "emergency roadway repair" OR "access restoration"
AND	
Type of process	"distribution of humanitarian aid" OR "aid delivery" OR "aid distribution" OR "distribution of aid" OR "relief distribution" OR "relief logistics" OR "distribution of relief goods"
AND	
Type of article	"Research Article" OR "Review Article"
AND	
Time horizon	2000–2020

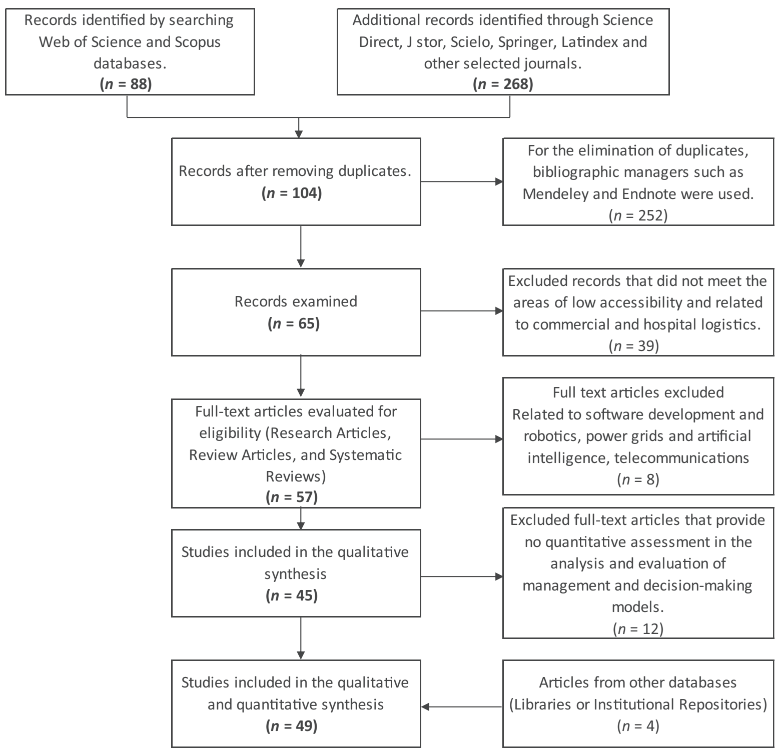
Source: Authors

Table 2 Criteria for study inclusion and exclusion

Criteria	Inclusion	Exclusion
Study design	Systematic reviews, research articles and review articles concerning the design and application of decision-making models and methods published in peer-reviewed journals	Qualitative studies that did not provide an analysis, or evaluation, of management and decision-making in the field under study were also excluded. Non-peer-reviewed papers, opinion articles, and book chapters were also excluded
Results	Systematic reviews, review articles and research articles of management and decision-making models based on humanitarian logistics networks in low or difficult to access areas framed by disasters	Studies related to software development and robotics, electrical networks and artificial intelligence, telecommunications
Interventions	Systematic reviews and research articles that have evaluated policies to improve performance in areas of low or difficult accessibility during disasters	Studies that evaluate humanitarian policies that are not framed in areas with accessibility limitations and studies related to commercial logistics

Source: Authors

Figure 1 PRISMA flowchart showing process of study selection



Source: Authors

An in-depth review of all relevant studies was conducted. Moreover, some issues of the study design and the models employed by the authors analyzed in this study were identified using a data extraction tool. Information on author, year, problem type, title, purpose and future work, performance measures employed, constraints, network type, decision level, resource characteristics employed, model type and nature, algorithm type and solution approach were extracted using the tool. The matrix where this information was extracted to may be found in (Supplementary file number 1).

The extracted data were examined through a keyword co-occurrence analysis, an identification of study approaches, a description of the characteristics of the decision-making models used and an analysis of the results of the papers themselves.

3. Results

3.1 Keyword co-occurrence network analysis

We developed a bibliometric analysis to provide some relevant results and insights according to the keywords. Specifically, we performed a co-occurrence mapping for keyword analysis (Van Eck and Waltman, 2017) in the field of humanitarian aid distribution logistics with accessibility constraints. We explored different structures of keyword maps in VOSviewer, considering a different number of groups, which allowed us to determine a minimum threshold of 3 keywords. As a result of the analysis, 8 clusters grouping 67 keywords were identified. Each word is represented by a node, whose size represents its relative weight and its color, the cluster to which it belongs (Figure 2 and Table 3).

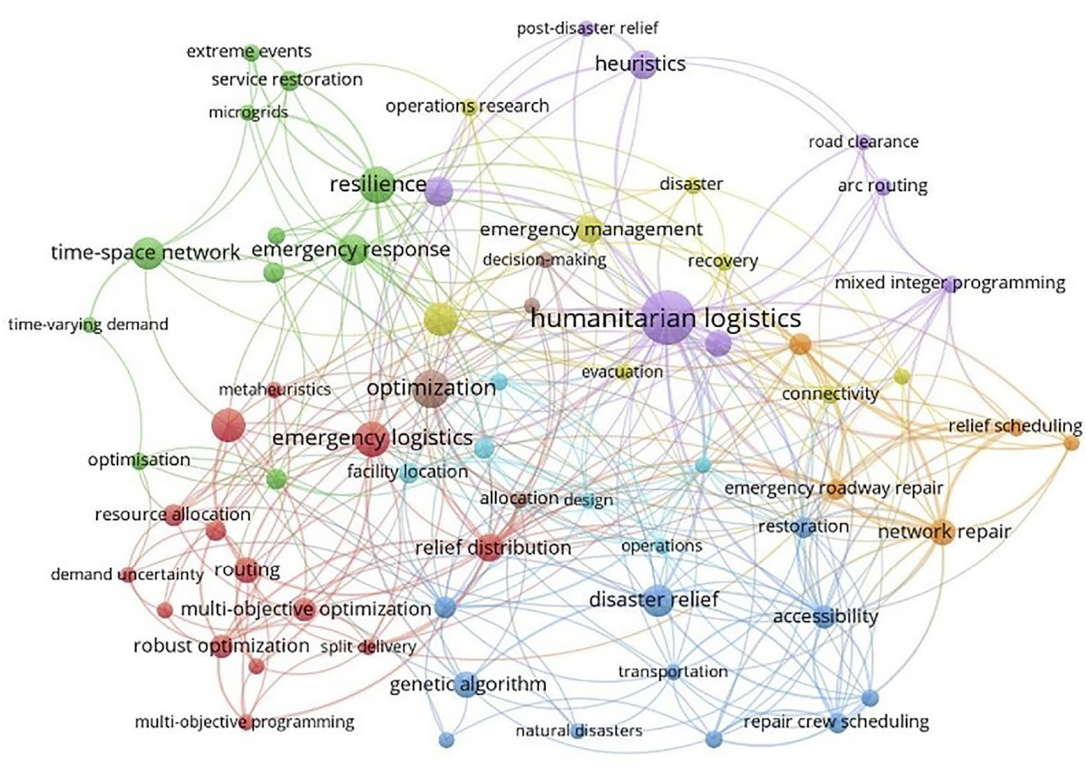
The red cluster groups 14 keywords and contains seminal articles that address supply chain management issues in the context of humanitarian operations, being more focused on theoretical approaches in the field of operations management. In this cluster, it can be clearly inferred that there are works associated with the development of decision-making models framed in the aid distribution, allocation and scheduling of distribution resources, characterized by being mono-objective and multi-objective in nature, as well as the consideration of deterministic parameters based on uncertainty; which requires the consideration of robust optimization methods, as well as the inclusion of metaheuristics.

The green cluster groups 11 keywords and presents works that aim to solve problems so that the access restoration in humanitarian operations can be optimized. The articles in this cluster make extensive use of mathematical modeling with the computational application. The violet cluster contains 11 keywords related to transportation and vehicle routing decisions, as well as to the scheduling of network-restoration activities used to improve accessibility constraints. The studies that analyze these issues have usually focused on disasters caused by natural phenomena, resilience and emergency response. With an operational research approach, the yellow cluster presents 8 keywords associated with contributions made by authors of quantitative methods for decision-making in humanitarian logistics operations, being framed not only in decisions associated with transportation, but also with infrastructure assessment and recovery work.

The purple cluster contains 8 keywords associated with vehicle-routing issues, road clearance and applied mathematical modeling in relief-distribution and repair decisions. The blue cluster contains 6 keywords and refers specifically to research associated with facility pre-positioning strategies, planning in disaster response, network design in the humanitarian context, distribution-point location and some stochastic elements. The orange cluster presents 5 keywords associated with work on access restoration, network repair and repair resource scheduling using mathematical programming models. Finally, the brown cluster focuses on operation management studies in the context of disaster management and the development of mathematical models to support the decision-making process in the humanitarian field, which contains 4 keywords.

Furthermore, we correlated the date of publication with the keyword co-occurrence network that we developed. Thus, we identified some trends in the topics of the papers reviewed. Figure 3 relates each keyword to the year where it was the most popular, from 2010 (dark purple) to 2020 (yellow). The most relevant studies between 2017 and 2020 encompassed topics associated with allocation, routing and scheduling of repair resources, resilience in humanitarian logistics networks, fractional deliveries, relief distribution, accessibility

Figure 2 Keywords map



Source: Authors

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Table 3 Cluster of keywords

Cluster	Keywords	Authors
Red	demand uncertainty, emergency logistics, emergency scheduling, location, metaheuristics, multi-objective, multi-objective optimization, multi-objective programming, relief distribution, resource allocation, robust optimization, routing, scheduling, split delivery	Tavana *et al.* (2018), Habib *et al.* (2016), Ibarra-Rojas *et al.* (2018), Sanci and Daskin (2019), Vahdani *et al.* (2018b), Zhou *et al.* (2017) and Shin *et al.* (2019)
Green	distribution system, emergency response, extreme events, microgrid, microgrids, optimisation, resilience, service restoration, stochastic programming, time-space network, time-varying demand	Sakuraba *et al*. (2016a, b), Tuzun Aksu and Ozdamar (2014), Nurre *et al.* (2012), Çelik (2016) and Kim *et al.* (2018)
Violet	accessibility, disaster relief, dynamic programming, emergency, genetic algorithm, natural disasters, repair crew routing, repair crew scheduling, restoration, transportation, vehicle routing problem	Edriss *et al.* (2015), Kim *et al.* (2018), Maya-Duque *et al.* (2016), Shin *et al.* (2019) and Tuzun Aksu and Ozdamar (2014)
Yellow	ant colony optimization, connectivity, disaster, disaster management, emergency management, evacuation, operations research, recovery	Ahmadi *et al.* (2015), Çelik (2016), Coco *et al.* (2020), Tuzun Aksu and Ozdamar (2014) and Wang *et al.* (2019)
Purple	arc routing, disaster response, heuristics, humanitarian logistics, mixed integer programming, post-disaster relief, road clearance, vehicle routing	Akbari and Salman (2017), Habib *et al.* (2016), Kim *et al.* (2018), Oruc and Kara (2018) and Yan and Shih (2009)
Blue	design, facility location, model, network restoration, operations, two-stage stochastic programming	Aslan and Celik (2019), Yan *et al.* (2012) and Zhou *et al.* (2017)
Orange	emergency roadway repair, mixed integer linear programming, network repair, relief scheduling, repair crew	Çelik (2016), Maya-Duque *et al.* (2016), Sakuraba *et al.* (2016b) and Tan *et al.* (2019)
Brown	allocation, decision-making, optimization, optimization model	Ahmadi *et al.* (2015), Habib *et al.* (2016) and Tavana *et al.* (2018)

Source: Authors

constraints, as well as topics of facility location, stochastic and multi-objective programming and robust optimization to consider elements of uncertainty. The first works carried out between 2010 and 2016 are concentrated on topics related to emergency management, the vehicle routing problem, time-varying demand for help, as well as the development of heuristic and metaheuristic algorithms to cope with the intrinsic computational complexity in relief distribution and access restoration models.

In addition, the top 20 keywords of the studied field with the highest total link strength were used to identify the most relevant topics in the field under study (Supplementary file number 2 – Table S1). Each link entails a connection between two keywords or nodes. The total amount of links of each node determines its degree of importance. Moreover, the strength of each link between two nodes can be represented with a positive numerical value. The higher this value, the stronger the link. The total link strength between two nodes is a reflection of the number of publications in which two keywords appear together. An analysis of the whole network shows that, between 2015 and 2018, research in the evaluated field has mostly focused on managing resources for road repairs and decision-making in the humanitarian aid area. However, these two problems did not begin to be considered simultaneously until 2019, where researchers started linking decision-making on aid distribution to road conditions (Figure 3).

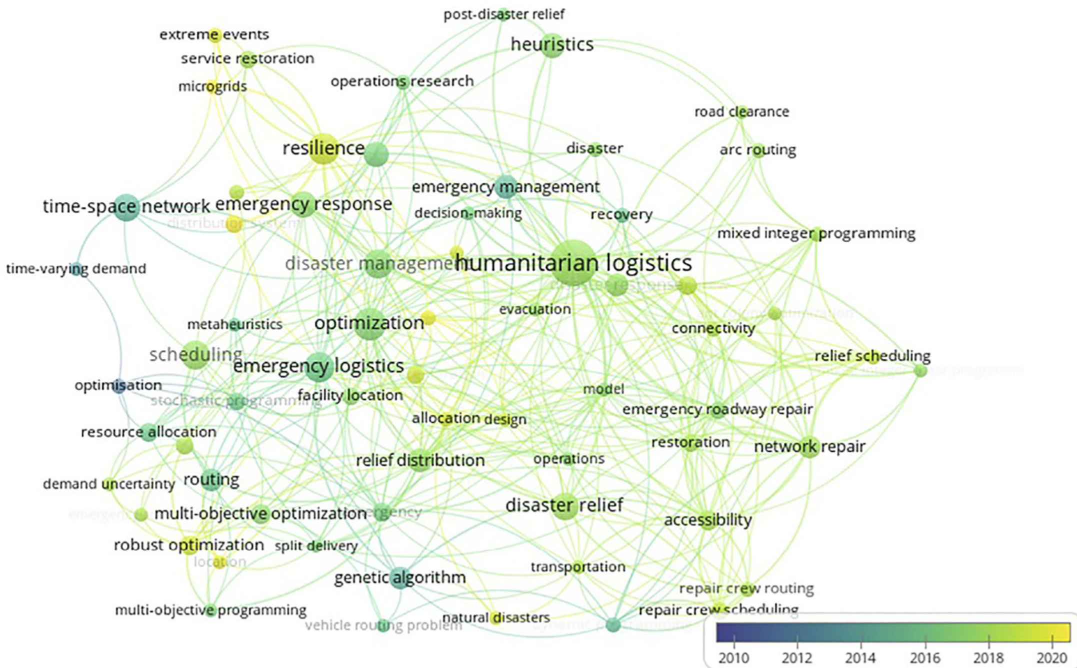
3.2 Purpose

Distribution logistics considering accessibility constraints is addressed in the literature from two main approaches, which are called aid distribution and access restoration. After the extraction and synthesis of the relevant information in the studies framed in the problem of interest, it was determined that 20 out of the 49 selected articles explored the problem of humanitarian aid distribution. In some research studies (Aksu and Ozdamar, 2014; Edrissi *et al.*, 2015; Sakiani *et al.*, 2020), it is clear that the works developed in this field are intended for developing a routing proposal for aid delivery to distribution points or population affected by a disaster. Although this problem has generally been addressed in the response phase, decisions such as determining the optimal location of facilities and inventory prepositioning (Rezaei-Malek *et al.*, 2016a, b) are specific to the preparedness phase (Bai *et al.*, 2018) (Supplementary file number 2 – Table S2).

On the other hand, 24 out of the 49 articles explored the problem of access restoration. Authors such as Barrera *et al.* (2012), Iloglu and Albert (2018), Maya Duque *et al.* (2016) and Nurre *et al.* (2012) aim to analyze the problem of emergency repair of a rural or urban network that has been damaged by the occurrence of a disaster. The most commonly used performance measures in this type of problem are framed in the efficiency dimension, generally based on maximizing the accessibility of the road network or minimizing the total time to repair, clean or rehabilitate the network. Minimization of the total repair cost is associated with the efficiency dimension (Maya Duque *et al.*, 2013). However, no performance measures framed in the social dimension were clear. Also, it could be determined that scheduling decisions for cleaning and repair activities and resources for network rehabilitation concerning the distribution problem are characterized as transient (Wu and Wang, 2020; Çelik, 2016) (Supplementary file number 2 – Table S3).

Finally, 5 out of the 49 articles made a first approach in integrating relief distribution operations and access restoration (Supplementary file number 2 – section 2) (Aslan and Celik, 2019; Sanci and Daskin, 2019; Shin *et al.*, 2019; Vahdani *et al.*, 2018b; Yan and Shih, 2009). These articles generally sought to determine the order of repairing destroyed roads and

Figure 3 Date of publication in the keyword co-occurrence network



Source: Authors

transporting relief items to demand areas after a disaster occurs, given a number of connected roads, thereby generating accessibility constraints (Supplementary file number 2 – Table S4). Among the performance measures that have been employed, some of them are based on efficiency and efficacy, such as minimizing logistics costs represented by distribution and repair costs and minimizing the total delivery time of humanitarian aid from local distribution centers to affected areas (Minas *et al.*, 2020; Wu and Wang, 2020; Yan *et al.*, 2020).

3.3 Characteristics of the models used

In humanitarian aid distribution logistics with accessibility constraints, aid distribution and access restoration models have generally been addressed separately (Karakoc *et al.*, 2020). However, some research papers (Iloglu and Albert, 2018; Maya Duque *et al.*, 2016) discuss the importance of integrating both processes. On the other hand, both problems have been represented through vehicle routing models or network flow problems (Özdamar and Ertem, 2015; Sakiani *et al.*, 2020). Vehicle routing problems are characterized as NP-hard (Ahmadi *et al.*, 2015; Yan and Shih, 2009). In the case of network flow problems, the vehicle fleet is designated by integer variables and the trajectory of each vehicle cannot be easily monitored in the distribution network; however, their computational complexity can be minimized (Edrissi *et al.*, 2015). These problems have been mainly represented using integer and mixed integer linear programming modeling (Lin *et al.*, 2011; Edrissi *et al.*, 2015; Ozdamar *et al.*, 2018; Tavana *et al.*, 2018; Tan *et al.*, 2019; Shin *et al.*, 2019; Hezam and Nayeem, 2020; Baxter *et al.*, 2020; Coco *et al.*, 2020).

Mathematical programming models have been used mainly from a deterministic rather than stochastic approach, using exact (18 out of 49), metaheuristic (14 out of 49) and heuristic (15 out of 49) algorithms, such as column generation, branch and price, branch and cut, Benders decomposition, dynamic programming, epsilon constraints, genetic algorithms, ant colony, NSGA-II and particle swarm optimization (Maya Duque *et al.*, 2013, 2016; Rodríguez-Espíndola *et al.*, 2018; Nurre *et al.*, 2012; Iloglu and Albert, 2020; Sakuraba *et al.*, 2016a; Vahdani *et al.*, 2018b; Ozdamar *et al.*, 2014; Averbakh, 2012; Rezaei-Malek *et al.*, 2016a; Sabbaghtorkan *et al.*, 2020; Yan and Shih, 2009; Tuzun Aksu and Ozdamar, 2014; Al Theeb and Murray, 2017; Victoria *et al.*, 2016; Lu *et al.*, 2016; Wohlgemuth *et al.*, 2012).

Aid distribution models developed by authors such as Alinaghian *et al.* (2019), Averbakh (2012), Moreno *et al.* (2019), Sanci and Daskin (2019), Shanshan *et al.* (2015), Zafri *et al.* (2021) and Zhou *et al.* (2017) have not considered constraints in vehicle access to certain routes or areas based on their geological and infrastructure conditions (Wu and Wang, 2020). In addition, the participation of different actors in this process is ignored (Ibarra-Rojas *et al.*, 2018). Fifteen of the analyzed models take multiple depots into account by implicitly assuming unlimited capacity (Chen *et al.*, 2020; Grass and Fischer, 2016; Liu *et al.*, 2019; Rezaei-Malek *et al.*, 2016a, b) (Supplementary file number 2- section 3).

In temporary operation scheduling problems for network rehabilitation, authors such as Averbakh (2012), Çelik (2016), Kim *et al.* (2018), Maya Duque *et al.* (2013, 2016), Özdamar and Ertem (2015) and Sakuraba *et al.* (2016a, b) consider remediation resources from a single central repository. Models framed in this problem generally assume a single type of unlimited resource for network remediation (Nurre et al., 2012; Sanci and Daskin, 2019; Vahdani et al., 2018b; Yan et al., 2014a, b). These models basically aim to solve resource allocation and routing problems on each of the damaged links in the network (Iloglu and Albert, 2018; Morshedlou et al., 2018; Reddy et al., 2017; Sanci and Daskin, 2019; Yan et al., 2014a, b) (Supplementary file number 2 – section 4).

Articles analyzing the problems of relief distribution and access restoration consider homogeneous (Victoria et al., 2016) or heterogeneous (Alinaghian et al., 2019) vehicle fleets, but they assume that the number of vehicles is unlimited. The vehicle fleet is also assumed to be owned by the relief agencies, when, in real contexts, part of it may be outsourced (Bai et al., 2018) (Supplementary file number 2 – section 5).

The relief distribution and access restorations models, which have been developed so far, have mainly considered multiperiod environments, but the dynamics of the system itself are omitted (Iloglu and Albert, 2018). Multiperiod models assume that the cumulative demand for humanitarian aid occurs at the beginning or end of the planning period or horizon (Özdamar and Ertem, 2015; Shanshan et al., 2015). In the actual context, demand may occur at different times, which depends on the dynamics of the disruptive event and the socio-demographic characteristics of the affected population and the gradual alleviation of suffering (Bai et al., 2018).

Furthermore, it was found that 38 of the papers considered relief distribution and access restoration models with a single performance measure or objective (Ahmadi et al., 2015; Al Theeb and Murray, 2017; Alinaghian et al., 2019; Arif et al., 2020; Averbakh, 2012; Li et al., 2019; Nurre et al., 2012) and some papers presented two or more performance measures or targets (Karakoc et al., 2020; Özdamar and Ertem, 2015; Rodríguez-Espíndola et al., 2018; Tavana et al., 2018; Vahdani et al., 2018a; Zhou et al., 2017).

According to the literature, performance measures can be generally grouped into three dimensions: social welfare and equity, efficiency and efficacy (Ransikarbum and Mason, 2016; Regis-Hernández et al., 2017; Rezaei-Malek et al., 2016a, b; Tavana et al., 2018) (Supplementary file number 2 – Table S5). The efficiency dimension includes performance measures associated with how resources are used or managed to carry out humanitarian operations (12 of 49) (Sanci and Daskin, 2019; Tzeng et al., 2007). The efficacy dimension determines the speed and accuracy of humanitarian aid delivery and response to the affected population (36 out of 49) (Jiang et al., 2012; Tzeng et al., 2007; Wang et al., 2019). On the other hand, the social welfare and equity dimension is associated with alleviating the suffering of people affected by a disaster (Zhou et al., 2017; Coco et al., 2020; Liu et al., 2019). However, only 4 of the 49 papers that dealt with aid distribution considered measures of social welfare and equity (Al Theeb and Murray, 2017; Zhou et al., 2017; Coco et al., 2020; Liu et al., 2019). In the case of the papers that dealt with models of access restoration, no measures of social benefit and equity could be identified (Wu and Wang, 2020). These measures framed in the three dimensions are generally in conflict, which closely resembles the actual contexts in humanitarian logistics (Sanci and Daskin, 2019).

It is also important to note that only one paper considered issues of equity in delivery (Chen et al., 2020; Rodríguez-Espíndola et al., 2018; Victoria et al., 2016). Equity is associated with impartiality and identified as an appropriate goal for humanitarian logistics (Chen et al., 2020). Aid items should be distributed impartially according to the level of need, which is why equity and priority have been used as key measures in the literature (Çelik, 2016; Karakoc et al., 2020). The former aims to provide services in an unbiased manner among recipients, while the latter attempts to give preferences based on the level of harm (Bai et al., 2018).

3.4 Types of results and knowledge generated

Studies focusing on the processes or sets of operations framed around aid distribution and restoring access generated some findings and insights on the characteristics of the operations and such important issues as the actual and potential organizations involved in both processes, the performance measures that have been used in each dimension and the resource constraints (Iloglu and Albert, 2020; Sanci and Daskin, 2019; Tavana et al., 2018; Çelik, 2016; Coco et al., 2020; Nurre et al., 2012; Özdamar and Ertem, 2015; Tuzun Aksu and Ozdamar, 2014).

In the process of distributing humanitarian aid, constraints in access should be taken into account; thus, decision-making is influenced by issues such as the types of resources used in the process, the available fleet of vehicles, the location of distribution centers, the characteristics of the demand and of the areas affected by the disaster, the current state of the routes at each instant of time and the measures or performance functions used, where the dimensions of efficiency, efficacy and social welfare and equity prevail (Anaya-Arenas et al., 2014; Edrissi et al., 2015; Rodríguez-Espíndola et al., 2018; Sakiani et al., 2020) (Supplementary file number 2 – Table S2).

On the other hand, the process of repairing and restoring access to the road network affected by a disruptive event is temporary (Baxter et al., 2020; Çelik, 2016; Kim et al., 2018; Maya Duque et al., 2016; Yan et al., 2012), and whose decisions are affected by the resource constraints required for cleaning and rehabilitating the affected networks to serve the affected population. Temporary network repair activities are characteristic of the response phase (Maya Duque et al., 2016; Nurre et al., 2012). Non-temporary or long-term road repair or rehabilitation activities are part of the recovery phase (Yan et al., 2020) (Supplementary file number 2 – section 4).

Finally, the first works, which closely addressed the integration between both processes or sets of operations (Yan and Shih, 2009) due to their complexity, generally assumed that the resources required for the optimal development of both processes were unlimited (Supplementary file number 2 – section 5) and used performance measures based on the efficiency and efficacy dimensions; however, the social dimension has been overlooked in this context (Karakoc et al., 2020).

4. Discussion

4.1 Contribution to theory and practice

Infrastructure networks play an important role in facilitating humanitarian aid operations to distribution points and disaster-affected areas by making them accessible (Iloglu and Albert, 2018; Lu et al., 2016; Maya Duque et al., 2016). Thus, the

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restoration and recovery of infrastructure networks becomes increasingly important in events such as natural or man-made disasters. This study contributes to determine the current state of the art in the field of aid distribution in humanitarian logistics while considering accessibility constraints, identifying trends and suggesting some directions for future research in the field.

The results of the systematic literature review show that most studies that take humanitarian aid distribution and access restoration into account focus on the two phases of disaster management preparedness and the response phase (46 of 49). In contrast, there is little research on the recovery phase (2 of 49) (Karakoc *et al.*, 2019; Yan *et al.*, 2020). Furthermore, only one study focuses on joint decisions that contemplate all three elements, response, preparedness and recovery (1 of 49) (Supplementary file number 1 – Section 2). For this reason, researchers ought to pay more attention to decision-making models framed across multiple disaster phases.

The main contributions are considered to be clearly framed in the models of distribution of humanitarian aid and the scheduling of teams and crews in the temporary repair of road networks in the response phase. From the 49 studies on distribution logistics in areas with accessibility constraints, 20 of them studied the problem of distributing humanitarian aid by taking into account the affected networks; on the other hand, 24 studies addressed the problem of restoring access to the road network and only 5 studies addressed both problems together. However, the distribution of humanitarian aid and the scheduling of teams and crews in the temporary repair of road networks have generally been addressed in isolation, ignoring the interdependence between these two processes. Therefore, actions aimed to alleviate suffering of people affected by a disaster tend to be suboptimized (Averbakh, 2012; Çelik, 2016; Dubey *et al.*, 2019; Sanci and Daskin, 2019; Tuzun Aksu and Ozdamar, 2014).

Regarding the decision-making models developed in aid distribution, typical constraints associated with demand requirements (Sabbaghtorkan *et al.*, 2020), vehicle capacity with homogeneous or heterogeneous fleet (Vahdani *et al.*, 2018a), as well as delivery sequencing decisions, opening decisions and allocation of facilities framed in a single and multi-period environment were considered (Habib *et al.*, 2016; Rodríguez-Espíndola *et al.*, 2018; Sabbaghtorkan *et al.*, 2020) (Supplementary file -number 2 – section 3). Aid distribution has also been analyzed from the multi-echelon (Balcik *et al.*, 2010; Balcik, 2016) and last-mile (Chen *et al.*, 2020) perspectives. However, few papers have considered inventory decisions and multiple transportation modes selection (Rezaei-Malek *et al.*, 2016a; Chen *et al.*, 2020), as there is a lack of recognition of the importance of collaborative aspects and process interdependence in logistics decisions. Most of the developed works were identified to have implicitly assumed a centralized approach to logistics decisions given a single actor (Faiz *et al.*, 2019). Therefore, there is still an incipient development in the study of the interrelationships of multiple actors and collaborative issues in centralized and decentralized contexts in distribution logistics taking accessibility constraints into consideration (López-Vargas and Cárdenas-Aguirre, 2018).

Additionally, other relevant research topics were identified according to the decision-making models developed in aid distribution. Specifically, it is still necessary to work on the integration of technologies in decision-making models, because they facilitate the coordination of logistics actors and processes (Habib *et al.*, 2016). Considering that resources are limited in disaster scenarios, it is also important to consider transport fleet outsourcing decisions, facility capacity constraints, transport mode allocation decisions based on the characteristics of each demand point and consideration of shared resources, as well as load redistribution decisions between distribution points (Sarma *et al.*, 2020; Tavana *et al.*, 2018). Finally, intermodality and transshipment decisions should intervene based on the dynamics of the disaster and the assessment of the affected geographical area, depending on the infrastructure and accessibility conditions of the area. Only two papers considered measures of social benefit (Macea *et al.*, 2018; Al Theeb and Murray, 2017), in relation to the most frequently considered efficiency and efficacy dimensions. Therefore, there is a need for further research on performance measures based on the social dimension that allow generating indicators that quantify the condition of the population affected and studying the trade-offs between various measures.

In the context of access restoration problems, repair resources have been considered to be unlimited and come from a single central repository (Maya Duque *et al.*, 2016; Iloglu and Albert, 2020; Morshedlou *et al.*, 2018; Reddy *et al.*, 2017; Sanci and Daskin, 2019); however, in the real-world context, these issues may come from different organizations located in different geographic locations (Matisziw *et al.*, 2010; Xue *et al.*, 2012). Decision-making models framed for this particular problem assume only the use of a single resource for network rehabilitation (Nurre *et al.*, 2012; Sanci and Daskin, 2019; Vahdani *et al.*, 2018b; Yan *et al.*, 2014a, b). From the results of the supplementary material (Supplementary file number 2 – Table S3), it can be determined that the decisions framed in the access restoration problem have implicitly assumed the presence of a single actor, i.e. when in real contexts there are several agents with different resources and capabilities whose decisions may be centralized or decentralized (Çelik, 2016; Yan *et al.*, 2020). Additionally, the constraints and decisions studied in this problem include the location, allocation and routing of repair and cleaning equipment in the network (Maya Duque *et al.*, 2013; Sakuraba *et al.*, 2016a), since they have been recognized as fundamental operations in the access restoration. However, it is also necessary to explore the repair crew selection mechanisms with respect to complexity of the road disruption and interdependence between the repair crew and the machinery needed for the repair.

Access restoration is yet another relatively overlooked topic. Indeed, it has generally been assumed that a damaged arch can only be assigned a single repair resource, when in fact more than one resource can be assigned (Kim *et al.*, 2018; Maya Duque *et al.*, 2016). Furthermore, it has generally been assumed that repair times are constant, but, depending on the severity or complexity of the damage in the network, these times may be variable. Although important contributions have been made to the restoration problem, it is necessary to involve some issues of collaboration between agents and consideration of shared resources (Sanci and Daskin, 2019). Moreover, a restoration-focused analysis showed that some measures based on efficiency (Faiz *et al.*, 2019; Sanci and Daskin, 2019) and efficacy (Edrissi *et al.*, 2015; Zhang *et al.*, 2016; Faiz *et al.*, 2019; Çelik, 2016) were being proposed to tackle this problem. Nevertheless, since studies that allow quantifying the contribution of access restoration operations to alleviate the suffering of the affected population are still lacking, measures of social performance, which are relevant in the humanitarian context, were not clear.

Although there are studies closely related to the integration of aid distribution and access restoration problems (Aslan and Celik, 2019; Sanci and Daskin, 2019; Shin *et al.*, 2019; Vahdani *et al.*, 2018b; Yan and Shih, 2009), studies related to inter-organizational collaboration mechanisms (Rodríguez-Espíndola *et al.*, 2018) and resource constraints (Coppola, 2011) that involve both problems are still lacking (Supplementary file number 2 – section 5). Furthermore, there are not enough efforts for developing models for transport-mode selection based on the accessibility conditions of the areas that require aid distribution (Çelik, 2016). Another relevant issue that integrates the aforementioned problems is the need to consider joint transportation and inventory decisions, given that they are relevant collaborative aspects that allow humanitarian aid products to be available to humanitarian organizations and the affected population.

4.2 Limitations

Some limitations in this review were taken into consideration. In the first instance, our review was necessarily limited by the exclusion of papers evaluating the impacts of artificial intelligence, information and communication technologies, data mining, software development and robotics. Studies associated with hospital logistics and commercial supply chains were excluded. Additionally, this review ignored items such as doctoral dissertations, master's theses, undergraduate theses, textbooks, documents derived from congresses and conferences, book chapters and technical reports from humanitarian aid organizations or agencies. It is likely that studies relevant to this research, which were found in other databases and institutional repositories in English, Spanish, Portuguese, among others, were not taken into account. Given the constraints of time and resources, we were not in contact with the authors of the studies to request clarification when information was missing or unclear. Additionally, most of the studies included in the review were conducted in high-income countries, which may limit the generalizability of the results to low-income countries. However, we focused on databases such as Web of science, Scopus, Science Direct, JSTOR, Emerald, EBSCO, Scielo and Redalyc, which cover the most important journals in humanitarian logistics. Furthermore, systematic reviews, research articles and review articles concerning the design and application of decision-making models and methods published in peer-reviewed journals were analyzed. Finally, a review of the references of the included studies was considered.

4.3 Recommendations for future research

In the reviewed studies, there are clear challenges and opportunities for future work. The findings suggest opportunities for research on relief distribution and road restoration in areas with accessibility constraints. These findings may contribute in the following areas. Firstly, due to widespread destruction resulting from disasters, assuming undamaged links and facilities is unrealistic (Rodríguez-Espíndola *et al.*, 2018). Secondly, at the time of disaster occurrence, since most roads and communication routes are destroyed and blocked; therefore, repair of affected roads can be considered a relief (Al Theeb and Murray, 2017; Maya Duque *et al.*, 2013). Thirdly, taking into account multiple disasters over several time periods represents another research line (Grass and Fischer, 2016), as well as conflicting goals such as cost minimization and maximization of satisfied demand are common in humanitarian logistics and they should be paid special attention (Macea *et al.*, 2018; Sabbaghtorkan *et al.*, 2020). Fourthly, there are no research works considering demand-side costs, i.e. there is a significant gap concerning most model objectives since they are constructed from supply-side costs and demand-side costs and these are rarely included (unmet demand penalty, deprivation, social welfare) (Grass and Fischer, 2016; Karakoc *et al.*, 2020); humanitarian supply chain generally contain two or more participants, so more realistic models can be achieved by considering the participation of two or more organizations (Minas *et al.*, 2020; Rodríguez-Espíndola *et al.*, 2018). Fifthly, to set priorities in route scheduling, delivery times have been used as the main driving factor; however, these can also be replaced by other priority rules, e.g. disaster-affected areas with a higher percentage of children - elderly and injured people may have higher priorities (Faiz *et al.*, 2019) and finding the best time to start providing supplies is also a challenge for emergency managers when facing a disaster (Maya Duque *et al.*, 2016). Next, logistical operations can incorporate the allocation of vehicles and work crews for debris removal (Karakoc *et al.*, 2020), as well as the rational availability of emergency vehicles can also be analyzed according to the delivery scheduling schemes obtained (Zhou *et al.*, 2017). Hence, different relief organizations or agencies are involved in emergency reconstruction operations for road network repair; additionally, collaboration and coordination issues should also be taken into account, such as how to deal with the situation when two or more repair teams may work simultaneously to repair a single damaged node (Prabawa and Choi, 2020). Similarly, distribution units and emergency centers are often operated by different agencies; therefore, the best possible disaster relief result can only be achieved through effective and efficient coordination (Rodríguez-Espíndola *et al.*, 2018). Also considering the limited number of resources available at each depot, repair decisions are limited by the need to meet the demand for relief from the cities being accessible (Victoria *et al.*, 2016). Also, considering partial outages could be another interesting research line, since developing systems that can operate with reduced capabilities would increase the effectiveness of aid distribution (Karakoc *et al.*, 2020). Lastly, socioeconomic characteristics, topography and population density could also be included in future studies (Karakoc *et al.*, 2019); Finally, coordination between repair and relief transport agencies is another challenge, due to the interdependence existing between both processes or set of operations (Shin *et al.*, 2019; Yan and Shih, 2009).

Integrating academia with the organizational, economic, institutional and psychological issues of the affected areas and population is yet another promising research avenue.

Moreover, we identified some important gaps in the current analyses of the interrelationships and hierarchies among multiple actors in the context of distribution logistics with accessibility constraints. Further analyses that address these gaps could be a logical consequence of the aforementioned integration. Additionally, researchers are invited to look for mechanisms to cope with uncertainty related to the optimization of one or more humanitarian objectives. It is also important to explore intermodality, redistribution and transshipment options and not just a single mode of transport. In relief goods distribution, attempts should be made to move essential goods from warehouses to demand points (Tavana *et al.*, 2018). Then, decision-makers may decide to transfer goods from one node, zone, or facility to another to achieve the optimal use of available goods. Therefore, one of the challenges of humanitarian aid distribution logistics with accessibility constraints is to redistribute relief goods to avoid severe shortages in some nodes and excess inventory in others. Likewise, it is important to work on alternative transport mechanisms such as drones for infrastructure network assessment and humanitarian aid delivery and their possibility of integration with networks and modes of transportation used in each particular area. It is also necessary to explore new supply systems, such as shared vehicles, whose structure allows an easy and safe sharing of different types of goods, or hybrid delivery vehicles, which are viable under various social, economic and infrastructure constraints.

The study of collaborative environments in inventory management, transportation, storage, location of facilities and stakeholder's coordination is relevant. Given that the distribution of aid may jointly involve decisions associated with the evacuation of victims, it may be an interesting research opportunity to analyze issues on coordination of these two processes. It is also necessary to generate maturity models for humanitarian distribution chains or networks, which allow the selection and evaluation of logistics suppliers that contribute to obtain inputs, supplies, and equipment in an effective manner.

Other future research lines were identified thanks to the literature review. For example, deliveries to a dispersed population, social conditions, and limited technological infrastructure can make it difficult to deliver aid properly. To address these limitations, it is necessary to propose traceability systems that improve coordination between deliveries and social conditions of the affected population.

On the other hand, study of the vulnerability of distribution or transport networks in the face of different types of concurrent disasters is relevant for future research. In addition, the statistical dependency or correlational analysis of link or road failures must be analyzed to allow formally defining interruption scenarios that help the decision maker to better plan distribution routes and select modes of transport. Critical links are generally identified as those whose removal or blocking would severely reduce network performance. However, such an understanding of critical links overlooks the aspect of increased demand. In order to cope with the increase in demand, researchers should identify the links whose capacity increase could greatly improve the performance of the network, that is, the potential links, which constitute an important research gap.

Finally, it is necessary to include work evaluating the impact of artificial intelligence, information and communication technologies, data mining, machine learning, software development, industry 4.0 and robotics on distribution logistics considering accessibility constraints for high-, middle- and low-income countries and contributions derived from other fields of study, such as commercial and hospital logistics.

5. Conclusion

This paper has presented a systematic literature review of recent studies on aid distribution and transitional network restoration in the context of humanitarian operations in areas with accessibility constraints. By categorizing studies according to problem areas, major decisions, objectives and solution methods, this paper not only serves as a guide for researchers and practitioners who are unfamiliar with this field, but also aims to help researchers in the field of humanitarian operations and network optimization to identify research opportunities.

From the studies quoted in this review, we were able to determine that when disasters occur, especially the so-called sudden-onset disasters (Zhou *et al.*, 2017), certain areas may become isolated and have difficulty in receiving relief supplies due to network destruction. Moreover, additional damage will occur if relief goods cannot reach isolated areas quickly (Coco *et al.*, 2020). Therefore, to provide adequate relief goods to the demand area it is essential to recover the destroyed networks and make the affected areas accessible (Kim *et al.*, 2018; Maya Duque *et al.*, 2016; Shin *et al.*, 2019; Tavana *et al.*, 2018).

More than one-third of casualties and losses caused by a disaster are directly related to delays in restoring the flow of critical services in an affected area (Sakuraba *et al.*, 2016a). Therefore, the problem of network restoration becomes a relevant operation for the provision of humanitarian aid; it is here where this research work shows the important interrelation between the restoration of accessibility and the distribution of aid. Then, the coordination of these operations constitutes a relevant mechanism in the process of humanitarian assistance at the country, regional and local levels.

Additionally, research addressing pre- and post-disaster response in this field of knowledge is still scarce. Therefore, there is a need for research on efficient preparedness, response and recovery operation systems and mitigation.

This review contributes to the literature by highlighting several important gaps in knowledge. In particular, it highlights the importance and interrelationship between the processes of distributing humanitarian aid and restoring access. Few studies analyze both issues in an integrated manner, as well as in collaborative environments in logistics operations management. By summarizing the available research, it was possible to identify mathematical modeling as an important tool for the analysis of this type of problem. However, it is also important to explore other types of modeling and tools based on social network analysis, discrete event simulation, agent-based simulation and system dynamics modeling to represent and analyze the interrelationships between different stakeholders or actors, resources, processes and complex behaviors in the context of accessibility-constrained distribution logistics. Finally, it is still necessary to strengthen relations between the academic world and humanitarian organizations in order to increase the number of applied research projects in this field of knowledge.

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Supplementary material

The supplementary material for this article can be found online.

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