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Supplier selection in disaster operations management: Review and research gap identification

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ABSTRACT

Selecting trustworthy suppliers is one of the most critical issues in disaster operations management (DOM), ensuring efficient procurement of relief supplies and preventing or alleviating human suffering. However, compared with the commercial supply chain, the topic of supplier selection (SS) has not received much attention in DOM. Therefore, the paper aims to review relevant work about SS in DOM and propose future research directions. This paper statistically analyzes articles published between 2010 and 2020 in major OR/OM journals and investigates SS in the disaster context from research problems, objectives, and methodologies. Furthermore, the research gaps of SS are identified, and future directions are proposed. The significant findings on SS topic are that there is a lack of papers that integrate qualitative criteria and evaluation of suppliers into SS; propose models that consider demand-side, supply-side, or transportation process in the uncertain environment; develop more models which consider not only economic-related costs but also human suffering for humanitarian operations; develop tailored SS models for the specific types of disaster; discuss the dynamic SS issue to balance capacity idleness and cost-efficiency; investigate alternative types of contracts to facilitate efficient cooperation between relief agencies and suppliers; link supplier segmentation and supplier development to SS to improve the overall performance of the humanitarian supply chain, and apply new technologies in SS to guarantee the reliable and responsive supply of humanitarian commodities.

1. Introduction

Natural hazards and other complex emergencies usually significantly destroy society, the environment, and economics. For instance, Hurricane Harvey ravaged in August 2017, affecting more than 13 million people in Texas, Louisiana, Mississippi, Tennessee, and Kentucky with a result of estimated $180 billion economic loss. Other recent events include Hurricane Maria in 2017, Indonesia earthquakes and tsunami in 2018, and the COVID-19 global pandemic since 2019. Disaster operations management (DOM) plays a critical part in better preparing for disasters, reducing injuries and damages, and easing the recovery process before, during, and after disasters [1]. Lack of relief supplies (e.g., food, medicines, and related equipment) would result in human suffering and even loss of lives. As one administrative function of DOM, the primary purpose of humanitarian logistics is to develop appropriate supply plans, including procurement, pre-positioning, allocation, and distribution of relief supplies [2]. Procurement is the most important activity in humanitarian logistics, which involves pre-positioning supplies purchased before disasters and procurement of additional supplies during and after disasters [3]. According to the report of [4], 65% of relief agencies' expenditures are related to procurement activities.

Since the increasing importance of procurement realized, a natural question will be "Where do the relief supplies come from?" presented by Starr and Van Wassenhove [5]. The relief supplies needed by disaster-affected locations always come from suppliers (e.g., retailers and manufacturers) regardless of pre-disaster or post-disaster procurement or donation. In the six-step model presented by Aissaoui et al. [6] and the four primary tasks given by Moshtari et al. [3], supplier selection (SS) is a part of procurement. Suppliers thus play a vital role in effective and efficient procurement. To put it simply, SS is to design an effective plan to select the proper suppliers and purchase relief supplies from them.

As one of the most essential decisions in procurement, current studies about SS involve three major concentrations. The first one is supplier

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selection criteria, such as pricing, quantity discount, transportation cost, delivery time, carbon emission tax, and available capacity of suppliers [7,8]. These criteria usually measure the degrees of suppliers' importance and suppliers' performance. The second one is how to deal with the uncertainty involved in the real world. It is highly unpredictable and complex in the disaster context, such as uncertain demand for relief supplies, labor and raw materials supply, and infrastructure conditions. The last concentration is to coordinate different stakeholders for better SS to reduce the influence of disastrous events. For instance, the collaboration between relief agencies and suppliers is critical to reducing inventory shortage/surplus risks, and the collaboration between logistics companies and suppliers can avoid delays in delivering relief supplies. Therefore, practitioners and researchers must create novel methodologies and present insights about selecting suppliers efficiently and effectively.

Although SS is a strategic issue in the procurement of relief supplies, it has received little attention in both literature and practice [7]. There are no review papers that have been published on SS in DOM, except only one on procurement. Moshtari et al. [3] grouped the procurement process into spend analysis, sourcing strategy, supplier selection, and contract design. For SS, they identified 11 papers that focused only on supplier selection criteria and the bidding process. A systematic literature review on SS is lacking. This paper aims to provide an analysis of SS-related research problems, objectives, and methodologies the existing studies focused on, as well as suggest future research directions to inspire new topics. The major contributions of this paper are summarized as follows.

(1) *Summary of related past work.* Although there are many review papers about disaster operations management, there is no review specific to SS decision making. Meanwhile, studies on SS in the disaster context are emerging (shown in Section 3).
(2) *Systematic review method.* In this paper, we will provide an overview of relevant papers in DOM, conduct an in-depth analysis of papers, and identify major future directions of SS. We explore paper distributions in different journals and the number of papers each year that cover SS topics and review SS's problems, objectives, and methodologies to help select proper suppliers in DOM. Specifically, for the research problems, we classify supplier characteristics, SS under uncertainty, and integration of SS into other disaster operations activities. Finally, we present future research directions for SS in DOM, including analysis on limitations of existing papers and observations from SS in the commercial supply chain. By providing this profound analysis on SS, we identify several research gaps and propose promising research directions.
(3) *Identification of research gaps.* Research gaps have been identified for SS. We intend to address some of these gaps through our continued research efforts and hope other researchers will be interested in working on other identified gaps. In this way, we can collectively complete the study of SS in DOM.

Our findings show several gaps and some research directions, including lack of papers that consider environmental and social characteristics in SS, qualitative criteria and qualitative evaluation of suppliers; a need of a strategy of capacity flexibility that allows the supplier to deliver a contingency quantity for uncertainties in demand-side; a need for papers to design strategies to protect suppliers or prepare backup suppliers in response to supply-side uncertainties; a need for more research on integrating the uncertainty in the transportation network into SS to reduce transportation cost and risk of delay; lack of studies that develop models consider both economic-related costs and human suffering to provide a solid foundation for decision makers to design an effective plan of better leverage resources provided by suppliers; lack of specific SS models for better dealing with different types of disasters with various demand in supplies; lack of articles that discuss dynamic supplier selection issues to balance capacity idleness and cost-efficiency; a need of investigating alternative types of contracts (e.g., buy-back contract and option contract) to facilitate successful cooperation between relief agencies and suppliers; a need of supplier relationship management that contains SS, supplier segmentation and supplier development to effectively improve overall performance of humanitarian supply chain; new technologies such as internet of things and big data analytics to guarantee the reliable and responsive supply of humanitarian products.

The rest of this paper is organized as follows. Section 2 describes the main scopes that this paper focuses on and specifies the search method applied to acquire relevant papers. Section 3 presents the statistical and characteristic analysis of the reviewed papers, including paper distributions in different journals and the number of relevant papers per year published. Section 4 conducts in-depth research of SS in DOM, including research problems, research objectives, and methodologies studied for different papers over the past few decades. Section 5 identifies important future research directions in SS for improving DOM. Finally, Section 6 provides a summary of this paper.

2. Methodology

A systematic review method has been applied [1] and the steps are summarized as follows:

(1) identifying the research need for a literature review;
(2) determining a sample of potentially relevant literature;
(3) selecting the most relevant papers;
(4) analyzing and briefing the evidence;
(5) presenting and reporting the results and findings.

Step 1 has been completed in Section 1. Section 2 conducts steps 2–3, and steps 4–5 will be covered in Sections 3-5.

2.1. Overview of supplier selection

Governments and relief agencies usually pre-position supplies at strategic locations in the preparedness phase so that performance of disaster response will be efficient (e.g., fast response time and low economic cost). They may suffer from excess or insufficient inventory, hence being exposed to inventory surplus/shortage risks [9]. To deal with these risks, a close relationship between the purchasers (i.e., relief agencies and governments) and suppliers is critical to streamline the procurement process and promise the availability and fast delivery of essential relief materials [10,11]. Therefore, it is vital for relief agencies to find suitable suppliers and procure needed relief supplies from them promptly [12]. defined SS as "a decision-making process to select the best supplier(s) from a prequalified pool based on predefined objectives and decision criteria." Minimizing the economic cost, such as procurement and agreement costs, is the common objective for SS in both commercial and disaster contexts. Since one primary goal of DOM is to save lives and alleviate suffering, integrating humanitarian aspect objectives (e.g., psychological cost and deprivation cost) and designing novel decision criteria [13,14] is crucial for SS in DOM.

Since SS is to find different suppliers that are most proper to procure the needed relief supplies, we do not study papers that only consider one single supplier. Instead, we focus on selection decisions for a series of potential suppliers. In addition, relief supplies include essential items for basic needs, like water, food, blanket, batteries, medical kits, as well as the asset items such as vehicles. SS papers that consider these relief supplies are all included. Given the description mentioned earlier, we applied the following search method to provide a comprehensive review of the literature in SS.

2.2. Search method

A few of literature exists in the field of SS for DOM. After understanding the fundamental concepts of SS (see Sections 2.1), we concentrated on finding published journal papers related to "supplier selection in DOM." We used Google Scholar as the major search engine and used INFORMS search engine, Web of Science, PubMed, and Wiley Online Library as supplements. We searched keywords including "humanitarian," "disaster," "supplier," "procure*" (i.e., procurement, procure, and procuring), and "sourcing" in the journal papers published in English. We have carefully chosen the set of keywords to have comprehensive coverage of the journal papers related to SS in DOM. Moreover, we excluded the conference proceedings, book chapters, and in-progressing papers, and the period of our research was limited to the year 2010 - 2020. After searching for our keywords through the described method, 2285 papers have been found, and a certain number of papers do not fit our scope. Therefore, we applied the following two criteria for further filtering [1]: we first checked the title and abstract of the papers and eliminated the papers with titles completely different from the supplier selection in the domain of DOM; then, we checked research problem, motivation, methodology description, and the conclusion to remove irrelevant papers. A total of 30 papers were left after the filtering based on our review efforts.

3. Statistics and characteristics of the articles

In this section, we provide statistics and characteristics for the 30 papers that we researched in detail to identify research gaps.

3.1. Distribution of papers in different journals

Fig. 1 indicates that the reviewed 30 papers were published in 19 major journals in the field of Operations Research and Management Science. As we can see from Fig. 1, the journal in which most papers (i.e., five papers) were published is "Journal of Humanitarian Logistics and Supply Chain Management (J of HL and SCM)." It is followed by "Computers & Industrial Engineering (C&IE)" and "International Journal of Engineering (Int J of Engineering)" with three papers each. "Production and Operations Management (POM)," "Omega," and "Operation Research Spectrum (OR Spectrum)" are all in the third place, with two papers published in each. For the remaining journals, there is only one paper published in each, including "International Journal of Production Economics (Int J of PE)," "Annals of Operation Research (Annuals of OR)," "Socio-Economic Planning Science (Socio-EPS)," "International Journal of Disaster Risk Reduction (International J of DRR)," "International Journal of Physical Distribution & Logistics Management (International J of PD&LM)," "Transportation Research Part E: Logistics and Transportation Review (TRE)," "Operational Research International Journal (ORIJ)," "Applied Mathematical Modelling (AMM)," "International Journal of Sustainable Transportation (IJST)," "Transportmetrica A: Transport Science (Transportmetrica A: TS)," "The International Journal of Advanced Manufacturing Technology (The Int J of AMT)," "Plos One," and "Journal of Operations Management (J of OM)." It is worth mentioning that even for "Journal of Humanitarian Logistics and Supply Chain Management," from year 2011–2019, only one paper was published in it every three years approximately, which indicates the lack of research and work in the DOM area even though many disasters happened around the world [15].

3.2. Trend in number of papers by year

Fig. 2 provides information about the number of papers published from 2010 to 2020. Based on Fig. 2, for most of the years between 2010 and 2016, only one paper was published each year, with three papers published in 2011 and two papers published in 2014. Between 2017 and 2019, the number of published papers has shown a stable, increasing trend but still relatively low, with four papers published in 2017, five papers published in 2018, six papers published in 2019, and five papers published in 2020. On average, we can see growing research interests in SS-related topics in the disaster context over the recent years. However, considering the importance of SS in DOM, it deserves much more attention. Therefore, we need to conduct more research on selecting suitable suppliers for DOM to provide service as needed to save human lives and reduce human suffering.

4. Supplier selection in DOM

In this section, we analyze papers of SS in DOM, which are presented

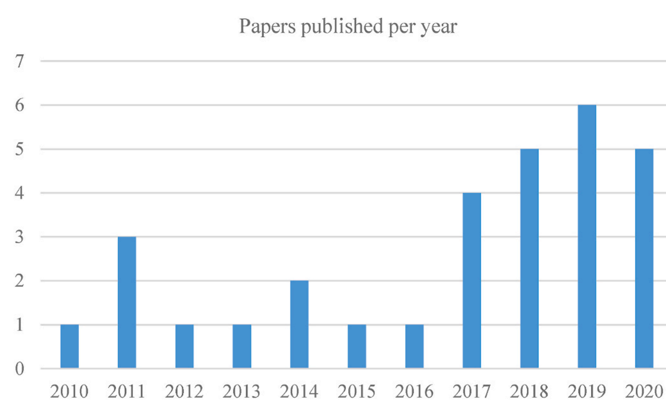

Fig. 2. Trend of published papers in SS over time.

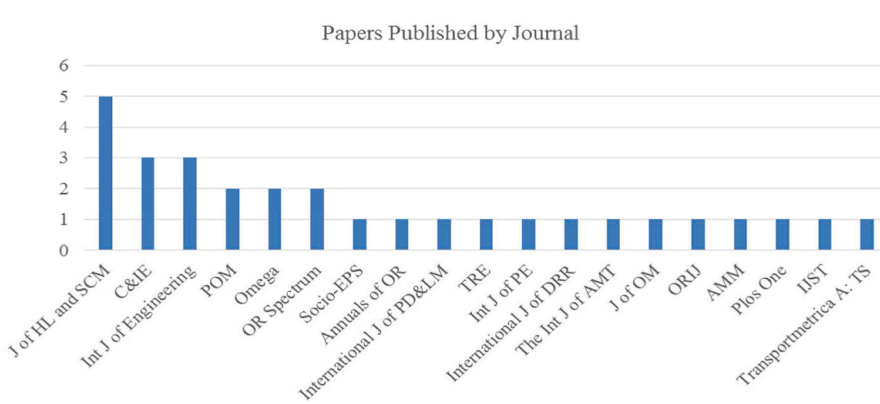

Fig. 1. Number of published articles in different journals in the period of 2010–2020.

by research problems in Section 4.1, and research objectives and methodologies in Section 4.2. Specifically, we group research problems into three categories: 1) suppliers' characteristics, 2) supplier selection under uncertainty, and 3) integration of supplier selection and other disaster operations activities.

4.1. Research problems in supplier selection

(1) Suppliers' characteristics

Suppliers' characteristics are critical to selecting proper suppliers. As shown in Table 1, the most considered characteristics in SS are procurement price and reserve capacity that both vary with suppliers. These two characteristics are practical because different suppliers usually offer various retail prices and reserve a certain number of relief supplies due to high holding costs. Other suppliers' characteristics studied in SS include agreement cost, procurement prices (which vary with order quantity and lead time), return price, bonus, commitment quantity, production capacity, transportation cost, delivery time, and substitute. The agreement cost represents associated administrative costs (e.g., overhead and coordination costs) to manage agreements or contracts.

Procurement price, return price, substitute, production capacity, and delivery time are introduced to incentivize relief agencies to work with suppliers. Procurement prices can also vary with order quantity and lead time requirements. The basic assumption is that the procurement price decreases as the order quantity increases and lead time increases. Return price (for buy-back) means that relief agencies can sell remaining supplies back to suppliers. These characteristics can be the incentive for relief agencies to buy more supplies. Substitute offers relief agencies an alternative to procure similar items from suppliers when contractual items are out of stock. A high inventory level can incur a series of costs, while a low level may incur shortage risks due to uncertain demand. Thus, production capacity is introduced to reduce the surplus and shortage risks. Delivery time is to ensure relief supplies can be delivered to victims as soon as possible. These characteristics are to guarantee the availability or fast delivery of relief supplies.

While bonus, commitment quantity, and transportation cost are introduced to incentivize suppliers involved in disaster operations by improving their profit. Although the primary purpose of relief agencies is to save lives under budget limitations, suppliers can be actively engaged in disaster operations if it is beneficial for them. The bonus allows suppliers to increase their profits by delivering supplies within a shorter lead time. However, suppliers' costs may be higher because they must pay more labor due to overtime work, rent for additional transportation capacity, and other expenses. Relief agencies usually will commit to purchasing a minimum total quantity of supplies from contractual suppliers regardless of the contract activation. This is to guarantee suppliers a fixed profit. This is also called a standby fee [37].

There are three papers not listed in Table 1 because they present more comprehensive suppliers' characteristics and propose more complex methods to evaluate these characteristics, which are hard to be fit into Table 1. We summarize the three papers separately as follows.

Sheu and Pan [38] proposed a relief supply collaboration approach to address the supply-demand imbalance. In the approach, they developed a relief supplier clustering mechanism for time-varying multi-source relief SS by considering the degree of the incentive alignment (i.e., the willingness of a supplier to share responsibilities), resource sharing, and information sharing. A stochastic dynamic programming model is presented to determine a multi-source relief supply that minimizes the impact of relief supply-demand imbalance.

Venkatesh et al. [7] developed a multi-criteria decision-making model for SS. Selection criteria attributes are verified by the extant literature and field experts, including humanitarian logistics performance, legal and governance, sustainable operations, responsiveness,

Table 1
Factors studied in supplier selection papers in DOM.

Authors	Supplier's characteristic												Uncertainty		Disaster operations activities			
	FC	Procurement prices vary			RP	BS	CQ	RC	PC	TC	DT	SE	DN	OL	PP	FL	CS	PS
		SR	OQ	LT														
Ertem et al. [16]		✓						✓				✓						
Bagchi et al. [17]		✓						✓		✓							✓	
Ertem and Buyurgan [18]		✓						✓				✓						
Falasca and Zobel [4]		✓					✓	✓										
Bozorgi-Amiri et al. [19]		✓						✓					✓		✓			
Bozorgi-Amiri et al. [20]		✓						✓							✓			
Balcik and Ak [10]		✓	✓	✓			✓	✓										
Iakovou et al. [21]		✓						✓			✓		✓					✓
Charles et al. [22]											✓				✓	✓		
Hu et al. [23]	✓	✓		✓					✓						✓			
Javadian et al. [24]								✓		✓					✓	✓	✓	
Shokr and Torabi [25]	✓	✓						✓		✓							✓	
Zhang et al. [26]	✓							✓							✓			
Dabbagh et al. [27]		✓						✓			✓		✓		✓		✓	
Dufour et al. [28]															✓			
Nikkhoo and Bozorgi-Amiri [29]										✓					✓		✓	
Torabi et al. [13]	✓	✓			✓		✓								✓	✓		
Safaei et al. [30]		✓						✓					✓	✓		✓		
Aghajani and Torabi [31]		✓		✓				✓					✓		✓			✓
Hu and Dong [11]		✓	✓	✓			✓	✓	✓				✓		✓	✓		
Velasquez et al. [32]		✓													✓	✓		
Wang et al. [33]		✓			✓	✓		✓			✓							
Aghajani et al. [9]	✓	✓						✓					✓		✓			
Boostani et al. [34]		✓						✓					✓		✓	✓		
Ghorbani and Ramezanian [14]	✓	✓			✓			✓		✓							✓	
Olanrewaju et al. [35]	✓	✓	✓				✓	✓										
Safaei et al. [36]		✓						✓					✓	✓		✓		

FC: fixed cost; SR: supplier; OQ: order quantity; LT: lead time; RP: return price; BS: bonus; CQ: commitment quantity; RC: reserve capacity; PC: production capacity; TC: transportation cost; DT: delivery time; SE: substitute; DN: disruption; OL: operational; PP: pre-positioning; FL: facility location; CS: carrier selection; PS: procurement lot-size.

partnership strategy, and operational factors (i.e., supply chain relevance). A fuzzy analytic hierarchy process is used to compute criterion weights, and a fuzzy technique for order performance by similarity to the ideal solution is used to rank supply partner alternatives.

Sigala and Wakolbinger [8] empirically explored the potential of outsourcing humanitarian logistics activities to commercial logistics service providers (LSPs). The selection criteria are categorized into quality, reputation, and size of organizations engaged in outsourcing. Quality includes quality of delivery and quality of service. Reputation is divided into networking and media. The type of organizations is divided into international organizations, UN agencies, and non-governmental organizations (NGOs). The size of organizations is divided into global big LSPs, national small or medium size LSPs, and consortia of organizations.

(2) Supplier selection under uncertainty

In our sample, we only found a few numbers of papers (9 of 30) that considered risks in SS. Two basic types of uncertainty have been identified. Disruption uncertainty refers to the major disruptions caused by natural, man-made, or technological threats, and examples include earthquakes, floods, terrorist attacks, and employee strikes. Operational uncertainty refers to inherent risks, such as customer demand, cost rate uncertainty, equipment failure, power outage, and critical personnel absence [39]. As shown in Table 1, seven papers consider disruption uncertainties because they claim disasters will disrupt suppliers. Two papers used term supply risk. We thus think these two papers considered both disruption and operational uncertainties.

The way of considering disruption uncertainties in those seven papers is to introduce stochastic parameters. Most of the time, uncertain demand is measured as a parameter in these papers. They usually consider that quantity of demand is uncertain. Iakovou et al. [21] also incorporated duration and beneficiary arrivals of demand. Then, four papers introduce an uncertain parameter to represent how much supplies in facilities will stay useable after disasters occur [9,11,19,34]. Two of them also assume that suppliers' capacities (e.g., stock and production) are uncertain [9,11]. Third, cost-related parameters, such as procurement and transportation cost for one unit of relief supplies, budget for pre-positioning, and SS are uncertain [9,19,27,34]. At last, two papers consider the lead time of supplies [21,27], and one paper considers criticality degree and carbon Emission [34]. Based on the methodology employed in different studies, the stochastic parameters are converted to deterministic differently. For instance, stochastic parameters are represented by a series of scenarios in stochastic programming, and the uncertainty set is used in robust programming. The methodologies used in these studies are discussed in detail in Section 4.2.

Two papers take into account supply risks. Safaei et al. [30] first employed the technique for order preference by similarity to ideal solution (TOPSIS) to identify risks of candidate suppliers based on four criteria (i.e., quality, trust, regional stability, and delivery time). It is evident that quality and trust are operation-related risks while regional stability is disruption-related risks. Then, the evaluation results are integrated into a robust bi-level optimization model to identify appropriate suppliers and optimize the flows in the relief distribution network. Safaei et al. [36] presented a bi-objective bi-level optimization model for relief logistics operations. The upper level includes decisions on inventory and distribution with the objectives of minimizing the total unsatisfied demand and operating costs; the second level is to select suppliers under supply risk. Supplier's risk is evaluated based on criteria, including suppliers' ability, reliability, proximity, and stability of the suppliers' location. The risk values are reported in a questionnaire, and their ranges are set between values 1 and 4.

(3) Integration of supplier selection and other disaster operations activities

A considerable number of papers have focused on integrating SS into one or multiple disaster operations activities, such as pre-positioning, facility location, carrier selection, and procurement lot sizes. This is because the nature of SS is to quickly procure the required relief supplies and make sure they can be timely available for victims. Since various disaster operations activities are involved in this process, analyzing these papers based on different disaster operations activities is meaningful. We first clarify definitions of pre-positioning, facility location, carrier selection, and procurement lot sizes as follows. **Pre-positioning**: optimal inventory level of relief supplies (e.g., food and water) to be stored at pre-determined facilities. **Facility location**: optimal location of facilities (e.g., temporal depots and distribution center). They do not consider decisions on inventory level. **Carrier selection**: multiple transportation modes or vehicles and optimal distribution decisions. **Procurement lot-sizes**: one-time procurement and re-order point.

Disasters cannot be easily anticipated, making it challenging for relief agencies to pre-position supplies [11,13]. Costs will be high if too many supplies are stored, while shortage risks may be high if supplies are insufficient. For solving this challenge, the joint decision of pre-positioning and SS has been studied to save costs for relief agencies and reduce shortage risks [20,31]. On the one hand, pre-disaster storage can be considered as a buffer that gives suppliers time to produce supplies to satisfy surging demand. On the other hand, suppliers have experience in inventory control, and their inventory strategies (e.g., first-in-first-out) are beneficial to avoid expiration for perishable supplies [23]. The two primary sources to meet victims' demands are pre-positioned supplies before disasters arrive and post-disaster procured supplies [37]. Locating facilities is integrated into pre-positioning and SS when facilities are unknown [11,13]. We found that two papers study the joint decision of facility location and SS [30,36]. They both present to set up temporary transfer facilities to receive, arrange, and send relief supplies to avoid over-supplying situations and congestion of affected areas.

The availability of relief supplies does not only mean enough but also focuses on timely delivery. Therefore, it is also essential to make sure pre-positioned and post-disaster procured relief supplies can be delivered to victims on time. Most studies in SS consider distribution decisions [10,35]. Especially, some authors integrated carrier selection into SS. This activity ensures vehicle availability by assigning contracts with vehicle suppliers in advance. Specifically, decisions include the type of vehicles, number of vehicles, and assignment of vehicles. Some instances can be found in Refs [14,24]. We found six papers that only study SS decisions with one-time procurement. They focused on optimal procurement quantity from each supplier for different items [4,10,16,18,33,35]. Two papers consider procurement lot size, and the procurement process are involved multiple periods (see Refs. [21,31]).

4.2. Research objectives and methodologies in supplier selection

(1) Research objective

According to Table 2, the most frequently considered objectives include procurement cost, transportation cost, holding host, and fixed costs (involving the agreement cost with suppliers). These objectives are common for commercial supply chain operations by focusing on the monetary cost. Given the nature of DOM is to mitigate victims' suffering, studies about SS also usually consider minimizing unmet demand for relief supplies. For instance, penalty cost for the shortage of supplies is the most common measurement to minimize the unmet demand by capturing the monetary cost when the demand for relief supplies is unsatisfied. There is a tradeoff between economic and penalty costs because governments and relief agencies have limited budgets for uncertain events. As economic cost increases, penalty cost decreases, i.e., more demand is satisfied. Other measurements include demand-weighted distance, covered demand, and satisfaction rate [9,32,34]. In our sample, only 8 out of 30 of the reviewed papers assume that all

Table 2
Objectives and methodologies in supplier selection papers in DOM.

Authors	Objective	Methodology
Ertem et al. [16]	Min: Original and substitute values for bidder Max: Original and substitute values for the auctioneer	Procurement auction mechanism, IP model
Bagchi et al. [17]	Min: PC, TC	Auction theory
Ertem and Buyurgan [18]	Same to Ertem et al. [16]	Same to Ertem et al. [16]
Falasca and Zobel [4]	Min: PC; penalty cost (shortage of supplies)	Two-stage SP model
Bozorgi-Amiri et al. [19]	Min: SC, PC, TC, HC; penalty cost (shortage of supplies)	Nonlinear RP model, particle swarm optimization
Bozorgi-Amiri et al. [20]	Min: SC, PC, TC, HC; maximum penalty cost (shortage of supplies)	Multi-objective RP model
Balcik and Ak [10]	Min: AC, PC; penalty cost (violation of commitment)	Two-stage SP model
Iakovou et al. [21]	Min: Costs of order, backorder, HC	Discrete event simulation
Sheu and Pan [38]	Min: Impacts of relief oversupply, relief undersupply	Two-stage clustering mechanism, dynamic SP model
Charles et al. [22]	Min: Air and boat TC, fixed and variable costs of facility; penalty cost for delay	MIP model
Hu et al. [23]	Min: AC, PC, TC, HC; penalty cost (shortage of supplies) Max: SV of unused inventories	Two-stage SP model
Javadian et al. [24]	Min: SC, PC, TC, HC; penalty cost (shortage of supplies); maximum travel time	Two-stage SP model, non-dominated ranking genetic algorithm, non-dominated sorting genetic algorithm
Shokr and Torabi [25]	Min: AC, PC, TC Max: Profit	Procurement auction mechanism, possibilistic non-linear MIP model, bi-objective MIP model
Zhang et al. [26]	Min: AC, PC, TC, HC	Two-stage SP model
Dabbagh et al. [27]	Min: PC; lead time Max: Profit	Procurement auction mechanism, multi-objective fuzzy model, two-step fuzzy approach
Dufour et al. [28]	Min: TC	IP model, simulation
Nikkhoo and Bozorgi-Amiri [29]	Min: PC, TC HC, vehicle allocation cost; penalty cost (shortage of supplies)	Possibilistic chance-constrained programming
Torabi et al. [13]	Min: AC, SC, PC, TC, HC; penalty cost (shortage of supplies) Max: SV of unused inventories	Two-stage fuzzy SP model, possibilistic programming approach, tailored differential evolution algorithm
Safaei et al. [30]	Min: SC, PC, TC, HC; supply risk	TOPSIS, bi-level RP model
Aghajani and Torabi [31]	Min: PC, HC, reorder cost; costs of delay, penalty cost (shortage of supplies)	MIP model, ε-constraint method
Hu and Dong [11]	Min: SC, PC, TC, HC; penalty cost (shortage of supplies)	Two-stage SP model
Sigala and Wakolbinger [8]	N/A	Interview
Velasquez et al. [32]	Min: Demand-weighted distance	RP model, greedy heuristic algorithm
Venkatesh et al. [7]	N/A	fuzzy Analytic Hierarchy Process, fuzzy TOPSIS
Wang et al. [33]	Min: PC Max: Effectiveness (Deprivation levels), SV of unused inventories	Performance measurement model using deprivation level functions
Aghajani et al. [9]	Min: AC, TC HC, costs of capacity reservation, exercise Max: Covered demand	Bi-objective two-stage possibilistic SP model, fuzzy mathematical programming approach
Boostani et al. [34]	Min: SC, PC, TC, HC; negative environmental impact Max: Satisfaction rate	Multi-objective two-stage SP model, compromise programing method, lexicographic optimization method
Ghorbani and Ramezanian [14]	Min: AC, PC, TC, costs of option, vehicle and commodity reservation, vehicle rental; penalty cost (shortage of supplies) Max: SV of unused inventories	Two-stage SP model, L-shaped method
Olanrewaju et al. [35]	Min: AC, PC, TC; penalty cost (violation of commitment)	Multi-stage SP model
Safaei et al. [36]	Min: SC, PC, TC, HC; the amount of unsatisfied demand, supply risk	Bi-objective bi-level programming, goal programming

AC: agreement cost with a supplier, SC: setup cost of facility, PC: procurement cost, HC: holding cost, TC: transportation cost, SV: Salvage value; MIP: mixed-integer programming, IP: integer programming, SP: stochastic programming, RP: robust programming, TOPSIS: a technique for order performance by similarity to an ideal solution.

demands for relief supplies must be satisfied, which are Refs [10,16–18,21,25,28,35]. In the studies of Balcik and Ak [10] and Olanrewaju et al. [35], penalty cost captures cost the relief agency should pay to the suppliers due to the violation of contractual terms that promise to buy a certain number of relief supplies.

Other objectives are rarely considered in SS, such as travel time, lead time, profit, salvage value, and humanitarian aspect cost [13,14,23–27]. Especially, only one paper of our literature considers humanitarian aspect cost (e.g., psychological cost and deprivation cost) in the study. Wang et al. [33] introduced deprivation levels to measure the effectiveness of offering relief supplies, defined as the degree of human suffering caused by the lack of access to goods or services.

(2) Methodology

The first category is to use mathematical programming with uncertainty, such as stochastic programming, robust programming, possibilistic programming, or/and a combination of these methodologies. The essence of these methodologies is to convert uncertain parameters to deterministic ones. The scenario-based two-stage stochastic programming model is frequently used in SS. In this model, some initial decisions must be made in the first stage before disaster scenarios are actually realized. The recourse decisions made in the second stage are to compensate for the first-stage decisions [40]. The possibilistic programming is mainly applied for imprecise/possibilistic scenarios. The approach is presented to convert the proposed model into the equivalent crisp (i.e., defuzzified) model [9,13]. Due to the computational complexity of models, these papers also develop algorithms for solving large-scale problems efficiently and effectively, such as particle swarm optimization, greedy heuristic algorithm, and L-shaped. Another category uses simulation, and there are only two papers [21,28]. For instance, Dufour et al. [28] generated 5000 simulated scenarios of discrete biannual demands as input of the proposed integer programming model. Then, they analyzed mean cost, standard deviation, and average savings to verify their decisions.

Five out of 30 of our reviewed papers design SS procurement auction mechanisms, which usually include announcement construction, bid construction, and bid evaluation phases [16,18,25,27,17]. The relief agency (auctioneer) invites certain suppliers (bidders) to the auction in the announcement phase. Next, the construction phase is formulated as a mathematical model from the suppliers' perspective. This phase integrates the suppliers' characteristics, such as price and lead time. Last, the relief agency determines suppliers in the evaluation phase and optimally assigns orders by another mathematical model.

Qualitative criteria of selecting suppliers are most neglected in SS in DOM. The corresponding methodologies thus appear to be rare. Only two papers of our literature study qualitative criteria by employing interview, fuzzy analytic hierarchy process, and fuzzy TOPSIS [7,8]. There are two papers proposing integrating the above methodologies and mathematical models. These approaches can be divided into two steps. First, a method is employed to evaluate available suppliers and assign them scores. Then these values are used as an input in mathematical models to help select proper suppliers [30,38].

5. Future research directions

This section identifies future research directions for SS in DOM through analysis on limitations of existing work, observations from SS in the commercial context, and analysis on practical needs.

5.1. Suppliers' characteristics

Although many characteristics are already widely explored in SS for DOM, researchers can fill gaps from two aspects. One direction is to further study existing characteristics. For instance, quantity discounts are among the most considered characteristics in SS in a commercial context [41–45]. The quantity discounts can be divided into two categories, all-units discount and incremental discount. The attained quantity discount is applied to all units ordered for all-units discounts (also known as business volume or total quantity discounts). In contrast, in the case of incremental discounts, the corresponding discount level only applies to those units exceeding the price break quantity. Therefore, studies on how all-units discount and incremental discount impact procurement, holding and transportation decisions can provide meaningful insight for SS. The other direction is to focus on environmental and social characteristics. Most characteristics are designed from the perspective of economy, so that the objectives of SS model are usually economic aspects, like costs or profits. However, from the perspective of sustainable DOM, environmental and social objectives are most neglected in SS [34]. For instance, some organizations (e.g., Oxfam and United Nations High Commissioner for Refugees) added environmental criteria to their supplier evaluation and selection scheme in terms of purchased goods, production process, transport, packaging, use, and disposal [46,47]. This not only contributes to decreasing negative environmental impacts, but also helps improve the firms' brand images and reputation [48]. Social criteria, such as equity, human rights, and social justice, in supplier networks would affect the credibility of the relief agency [47,49], which is very important to keep the stability of donor revenues [50].

Qualitative evaluation of suppliers is rarely discussed in SS for DOM. Only two papers of our literature consider qualitative criteria of SS. Sigala and Wakolbinger [8] and Venkatesh et al. [7] focused on partner selection for all humanitarian logistics activities, including warehouse, transportation, procurement, data analysis, and reverse logistics. On the one hand, SS is not discussed explicitly; and on the other hand, a systematic list of criteria for selecting suppliers lacks. Researchers are encouraged to develop a comprehensive framework for SS for humanitarian agencies. Moreover, measurements to evaluate the performance of suppliers appear to be lacking. The studies of SS in commercial context provide researchers a large number of methodologies for guidance, such as Analytical Hierarchy Process, Technique for Order Preference by Similarity to Ideal Solution, Rule-based Weighted Fuzzy Method, Quality Function Deployment, Analytic Network Process, Decision Making Trial and Evaluation Laboratory, Taguchi Loss Functions, and Best–Worst Method [51–57].

5.2. Supplier selection under uncertainty

Disasters are generally characterized by uncertainties because both their occurrences (e.g., hit time, geographic location, and intensity) and consequences are not easily anticipated. Moreover, when disasters occur, chaos and unpredictable human behavior lead to the failure of information flow transmission, resulting in the lack of information. Even if the information is provided, it may not be accurate. All such variabilities are reflected in different uncertainties, such as demand-side, supply-side, and transportation process. To be more specific, major uncertainties include (1) uncertain demand regarding the number of affected population and demand of required relief goods, (2) partial or complete supply losses at suppliers, and (3) uncertainty in the transportation network in terms of capacity, reliability, availability, and traversal time [58]. Therefore, SS with consideration of these uncertainties is a promising future direction.

As discussed in Section 4.2, most papers in SS for DOM simply introduce uncertain parameters to represent disruption and operational risks. To better deal with these risks, proper strategies are indispensable. First, for uncertainty in the demand side, strategies that consider suppliers' capacity flexibility can allow the relief agency to take advantage of the contingency inventory in case some suppliers fail [39,59,60]. Then, for uncertainty in the supply side, strategies are designed to either protect suppliers from being destroyed during disasters, or prepare backup suppliers to provide relief supplies when some of the suppliers are disrupted [61–63]. Last, for uncertainty in the transportation network, relief distribution decisions may not work due to a collapsed network. It is useless to store sufficient relief supplies if they cannot be effectively delivered to affected locations [64–66]. Therefore, integrating uncertainties of transportation networks into SS can reduce transportation costs and avoid delay risks.

5.3. Mitigating human suffering

Unlike commercial logistics, for responding to disasters, minimizing economic-related costs (e.g., procurement, transportation, and holding costs) may not be the most important goal for humanitarian logistics. In humanitarian relief, the primary goal is to timely allocate the limited resources to mitigate human suffering as much as possible [67]. Most current SS papers simply aim to minimize unmet demands or maximize the cargo delivered but ignore the time that people may have been suffering without supplies. The employed methods in these papers do not account for the urgency with which supplies may be needed at different locations, and the optimal allocation of those resources cannot be determined to achieve the maximum social benefit. Also, existing analytical models fail to capture human suffering. This topic has been studied in other fields of DOM, such as pre-positioning, post-disaster transportation, and evacuation. The fatality cost is introduced to capture penalties induced by casualties due to lack or delay of relief supplies [68,69]. Rezaei-Malek et al. [70] designed utility level of demand points to measure the benefit level of each demand point. Another type of cost to measure human suffering is deprivation costs, which is defined as the social impact cost caused by a lack of access to a good or service [33,71,72]. The last type we want to mention is the psychological cost caused by the anxiety and panic of victims, which is also one type of social cost [73,74]. Therefore, we encourage researchers to concentrate on developing quantitative multi-objective models which not only consider economic-related costs, but also human suffering and responsiveness measures (e.g., response time) in SS. This would provide a solid foundation for decision makers to design and plan effective use of suppliers, as well as a better way to assess the impacts of delivery options and actions.

5.4. Tailoring SS for different types of disaster

We found that most of our reviewed papers consider disasters in general, without specifying the disaster type [75]. Extending these studies to all types of disasters may lead to erroneous conclusions and unsuitable applications. This is because disasters are so different. For example, hurricanes are relatively slow-onset disasters whereas earthquakes are classified as sudden-onset disasters [2]. SS with consideration of production capacity is suitable to deal with hurricanes because there is some lead time for preparation. While for earthquakes, SS with a large reserve capacity may be more appropriate, otherwise, a large shortage may be incurred. In addition, the global supply chains have recently experienced severe and continuing disruption due to COVID-19. These worldwide supply chain disruptions motivate the resilient design for the supply chain in response to the potential long-term disruption. Resilient SS plays a vital role in the context of managing supply chain disruption, which has been studied in many works [76,77,78]. However, only a few works are focusing on resilient SS strategy design for long-term disruption, such as the current COVID-19 pandemic. Orji et al. [79] analyzed the relationships between pandemic response strategy and the criteria of resilient SS through a multi-criteria decision-making approach. Sawik [80] presented a multi-portfolio approach and scenario-based stochastic mixed integer programming models for optimization of supply chain resilience under ripple effect caused by the COVID-19 pandemic. These works have investigated the impact of the pandemic on suppliers, including the criteria of SS in the pandemic, and the SS strategy in response to the disruption. Future research should focus on developing tailored SS models to better formulate the features of disasters (or complex emergencies in general) to resist long-term disruption.

5.5. Dynamic supplier selection

Existing literature majorly focused on the uncertainty of disasters in location and severity, while the unpredictability of the occurrence time has largely been ignored. Even though timing cannot be precisely predicted, there are some patterns that can be observed. For example, hurricane season usually runs from June to September in coastal areas [23]. Relief agencies need to consider the time of disaster to balance capacity idleness and cost-efficiency. However, the dynamic SS issue has not received attention yet in DOM. Stauffer et al. [81] and Jena et al. [82] focused on where and when to build a relief center to make dynamic facility location decisions. When selecting suppliers is also important because suppliers' capacity, quality level, lead time, unit part cost, and fixed transportation cost, as well as clients' demands usually vary with time [83]. Therefore, as supplier identified for one period may not necessarily be the same for the next period to offer the same set of products. Dynamic SS is to examine whether the suppliers are being selected in multiple periods is worthy, and this has become a popular topic in the commercial supply chain. Hamdan and Cheaitou [44] addressed a multi-period green SS and order allocation problem. They considered that the availability of suppliers differs from one period to another. More instances can be found in Razmi and Maghool [84]; Ware et al. [83]; Hamdan and Cheaitou [54]. Because of the nature of DOM and the importance of dynamic SS, we encourage researchers to fill this gap in the future.

5.6. Investigating alternative types of contracts

Contracts have been widely used in the commercial supply chain to offer multiple benefits [85]. In SS, one of the main purposes of introducing contracts is to stimulate much-needed flexibility. It can ensure that relief agencies and suppliers can share risks with reducing costs and increasing profits. For instance, the buy-back contract makes sure that if the relief agencies' requests are less than the promised procurement amount for contractual relief supplies, the supplier takes the remaining amount at a return price, which is usually cheaper than the original purchase price [13,14,33]. The optional contract offers the relief agency the flexibility by purchasing the right (but not obligation) to increase or cancel the order at a specified price; while the supplier will charge a premium for an early commitment to planning the capacity [9,85,86]. Designing appropriate contracts plays an important role in facilitating successful cooperation between relief agencies and suppliers to mitigate human suffering. Future research can develop analytical models to explore which types of contracts are suitable for different participants, disasters, and relief supplies.

5.7. Linking supplier segmentation and supplier development to SS

In the commercial context, supplier relationship management (SRM) is developed to improve supply chain performance. SRM usually focuses on three steps (SS, supplier segmentation, and supplier development) to build strategic supplier relationships [87,88]. After the SS step, suppliers have been selected with of different capabilities in terms of product quality, delivery, and service [87], various willingness to improve performance and share information, etc. [89]. Supplier segmentation is forming different groups from the selected suppliers to create different supplier management strategies for different segments. Supplier development is designed to upgrade the performance level of suppliers to enhance the competitive advantages of the supply chain [90]. Joint action, investment, long-term commitment, and supplier incentives are useful strategies for supplier development [91–93]. There are some examples that link supplier development to SS for saving costs and reducing the shortage of relief supplies in a disaster context. The joint decision of pre-positioning and SS is the case of joint action that the relief agency and suppliers carry out cooperatively [20,31,94]. Future research can develop tailored SRM models containing SS, supplier segmentation, or/and supplier development to effectively improve the humanitarian supply chain's overall performance.

5.8. Application of new technologies in SS

New technologies such as the internet of things (IoT) and big data analytics (BDA) have been acknowledged to improve the performance and efficiency of modern supply chains in the commercial context. Agarwal et al. [95] and Ghadimi et al. [96] explored the IoT solutions for the SS problems and demonstrated this IoT solution could reduce the human interaction and operational time during the SS process. Lamba et al. [97] developed a SS model with multi-periods, multi-products, and multi-suppliers to reduce the cost of the supply chain through the essential parameters of Big Data. These technologies can enhance humanitarian supply chain management. Khan et al. [98] have demonstrated that transparency, public trust, and coordination in the humanitarian supply chain can be improved by integrating IoT with Blockchain. Bag et al. [99] have investigated the potentials and barriers of applying BDA-driven approaches to humanitarian supply chain management. However, applying these technologies to SS in the humanitarian supply chain is not considered. Future research involving these technologies to SS in a humanitarian context can study the potentials of IoT to accelerate the SS process to guarantee the reliable and responsive supply of humanitarian products and BDA to present more information about suppliers and the environment.

6. Conclusions

Lack of relief supplies and timely delivery plans would considerably affect human lives. SS is essential to DOM operations; however, this field has still received little attention. In this paper, we reviewed major journals in Operations Research and Management Science from 2010 to 2020 that studied SS problems for DOM. We analyzed the relevant papers in several different ways to present the distribution of papers in various journals and the trend in the number of papers by year (see Section 3). We further detailed discussed SS in the disaster context, including research problems, objectives, and methodologies involved in this domain (see Section 4). Specifically, research problems are grouped into the suppliers' characteristics, SS under uncertainty, the integration of SS, and other disaster operations activity. Finally, we identified the research gaps and presented future research directions for SS in DOM through reviewing relevant papers. We believe that these proposed future research directions will lead to models and strategies close to reality and applicable in the future DOM (see Section 5).

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