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Operations Research Applications for Coordination, Cooperation, and Collaboration in Humanitarian Relief Chains: A Framework and Literature Review

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Abstract. Given the large number of actors in the humanitarian space, coordination is essential for successful disaster response. Moreover, the sheer size of challenges and limited resources increasingly highlight the need for improved cooperation and collaboration. The concepts of coordination, cooperation, and collaboration (3Cs) in humanitarian relief chains are well-recognized in literature and practice. A considerable amount of research explores 3Cs using conceptual, empirical, and analytical methods. However, none of the existing studies provide an overview and analysis of the Operations research (OR) approaches that support decision making for improved 3Cs in humanitarian relief chains. In this paper, we first present a holistic view of the discussions in the literature and derive a conceptual framework for the 3C mechanisms in humanitarian operations. Based on our framework, we then analyze studies that develop OR methods to address the design and management of 3C mechanisms in the humanitarian relief chain. We also identify the current gaps and future research directions by considering both problem and methodological aspects.

Keywords: Humanitarian logistics, coordination, cooperation, collaboration.

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1 Introduction

Disasters disrupt the well-being and functioning of communities and result in economic and human losses. The international disasters database (EM-DAT) recorded 4,212 natural disasters worldwide that occurred between 1980 and 1999, which almost doubled from 2000 to 2019 reaching 7,348, mainly due to the sharp increase in climate-related disasters (UNDRR, 2020). Over those two decades, disasters impacted 4 billion people, resulting in 1.23 million loss of life and 2.97 trillion US dollars in economic damage (UNDRR, 2020). In severe events, a large number of actors are involved in humanitarian operations to assist the affected communities (Clarke and Campbell, 2018). For example, about 700 non-governmental organizations (NGOs) were engaged in response to the 2004 Indian Ocean Earthquake (Chia, 2007), while the 2010 Haiti Earthquake brought thousands of NGOs to the disaster stage (Kristoff and Panarelli, 2010; OCHA, 2010). The involvement of a large number of actors, however, does not guarantee better response (Rodríguez-Espíndola et al., 2018a). Inefficiencies during the 2004 Indian and 2010 Haiti earthquakes were concrete evidence in this regard (see Holguín-Veras et al. (2012), Van Wassenhove (2006)).

Relief operations are often criticized for being slow, unresponsive, and inefficient in terms of resource utilization (Swaminathan, 2018). In some cases, existing capacities are sufficient to deliver a better response, but they are not leveraged effectively to increase performance (Yeo and Comfort, 2017). The absence of coordination, cooperation, and collaboration, which will be referred to as 3Cs, is a major problem impeding the success of humanitarian efforts, resulting in duplication of efforts and deployment of excess or insufficient aid, thereby leading to the waste of valuable resources, supplies, time, and funds (Acimovic and Goentzel, 2016; Shokr et al., 2022). Given that logistics operations account for 80% of relief efforts, improving 3Cs in humanitarian relief chains is an important challenge and can have a significant impact (Van Wassenhove, 2006).

The terms *coordination*, *cooperation* and *collaboration* (3Cs) describe the relationships and interactions between the actors (Balcik et al., 2010; Wankmüller and Reiner, 2020). Researchers and practitioners often use the terms interchangeably (Balcik et al., 2010; Cozzolino et al., 2017; Nolte et al., 2012; Wankmüller and Reiner, 2020). Although the terms have terminological and practical overlaps as all stand for 'working together', establishing boundaries between these terms is necessary to comprehend the nature of interactions. In this study, we define coordination as the alignment of activities to operate efficiently and effectively (Ergun et al., 2014), whereas cooperation is the process of operating jointly without being committed to seeking the same objectives (Nolte et al., 2012). Coordination and cooperation form the basis of 'collaboration', which refers to the joint pursuit of coordinated activities to achieve a shared goal (Ergun et al., 2014; Gulati et al., 2012; Kapucu and Garayev, 2011). Various actors may initiate the 3Cs throughout the relief chain, such as governments, relief organizations, and private sector companies. Moreover, the 3C relationships can be differentiated as horizontal and vertical (Balcik et al., 2010; Schulz and Blecken, 2010). Accordingly, horizontal 3Cs occur between actors at the same level of the relief chain (e.g., between the relief organizations), while vertical 3Cs involve actors at different levels (e.g., between the relief organizations and private companies).

Over decades, efforts in the humanitarian sector for supporting 3Cs have been shaped in line with the lessons learned from past events. The need for coordination has long been recognized, while there is an increasing emphasis on the importance of collaboration that mandates both coordination and cooperation. Various initiatives and the United Nations (UN) bodies, such as the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), have consistently fostered 3Cs while prioritizing global partnerships and shared goals in line with the Sustainable Development Goal 17 (see UNDRR (2022), UN (2022)). Given the importance of the topic, a number of conceptual frameworks and literature reviews have addressed 3Cs in humanitarian relief chains. For instance, Grange et al. (2020) discuss how coordination evolves over the years by revealing triggers (i.e., major disasters, such as the 2010 Haiti Earthquake) and facilitators (i.e., establishments, such as OCHA). Wankmüller and Reiner (2020) provide a qualitative content analysis to identify the terminological differences between 3Cs. Balcik et al. (2010) present a broad overview of relief chain coordination mechanisms, and Moshtari and Gonçalves (2017) reveal the factors affecting collaboration. However, there exists no study that provides a broad assessment and detailed analysis of 3Cs to present how decisions are made and how they could be altered for improving the performance of relief chains. Therefore, we focus on the applications of Operations Research (OR), which is a scientific discipline that is concerned with improved decision-making (IFORS, 2022). In this study, we review the existing literature in order to provide an overview of the state of knowledge about 3Cs in humanitarian relief chains, that could further ground research in OR methods to improve 3Cs. Specifically, we (i) conduct a qualitative assessment of the 3C mechanisms and present a conceptual framework, (ii) examine papers from OR literature in terms of their problem and methodological aspects, and linking them within the proposed conceptual framework, and (iii) reveal gaps and avenues for research and practice. Ultimately, we address the following research questions that focus on 3Cs in the relief chain context:

RQ1. What types of 3C mechanisms do exist, and what factors do affect the planning and implementation of decisions in practice?

RQ2. Which OR methods are studied to support decision-making for 3C mechanisms, and what are the main findings and insights from the OR studies?

RQ3. What are the gaps that needed to be addressed by OR methods to support the design and implementation of 3Cs?

We conduct a narrative literature review to address our research questions. Specifically, we investigate conceptual paradigms discussed in the reviewed papers and derive a conceptual framework in order to answer *RQ1*. To answer *RQ2*, we analyze the OR studies in terms of problem and methodological aspects, and assess their main findings, and scientific and practical insights. Finally, we synthesize our findings based on our framework and reveal the avenues for future research to address *RQ3*.

The rest of our paper is organized as follows. In Section 2, we describe our survey methodology and the scope of this study. Section 3 presents an overview of 3Cs in humanitarian relief chains based on our conceptual framework. In Section 4, we present a review of OR studies that address 3C mechanisms. Section 5 discusses our findings and future research directions. Finally, we conclude in Section 6.

2 Scope and methodology

We define the key concepts to highlight the scope of this research. In this study, we use the term "disaster" as described by Galindo and Batta (2013), which is "a shocking event that seriously disrupts the functioning of a community or society, by causing human, material, economic or environmental damage that cannot be handled by local agencies through standard procedures". Disasters can be categorized as sudden-onset (e.g., earthquake, hurricane) and slow-onset (e.g., drought, famine) (Çelik et al., 2012). The scope of this study is limited to inter-organizational 3C efforts for sudden-onset disasters and humanitarian relief operations conducted to alleviate disasters' impacts on people. Therefore, we ignore any 3C efforts between different corporate of local responders for small-scale disasters, such as bushfires. We also ignore studies that focus on coordination of resources and functions within one agency.

Our study focuses on providing an overview and analysis of OR based approaches. To capture the relevant papers, we adapt the definition provided by the International Federation of Operational Research Societies (IFORS, 2022), such that "OR is a discipline on the process of making better decision through the development and the application of a wide range of problem-solving methods and techniques." OR approaches include analytical models, such as optimization models, simulation, and game theory (Choi et al., 2016). In line with our goals and the interdisciplinary nature of OR, we provide a narrative literature review. A narrative literature review help to grasp complex topics when the author attempts to integrate studies on various subjects and/or when the studies are methodologically diverse (Baumeister and Leary, 1997; Snyder, 2019).

Our literature search starts with the investigation of peer-reviewed English-language journal articles from online databases, including Web of Science, ABI/Inform, and ScienceDirect. We define two sets of keywords that we use the combination of them (one from each set) in the search string. The first set involves the following keywords: "coordination", "cooperation", "collaboration", "cooperative", "collaborative", "coordinate", "cooperate", and "collaborate", while the second set involves "humanitarian", "catastrophe", "emergency", "disaster", and "relief". We filter the research areas to the fields related to OR, such as *Operations Research and Management Science, Engineering, Computer Science, Transportation, Mathematics, Decision Sciences* and *Business Economics*. These steps result in 5,561 papers.

We then screen the titles and the abstracts to determine the relevance of the papers. Considering the scope of this study, we examine if the paper's primary focus is on 3Cs for the disaster relief operations. Our primary focus is on OR papers, yet, we also examine several conceptual and empirical studies for addressing *RQ1* and *RQ3*. We finally extend our search only for the OR studies by assessing their references, which is known as going backward (Webster and Watson, 2002). We capture six more articles with this final step. Our literature search methodology resulted in a total of 100 papers, among 38 provides OR approaches.

We analyze the 100 papers based on the extraction grid that we develop to address *RQ1*. Specifically, we explore the (i) actors and how they engage in 3Cs, (ii) actors' motivations for 3Cs, (iii) factors affecting the success of 3Cs, and (iv) challenges of 3Cs. For *RQ2*, we further analyze the OR papers in terms of problem settings, parameters, decisions, solution methods, and performance metrics. Except for the OR studies, the list of papers cited in our discussions is not exhaustive for brevity, as we aim to highlight the key concepts that serve as the foundation for OR applications addressing 3C mechanisms in relief chains.

3 A framework for 3C decision making

There has been a growing body of research on the 3Cs in humanitarian relief chains. Each study focuses on a specific aspect of the 3Cs, such as benefits, challenges, facilitators, and impediments, and none of the studies provide an overarching framework. Therefore, developing a framework that provides comprehensive guidance for decision-making models for successful and implementable 3Cs was necessary. In this study, we synthesize the literature and conceptualize the interrelated aspects of the 3Cs studied so far. Our review leads us to derive a conceptual framework that can provide a solid basis for OR studies to position their problems and develop tools and approaches to support decision-making in realistic and practical settings.

Figure 1 depicts our conceptual framework. In our framework, we present 3C mechanisms among relief chain actors based on three main dimensions: (i) drivers/benefits (why to engage in 3Cs?), (ii) design factors (what are the factors affecting the success and sustainability of 3Cs?), (iii) enablers/facilitators (how to enable and facilitate 3Cs in practice?). We also exemplify 3C mechanisms that can be observed throughout a typical relief chain. Below, we first provide an overview of relief chain functions where 3C mechanisms are observed most often. We then characterize the 3Cs and explain each component of the proposed framework.

3.1 Relief chain functions

Humanitarian relief chain operations are commonly classified into four stages based on the disaster life cycle: mitigation, preparedness, response, and recovery (Çelik et al., 2012). The mitigation phase involves actions that aim to prevent disasters or alleviate their effects, such as locating early warning systems, and strengthening the building environment (Altay and Green, 2006; Çelik et al., 2012). The main purpose of preparedness activities is to develop systems and plans for the effectiveness and efficiency of disaster response operations, such as pre-positioning of relief supplies (Çelik et al., 2012). Response activities, such as needs assessment and relief supply distribution, are employed in the aftermath of the disaster (Çelik et al., 2012). There is time pressure during the response stage as the immediate needs of the beneficiaries must be met quickly. The recovery stage spans post-response actions that stabilize the affected community and rebuild the damaged structures, such as restoration of the built environment and debris removal (Altay and Green, 2006).

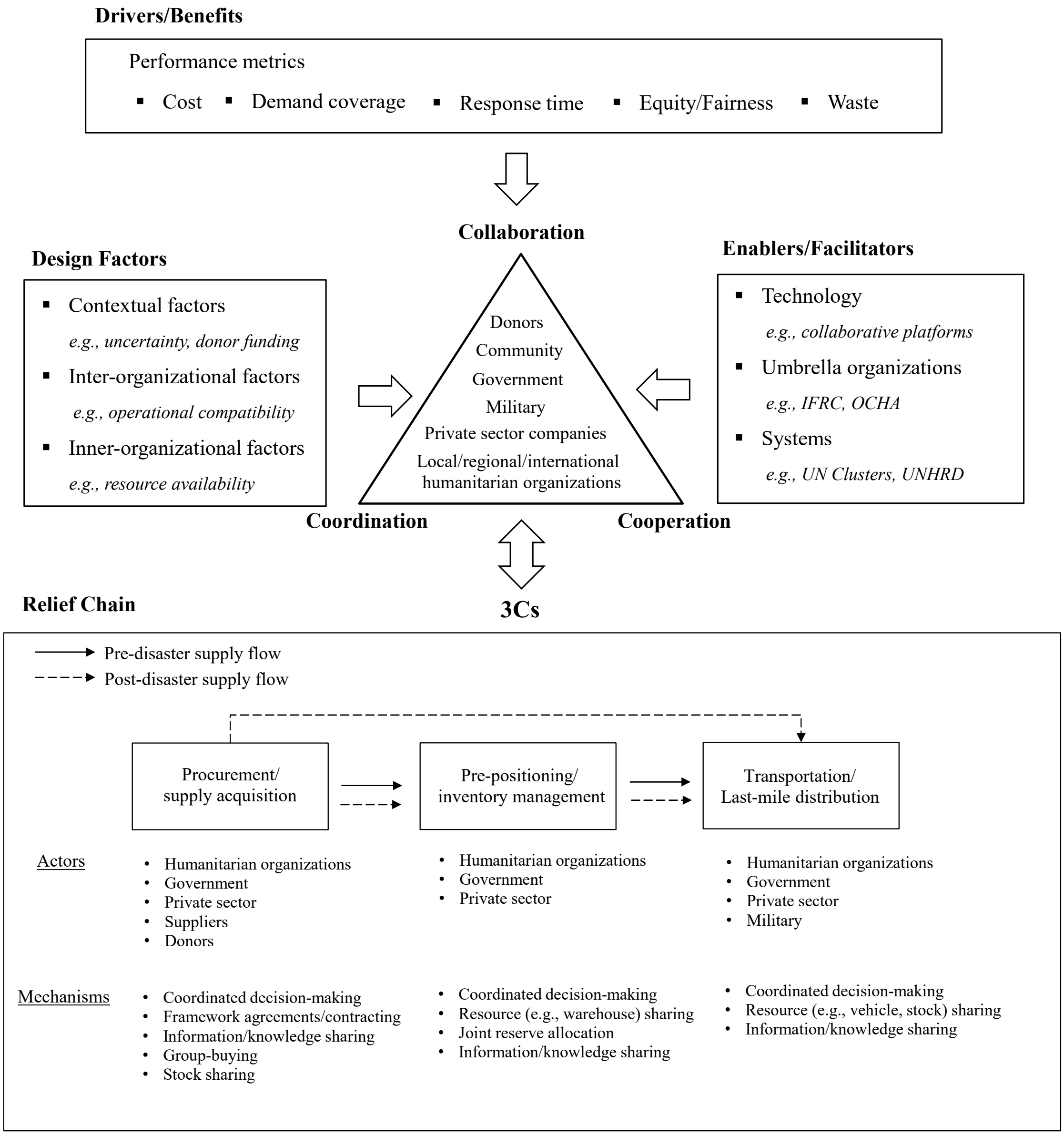

Figure 1: A framework for 3Cs in relief supply chains

In each stage, a diverse number of stakeholders take roles, including the affected population (community), host governments, local, regional and international humanitarian relief organizations, military, private sector companies (PS), and donors (Kovács and Spens, 2007; Çelik et al., 2012). Most literature focuses on the decision-making problems faced by governmental organizations (GOs) and NGOs as they are the primary decision makers in relief operations. In the remainder of this paper, GOs and all relief organizations are referred to as humanitarian organizations (HOs) unless we specifically distinguish them.

While each disaster is unique, and hence the corresponding number and layers of the supply chain, a typical relief chain involves three main functions: (i) procurement/supply acquisition, (ii) pre-positioning/inventory management, and (iii) transportation (see Figure 1). Each of these functions can be performed before and/or after a disaster's occurrence.

- *Procurement/supply acquisition.* HOs may receive in-kind donations and purchase relief supplies in both pre- and post-disaster periods. Donations may cause difficulties in planning and decision-making due to uncertainties regarding their type, amount, and timing. They also bring additional constraints when they are earmarked for certain operations. The main challenge of pre-disaster purchasing is to determine the quantity of relief supplies to be stored under the uncertainty of demand and donations. On the one hand, stocking a large amount of supplies increase the chance of rapid response to people in need. On the other hand, excessive storage of supplies wastes the limited budget from being deployed in a more effective manner (Coskun et al., 2019; Hu et al., 2019). In addition, if the supplies are not available before the disaster, post-disaster purchase will be required, which is also challenging. For example, the vendors may face warehouse and supply damages if their location is struck by the disaster, which may reduce the availability of relief supplies and their quality, and increase prices and lead times due to scarcity. These uncertainties and complications bring various decision-making problems for organizations.
- *Pre-positioning/inventory management.* The aim of stocking relief supplies prior to disasters (i.e., pre-positioning) is to ensure that the supplies are ready for immediate distribution (Altay and Green, 2006; Balcik and Beamon, 2008). The supplies can be stored in distribution centers, such as regional and local humanitarian depots. Accordingly, fundamental decisions involve facility location and supply allocation.
- *Transportation/last-mile distribution.* Transportation is a fundamental component of relief operations for the shipment of materials, goods, and staffs. The function involves pre- and post-disaster supply flows, and generates a significant amount of relief chain costs (Martinez et al., 2011). Moreover, post-disaster supply flows are related to the last-mile distribution, such as a distribution from the humanitarian warehouses to the beneficiaries, and have a critical role in a timely response. Primary decisions related to transportation and last-mile distribution includes relief supply distribution, resource allocation, and vehicle routing.

We next characterize 3Cs among different actors in performing these relief chain functions.

3.2 3C characterization

3Cs are being discussed in the literature without a consensus on the interpretation of the terms. Studies generally provide definitions based on their contexts, but the boundaries between the terms remain blurry. We review all sampled papers to comprehend the nature of 3Cs, focusing on their characteristics related to decision-making along the relief chain. Our intention is not to provide a survey for different definitions from the literature; but rather to clarify practical boundaries between 3Cs by deriving the main characteristics of the terms as shown in Table 1. Afterwards, we identify 3C mechanisms in humanitarian relief chains, differentiate their operational aspects, and analyze the OR studies based on our definitions and Table 1.

Similar to Ergun et al. (2014), we define *coordination* as the alignment of actors' actions in order for them to work efficiently and effectively. When actors coordinate their operations, the decisions are made either jointly (e.g., by discussing one another) or centrally (e.g., by a decision-maker authority). Therefore, planned communication (e.g., coordination meetings) and frequent information flow between actors are essential during operations (Wankmüller and Reiner, 2020). In a coordinated system, actors may not share strategic or short-term goals. In other words, the purpose of coordination is to improve the efficiency and effectiveness of the operations held by different actors that may have different objectives. Accordingly, actors may operate with independent resources; that is, coordination does not mandate an effort based on resource sharing.

In line with the definition provided by Nolte et al. (2012), *cooperation* is working alongside other actors and assisting each others' operations through sharing (e.g., information, resources) as applicable to the context. Cooperation does not necessarily involve intense and long-term relationships (Diehlmann et al., 2021). Actors may cooperate on an ad hoc basis while pursuing their individual goals. Decision making and implementation processes of cooperative actions can be autonomous in an uncoordinated way. Therefore, communication between actors can be less structured.

Collaboration, on the other hand, is a longer phenomenon requiring close relationships. Similar to Gulati et al. (2012) and Shokr et al. (2021), we position coordination and cooperation as the foundation of 'collaboration', which refers to the joint pursuit of coordinated actions to achieve a shared goal. By definition, collaboration necessitate structured communication and coordinated decision-making. Actors' operations involve aligned and collective actions (Abdeen et al., 2021). In a collaborative system, resources may not be owned by a single entity but rather pooled and used to achieve the system's goal. Therefore, collaboration is framed by relationship-specific investments, as well as sharing of costs and benefits (Kovacs and Spens, 2010).

Based on these definitions, we define 3C mechanisms along the relief chain as a set of interactions and methods that constitute the process of actors coordinate, cooperate or collaborate. The reviewed papers discuss a number of interactions and methods that form 3C mechanisms in relief chains among different actors, such as joint or centralized decision-making, information and knowledge sharing, resource sharing, joint capacity building, and contracting (see Figure 1). Joint or centralized decision-making is a way of coordinating operation planning and execution. Information can be defined as a fact about something, such as disaster data, whereas knowledge is more comprehensive and requires a cognitive process on information. According to Kovacs and Spens (2010), organizational knowledge is the accumulation of information, expertise, and experience. Based on our definition, information/knowledge sharing is a cooperative behavior that is also a requirement for coordination. Resources involve the assets (e.g., facilities, employees, money) that organizations utilize to operate and relief supplies (e.g., water, food, hygiene kit) that are distributed to the beneficiaries. Sharing may occur in two different ways: through (i) a transfer from one organization (e.g., lender) to another (e.g., borrower), or (ii) pooling resources under joint ownerships. Based on our definition, the first corresponds to a cooperation mechanism, while the second to a collaboration mechanism. Actors can collaborate through joint investments, such as joint capacity building to integrate compatible resources, technologies, and processes. Finally, 3C mechanisms can be non-contractual (voluntary-based) or legally binding by formal contracts (Tang and Wang, 2020). Contractual agreements are often useful to facilitate trust between actors and mitigate conflicts (Prakash et al., 2021).

Table 1: Characteristics of 3Cs

	Coordination	Cooperation	Collaboration
Communication	Planned	Unplanned	Planned
Resources	Independent	Shareable	Pooled
Decisions	Joint/centralized	Independent/aligned	Joint/centralized
Actions	Aligned	Independent/aligned	Aligned, collective
Goals	Individual/joint	Individual/joint	Shared

3.3 Drivers/Benefits

Drivers are the motivations for actors to engage in 3Cs, which can be assessed by benefits. They are important component of decision-making as they often define the objectives for the design and management of 3Cs. Benefits of 3Cs are widely discussed in the literature (e.g., Balcik et al. (2010), Schulz and Blecken (2010), Sigala and Wakolbinger (2019), Pazirandeh and Maghsoudi (2018)). In general, improving 3Cs lead to cost reduction, waste reduction (e.g., avoid duplication of effort), increased demand coverage, faster response, and equity in humanitarian aid, which are critical performance measures.

In the relief chains, actors may have specific agendas, resources, networks, missions, and expertise. Therefore, their involvement in operations and drivers to establish 3C relationships with other actors differ (Shaheen and Azadegan, 2020), as briefly discussed below. Typically, governments are the key actors responsible for disaster management (Balcik et al., 2010; Lee, 2020). Excessive demand created by catastrophes drives host governments to establish 3Cs with other actors. These actors participate in relief operations by adhering to government policies (Balcik et al., 2010). The government policies are one of the major factors affecting 3Cs and actors' decisions (Lee and Fleming, 2015).

The military is known as its readiness, systematic organizational structure, and a great resource capacity (Zaw and Lim, 2017). Besides the government, they are often the most responsive actors in terms of information sharing. Military is mostly involved in response operations by sharing its assets, coordinating humanitarian agencies, and supporting communication (Zaw and Lim, 2017).

Larger HOs have more capacity and resources than smaller organizations. This makes it easier for them to take strategic roles in addition to the operational roles. For instance, the leadership roles in the coordination mechanisms are often assigned to international organizations (e.g., the UN) since they are more able to conduct coordination meetings and be active in different tasks during response operations (Nolte et al., 2012). Still, local organizations are in a significant position due to their local network, and knowledge about local conditions and culture (Ruesch et al., 2022; Kovacs and Spens, 2010). Therefore, besides the other benefits discussed previously, resource complementarity is one of the main drivers for 3Cs between relief organizations (Pazirandeh and Maghsoudi, 2018).

Private sector is recognized with their large resources and network, operational knowledge, expertise in supply chain activities, capabilities of management, and technology capacity (Abidi et al., 2015; Cozzolino et al., 2017). There are many real-world examples demonstrating how private sector's experiences facilitates effective aid distribution (see Horwitz (2020)). Moreover, outsourcing logistics activities to private sector can eliminate the requirement for investment in facilities and resources, which is advantageous for small-size organizations (Sigala and Wakolbinger, 2019). Although these relationships are not necessarily profitable for the private sector, supporting aid operations are beneficial in terms of corporate social responsibility and brand image.

The aforementioned benefits are not the only factors affecting motivation for 3Cs. Specifically, 3Cs may incur cost, such as contracting and investment costs (Ergun et al., 2014; Li et al., 2019). To initiate and sustain 3C mechanisms, benefits must exceed the costs associated with the 3Cs, but most importantly, costs and benefits should be fairly allocated to the partners. Sustaining relationships is more demanding than establishing them, which requires well-defined cost and benefit allocation mechanisms (Lu and Xu, 2015).

3.4 Design factors

There exist many factors that affect the design and performance of 3Cs. Considering these factors affecting the effectiveness of 3C mechanisms is critical to develop realistic decision-making models. Numerous conceptual and empirical studies identify these factors and analyze their impact on 3Cs using different methods, such as surveys (e.g., Lu et al. (2018)), interviews (e.g., Schiffling et al. (2020)), case studies (e.g., Tang and Wang (2020)), and agent-based simulation (e.g., Aros and Gibbons (2018)). In this section, we summarize the factors under two categories: (i) contextual factors and (ii) inter- and inner-organizational factors. We should note that the literature review provided by Moshtari and Gonçalves (2017) also present these factors with a particular focus on collaboration. Below, we combine and enhance their study with our findings.

3.4.1 Contextual factors

Contextual factors are associated with the characteristics of humanitarian context, such as number and diversity of stakeholders, unpredictability of the environment, donor expectations and funding structure, competition between actors, and information management and communication challenges (Balcik et al., 2010; Moshtari and Gonçalves, 2017).

- *Number and diversity of stakeholders.* As previously discussed, relief chain actors are diverse in many aspects, including their incentives, missions, processes, resources, and abilities. This often cause incompatibilities between actors that complicates or impedes 3Cs. Identifying the roles, responsibilities, and capabilities is essential for establishing realistic and sustainable 3C mechanisms (Curnin et al., 2015; Curnin and O'Hara, 2019; Maghsoudi et al., 2018). Moreover, the number of stakeholders is large and also unpredictable. Particularly in the aftermath of a disaster, uncertain number of volunteer groups (e.g., churches, self-organised rescue teams) often emerge (Kapucu et al., 2021). Coordinating all the actors for resource deployment is demanding and challenging, as is determining which ones and how many are needed (Rodríguez-Espíndola et al., 2018a). Furthermore, identifying actors to participate in 3Cs is critical. Tang and Wang (2022) suggest that small-scale alliances (i.e., coalitions) can be more sustainable for collaboration. Specifically, extending the alliance may cause difficulties in coordination and describing roles, and further weakens members' willingness to contribute to collective efforts. These necessitate the development of equitable cost/benefit allocation mechanisms for effective 3Cs.
- *Environmental unpredictability.* Relief environments are associated with several sources of ambiguity that complicate the planning and execution of operations. For most disasters, the time, location, and impact of disasters (e.g., quantity and the characteristics of demand) are unpredictable before the events occur. The availability of supplies and the condition of transportation networks are volatile due to the disruptive post-disaster impacts. Additionally, the post-disaster environment is characterized by political uncertainty, which may impose unforeseen limitations on both international and national actors. Uncertainty, which is a critical aspect of relief chain design, must be considered a key factor affecting the 3C mechanisms.
- *Donor expectations and funding structure.* Donors are the source of funding and supply for most HOs,

providing services, cash, or in-kind donations (Çelik et al., 2012). The structure of these helps is vague in terms of their type, amount, and timing. Unpredictable and insufficient funding prevents organizations from making necessary investments in 3Cs, further leading them to self-preservation rather than interacting with others. Besides, donors sometimes impose obligations through earmarked donations that may include limits for 3Cs. Therefore, the limitations imposed by donated supplies must be considered an important factor.

- *Competition between actors.* Relief organizations often compete for fundraising and scarce resources. Competition is severe especially during the immediate response stage, in which media and donor attention is high (Balcik et al., 2010). Specifically, organizations seek visibility in media in order to attract donor attention (Eftekhar et al., 2017). Therefore, they may be reluctant to engage in 3Cs, even if it is for the sake of the success of humanitarian activities, especially if there is a risk of losing visibility and funding.
- *Information management and communication challenges.* Reliable and timely information is essential to deliver adequate services and avoid duplication of efforts. In a disaster environment, however, communication and information gathering can be very difficult due to the disrupted communication networks and scarce resources. Besides, perceiving information as a competitive advantage may discourage information sharing between actors (Kovács and Spens, 2007). Infrequent information flows result in poor coordination, speculation and rumors, and localized decision-making (Comes et al., 2020). The type and success of the 3Cs will be highly affected by the availability of communication means.

3.4.2 Inter- and inner-organizational factors

Inter-organizational factors are related to relational characteristics of different organizations, whereas inner-organizational factors are related to characteristics that are impacted by the organization itself (Moshtari and Gonçalves, 2017). These factors affect actors' decisions regarding how they engage in 3Cs, therefore designing 3C mechanisms.

- *Inter-organizational factors.* The literature reveals a number of inter-organizational factors that affect actors' engagement and alignment of efforts. Trust is a prominent one that increase actors' willingness for 3Cs, such as information sharing (e.g., Curnin et al. (2015) , Dubey et al. (2019), John et al. (2019)). Other factors involve strategic compatibility (e.g., shared objectives and cultural values), operational compatibility (e.g., similar operational policies and technologies), and power compatibility (e.g., similar capacities and resources) (Moshtari, 2016; Moshtari and Gonçalves, 2017).
- *Inner-organizational factors.* Organizations' incentives for 3Cs, personnel capability (e.g., knowledge and experience), innovativeness, size, access to technological tools, and management capacity are some of the inner-organizational factors affecting 3Cs (Bharosa et al., 2010; Moshtari, 2016; Moshtari and Gonçalves, 2017; Mutebi et al., 2020). In particular, actors should be motivated and competent to develop 3C mechanisms. Moreover, some studies highlight the negative effect of a high staff turnover rate, such as impeding the collection of historical knowledge and the creation of the trust (Pateman et al., 2013; Wagner and Thakur-Weigold, 2018).

We note that these factors can be interdependent. For instance, Mutebi et al. (2020) reveal that the level of innovativeness increases in relation to the size of the organization due to the diverse skills and experience of a great number of employees. According to Lu et al. (2018), organizational compatibility may enhance trust. Dubey et al. (2018) consider swift trust as a key prerequisite for commitment, while commitment and communication (i.e., information sharing) to be essential for coordination process. Information sharing promote transparency while facilitated by visibility (Maghsoudi and Pazirandeh, 2016). It is challenging, yet essential to take into account these complex and intangible factors in 3C design and practice.

3.5 Enablers/facilitators

As discussed in Section 3.4, there are several factors that can hinder practicing 3Cs successfully. Some of these challenges can be overcome. Our review reveals several enablers/facilitators that support the practicability of 3C mechanisms. Below, we summarize them as (i) technology and (ii) umbrella organizations and systems.

3.5.1 Technology

Technology is often an important determinant for how 3C mechanisms are implemented in practice, and therefore can be a critical aspect for decision-making. For instance, information technologies (ITs) enable and facilitate communication and information sharing between actors, which are essential for maintaining 3Cs (Bharosa et al., 2010; Fu and Lai, 2021; Sagun et al., 2009). ITs also enable visibility, which is one of the key design factors of 3Cs. In particular, information visibility improves resource allocation decisions, willingness for resource sharing, process integration, and flexibility of organizations (Maghsoudi and Pazirandeh, 2016). It is critical that organizations adapt compatible technologies in order to enhance their performance and 3Cs.

Development of collaborative platforms are also encouraged to facilitate the coordination of collective actions and regulate individual actions (Wu and Chang, 2018). An example to collaborative platforms is presented by Acimovic and Goentzel (2016) for mapping emergency stockpiles. The platform provides information on the stockpiles (amounts, types, and locations) of the stocks owned by different agencies operating in a region, facilitating coordinated pre-positioning.

3.5.2 Umbrella organizations and systems

Establishing and sustaining 3Cs among a diverse and large number of actors is highly difficult, particularly when they operate in a decentralized way. Umbrella organizations and systems are important elements to consider when making decisions, as they clarify roles and responsibilities by specifying decision-makers and how actors interact.

Umbrella organizations are the associations that provide guidance and assistance for relief operations. They can be temporary or permanent establishments (Zhao et al., 2012). For example, OCHA supports information sharing, decision-making, and advocacy, so that enables coordinated relief chains by ensuring that all actors contribute to the response effort and that the beneficiaries receive adequate relief (OCHA, 2020). The International Federation of Red Cross and Red Crescent Societies (IFRC), and The European Community Humanitarian Aid Department's (ECHO) are also examples for umbrella organizations facilitating 3Cs (see Schulz and Blecken (2010)).

The Cluster Approach, which is introduced in 2005 and well accepted by the humanitarian community, is an effective system that supports international coordination (Jahre and Jensen, 2010; Jensen and Hertz, 2016). There are 11 clusters, and each of them corresponds to a main sector of humanitarian action (e.g., logistics, nutrition, shelter). A cluster involves UN and non-UN HOs who are responsible for the corresponding action. With a predefined leadership, the clusters aim to improve efficiency and effectiveness in sufficient global capacity, predictable leadership, accountability, field-level coordination and prioritization, and partnership among UN organizations, NGOs, and local actors (Jahre and Jensen, 2010). Umbrella organizations can also act as logistics service providers (LSPs) and enable physical structures needed for relief chain activities. For instance, The United Nations Humanitarian Response Depot (UNHRD) managed by World Food Program (WFP) represents an important network of six humanitarian hubs. The hubs facilitates procurement, storage, and transportation of relief supplies for the UN agencies or international actors (Toyasaki et al., 2017). Similarly, IFRC operates Regional Logistics Units (RLUs) aiming to support logistics activities of national societies (Schulz and Blecken, 2010). ECHO Humanitarian Procurement Centres (HPCs) are also enables 3C mechanisms related to procurement and logistics operations (Gossler et al., 2020; Schulz and Blecken, 2010).

4 Review of OR applications

In this section, we present an overview and analysis of the OR based approaches to address *RQ2*. Based on our framework, we first explore the problem contexts focused by OR studies in terms of 3C mechanisms, and then analyze the methodologies, drivers (performance measures), design factors, and enablers.

4.1 Decision-making problems

The OR studies in our review are motivated by different 3C mechanisms with a focus on several settings and relief chain functions. Table 2 and Table 3 summarize the main characteristics of each article, which are grouped based on the 3C mechanisms they address. Specifically, Table 2 shows the actors engaged in 3Cs, the relief chain function associated with 3Cs, the type of 3C mechanisms, and the network that the study focus on, and Table 3 demonstrates the key problem decisions by differentiating the decisions involved in 3Cs.

As presented in Table 2, studies address 3Cs between various actors. Some studies specify humanitarian organizations (HOs) as governmental organizations (GOs) or non-governmental organizations (NGOs). Moreover, studies generally consider one of the three levels of networks: local (e.g., city), country, and regional. A majority of papers present case studies on the areas that are prone to several types of disasters, including hurricane (e.g., Balcik et al. (2019), Davis et al. (2013)), earthquake (e.g., Coskun et al. (2019); Ghasemi et al. (2022)), typhoon (e.g., Sheu and Pan (2015)) and flood (e.g., Rodríguez-Espíndola et al. (2018a), Rodríguez-Espíndola et al. (2018b)). Some papers conduct case studies with various umbrella organizations and HOs, such as UNHRD (Toyasaki et al., 2017), the United Nations International Children's Emergency Fund (UNICEF) (John et al., 2020), and The Caribbean Disaster Emergency Management Agency (CDEMA) (Balcik et al., 2019; Rodríguez-Pereira et al., 2021). There are also some studies that consider hypothetical networks.

Below, we discuss the 3C mechanisms modeled in these studies for each relief chain function.

Table 2: Overview of 3C mechanisms

Author(s)	3C actors*	Function*	3C mechanisms	Network (Case study)
Coordination				
Acimovic and Goentzel (2016)	HOs	Inv	Joint decision-making	Regional (UNHRD, OCHA)
Aghajani et al. (2020)	HO, suppliers	Pro	Framework agreements	Country (Iran)
Balcik and Ak (2014)	HO, suppliers	Pro	Framework agreements	Country (Turkey)
Bakhshi et al. (2022)	NGOs, GOs	Lmd	Centralized decision-making	Local (Dorud)
Edrissi et al. (2013)	HOs	Inv, Lmd	Joint decision-making	Hypothetical
Hu et al. (2019)	GO, supplier	Pro	Framework agreements	Hypothetical
John and Gurumurthy (2022)	HO, supplier	Pro	Framework agreements	(UNICEF)
John et al. (2020)	HO, supplier	Pro	Framework agreements	(UNICEF)
Liu et al. (2019)	Government, suppliers	Pro	Framework agreements	Hypothetical
Nikkhoo and Bozorgi-Amiri (2018)	HO, LSP	Lmd	Information sharing	Hypothetical
Nikkhoo et al. (2018)	HO, supplier	Pro	Framework agreements	Hypothetical
Patra and Jha (2022)	HO, supplier	Pro	Framework agreements	Hypothetical
Rodríguez-Espíndola et al. (2018a)	GOs	Inv, Lmd	Centralized decision-making	Country (Mexico)
Rodríguez-Espíndola et al. (2018b)	GOs	Lmd	Centralized decision-making	Country (Mexico)
Rodríguez-Espíndola et al. (2020)	GOs	Inv, Lmd	Centralized decision-making	Country (Mexico)
Sarma et al. (2019)	GO, NGOs	Lmd	Centralized decision-making	Hypothetical
Torabi et al. (2018)	HO, suppliers	Pro	Framework agreements	Local (Tehran)
Velasquez et al. (2019)	HOs	Inv, Lmd	Centralized decision-making	Local (North Carolina)
Wang et al. (2015)	HO, supplier	Pro	Framework agreements	Hypothetical
Cooperation				
Baskaya et al. (2017)	HOs	Lmd	Stock sharing	Local (Istanbul)
Chen et al. (2020)	NGOs	Lmd	Resource sharing	Country (Wuhan)
Coskun et al. (2019)	HOs	Lmd	Stock sharing	Local (Istanbul)
Davis et al. (2013)	HOs	Lmd	Stock re-allocation	Local (Southern US)
Fathalikhani et al. (2018)	NGOs	Lmd	Joint decision-making/action	Country (Iran)
Fathalikhani et al. (2020)	NGOs	Lmd	Joint decision-making/action	Local (Kermanshah)
Li et al. (2019)	HO, PS	Lmd	Philantropic help	Hypothetical
Shokr et al. (2021)	HO, LSPs	Lmd	Vehicle sharing	Local (Kermanshah)
Toyasaki et al. (2017)	HOs	Lmd	Stock sharing	Regional (UNHRD)
Zhang (2021)	Government, PS	Pro, Inv	Reserve allocation	Hypothetical
Zhang and Kong (2022)	Government, PS	Pro, Inv	Reserve allocation	Hypothetical
Collaboration				
Akbari et al. (2022)	HOs	Lmd	Vehicle pooling	Local (Tehran)
Balcik et al. (2019)	Governments	Inv	Joint pre-positioning	Regional (CDEMA)
Ergun et al. (2014)	NGOs	Lmd	Joint capacity building	Country (Haiti 2010)
Ghasemi et al. (2022)	HOs	Lmd	Vehicle pooling	Local (Tehran)
Nagurney and Qiang (2019)	HOs	Pro, Inv, Tra	Relief chain integration	Hypothetical
Rodríguez-Pereira et al. (2021)	Governments	Inv	Joint pre-positioning	Regional (CDEMA)
Sheu and Pan (2015)	GO, NGOs	Lmd	Central decision-making, resource pooling	Country (Philippines)
Shokr et al. (2022)	HOs	Inv, Lmd	Joint pre-positioning	Local (Kermanshah)

*Note: PS-Private sector, Pro-Procurement, Inv-Inventory management, Tra-Transportation, Lmd-Last-mile distribution

Table 3: Decisions related to relief chain operations

Author(s)	Procurement		Pre-positioning/ inventory management		Transportation/last-mile distribution			
	Supplier selection	Ordering quantity	Facility location	Supply allocation	Supply allocation	Resource allocation	Transportation/ Routing	Cost/Benefit allocation
Coordination								
Acimovic and Goentzel (2016)				✓*				
Aghajani et al. (2020)	✓*	✓*		✓				
Balcik and Ak (2014)	✓*	✓*		✓				
Edrissi et al. (2013)					✓*			
Bakhshi et al. (2022)		✓*	✓*	✓*	✓*			
Hu et al. (2019)		✓*						
John and Gurumurthy (2022)		✓*						
John et al. (2020)		✓*						
Liu et al. (2019)	✓*	✓*						
Nikkhoo and Bozorgi-Amiri (2018)		✓*			✓*			
Nikkhoo et al. (2018)		✓*						
Patra and Jha (2022)		✓*						
Rodríguez-Espíndola et al. (2018a)			✓*	✓*	✓*	✓*	✓*	
Rodríguez-Espíndola et al. (2018b)					✓*	✓*	✓*	
Rodríguez-Espíndola et al. (2020)			✓*	✓*	✓*	✓*	✓*	
Sarma et al. (2019)			✓		✓*		✓*	
Torabi et al. (2018)	✓*	✓*	✓	✓	✓			
Velasquez et al. (2019)	✓	✓*	✓	✓*	✓*			
Wang et al. (2015)		✓*						
Cooperation								
Baskaya et al. (2017)			✓	✓	✓*			
Chen et al. (2020)								
Coskun et al. (2019)		✓						
Davis et al. (2013)				✓*	✓			
Fathalikhani et al. (2018)					✓*			
Fathalikhani et al. (2020)					✓*			
Li et al. (2019)								
Shokr et al. (2021)	✓	✓	✓	✓	✓		✓	
Toyasaki et al. (2017)		✓						
Zhang (2021)		✓*		✓*				
Zhang and Kong (2022)		✓*		✓*				
Collaboration								
Akbari et al. (2022)				✓	✓*		✓*	✓*
Balcik et al. (2019)		✓*	✓*	✓*	✓			✓*
Ergun et al. (2014)								✓*
Ghasemi et al. (2022)			✓	✓	✓*		✓*	✓*
Nagurney and Qiang (2019)				✓*	✓*		✓*	
Rodríguez-Pereira et al. (2021)		✓*	✓*	✓*	✓			✓*
Sheu and Pan (2015)					✓*			
Shokr et al. (2022)	✓	✓*	✓*	✓*	✓*			

*Note: Decisions associated with 3C mechanisms

4.1.1 3C mechanisms for procurement

Acquisition of relief supplies through procurement and donations is an integral part of relief chain. As shown in Table 3, decisions related to supply procurement involve selecting suppliers and determining order quantity, which significantly affects response performance and are challenging due to the under and over-supply risks. Below, we summarize the 3C mechanisms that are developed to mitigate these risks (Table 2 and Table 3).

Coordination mechanisms. We observe that the coordinated relationships of HOs and suppliers have been modelled by various studies. Framework agreements (FAs) are among the contractual mechanisms that coordinate pre- and post-disaster procurement decisions in order to reduce the risks related to demand and supply uncertainty (Balcik and Ak, 2014). In particular, the supplier and the buyer agree on long-term purchasing terms (e.g., pricing) before a disaster occurs. The buyer may use the existing agreement whenever it is required. To deliver supplies according to pre-specified terms, the supplier reserves inventory for the relief groups; hence, framework agreements can also be considered as a form of pre-positioning (Balcik and Ak, 2014). FAs are the mostly addressed vertical coordination mechanisms in the OR papers. The contract types include quantity flexibility contracts (e.g., Balcik and Ak (2014), Torabi et al. (2018)), options contracts (e.g., Aghajani et al. (2020), Hu et al. (2019), Liu et al. (2019), Patra and Jha (2022), John et al. (2020)), wholesale contracts (e.g., Liu et al. (2019)) and buyback contracts (e.g., Hu et al. (2019)). As shown in Table 3, key decisions in these studies involve supplier selection and ordering quantity.

Another coordination mechanism that is discussed in the literature is group-buying, which refers to planning supply orders in a coordinated way to achieve cost benefits from the suppliers, such as quantity discounts (Shokr et al., 2022). The coordinated decisions involve supplier selection and order time, while quantity of supplies can be decided independently by each organization. For instance, Shokr et al. (2022) address a problem that the organizations operating nearby warehouses in a local network form purchasing groups to benefit from the supplier's quantity discount. In their setting, a coordinator is responsible for centralizing the HOs decisions, including supplier selection and ordering quantities.

Lastly, Nikkhoo et al. (2018) develop a mechanism to coordinate together procurement and last-mile distribution decisions. The authors focus on a setting that an HO outsources logistics activities to an LSP. The HO is responsible for procurement of relief supplies, while the LSP plans and operates last-mile distribution. The actors achieve a coordinated decision-making process by information-sharing; that is, the HO adjusts the ordering quantity based on the supply requests provided by the LSP.

Cooperation mechanisms. Cooperation in procurement may occur through stock sharing to mitigate post-disaster shortage risks. The mechanism is in the form of borrowing and lending of the relief stocks among HOs (Toyasaki et al., 2017). That is, HOs may supply (i.e., borrow) relief items from other HOs' inventory instead of purchasing them from the suppliers in order to reduce lead time. The primary decisions may involve (i) how to allocate stocks among more than one HOs and (ii) how much to share. Furthermore, the stock levels must be determined by considering the sharing opportunities. As shown in Table 2, there are several studies that address stock sharing between HOs (e.g., Coskun et al. (2019), Toyasaki et al. (2017)). Among them, only Toyasaki et al. (2017) specify an allocation rule that is based on proportional allocation.

Collaboration mechanisms. We observe that collaborative (i.e., joint) procurement involves purchasing joint supplies, such that the stocks are pooled under the shared ownership of each actor. A cost allocation scheme is essential to share total procurement costs among the actors. For instance, Balcik et al. (2019) and Rodríguez-Pereira et al. (2021) design a collaborative pre-positioning network that engage a set of partner countries (i.e., governments). The network involves joint stocks that can be mobilized for each country, and an umbrella organization decides the ordering quantity and cost allocation. Accordingly, the main challenge is deciding the amount of investment to be provided by each country. Nagurney and Qiang (2019) focus on the integration of different relief chains that involve a number of HOs managing procurement, transportation, storage, and last-mile distribution. The integrated relief chain performs similarly to a single relief chain in that operations are conducted with pooled resources and coordinated decisions and actions.

4.1.2 3C mechanisms for pre-positioning/inventory management

Decisions related to pre-positioning and inventory management involve location of facilities and allocation of relief supplies among the facilities (Table 3). These decisions are sometimes made together with procurement decisions as both functions are fundamental for pre-positioning.

Coordination mechanisms. Relief chains engage numerous humanitarian actors deploying vast amount of inventory all across the world. When allocation decisions are given independently, the optimal solution for each actor may lead to sub-optimal decisions for the system capacity, such as allocating stocks to the same location (Acimovic and Goentzel, 2016). This further results in inequities for the demand points since some areas may experience a lack of supply while others have supply surplus. Therefore, coordinating pre-positioning decisions through centralized or joint decision-making, as well as transparency and information sharing regarding global capacities is essential. There are a number of OR studies focusing on coordinated decision-making for pre-positioning. For example, Acimovic and Goentzel (2016) consider joint decision-making between humanitarian actors to decide allocation of supplies among the warehouses. Other studies mostly consider an assumption that the decisions of multiple HOs are planned and coordinated by a centralized decision-maker authority, such as the host government (e.g., Bakhshi et al. (2022), Velasquez et al. (2019)) or an umbrella organization (e.g., Shokr et al. (2022)).

Cooperation mechanisms. Pre-positioning incurs a large amount of setup and operational costs that might exceed the budget of some HOs. Therefore, HOs may stock inventory in the shared warehouses to benefit from cost savings and flexibility (Schulz and Blecken, 2010). In Zhang (2021) and Zhang and Kong (2022), a contractual cooperation mechanism is built between the government and the private sector (e.g., local enterprises and stores) through joint reserve allocation strategy to reduce shortage risk. Specifically, the government reserve relief supplies in the local enterprises by covering the cost of procurement, storage, and other services. To establish such a mechanism, the quantity to be held by each store must be determined. Another cooperation mechanism is defined by Davis et al. (2013), which addresses the relocation of stocks between warehouses operated by different HOs during the post-warning stage. In particular, the authors focus on a hurricane setting in which it is possible to predict the potentially damaged facilities before the hurricane hits the region. Thus, the authors define a cooperation mechanism to reallocate relief stocks to the facilities in safer areas to prevent supply damage.

Collaboration mechanisms. Collaborative (joint) pre-positioning involves joint ownership of warehouses and stocks. Balcik et al. (2019) and Rodríguez-Pereira et al. (2021) focus on collaborative pre-positioning that involves warehouse sharing in addition to keeping joint stocks. Shokr et al. (2022) consider both shared and independent warehouses, such that organizations may either manage their own stocks in the individual warehouses or use the shared warehouses by authorizing a coordinator for post-disaster distribution of stocks.

4.1.3 3C mechanisms for transportation and last-mile distribution

3Cs in transportation and last-mile distribution are associated with the decisions of allocating relief supplies among the demand points (e.g., beneficiaries, distribution centers) and routing of vehicles.

Coordination mechanisms. Similar to other relief chain functions, actors may engage in joint or centralized decision-making for transportation and last-mile distribution. In this regard, Rodríguez-Espíndola et al. (2018a,b, 2020) address horizontal coordination for a country network that involves three levels of GOs (local, regional, and national) engaging in disaster management. The coordination mechanism is based on activating the levels of GOs one by one according to the needs in order to prevent shortages and surplus. A centralized decision-maker determines whether or not to activate a level and the allocation of supplies to the distribution centers. Similarly, a number of papers consider a setting that the HOs operating in a relief chain network make their stocks available to a coordinator, who is responsible for managing the allocation of supplies among demand points (e.g., Sarma et al. (2019), Bakhshi et al. (2022)). Moreover, Edrissi et al. (2013) focus on coordination of different relief chain stage activities and address a setting that different organizations conduct mitigation, preparedness, and response activities. Coordinated decisions involve building renovation, transportation network improvement, and relief distribution.

Cooperation mechanisms. In transportation, cooperation often involves sharing assets, such as vehicles. For instance, Shokr et al. (2021) focus on vertical cooperation between several LSPs and a humanitarian organization. In particular, the humanitarian organization is responsible for the procurement of relief items, and the LSPs support relief operations by delivering items to the beneficiaries with their own vehicles. The authors assume that the operational cost incurred by all actors is covered by the humanitarian organization. Furthermore, the authors include a pre-disaster contract in their assumptions that ensures post-disaster cooperation.

Collaboration mechanisms. Actors may collaborate by operating joint vehicles while transporting relief supplies. For instance, Akbari et al. (2022) and Ghasemi et al. (2022) develop a collaboration mechanism based on joint usage of vehicles among the HOs. In particular, the authors define collaborative groups in which the vehicles are pooled and can be used by each actor. To establish such a mechanism, the authors determine the member of groups and the allocation of costs and benefits. Similarly, Sheu and Pan (2015) divide the NGOs into collaborative groups based on their attributes (see Section 4.3). That is, NGOs in the same group pool their relief supplies and act jointly during response operations. Finally, Ergun et al. (2014) develop a cost-sharing mechanism to address joint capacity building through an IT adaptation in order to improve coordination between different HOs during relief distribution.

4.2 Methodologies

This section presents an overview of OR methodologies developed to improve decision-making on 3C mechanisms. We first discuss the modeling approaches, and then present performance measures.

4.2.1 Modeling approaches

As shown in Table 4, several modeling approaches are used to address 3Cs, including mathematical programming models (e.g., integer, linear and non-linear programming, stochastic programming), game theory, and inventory models. Below, we briefly describe the types of modeling and solution approaches followed.

Mathematical programming. Mathematical programming models are developed to address almost all 3C mechanisms, involving coordinated decision-making, FAs, and resource sharing. Stochastic and robust programming mostly used models to incorporate uncertainty related design factors; yet, there are also a few

Table 4: Modeling and solution approaches

Author(s)	Modeling Approach	Solution Approach
Coordination		
Acimovic and Goentzel (2016)	Stochastic programming	Exact: Optimization solver
Aghajani et al. (2020)	Two-stage stochastic programming	Heuristic: Problem-specific heuristic
Balcik and Ak (2014)	Two-stage stochastic programming	Exact: Optimization solver
Bakhshi et al. (2022)	Nonlinear mixed integer programming	Exact: Optimization solver; Heuristic: Grasshopper algorithm
Edrissi et al. (2013)	Multi-agent optimization	Heuristic: Problem-specific heuristic
Hu et al. (2019)	Newsvendor model	Exact:Numerical techniques
John and Gurumurthy (2022)	Game theory (Stackelberg)	Exact: Numerical techniques
John et al. (2020)	Game theory (Stackelberg)	Exact: Numerical techniques
Liu et al. (2019)	Game theory (Stackelberg)	Exact:Numerical techniques
Nikkhoo and Bozorgi-Amiri (2018)	Possibilistic chance constraint programming	Exact: Optimization solver
Nikkhoo et al. (2018)	Newsvendor model	Exact: Numerical techniques
Patra and Jha (2022)	Newsvendor model	Exact: Numerical techniques
Rodríguez-Espíndola et al. (2018a)	Integer programming	Exact: Optimization solver
Rodríguez-Espíndola et al. (2018b)	Integer programming	Exact: Optimization solver
Rodríguez-Espíndola et al. (2020)	Two-stage stochastic programming	Exact: Optimization solver
Sarma et al. (2019)	Nonlinear programming	Exact: Optimization solver
Torabi et al. (2018)	Two-stage fuzzy-stochastic programming	Heuristic: Differential evolution algorithm
Velasquez et al. (2019)	Robust Optimization	Heuristic: Greedy heuristic
Wang et al. (2015)	Newsvendor model	Exact: Numerical techniques
Cooperation		
Baskaya et al. (2017)	Mixed integer linear programming	Exact: Optimization solver
Chen et al. (2020)	Evalutionary game theory model	Exact: Numerical techniques
Coskun et al. (2019)	Game theory (non-cooperative)	Exact:Numerical techniques
Davis et al. (2013)	Two-stage stochastic programming	Exact: Optimization solver
Fathalikhani et al. (2018)	Game theory (Stackelberg)	Exact: Numerical techniques
Fathalikhani et al. (2020)	Game theory (Stackelberg)	Exact: Numerical techniques
Li et al. (2019)	Evalutionary game theory model	Exact: Numerical techniques
Shokr et al. (2021)	Bi-level stochastic optimization, robust optimization	Exact: Optimization solver, Benders decomposition
Toyasaki et al. (2017)	Game theory (non-cooperative)	Exact: Numerical techniques
Zhang (2021)	Stochastic programming	Exact: Optimization solver
Zhang and Kong (2022)	Evalutionary game theory model	Exact: Numerical techniques
Collaboration		
Akbari et al. (2022)	Robust scenario-based optimization, game theory	Heuristic: Genetic algorithm
Balcik et al. (2019)	Two-stage stochastic programming	Exact: Optimization solver
Ergun et al. (2014)	Game theory (cooperative)	Exact: Numerical techniques
Ghasemi et al. (2022)	Chance-constraint programming, game theory	Model I; Exact: Optimization solver; Model II; Heuristic: Stochastic fractal search
Nagurney and Qiang (2019)	Game theory (cooperative)	Exact:Numerical techniques
Rodríguez-Pereira et al. (2021)	Two-stage stochastic programming, game theory	Exact: Optimization solver
Sheu and Pan (2015)	Stochastic dynamic nonlinear programming	Heuristic: Scenario-based method
Shokr et al. (2022)	Two-stage stochastic programming	Heuristic: Lagrangian relaxation

deterministic models. Some of the studies model decision-making problems of different actors with different drivers to engage in 3Cs. For example, Shokr et al. (2021) develop bi-level programming to model a last-mile distribution problem that involves an HO, which is responsible for the relief operations as a leader and seeks to minimize cost and reduce unmet demand, and a private sector company that supports relief operations as a follower and aims to maximize their distribution flow and revenue. Nikkhoo and Bozorgi-Amiri (2018) also develop two different models for a coordinated procurement and supply distribution problem, and solve them subsequently to achieve coordination. Specifically, the first model determines the order quantity of relief supplies that is managed by an HO, whereas the second model support decisions of an LSP by determining the number of supplies to be allocated to the beneficiaries. As shown in Table 4, most of the models are solved by using optimization solvers and some studies employ heuristics or exact algorithms.

Game theory. The reviewed papers use several game theory approaches, including cooperative and non-cooperative games, Stackelberg game, and evolutionary game theory models. Cooperative and non-cooperative game settings are mostly considered to model resource sharing. Specifically, cooperative game setting involves groups of actors (i.e., coalitions) pursuing cooperative behaviors within the coalition. For example, Ghasemi et al. (2022) address vehicle sharing between HOs and propose a two-step modeling approach by developing a chance constraint programming in a cooperative game setting. The first model solves a facility location and supply allocation problem as a first step and the second model solves the post-disaster routing problem as a second step. A cooperation mechanism through vehicle sharing is considered in the second model for different coalitions of cooperators' vehicles. The perspective of non-cooperative game can be utilized when the actors make decisions independently. For instance, Toyasaki et al. (2017) and Coskun et al. (2019) consider a non-cooperative game to address stock sharing between HOs, each determines pre-disaster inventory levels independently by considering post-disaster stock sharing opportunities. Stackelberg game is used to model sequential decision-making process, which assumes that the leader makes the first decision and the follower moves afterward. This approach is mostly considered in the studies addressing FAs due to the assumption of a buyer-dominant supply chain, in which humanitarian actors (a.k.a, leaders) choose from suppliers (a.k.a., followers) who compete for providing better procurement options. Stackelberg game is also used to model interactions between the NGOs and the donors (e.g., Fathalikhani et al. (2018), Fathalikhani et al. (2020)). In these models, donors are represented as followers who decide the amount of donations based on the NGOs' performance on response operations. Evolutionary game theory models are used to explore the sustainability of 3Cs by considering that actors' choices for engaging in 3Cs change over time. Finally, except Balcik et al. (2019) that design a cost-allocation scheme based on an insurance framework, studies considering cost and benefit allocation decisions use game theoretical approaches, such as Shapley value (e.g., Rodríguez-Pereira et al. (2021)).

Inventory models. Studies focusing on FAs mostly develop inventory models in a newsvendor setting to analytically derive order quantities. Some of them extend newsvendor problem by incorporating Stackelberg game, such that the contract terms (i.e., parameters) depend upon the humanitarian actors (a.k.a., leaders). There are also several studies that consider supplier selection (e.g., Liu et al. (2019)).

4.2.2 Performance measures

The performance measures considered in modeling 3C mechanisms are shown in Table 5. These measures are incorporated into the objective functions and/or constraints, or assessed through the model results. We should note that studies developing game theory models use utility functions to capture the benefits of 3Cs for each actor. Some studies consider intangible benefits, while some of them do not define the drivers explicitly (e.g., Chen et al. (2020), Li et al. (2019)). In particular, the authors use hypothetical parameter values to represent benefits numerically and compare the utility of alternate 3C mechanisms. Table 5 also present the aspects that the authors consider in the utility functions. The following are brief summaries of the main performance measures:

- *Costs.* HOs operate with limited budget and often have to meet the expectations of donors. It is essential for them to conduct operations in a most efficient way. Accordingly, cost is the primary concern in the majority of the studies. Studies focusing on pre-positioning are mostly concerned with cost related to facility opening, procurement, inventory holding, shortage and surplus. Transportation costs are considered in the studies addressing relief supply distribution. Some studies also consider costs incurred by 3Cs, such as stock sharing (transshipment) (e.g., Davis et al. (2013), Toyasaki et al. (2017)), investment (e.g., Balcik et al. (2019), Ergun et al. (2014)), and contract agreement costs (e.g., Torabi et al. (2018), Aghajani et al. (2020)).
- *Demand coverage.* There exist several studies that focus on maximizing the covered demand (e.g., Bakhshi et al. (2022)) or minimizing the uncovered demand (e.g., Rodríguez-Espíndola et al. (2018b)). The objective of minimizing supply and demand mismatch is also concerned with demand coverage. Moreover, some studies focus on conflicting objectives, such as maximizing demand coverage while minimizing procurement costs of relief supplies (e.g., Nikkhoo et al. (2018), John et al. (2020)).

Table 5: Metrics/objectives

Author(s)	Metrics/Objectives
Coordination	
Acimovic and Goentzel (2016)	[min] response time
Aghajani et al. (2020)	[min] cost (FAs, procurement, warehousing, transportation); [max] demand coverage
Balcik and Ak (2014)	[min] cost (FAs, procurement)
Bakhshi et al. (2022)	[min] cost(procurement, warehousing, transportation, shortage); [max] demand coverage
Edrissi et al. (2013)	[min] survival of the affected population
Hu et al. (2019)	[min] cost (procurement, warehousing, transportation, salvage)
John and Gurumurthy (2022)	[min] cost (procurement, salvage)
John et al. (2020)	[max] demand coverage; [min] cost (procurement, salvage)
Liu et al. (2019)	[min] cost (procurement,warehousing, salvage)
Nikkhoo and Bozorgi-Amiri (2018)	[min] cost (procurement, warehousing, transportation, shortage, vehicle allocation)
Nikkhoo et al. (2018)	[min] cost (inventory, transportation, shortage, salvage); [max] demand coverage
Patra and Jha (2022)	[min] cost (procurement, deprivation, salvage)
Rodríguez-Espíndola et al. (2018a)	[min] cost (warehousing, transportation), maximum unfulfilment of demand
Rodríguez-Espíndola et al. (2018b)	[min] cost (procurement, transportation), unmet demand
Rodríguez-Espíndola et al. (2020)	[min] shortage, cost (warehousing, transportation)
Sarma et al. (2019)	[min] cost (warehousing, transportation), response time
Torabi et al. (2018)	[min] cost (FAs, procurement, warehousing, transportation
Velasquez et al. (2019)	[min] total demand-weighted distance; fraction of demand (constraint)
Wang et al. (2015)	[min] cost; [max] demand coverage
Cooperation	
Baskaya et al. (2017)	[min] vulnerability factor of roads weighted average distance travelled
Chen et al. (2020)	[max] utility (3C cost, inventory risk, knowledge sharing)
Coskun et al. (2019)	[min] cost (procurement, warehousing, salvage)
Davis et al. (2013)	[min] cost (stock sharing, shortage, supply loss, transportation)
Fathalikhani et al. (2018)	[max] cost effectiveness
Fathalikhani et al. (2020)	[max] cost effectiveness
Li et al. (2019)	[max] utility (3C costs, demand coverage, response time)
Shokr et al. (2021)	[min] cost (procurement, warehousing, transportation), unmet demand
Toyasaki et al. (2017)	[min] cost (procurement, warehousing, stock sharing, leftover
Zhang (2021)	[min] total cost (procurement, warehousing, shortage)
Zhang and Kong (2022)	[max] demand coverage
Collaboration	
Akbari et al. (2022)	[min] cost (transportation, dispatch)
Balcik et al. (2019)	[min] cost (3Cs investment, warehousing, transportation)
Ergun et al. (2014)	[min] cost (3Cs investment)
Ghasemi et al. (2022)	[min] cost (warehousing), response time
Nagurney and Qiang (2019)	[min] cost (procurement, transportation, supply and demand mismatch)
Rodríguez-Pereira et al. (2021)	[min] cost (3Cs investment, warehousing, transportation)
Sheu and Pan (2015)	[min] supply and demand mismatch
Shokr et al. (2022)	[min] cost (procurement, warehousing, transportation, stock sharing)

- *Response time.* Timely and effective response is one of the major concern in humanitarian relief chain. Response time objectives include minimizing response time (e.g., Ghasemi et al. (2022)), demand weighted distance (e.g., Velasquez et al. (2019)) or average distance travelled per relief item (e.g., Baskaya et al. (2017)).
- *Equity/fairness.* The concepts of equity and fairness can be interpreted in a variety of ways and different metrics can be considered (Balcik et al., 2010). Moreover, the 3C benefits on equity and fairness metrics can be assessed for both beneficiaries and the 3C actors. Among the reviewed papers, Rodríguez-Espíndola et al. (2018a) aim to provide equitable service to beneficiaries by minimizing the maximum uncovered demand. Balcik et al. (2019) and Rodríguez-Pereira et al. (2021) focus on the fair allocation of investment costs required by the collaborative pre-positioning network that is covered by the governments (i.e., countries). As the partner countries engaged in 3Cs are also the beneficiaries, their approach can be considered as addressing concerns of equity for the beneficiaries. As discussed in Section 4.2, several

papers also consider equitable cost and benefit allocation among the 3C actors.

- *Waste.* Some studies aim to reduce waste of supplies by minimizing supply and demand mismatch (e.g., Sheu and Pan (2015), Nagurney and Qiang (2019)) or salvage cost (e.g., Coskun et al. (2019), Nikkhoo et al. (2018)). Minimizing supply loss due to post-disaster damage is also considered by Davis et al. (2013). Specifically, the authors address a post-warning stage problem that involves decisions related to shipping pre-positioned items from potentially damaged warehouses to the non-damaged warehouses.

Some of these studies present insights highlighting the benefits of 3Cs. For instance, pre-positioning strategies result in sub-optimal solutions when the organizations act in isolation (Velasquez et al., 2019). However, coordinating actors' inventory decisions increasingly reduce the system cost as the number of organizations grows, and provide better response (Acimovic and Goentzel, 2016). Moreover, stock sharing and risk pooling strategies lead significant cost savings and waste reduction (Balcik et al., 2019). Those benefits may also increase when the variation of demand is high (Coskun et al., 2019). As previously discussed, mobilization of all resources during the response operations does not lead to better results but rather causes several issues, such as supply congestion-related disruptions (Rodríguez-Espíndola et al., 2020). These issues amplify with the involvement of an ambiguous number of self-deployed NGOs that may bring excessive supplies to the disaster areas (Sheu and Pan, 2015). Indeed, instead of increasing the number of resources, coordinating relief efforts based on the actors' capabilities and resources is essential to improve the efficiency and effectiveness of relief operations. Aside from the benefits to the beneficiaries, improving performances through 3Cs may increase the amount of donations since donors observe the impact of their contributions grows (Fathalikhani et al., 2018).

4.3 Design factors

It is important to consider factors that influence the success and performance of 3Cs. The reviewed papers are concerned with several contextual, inter- and inner-organizational factors. Since the studies focus on a variety of problem contexts and modeling approaches, we are able to observe different applications and aspects regarding the design factors.

Studies address 3Cs among a diverse number of stakeholders, which are mostly considered decision-makers. Decision-makers involve local and international NGOs, governments, suppliers, and the private sector. Studies focusing on vertical 3Cs mostly consider FAs with the suppliers. Only a few studies address relationships between HOs and the LSPs (e.g., Nikkhoo and Bozorgi-Amiri (2018), Shokr et al. (2021)). Most of the studies focusing on horizontal 3Cs do not diversify relief actors in terms of inner-organizational factors. Exceptions to this include Bakhshi et al. (2022) and Sheu and Pan (2015), which differentiate GOs and NGOs based on resource availability by assuming that the NGOs' resources are dependent on the donations. Similarly, Chen et al. (2020) consider the differences in resource endowments of local and international organizations.

Environmental unpredictability has received the most attention as it is commonly included in humanitarian logistics literature. Table 6 shows different sources of uncertainties that we observe in the proposed models. Almost all studies consider uncertainty in demand when addressing relief distribution. Several studies focusing on relief distribution consider supply uncertainty related to warehouse damage (e.g., Balcik et al. (2019)) or supplier capacity (e.g., Aghajani et al. (2020)). Similarly, uncertainty in road network condition (e.g., Rodríguez-Espíndola et al. (2020), Velasquez et al. (2019)), purchasing cost (e.g., Bakhshi et al. (2022)) and transportation cost (e.g.,Aghajani et al. (2020)) are also embedded some of the models. Some studies are concerned with the ambiguity in quantity (e.g., Shokr et al. (2022)) and type (e.g., Sheu and Pan (2015)) of donated relief supplies.

Table 6: Source of uncertainties

Author(s)	Demand	Supplier capacity	Facility damage	Road network	Budget/ Donation	Purchs. cost	Transp. cost
Coordination							
Acimovic and Goentzel (2016)	✓						
Aghajani et al. (2020)	✓	✓	✓		✓	✓	✓
Balcik and Ak (2014)	✓					✓	
Bakhshi et al. (2022)	✓	✓			✓		✓
Edrissi et al. (2013)				✓			
Hu et al. (2019)	✓						
John and Gurumurthy (2022)	✓						
John et al. (2020)	✓						
Liu et al. (2019)	✓						
Nikkhoo and Bozorgi-Amiri (2018)	✓				✓		✓
Nikkhoo et al. (2018)	✓						
Patra and Jha (2022)	✓						
Rodríguez-Espíndola et al. (2018a)							
Rodríguez-Espíndola et al. (2018b)							
Rodríguez-Espíndola et al. (2020)	✓			✓		✓	
Sarma et al. (2019)	✓				✓		
Torabi et al. (2018)	✓						✓
Velasquez et al. (2019)	✓			✓			
Wang et al. (2015)	✓						
Cooperation							
Baskaya et al. (2017)							
Chen et al. (2020)							
Coskun et al. (2019)	✓						
Davis et al. (2013)	✓		✓				
Fathalikhani et al. (2018)							
Fathalikhani et al. (2020)							
Li et al. (2019)							
Shokr et al. (2021)	✓				✓	✓	
Toyasaki et al. (2017)	✓						
Zhang (2021)	✓		✓				
Zhang and Kong (2022)							
Collaboration							
Akbari et al. (2022)	✓						
Balcik et al. (2019)	✓		✓				
Ergun et al. (2014)							
Ghasemi et al. (2022)	✓			✓			
Nagurney and Qiang (2019)	✓			✓		✓	✓
Rodríguez-Pereira et al. (2021)	✓		✓				
Sheu and Pan (2015)					✓		
Shokr et al. (2022)	✓				✓		✓

There are a few papers that study inter- and inner-organizational factors. For instance, Li et al. (2019) incorporated level of trust into their game theory model. Specifically, the authors consider that trust enhances coordination benefits (i.e., returns) by improving information sharing and other interactions. Thus, they define parameters denoting trust levels and associate them with coordination benefits in the payoff functions. In Chen et al. (2020), the authors focus on resource and knowledge sharing and consider resource complementarity as a driver to cooperate. Similar to Li et al. (2019), they parameterize benefits of cooperation that can be gained by sharing tangible (e.g., equipment) and intangible (e.g., expertise) resources. Nevertheless, due to the lack of exact data on intangible benefits, the authors set the parameter values by referring Li et al. (2019)'s study. Some of the inner-organizational factors are addressed by Sheu and Pan (2015). Specifically, the authors assign NGOs to different groups based on three organizational factors, so that the NGOs within each group collaborate. The first factor is related to degree of incentive alignment of the NGOs, such as willingness to collaborate. The second factor refers to the willingness to share relief capabilities, including the organizations' experience and equipment. The last factor is the degree of information sharing, considering the accuracy and confidentiality.

4.4 Enablers

There are a number of studies considering the presence of an IT system as a problem assumption (e.g., Rodríguez-Espíndola et al. (2018b), Sheu and Pan (2015)). Besides these studies, only Ergun et al. (2014)

primarily focus on integrating a technology to enable 3Cs. Specifically, the authors address a coordination problem among camps for internally displaced people. They highlight the benefits of an IT system for multi-agency coordination and data management. Finally, Acimovic and Goentzel (2016) collaborate with the OCHA and present a process that combine their analytical approach with a global map of emergency stockpiles.

The reviewed studies often involve umbrella organizations as an actor that facilitate coordinated decision-making. For instance, Rodríguez-Espíndola et al. (2020, 2018a,b) focus on a country network, where relief chain coordination is supported by a governmental structure. Balcik et al. (2019) and Rodríguez-Pereira et al. (2021) focus on activities of an inter-governmental agency that mobilize and support disaster relief in Caribbean (CDEMA, 2022). Specifically, the agency coordinates HOs and motivates cooperative arrangements and mechanisms among the participating countries. In Balcik et al. (2019) and Rodríguez-Pereira et al. (2021), an umbrella organization enables partners to keep joint stocks in the regional warehouses. Toyasaki et al. (2017) focus on the UNHRD network and build their model based on the network's inventory management system. The authors develop a cooperation mechanism based on the findings from the interviews that they conducted with member and non-member HOs to understand their incentives for joining the network.

5 Research gaps

Over years, different aspects of relief chain 3Cs have been widely studied. The interest within the OR community has also grown; yet, there are still many research avenues to be explored. In this section, we synthesize the insights and findings that we derive from the reviewed papers and shed light on research gaps to address *RQ3*.

- *3C mechanisms for procurement.* FAs are highly addressed for coordinating pre- and post-disaster procurement. The studies focusing on FAs are mostly concerned with demand uncertainty but ignore other factors, such as supply uncertainty. Moreover, other supply sources than procurement, such as donations, also receive little attention. Therefore, one useful extension to the existing models could be the inclusion of donors. For instance, pre-disaster ordering quantities could be decided under the uncertainty of cash and in-kind donations. In addition to revealing unexplored benefits of FAs, modeling these factors may provide valuable insights for donors.
- *3C mechanisms for pre-positioning/inventory management.* Although different types of 3Cs for pre-positioning strategies are studied, no study incorporates pre-disaster in-kind donations. For example, organizations may refuse the in-kind donations unwillingly due to the insufficient resource and storage capacity. Besides, perishable in-kind donations might be wasted if they are not used for some time. In this regard, 3C mechanisms through resource (e.g., warehouse, stock) sharing could provide opportunities, and it would be very useful to explore their benefits in terms of reducing cost and waste.
- *3C mechanisms for transportation and last-mile distribution.* Efficient planning and execution of transportation operations are critical since the function generates a large portion of overhead costs in relief chains. One important decision is whether to handle transportation in-house or outsource. Both options have advantages and disadvantages, but outsourcing is the only option for some organizations due to budgetary constraints. In this regard, future research may discover the benefits of fleet sharing. It would be beneficial to develop cost-sharing mechanisms for the fair allocation of investment and operating costs.
- *3C actors.* Our review suggests that 3Cs among different stakeholders needs more attention. Specifically, the majority of papers focus on horizontal 3Cs between humanitarian (i.e., governmental and non-governmental) organizations. Although the critical role of business partners (e.g., LSPs) and donors is widely discussed in practice and conceptual studies, 3C mechanisms between these stakeholders receive

little attention from OR community. Moreover, there is only a few studies that focus on collaboration in a global scale. Given the growing importance of SDG 17, it would be extremely valuable to develop OR approaches that support decisions for global partnerships.

- *Drivers/benefits.* We observe that most of the studies are concerned with cost-based objectives and performance metrics. A number of papers address multi-objective decision-making by focusing on cost-based and response-based measures. In this respect, it would be valuable to analyze the impact of different 3Cs on increasing equity and fairness, reducing waste, and the trade-off between conflicting metrics, such as demand coverage and waste.
- *Cost/benefit allocation.* According to our findings, most of the studies use game theoretical approaches to allocate costs and benefits of the 3Cs. Some of these approaches are computationally demanding and can only be applied to a limited number of actors. Nevertheless, a few reviewed papers propose alternative methods based on their problem settings and show their superiority in terms of performance metrics and computational efficiency. Future research can investigate the problem-specific rule of thumbs or simple methods for allocating costs and benefits.
- *Design factors.* Contextual factors are well-recognized in the reviewed papers as they are fundamental to the humanitarian relief context. Accordingly, the majority of them, especially the various sources of uncertainty, are incorporated into the OR models. However, inter- and intra-organizational factors have been overlooked in OR studies as it is a challenge to characterize and measure them, which may require conducting interdisciplinary and empirical research. Future research can study those factors using OR approaches based on the findings of conceptual and empirical works. For example, several studies highlight that 3Cs can be more beneficial for small-sized organizations (e.g., Schulz and Blecken (2010), Gossler et al. (2020)). It would be interesting to explore the benefits of different 3C mechanisms for organizations that are differentiated by size-related aspects, such as amount of budget and resource capacity. Furthermore, incorporating behavioral factors, such as trust and commitment, is a significant challenge, yet necessary. For instance, most models assume sharing mechanisms based on structured allocation policies (e.g., Toyasaki et al. (2017)), which may not be applicable in practice due to inter-organizational relationships. An alternative to this approach can be defining an allocation rule that prioritizes organizations based on the level of relations.
- *Enablers/facilitators.* How to apply the proposed OR approaches in practice is a critical and major concern. Indeed, OR models are often constructed on a set of assumptions that limit the accurate representation of real-world situations, which may result in criticism of their managerial insights for not being practical enough (Choi et al., 2016). Enablers are one of the essentials of many 3Cs mechanisms and have an important role in models' applicability; therefore, they should not be overlooked in OR approaches. Future research may either consider enablers in modeling assumptions, or develop models to support integration (e.g., technology) or applications (e.g., umbrella organizations) of them.
- *Practical implications.* A number of studies test the proposed models on the real-world case studies, generate data sets based on historical data, and/or interview with practitioners to define their problem settings realistically. Moreover, some authors conduct their research in close collaboration with practitioners and develop decision-support tools for the organizations' existing problems. Indeed, our review reveals a growing trend for the collaboration between practitioners and scholars. We encourage researchers to pursue this trend to create practical value while ensuring the rigor of the studies. We also suggest designing simulation models to highlight the benefits of 3Cs by comparing the current state and the proposed approaches. Simulations can make results more understandable and answer important questions, such as

when and in which circumstances the 3Cs are worthwhile. We believe that insights derived from these studies would motivate practitioners for the 3Cs.

6 Conclusion

In this study, we review and analyze the literature to provide insights into OR applications that support decision-making for 3Cs in relief chains. In particular, we review the articles studying 3Cs conceptually and analytically. We synthesize our findings and present a conceptual framework that sets a research agenda for scholars to improve relief chain 3Cs. We then analyze the OR studies based on our conceptual framework, specifically by focusing on problem settings and methodologies. Finally, we identify research gaps and avenues based on our findings from conceptual and empirical works, and present insights to enhance the practical values of proposed approaches.

We hope that our conceptual framework and findings contribute to the advancement of OR approaches to improve decision-making in relief chains. Despite this research having limitations since the listed references are obtained from a set of databases, the sampled articles can be considered representative of the existing studies.

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