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## Article

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## A Multi-Criteria Vertical Coordination Framework for a Reliable Aid Distribution

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### Abstract:

**Purpose:** This study proposes a methodology that translates multiple humanitarian supply chain stakeholders' preferences from qualitative to quantitative values, enabling these preferences to be integrated into optimization models to ensure their balanced and simultaneous implementation during the decision-making process.

**Design/methodology/approach:** An extensive literature review is used to justify the importance of developing a strategy that minimizes the impact of a lack of coordination on humanitarian logistics decisions. A methodology for a multi-criteria framework is presented that allows humanitarian stakeholders' interests to be integrated into the humanitarian decision-making process.

**Findings:** The findings suggest that integrating stakeholders' interests into the humanitarian decision-making process will improve its reliability.

**Research limitations/implications:** To further validate the weights of each stakeholder's interests obtained from the literature review requires interviews with the corresponding organizations. However, the literature review supports the statements in this paper.

**Practical implications:** The cost of a lack of coordination between stakeholders in humanitarian logistics has been increasing during the last decade. These coordination costs can be minimized if humanitarian logistics' decision-makers measure and simultaneously consider multiple stakeholders' preferences.

**Social implications:** When stakeholders' goals are aligned, the humanitarian logistics response becomes more efficient, increasing the quality of delivered aid and providing timely assistance to the affected population in order to minimize their suffering.

**Originality/value:** This study provides a methodology that translates humanitarian supply chain stakeholders' interests into quantitative values, enabling them to be integrated into mathematical models to ensure relief distribution based on the stakeholders' preferences.

**Keywords:** humanitarian logistics, relief distribution, stakeholders, response, methodology, vertical coordination, multi-criteria

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## 1. Introduction

Humanitarian logistics represents the activities performed before, during, and after a disaster in order to diminish its impact. The main task of humanitarian logistics is delivering appropriate supplies in good condition and in the required amounts to the right places at the right moment (Ortuño, Cristóbal, Ferrer, Martín-Campo, Muñoz, Tirado et al., 2013).

Disasters are divided into four life-cycle stages, as presented in Altay and Green (2006) (Figure 1). "Mitigation" and "preparedness," better known as the pre-disaster stages, take place before the disaster occurs in order to minimize its occurrence probability or, in the worst case, its negative effects. In these stages, protocols are reinforced, and people are trained to be prepared for a new disaster. Then, the post-disaster stages are "response" and "recovery," which try to minimize the effects of a disaster by helping people as quickly as possible, and by supporting the community in returning their lives to how they were prior to the disaster (Altay & Green, 2006; Ang & Hern, 2015).

The response life-cycle stage requires the intervention of international and local actors, largely owing to its characteristics (e.g., the increase in demand urgency and volume) (Ang & Hern, 2015). The uncertainty of demand, resource scarcity, and competition for funds are already challenges in relief distribution. However, the number and diversity of actors involved in the process directly impact the efficiency of the humanitarian supply chain (Balcik, Beamon, Krejci, Muramatsu & Ramirez, 2010), making coordination among these actors a key aspect.

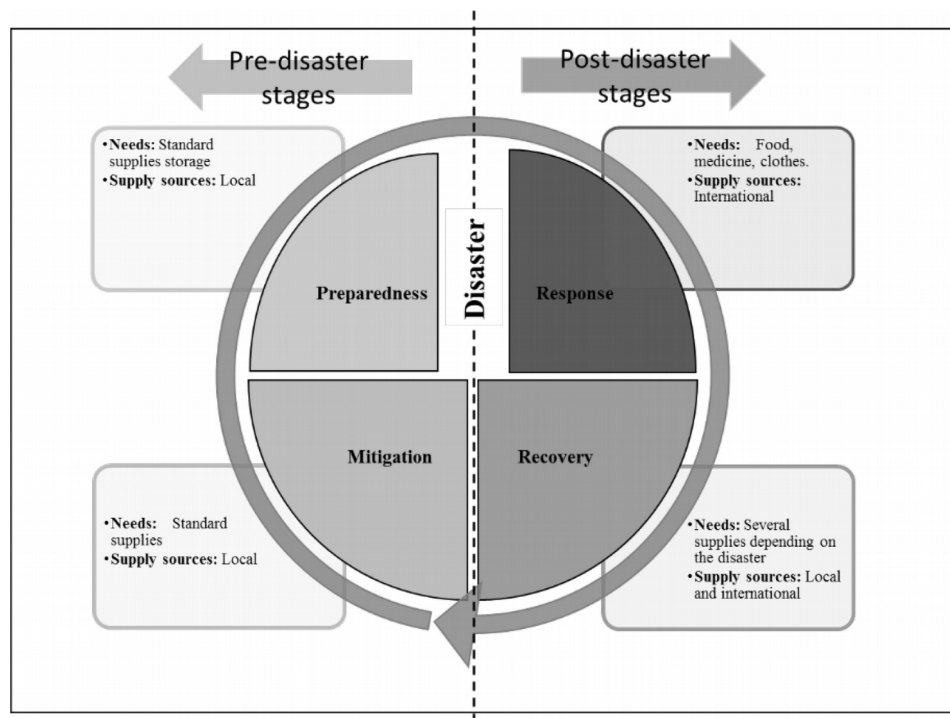


Figure 1. Disaster life cycle stages (Altay & Green, 2006)

The mandatory intervention of several stakeholders, each with their own goals, interests, capacities, and expertise, means a lack of coordination among them results in ineffective relief distribution. This can cause, for example, resources to be used in an inadequate manner, and relief efforts to be duplicated (Moshtari & Gonçalves, 2011).

Coordination can be represented in a horizontal or a vertical manner. Horizontal coordination refers to the relations among competitors and/or non-competitors who provide similar services, or among internal departments with similar functions (Akhtar, Marr & Garnevsca, 2012). Vertical coordination refers to the parallel actions of suppliers and customers, or across departments within the same organization. This type of coordination can be found in upstream or downstream activities (Balcik et al., 2010; Moshtari & Gonçalves, 2011).

To solve the relief distribution problem, several optimization models have been proposed, each tackling the problem from a different perspective and, in most cases, resulting in multi-objective models. The pursuit of more than one objective and the intervention of several actors (horizontal and vertical coordination) requires using multi-criteria decision-making methods to achieve a balanced and effective solution to realize the goals of the humanitarian supply chain. In addition, there is increased interest in developing metrics to evaluate humanitarian supply chain performance. To integrate these metrics into the decision-making process, and to combine them with stakeholders' preferences, we need to translate these preferences into quantified values in order to make effective and efficient decisions.

This work presents and applies a methodology as a strategy to solve the problem of a lack of coordination in the humanitarian supply chain. The remainder of the paper is organized into four sections. Section 1 introduces the problem and states the goals of the research. Section 2 reviews the literature on coordinating the humanitarian supply chain. Section 3 describes the proposed methodology for developing a multi-criteria framework. Lastly, Section 4 concludes the paper, and suggests possible areas for future research.

## **2. Literature Review**

In order to provide a context for this research, this section reviews existing literature related to coordinating humanitarian logistics. This section establishes the importance of this study. The contributions presented in this section were identified through a detailed search of the ISI Web of Knowledge and Scopus. The keywords used in the search were coordination, disaster, humanitarian, relief, response, distribution, and supply chain.

Many studies have examined coordination in the context of commercial supply chains, but few have done so in the context of their humanitarian counterparts. Several authors have focused on understanding coordination itself, and the challenges resulting from a lack thereof in humanitarian supply chains. Furthermore, the number of studies related to the development of qualitative and quantitative strategies to overcome these challenges has increased in the last five years.

In order to make this research as complete as possible and given the limited number of contributions related to the response in the aftermath of natural disasters, a systematic review methodology was used as follows:

1. Identification of the investigation. With this literature review, we intend to find as many as possible contributions related to the coordination problem in the humanitarian logistics context, specifically in the relief distribution during the response phase.
2. Material collection. In order to do this research, a query considering the keywords “coordination”, “disaster”, “humanitarian”, “relief”, and “response”, was submitted to ISI Web of Knowledge and Scopus databases. The keywords were explored in titles and abstracts.
3. Inclusion and exclusion criteria
  - a) Inclusion criteria. The literature review considered analytical and empirical academic publications such as peer-reviewed papers, conference proceedings with full-paper, and dissertations due to their academic relevance. All the references included in this literature review meet the characteristics presented in the identification of research point. Also, the references are aligned with the Operational Research, Transportation, and Industrial Engineering categories. Due to the lack of contributions related to the coordination problem in humanitarian logistics, the date range was established between 1996 and 2017, justified by the fact that most of the contributions related to humanitarian logistics are presented within this period. Considering the limited number of contributions, books’ chapters and the governmental and military reports were included in this research.
  - b) Exclusion criteria. Non-English articles and manuals were excluded from the analysis.

After this search, a total of 384 documents were found in the databases. With a second filter, duplicates were eliminated and the sample was reviewed to ensure that the remaining papers meet the inclusion and exclusion criteria. As the articles were reviewed the inclusion of other pertinent cited articles was carried out. Finally, a total of 27 papers met the inclusion and exclusion criteria.

Following, some of the most important contributions related to coordination in humanitarian logistics are presented. Due to the recent concern about to deal with the lack of coordination among stakeholders in the humanitarian logistics, most of the contributions remains in a qualitative context.

In 2010, Balcik et al. (2010), presented an overview of the coordination issues related to relief chains, and concluded that coordination is one of the critical aspects of the humanitarian supply chain that must be improved in order to increase its efficiency. Then, the behavior, drivers, and barriers related to the horizontal coordination of organizations in the humanitarian supply chain are presented in Moshtari and Gonçalves (2011). Dolinskaya, Shi and Smilowitz (2011), identify that the large number and diversity of actors, urgency of a humanitarian relief response, short period in which to establish coordination, limited information sharing and communication, allocation of costs, risk, and insufficient

personnel dedicated to logistics coordination are the main challenges to improving the coordination among humanitarian stakeholders. Strategies to overcome these challenges are also presented in the latter work, but they focus on a qualitative aspect. Another example of qualitative research is that of Hovhannessian (2012), who uses interviews and a literature review to analyze the vertical coordination barriers that exist between humanitarian organizations and commercial agencies in relief distribution. In addition, Heaslip (2012) contributes to the literature with an empirical comparison of military and humanitarian organizations, proposing a framework that identifies the interactions between stakeholders and involved components.

In addition to these qualitative studies, Huang, Li and Omitaomu (2011) propose a conceptual mathematical model to evaluate the coordination within the humanitarian supply chain, taking into account the overall coordination costs of procurement, and warehousing and transportation activities (pre- and post- disaster stages). Kabra, Ramesh and Arshinder (2015) present a pioneering attempt to prioritize barriers to coordination. They identify, classify, verify, and prioritize the coordination barriers, specifically for the Indian context. Their study concludes that management and technological barriers have the greatest impact on coordination. Finally, Gralla, Goentzel and Fine (2014), using a conjoint analysis, evaluate and develop an objective function to represent the goals of humanitarian relief. These authors used a group of humanitarian logisticians (horizontal coordination) to value the trade-offs among the multiple humanitarian aid goals.

Based on the literature review, we conclude that researchers attach great importance to the lack of coordination among humanitarian supply chain stakeholders. Many studies quantify the impact of a lack of coordination on supply chains, but recently, there has been growing interest in translating humanitarian supply chain stakeholders' preferences from qualitative into quantitative values, thus, making it possible to integrate them into the decision-making process.

### **3. Multi-Criteria Framework Development Methodology**

The intervention of several stakeholders in the aftermath of a disaster is unavoidable, and a lack of coordination between them can cause a lack of efficiency and duplicated efforts. Humanitarian logistics experts must make decisions under uncertainty and within a short time, but must also consider multiple stakeholders' preferences during the decision-making process. This becomes a challenge, owing to the complexity of decisions problems that involve ranking, choice, and sorting. Often, a perfect solution that satisfies all stakeholder preferences is not possible. However, it is possible to identify a good solution that satisfies most stakeholder preferences.

In this section, based on the literature review, we present the proposed methodology that translates the humanitarian supply chain stakeholders' preferences from qualitative into quantitative values. As such, these preferences can be integrated into the decision-making process. After prioritizing stakeholders' interests, these are integrated into a multi-criteria objective function used to evaluate the distribution of relief.

To achieve our goal, we consider a general relief distribution scenario during the response stage. Once a disaster occurs, vertical coordination is used to coordinate the intervention of governmental and non-governmental organizations, donors, the private sector, and military organizations to attend to the affected population.

In order to identify, prioritize, and translate the preferred objectives in the humanitarian supply chain from qualitative to quantitative values, we propose the methodology shown in Figure 2 to develop a multi-criteria framework.

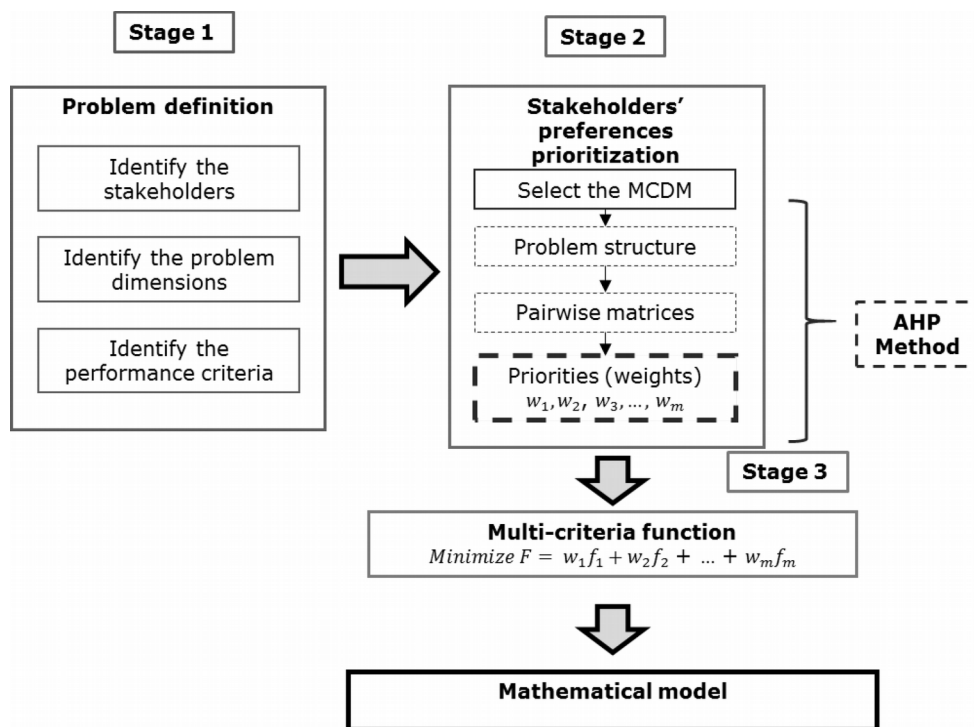


Figure 2. Methodology

The methodology comprises three main stages: defining the problem; selecting and applying a multi-criteria decision-making (MCDM) method to translate the stakeholders' interests into



quantitative values; and formulating the multi-criteria function, enabling it to be solved using mathematical programming.

### 3.1. Problem Definition (Stage 1)

This stage aims to identify the (1) stakeholders, (2) problem dimensions, and (3) performance criteria.

#### 3.1.1. Stakeholders

As stated earlier, for the purpose of this work, we use vertical coordination (see Figure 3). Here, in a hierarchy, governmental organizations are identified as Level 1, non-governmental organizations as Level 2, and donors, private sector companies, and military organizations as Level 3. The stakeholder profiles are determined by identifying their responsibilities (Table 1) and their goals (Table 2).



Figure 3. Vertical coordination (Balcik et al., 2010; Moshtari & Gonçalves, 2011)

Vertical coordination level	Responsibilities
Governmental organizations	The coordination of actors involved in the relief distribution process.
Non-governmental organizations	Relief distribution (food, water, and medical supplies).
Private sector companies/Donors	Provide financial or in-kind donations, and share transportation resources (physical or/and knowledge).
Military	Provide security, logistics skills, repair, communications, and medical care.

Table 1. Vertical coordination stakeholders' responsibilities (Balcik et al., 2010)

Vertical coordination level	Goals
Governmental organizations	To minimize the costs related to the lack of coordination among organizations.
Non-governmental organizations	To manage resources in order to maximize the coverage and equity of the demand.
Private sector companies / Donors	To increase the efficiency of the humanitarian supply chain.
Military	To maximize the reliability of the aid delivery process (planned vs real, considering the complications linked to the relief distribution problem), but also to minimize the relief response time.

Table 2. Vertical coordination to address stakeholders' goals

### 3.1.2. Problem Dimensions

The dimensions of the problem are the aspects to be evaluated. Based on the literature review presented in Table 3, the most used objective functions can be classified into three dimensions (social, reliable, and economic). The **social** dimension refers to the impact on the affected population of a lack of access to a good or service. The **reliability** dimension aims to meet the demand as planned, considering most of the cases, the response/travel time linked to the damaged infrastructure, and the possibility of second, third, or more disasters occurring during the relief distribution. Finally, in the **economic** dimension, although minimizing costs (financial, human, technical, and material) is not the main objective, when NGO decision-makers define where and how aid will be delivered and the resources required to do so, minimizing relevant costs is one of the metrics used to evaluate a supply chain and stakeholders' interests. This measure usually evaluates how the inputs are converted into outputs (e.g., the number of vehicles required, and the travel distance or travel time).

### 3.1.3. Performance Criteria

The concept of performance criteria refers to how the dimensions (economic, social, and reliable) are measured. To determine the performance criteria for this framework, an extensive literature review was performed.

To make this research as complete as possible, a query containing the keywords “disaster”, “humanitarian”, “relief”, “mathematical programming”, and “distribution”, was submitted to ISI Web and Scopus databases. As inclusion criteria, the literature review considered analytical and empirical academic publications such as peer-reviewed papers, conference proceedings with full-paper, books, and dissertations. To restrict more our research, the search was limited to the contributions within the Operational Research, Transportation, and Industrial Engineering categories. The data range was

established between 1996 and 2016. Additionally, to reflect our interest in the response stage, the selected contributions were focused on this phase. The research was limited to the network design and transportation, justified by the fact those are the main activities during the relief distribution and are the ones analyzed in this paper. Furthermore, given a large number of contributions in the response stage context, we limited our search to papers tackling sudden-onset disasters only. The manuals and governmental or military reports were excluded from this research. Articles solely focused on pre-positioning and warehousing were also excluded. The contributions only consider those written in English. Finally, after a debug of the initial 1040 documents, a total of 59 papers that meet the inclusion and exclusion criteria were found (see Table 3).

Reference	MC	MTD	MPC	MV	MUD	MLAT	MESD	MRT	MTT	MTR
Haghani and Oh (1996)	X									
Oh and Haghani (1997)	X							X		
Barbarosoglu, Özdamar and Cevik (2002)	X							X		
Viswanath and Peeta (2003)	X									
Barbarosoglu and Arda (2004)	X									
Özdamar, Ekinci and Küçükyazici (2004)					X					
Tzeng, Cheng and Huang (2007)	X				X			X		
Yi and Kumar (2007)					X					
Yi and Özdamar (2007)					X			X		
de Angelis, Mecoli, Nikoi and Storchi (2007)					X					
Horner and Downs (2007)	X									
Jia, Ordo and Dessouky (2007)					X					
Sheu (2007)								X		
Balcik, Beamon and Smilowitz (2008)	X									
Balcik and Beamon (2008)					X					
Campbell, Vandenbussche and Hermann (2008)	X					X		X		
Hsueh, Chen and Chou (2008)									X	
Zografos and Androustopoulos (2008)	X									X
Lin (2009)					X			X	X	
Vitoriano, Ortuño and Tirado (2009)	X									X
Yuan and Wang (2009)			X						X	
Zhu and Ji (2009)	X				X					
Afshar and Haghani (2009)					X					
Adivar and Mert (2010)	X									X
Chern, Chen and Kung (2010)								X		X
Campbell and Jones (2011)	X									
Horner and Downs (2010)	X									
Mete and Zabinsky (2010)	X				X				X	

Reference	MC	MTD	MPC	MV	MUD	MLAT	MESD	MRT	MTT	MTR
Nolz, Doerner, Gutjahr and Hartl (2010)	X					X		X		
Rawls and Turnquist (2010)	X				X					
Nolz, Doerner and Hartl (2010)	X	X			X					
Vitoriano, Ortuño, Tirado and Montero (2011)	X				X		X		X	X
Görmez, Köksalan and Salman (2011)		X								
Gu (2011)					X			X		
Horner and Widener (2011)	X				X					
Lin, Batta, Rogerson, Blatt and Flanigan (2011)	X				X		X		X	
Zhan and Liu (2011)					X				X	
Clark and Culkin (2013)	X			X	X					X
Huang, Smilowitz and Balcik (2012)							X	X	X	
Abounacer, Renaud and Rekik (2012)	X				X				X	
Berkoune, Renaud, Rekik and Ruiz (2012)									X	
Bozorgi-Amiri, Jabalameli and Al-e-Hashem (2013)	X				X				X	
Buzón (2012)					X		X	X	X	
Ben-Tal, Chung, Mandala and Yao (2011)	X									
Naji-Azimi, Renaud, Ruiz and Salari (2012)		X								
Noyan (2012)										X
Özdamar and Demir (2012)									X	
Rottkemper, Fischer and Blecken (2012)	X				X					
Tricoire, Graf and Gutjahr (2012)	X				X					
Wohlgemuth, Oloruntoba and Clausen (2012)				X					X	
Zhang, Zhang, Zhang, Wei and Deng (2013)		X							X	
Anaya-Arenas, Ruiz and Renaud (2013)	X				X		X			
Najafi, Eshghi and Dullaert (2013)				X	X					
Battini, Peretti, Persona and Sgarbossa (2014)	X			X	X				X	
Barzinpour and Esmacili (2014)	X				X					
Rath and Gutjahr (2014)	X				X					
Rennemo, Rø, Hvattum and Tirado (2014)	X							X		
Edrissi, Nourinejad and Roorda (2015)		X			X			X		
Hong, Jeong and Feng (2015)	X				X					

MC: Min costs; MTD: minimize Traveled Distance; MPC: Minimize Path Complexity; MV: Minimize Vehicles; MUD: Min Unmet Demand; MLAT: Minimize Latest Arrival Time; MESD: Minimize Equity of Satisfied Demand; MRT: Minimize Response Time; MTT: Minimize Traveled Time; MTR: Minimize Travel Reliability.

Table 3. Main pursued performance criteria for a relief distribution problem

Based on Table 3, it can be observed that minimizing costs (28.26%), unmet demand (27.17%), travel time (15.22%), and the response time (13.04%) are all important. Although the risk and the equity of satisfying demand are not necessarily the most sought-after performance criteria in humanitarian logistics

supply chains (5.43% and 4.35%, respectively), an increasing number of studies have begun to examine these areas in the last decade.

Once each stakeholder's profile, dimensions, and performance criteria are identified, their interests are prioritized by applying multi-criteria decision-making (MCDM) methods.

### 3.2. Stakeholders Preference Prioritization (Stage 2)

This stage defines and translates preferences from qualitative to quantitative values. To do so, a multi-criteria decision-making (MCDM) method is chosen. Here, we adopt the analytic hierarchy process (AHP) for its flexibility and ability to handle the imprecise judgment of experts in order to prioritize the stakeholders' preferences. This method assesses the relative importance of criteria and alternatives, and translates subjective judgments into relative weights of importance (Saaty, 1997). Nevertheless, a different MCDM method can be used according to the information availability.

#### 3.2.1. Problem Structure (AHP Method)

The dimensions and performance criteria must be linked. To do so, the problem is hierarchized, which means the problem, its dimensions, and its performance criteria are linked and presented in a hierarchical structure.

In this case, the problem is identified in the first level of the hierarchy as one of reliable aid distribution. According to the given definitions, each identified performance criterion is linked to a dimension. In order to present these in a hierarchical structure, the dimensions occupy the second level and the performance criteria the third level, as shown in Figure 4.

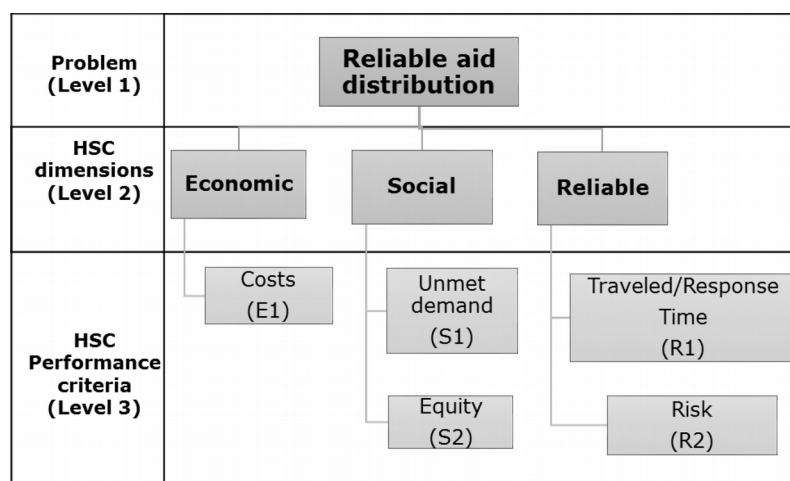


Figure 4. Reliable aid distribution problem structure

### 3.2.2. Pairwise Matrices

Once the problem, dimensions, and performance criteria have been linked and presented in a hierarchical way, the pairwise matrices are developed.

To determine the importance each stakeholder assigns to a performance criterion, a literature review is performed, considering a query containing “coordination”, “humanitarian logistics” and “performance criteria” as keywords to ISI Web and Scopus databases. As inclusion criteria, the literature review considered analytical publications such as peer-reviewed papers and conference proceedings with full-paper. The search was limited to the contributions within the Operational Research, Transportation, and Industrial Engineering categories and the data range was established between 1996 and 2016. The manuals and governmental or military reports were excluded from this research. Only written English contributions were considered. After this initial search, a total of 265 documents were found in the databases. A second filter helped us to eliminate duplicates and to ensure that the remaining papers integrate at least one of the stakeholders presented in Section 3.1. As the articles were reviewed the inclusion of other pertinent cited articles was carried out. Finally, a total of 21 papers met the inclusion and exclusion criteria (Table 4 and Table 7). In Table 4 the contributions are presented according to the stakeholder and Table 7 presents the contributions linking the performance criteria and each stakeholder. In Table 4, the contributions related to coordination are presented for the relationship between the performance criteria and the stakeholders.

Note that each stakeholder has a priority in humanitarian supply chain decisions. Thus, establishing the weight of each stakeholder is crucial. According to the AHP method, to determine the priority of each stakeholder over the humanitarian supply chain, an initial pairwise matrix must be developed (Table 6), as well as matrices to determine the stakeholders’ preferences over each performance criterion (Tables 8-11).

GOV	NGO	PS/D	M
Akhtar et al., 2012; McLachlin and Larson, 2011; Balland, 2013	Tatham and Kovacs, 2010; Tomasini and Van Wassenhove, 2009; Cozzolino, 2012; Heaslip, 2013; Heaslip and Barber, 2014; Heaslip, 2012; Hovhanessian, 2012; Kovács and Spens, 2007; McLachlin and Larson, 2011; Pettit, Beresford and Drive, 2007; Balland, 2013; Dolinskaya et al., 2011; Egan, 2010; Moshtari and Gonçalves, 2011; Scholten, Scott and Fynes, 2010; Schulz and Blecken, 2010; Tzeng et al., 2007; Huang et al., 2011	Balland, 2013; Cozzolino, 2012; Egan, 2010; Heaslip, 2013; Heaslip, 2012; Hovhanessian, 2012; Huang et al., 2011; Moshtari and Gonçalves, 2011; Scholten et al., 2010; Tomasini and Van Wassenhove, 2009; Kovács and Spens, 2007; McLachlin and Larson, 2011	Barbarosglu et al., 2002; Heaslip, 2013; Heaslip and Barber, 2014; Heaslip, 2012; Kovács and Spens, 2007; McLachlin and Larson, 2011; Pettit et al., 2007

Table 4. Contributions (stakeholders)

From equation (1), five pairwise matrices are developed (Table 6, Tables 8-11). The relationship with no contributions for  $i$  or  $j$  will be considered as 9.00 or 0.11, depending on whether zero lies in the denominator or numerator, respectively.

$$RI(i,j) = \text{No. of references}(i) / \text{No. of references}(j) \tag{1}$$

Saaty's scale	Relative importance of the two sub-elements
1	Equally important
3	Moderate importance of one over another
5	Strongly important
7	Very strongly important
9	Extremely important

Table 5. Saaty's scale (Saaty, 1980)

Usually, the AHP method is applied using the Saaty's scale (Table 5). Nevertheless, due to the unavailability of real information, we generate the Tables 6-10 considering the number of contributions related to each concept (stakeholder or performance criteria). To develop the Table 6, we took into account the number of contributions that deal with each stakeholder, which in the case for the Government are 3 (Akhtar et al., 2012; McLachlin & Larson, 2011; Balland, 2013) (see Table 4). The same procedure based on Table 4 is performed for the rest of Table 6 (for the NGO's are 18, for the Private Sector and Donors are 12, and for the Military are 7).

	Stakeholders			
	GOV	NGO	PS/D	M
GOV	1.00(3/3)	0.17(3/18)	0.25(3/12)	0.43(3/7)
NGO	6.00(18/3)	1.00(18/18)	1.50(18/12)	2.57(18/7)
PS/D	4.00(12/3)	0.67(12/18)	1.00(12/12)	1.71(12/7)
M	2.33(7/3)	0.39(7/18)	0.58(7/12)	1.00(7/7)

Table 6. Priorities among stakeholders

To develop the Tables 8-11, we considered the Table 7, which shows the number of contributions that linked the performance criteria with each stakeholder. To develop the Table 8 (Government), we considered the number of contributions that deal with each stakeholder, which in the case of E1 is 3 (Akhtar et al., 2012; McLachlin & Larson, 2011) (see Table 7). The same procedure based on Table 7 is

performed for the rest of Table 8 (for S1 is 0, for S2 is 0, for R1 is 2 and for R2 is 1). Table 7 and the same procedure are used to generate the Tables 9-11.

Criteria	GOV	NGO	PS/D	M
E1	Akhtar et al., 2012; McLachlin and Larson, 2011	Tatham and Kovacs, 2010; Tomasini and Van Wassenhove, 2009	Balland, 2013; Cozzolino, 2012; Egan, 2010; Heaslip, 2013; Heaslip, 2012; Hovhanessian, 2012; Huang, Li and Omitaomu, 2011; Moshtari and Gonçalves, 2011; Scholten, Scott and Fynes, 2010; Tomasini and Van Wassenhove, 2009	Barbarosolu et al., 2002
S1		Cozzolino, 2012; Heaslip, 2013; Heaslip and Barber, 2014; Heaslip, 2012; Hovhanessian, 2012; Kovács and Spens, 2007; McLachlin and Larson, 2011; Pettit, Beresford and Drive, 2007	(Balland, 2013)	Barbarosolu et al., 2002
S2		Balland, 2013; Heaslip, 2013; Heaslip, 2012; McLachlin and Larson, 2011		
R1	Balland, 2013; McLachlin and Larson, 2011	Balland, 2013; Cozzolino, 2012; Dolinskaya et al., 2011; Egan, 2010; Heaslip, 2013; Hovhanessian, 2012; Kovács and Spens, 2007; McLachlin and Larson, 2011; Moshtari and Gonçalves, 2011; Pettit et al., 2007; Scholten et al., 2010; Schulz and Blecken, 2010; Tatham and Kovacs, 2010; Tomasini and Van Wassenhove, 2009; Tzeng et al., 2007	Balland, 2013; Heaslip, 2013; Kovács and Spens, 2007; McLachlin and Larson, 2011; Tomasini and Van Wassenhove, 2009	
R2	(Balland, 2013)	Balland, 2013; Huang et al., 2011		Barbarosolu et al., 2002; Heaslip, 2013; Heaslip and Barber, 2014; Heaslip, 2012; Kovács and Spens, 2007; McLachlin and Larson, 2011; Pettit et al., 2007

Table 7. Contributions (stakeholder vs performance criteria)



Government					
	E1	S1	S2	R1	R2
E1	1.00(2/2)	9.00(2/0)	9.00(2/0)	1.00(2/2)	2.00(2/1)
S1	0.11(0/2)	1.00(0/0)	1.00(0/0)	0.11(0/2)	0.11(0/1)
S2	0.11(0/2)	1.00(0/0)	1.00(0/0)	0.11(0/2)	0.11(0/1)
R1	1.00(2/2)	9.00(2/0)	9.00(2/0)	1.00(2/2)	2.00(2/1)
R2	0.50(1/2)	9.00(1/0)	9.00(1/0)	0.50(1/2)	1.00(1/1)

Table 8. Government's performance criteria priorities

NGOs					
	E1	S1	S2	R1	R2
E1	1.00(4/4)	2.00(4/2)	1.33(4/3)	4.00(4/1)	1.00(4/4)
S1	0.50(2/4)	1.00(2/2)	0.67(2/3)	2.00(2/1)	0.50(2/4)
S2	0.75(3/4)	1.50(3/2)	1.00(3/3)	3.00(3/1)	0.75(3/4)
R1	0.25(1/4)	0.50(1/2)	0.33(1/3)	1.00(1/1)	0.25(1/4)
R2	1.00(4/4)	2.00(4/2)	1.33(4/3)	4.00(4/1)	1.00(4/4)

Table 9. NGO performance criteria priorities

Private sector/Donors					
	E1	S1	S2	R1	R2
E1	1.00(9/9)	9.00(9/1)	9.00(9/0)	1.80(9/5)	9.00(9/0)
S1	0.11(1/9)	1.00(1/1)	9.00(1/0)	0.20(1/5)	9.00(1/0)
S2	0.11(0/9)	0.11(0/1)	1.00(0/0)	0.11(0/5)	1.00(0/0)
R1	0.56(5/9)	5.00(5/1)	9.00(5/0)	1.00(5/5)	9.00(5/0)
R2	0.11(0/9)	0.11(0/1)	1.00(0/0)	0.11(0/5)	1.00(0/0)

Table 10. Private sector/donors' performance criteria priorities

Military					
	E1	S1	S2	R1	R2
E1	1.00(1/1)	1.00(1/1)	9.00(1/0)	9.00(1/0)	0.14(1/7)
S1	1.00(1/1)	1.00(1/1)	9.00(1/0)	9.00(1/0)	0.14(1/7)
S2	0.11(0/1)	0.11(0/1)	1.00(0/0)	1.00(0/0)	0.11(0/7)
R1	0.11(0/1)	0.11(0/1)	1.00(0/0)	1.00(0/0)	0.11(0/7)
R2	7.00(7/1)	7.00(7/1)	9.00(7/0)	9.00(7/0)	1.00(7/7)

Table 11. Military's performance criteria priorities

The five  $RI(i,j)$  matrices represent the relationships among stakeholders (Table 6). Table 8 shows the performance criteria priorities of the government, and Table 9, Table 10, and Table 11 show the same information for NGOs, the private sector/donors, and the military, respectively.

### 3.2.3. Stakeholders' Preference Priorities (weights)

Finally, considering the pairwise matrices, the relative importance of each stakeholder in the humanitarian supply chain and their performance criteria priorities are shown Table 12 and Table 13, respectively. Then, the stakeholders' priorities are used to develop a final matrix (Table 14), which represents the interests of stakeholders based on the performance criteria established previously.

Stakeholder	Stakeholder priority
Government	7.80%
NGO	46.79%
Private Sector/Donors	27.21%
Military	18.20%

Table 12. Stakeholders' priorities

Stakeholder	Performance criteria priorities				
	E1	S1	S2	R1	R2
Government	34.92%	3.37%	3.37%	34.92%	23.43%
NGO	28.57%	14.29%	21.43%	7.14%	28.57%
Private Sector/Donors	49.30%	13.55%	2.86%	31.43%	2.86%
Military	16.58%	16.58%	2.87%	2.87%	61.10%

Table 13. Stakeholders' performance criteria priorities

Based on Table 13, we conclude that the priority for governmental organizations is the economic aspect, but without losing control of the response/travel time. Non-governmental organizations focus on the delivery of relief, according to a plan, but are also concerned about the economic aspect (turning limited inputs into outputs). Then, the private sector and donors look to minimize the economic aspect. Finally, military organizations prioritize the reliability aspect, which, in this case, means delivering the relief according to a plan.

Performance criteria	Criteria priority
Costs (E1)	32.53%
Unmet demand (S1)	13.65%
Equity (S2)	11.59%
Response/travel time (R1)	15.14%
Risk (R2)	27.09%

Table 14. Performance criteria priorities

### 3.3. Multi-criteria function (Stage 3)

The five performance indicators (economic, unmet demand, equity, response/travel time, and risk) are integrated into a single minimization objective function, the general form of which is given by an equation that considers the adjustment of the aspects to be minimized. Note that, in order to formulate a single objective function to be minimized, equity is translated into inequity (i.e., Max Equity is translated into Min Inequity):

$$\text{Min } \alpha * E1 + \beta * S1 + \gamma * S2 + \delta * R1 + \varepsilon * R2 \quad (2)$$

where:

$\alpha$ : Economic (E) weight

$\beta$ : Unmet demand (S1) weight

$\gamma$ : Inequity (S2) weight

$\delta$ : Response/travel time (R1) weight

$\varepsilon$ : Risk (R2) weight

Where:  $\alpha = 0.3253$ ;  $\beta = 0.1365$ ;  $\gamma = 0.1159$ ;  $\delta = 0.1514$ ; and  $\varepsilon = 0.2709$ .

$$\text{Min } \alpha + \beta + \gamma + \delta + \varepsilon = 1 \quad (3)$$

Leading to:

$$\text{Min } 0.3253 * E1 + 0.1365 * S1 + 0.1159 * S2 + 0.1514 * R1 + 0.2709 * R2 \quad (4)$$

#### 4. Conclusions and Future Research Work

Motivated by the lack of applied research and the increased level of interest in this area, this study proposes a methodology that defines a multi-criteria framework for the hierarchical coordination of humanitarian supply chains. Although several works have presented optimization models and performance metrics, they are a long way from offering an integrated approach. Based on a literature review, we identified five performance criteria, namely economic, unmet demand, equity, response/travel time, and risk, in order to measure a reliable relief distribution process. These criteria were then prioritized based on the extensive literature review of research related to coordination in humanitarian supply chains.

Furthermore, in developing the multi-criteria framework, we noted the following: (1) the close relationship between the economic aspect and the private sector/donors; (2) the preference of NGOs to maximize demand, in an equitable manner, and in the shortest time; and (3) the military's priority of minimizing risk during the relief distribution process.

Note that the priorities (% contributions) identified in the literature related to the performance criteria differ from the priorities obtained here with regard to the stakeholders' preferences (Table 13). However, in both cases, the economic aspect remains the highest priority (28.26%, 32.53%). Then, risk (27.09%) is the second-most important in terms of the relationship with stakeholders, but in the literature, it appears in 5.43% of the contributions. In addition, unmet demand is ranked second in the literature (27.17%), but is fourth after applying the AHP method (13.65%). This reinforces the importance of this study, which establishes that quantifying stakeholders' interests in order for them to be integrated into humanitarian decision-making processes increases the reliability of subsequent decisions. Once the performance criteria are prioritized, their integration into an objective function is possible, enabling them to be integrated into a mathematical optimization decision support system.

Illustrating the applicability of the methodology to reliable aid distribution is left for future work. Furthermore, conducting a sensitivity analysis of the performance of the indicators under different scenarios is highly recommended.

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