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Logistics service network design for humanitarian response in East Africa☆

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ABSTRACT

The outsourcing of management and logistics functions for the humanitarian sector has become increasingly common following similar trends in the commercial sector. The United Nations Humanitarian Response Depot (UNHRD) is an important logistics service provider that manages a network of depots and offers multiple supply chain solutions to its partners of the humanitarian community. In its 2014–2017 strategic plan, the UNHRD targeted the reduction of the operational costs of its network. This research project aims to analyze the potential cost benefits of adding a regional distribution center in Kampala, Uganda, to the existing network of the UNHRD in order to better respond to humanitarian crises in East Africa. To this end, we used fieldwork, simulation, network optimization and statistical analyses to assess the costs of prepositioning high-demand non-food items in Kampala and to propose a robust stocking solution. Our study is based on an actual case and uses real data. Results show that adding a regional depot in Kampala would be cost-efficient even if the UNHRD transport costs were subject to change. The UNHRD has already started to implement the solution proposed in this study, which should result in a mean cost reduction of around 21% over 5000 demand scenarios.

1. Introduction

East Saharan Africa faces several complex humanitarian challenges arising from famines, civil wars and natural disasters. This region, which is our area of interest, hosts the populations that are the most vulnerable to humanitarian crises in the world [28,52]. It also suffers from the most important lack of coping capacity, an indicator that measures the national resources available to help people whenever a humanitarian crisis occurs [28]. In such a context, the international community support to manage, procure and distribute aid is crucial. Nevertheless, because multiple humanitarian organizations are involved and deployed when a crisis occurs, the coordination of their efforts induces major difficulties and constitutes an important challenge [8,29,51]. Poor coordination of relief efforts often leads to network congestion [27,63,65] and may have serious consequences for the victims. This issue becomes especially important when interventions take place in the less developed regions, such as most East African countries, where infrastructures are inadequate [35,43].

The recent years have been marked by the emergence of logistics service providers in the humanitarian landscape, which should help improve the coordination between the relief actors [24]. The best known humanitarian logistics service providers (HLSP) are the United Nations Humanitarian Response Depot (UNHRD), the Regional Logistics Units (RLUs) and the Humanitarian Procurement Centers (HPCs) [51]. The rise of these logistics intermediaries has a major effect on the supply chain management activities of several humanitarian organizations that use their services. It follows a similar trend in the commercial sector, where third-party logistics providers (3PL) have already imposed themselves as major partners in the past fifteen years [3]. The lag observed in the humanitarian field can be explained by the multiplicity of supply chains and stakeholders, which exacerbates coordination problems, insufficient recorded documentation and information, as well as the lack of standardized processes [51,62].

The project described in this study was developed in close collaboration with the UNHRD, a United Nations (UN) service provider managed by the World Food Programme (WFP). The UNHRD operates a network of permanent strategic depots, where emergency non-food items (ENFI) are prepositioned, stored and handled. It transports relief goods and equipment on behalf of the humanitarian community. In order to meet an increasing demand with limited resources, the UNHRD continuously reviews the efficiency of its supply chain and field operations and made cost reductions

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a priority in its 2014–2017 strategic plan [60]. Our research project aims to support this effort by developing an analytical framework to assess the performance of a new network structure. Our case study focuses on crisis response in East Africa. The proposed network includes a new regional distribution center (RDC) located in Kampala, Uganda. We compare its performance with that of the existing UNHRD network.

2. The UNHRD logistics service network for East Africa

East Africa is greatly affected by armed conflicts, food insecurity, malaria, and natural disasters such as droughts [57,17,61,16]. The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) has recently identified a list of threats that could severely affect people in this region [40]. For example, the intensification of violence in countries such as Burundi and South Sudan has brought new waves of displaced populations, and a large movement of refugees from Yemen is also expected over the next few years. The main countries receiving these refugees are Ethiopia, Kenya and Uganda. The OCHA has reported an increase of communicable diseases, such as cholera, in Somalia, South Sudan, Burundi and Tanzania. The World Health Organization reported that in 2015 malaria cases and deaths occured in Sub-Saharan Africa [71]. It also estimates that the malnutrition and food insecurity conditions could deteriorate, especially in South Sudan, Burundi, the eastern part of the Democratic Republic of Congo and southern Somalia. The OCHA also mentioned two main constraints to humanitarian work in this context: the humanitarian space is shrinking due to restrictive legislation and violence, and the humanitarian operations suffer from a lack of funding. Since the most vulnerable regions also figure among the least developed ones [37,34], the UNHCR has raised more technical and operational obstacles to the humanitarian work. Indeed, the transportation and communication infrastructures are inefficient and sometimes impracticable during the rainy season [40]. In order to alleviate these difficulties, humanitarian organizations conduct fundraising campaigns for supply prepositioning projects and maintain transportation infrastructures in sensitive regions [39]. East Africa is a region particularly vulnerable to slow-onset humanitarian crises for which it is more difficult to raise donations and which are easier to forecast compared to sudden-onset disasters. For an organization like the UNHRD, it is thus important to efficiently design and manage its supply chain in order to ensure proper response in this area and to reduce cost.

2.1. Existing network

Established in 2000, the UNHRD is a WFP branch that offers humanitarian logistics services to its partners [51]. These include WFP country offices (internal partners), as well as UN agencies (e.g. the United Nations High Commissioner for Refugees (UNHCR), the United Nations Children's Emergency Fund (UNICEF), governmental and non-governmental organizations (external partners), such as Save the Children, Irish Aid, CARE and the Red Cross). The UNHRD offers storage capacity to its partners so that they can preposition ENFIs in six depots located in Brindisi (Italy), Dubai (the United Arab Emirates, UAE), Panama City (Panama), Kuala Lumpur (Malaysia), Accra (Ghana), and Las Palmas (Spain). The structure of the UNHRD network (Fig. 1) was designed to be able to deliver relief items worldwide within 24 to 48 hours [58]. Whereas the depots of Brindisi and Las Palmas offer a worldwide coverage, the other depots have a more regional scope. Partners can store emergency supplies free of charge in this network, but the UNHRD also proposes other logistics services on a pay-for-use basis.

The UNHRD activities are enabled through three main sources of funding. The first source consists of state contributions for which the main governmental donors are Italy, Panama, Ireland, Malaysia, Norway, the UAE, Switzerland, Spain and Ghana [59]. The second source comes from the benefits generated from paid services offered by the UNHRD to its partners, such as procurement, repackaging, or rental of premises for training purposes. The third source results from the transportation service fees charged to its partners. These fees consist of a 7% supplement applied to the transportation cost, whether it is for moving items from suppliers to depots (inbound flow) or from depots to distribution points (outbound flow). Table 1 summarizes the main free-of-charge and fixed-rate services offered by the UNHRD.

The strategy supported by the UNHRD for humanitarian response in East Africa mainly consists of assisting its partners in supply-prepositioning activities. It uses three of the six depots (Brindisi, Dubai and Accra) to cover the East African demand. Currently, the relief supplies come directly from these UNHRD depots up to the demand points of the end-users. When a demand materializes, the UNHRD ships the relief items requested by its partners from the appropriate depot to a specific location in East Africa.

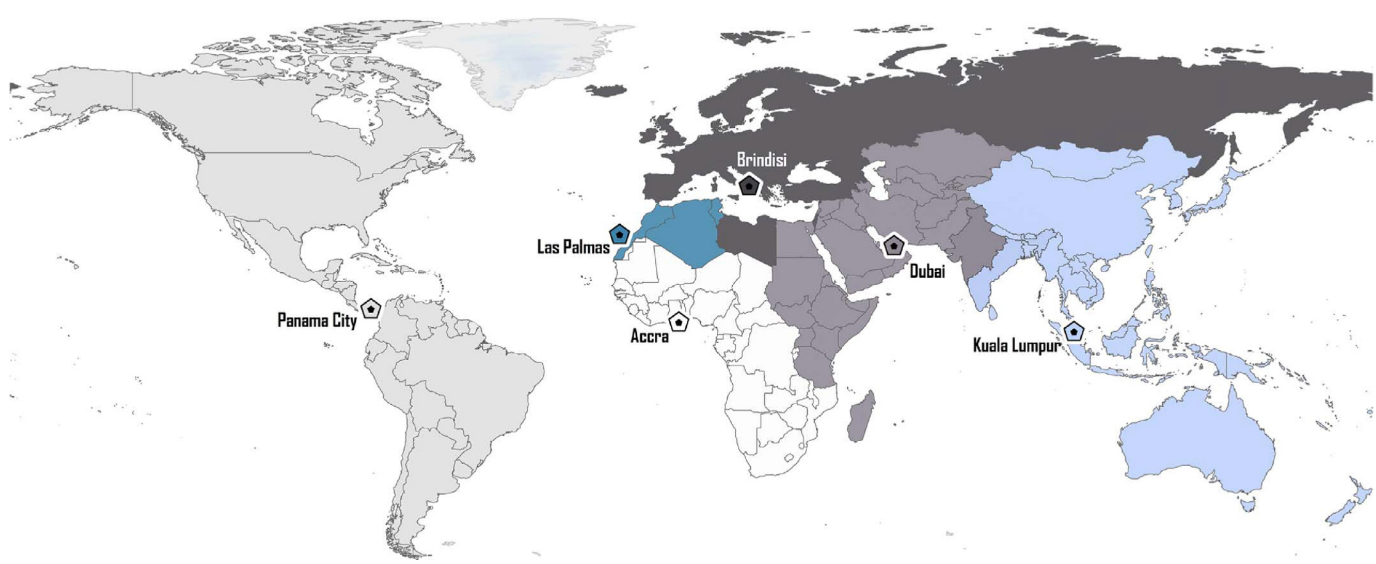

Fig. 1. Map of the UNRDH worldwide depot network and its coverage.

Table 1
UNHRD service offer. Source: UNHRD [58].

Standard services (free of charge)	Specific services (fixed rates)
• Offloading of cargo received, packaged according to the Standard Operating Procedures (SOPs)	• Maintenance of assets during their storage period in a depot
• Issuance of inspection reports	• Maintenance and management of vehicles and drugs, including those under international control
• Import custom procedures	• Handling and repackaging of stocks received, not packaged in compliance with SOPs
• Placing stocks in store	• Procurement of stock and services (including transportation services) on behalf of users
• Providing storekeeping services	• Kitting, palletizing, loading out, technical missions, use of training facilities, stock insurance, etc.
• Issuing regular stock reports	• Any service provided by the WFP and requested through the UNHRD, under the Technical Agreement umbrella and related to the SOPs
• Preparing cargo for dispatch	
• Preparing export documentation packages	
• Preparing activity reports (upon receipt or dispatch)	
• Annual stock inventory	

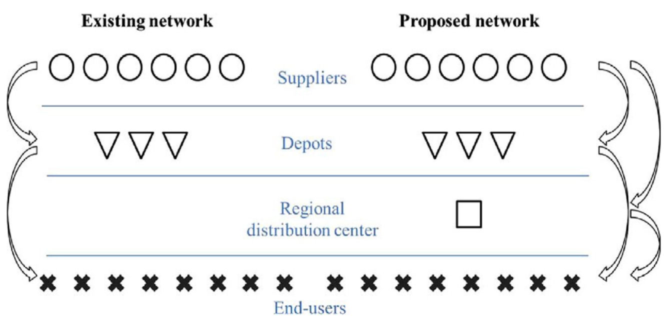

Fig. 2. Depiction of the UNHRD existing logistics service network (left-hand side) and proposed logistics service network (right-hand side).

Thus, the final delivery points are located where the partners receive their requested items. These are therefore the end-users in the UNHRD supply chain. The left-hand side of Fig. 2 depicts this existing logistics service network. The suppliers (e.g. Edilsider, W.Giertsen, OBwiik, Alpinter) are located worldwide.

2.2. Proposed network

Whereas the UNHRD centralized storage structure allows economies of scale for procurement activities, the design of its network involves high transportation costs due to the frequent use of air transport when urgent response is needed. The UNHRD stressed the necessity of optimizing the utilization of white stocks in its regional prepositioning strategy. These are the high-demand relief items owned by the suppliers. Pursuant to the Long Term Agreement (LTA) between suppliers and the UNHRD, these items are prepositioned by UNHRD, as it pleases, in its network until a regional demand occurs [58]. They are then sold and shipped to the partners who request them. Thus, the supplier bears the risk until the product leaves the UNHRD depot. The UNHRD then bears the risk up to the end-user. Adding a regional distribution center (RDC) for high-demand white stock items, as shown on right-hand side of Fig. 2, may improve humanitarian operations by transporting and locating these items closer to disaster-prone areas and thus yield economies by taking advantage of sea transportation. Also, this configuration offers protection against disruptions since there are two possible paths between the suppliers and the end-users.

Based on different criteria, Kampala, the capital of Uganda, was selected as a potential strategic site for the RDC. One of the most important criteria was the available storage capacity at the WFP facilities, located in the Nalukolongo neighborhood of Kampala. We ensured that Kampala could cover a wide territory with high potential demand within a reasonable lead time. Kampala can cover a large territory comprising nine countries which, based on the UNHRD historical data, have a large demand. Indeed, Kampala can cover most of the countries of the Horn of Africa and the Great Lakes Region (the area of interest), an area particularly afflicted by humanitarian crises. The area of interest is depicted in Fig. 3, as well as the average percentage of relief items sent between 2010 and 2014 from the three UNHRD depots serving this area. Another important criterion was the connectivity of Kampala with the existing transportation infrastructures, which is crucial for receiving relief items and for reaching the demand points. Kampala has the distinct advantage of being directly connected to the regional railway structure. For the inbound flow into Uganda, the rail connection offers two port options: Mombasa in Kenya and Dar Es Salaam in Tanzania. Because the material that would be prepositioned in the selected RDC should move frequently across borders, another important criterion is the ease of carrying import-export related activities. This criterion was assessed on the basis of the ease-of-doing-business index computed by the World Bank [70]. Across the 190 countries that were analyzed, Uganda ranked 116th in 2015, which is a better score than that of most East African countries. Another criterion considered concerns the political context. To assess this aspect, we analyzed some relevant indicators produced by major international institutions. Namely, we studied the corruption perception index [55] and the worldwide governance indicators [68] that includes corruption control, rule of law, regulatory quality, political stability and absence of violence. For the corruption perception index, 168 countries were compared and ranked, whereas a percentile was assigned to more than 200 countries and territories for the worldwide governance indicators. The Logistics Performance Index (LPI), a measure of supply chains' friendliness and efficiency developed by the World Bank [69], was also considered. The LPI depicts domestic and international logistics performance; it compares and ranks 160 different countries. All these indicators evaluate various aspects may impact the success of the implementation of an RDC.

Overall, the performance of Uganda based on these indicators was superior to that of others countries in the region. Indeed, five different potential sites were analyzed to implement an RDC and the results are summarized in Table 2, that shows whether or not there were available storage capacity from the WFP country office. The potential locations were selected by the UNHRD and the WFP Regional Bureau in Nairobi, which supervises WFP's activities in East Africa, mainly because they represent strategic centers supporting WFP logistics operations across this region. The performance of Kampala and Kigali over the different criteria was generally good. That said, the availability of free storage capacity

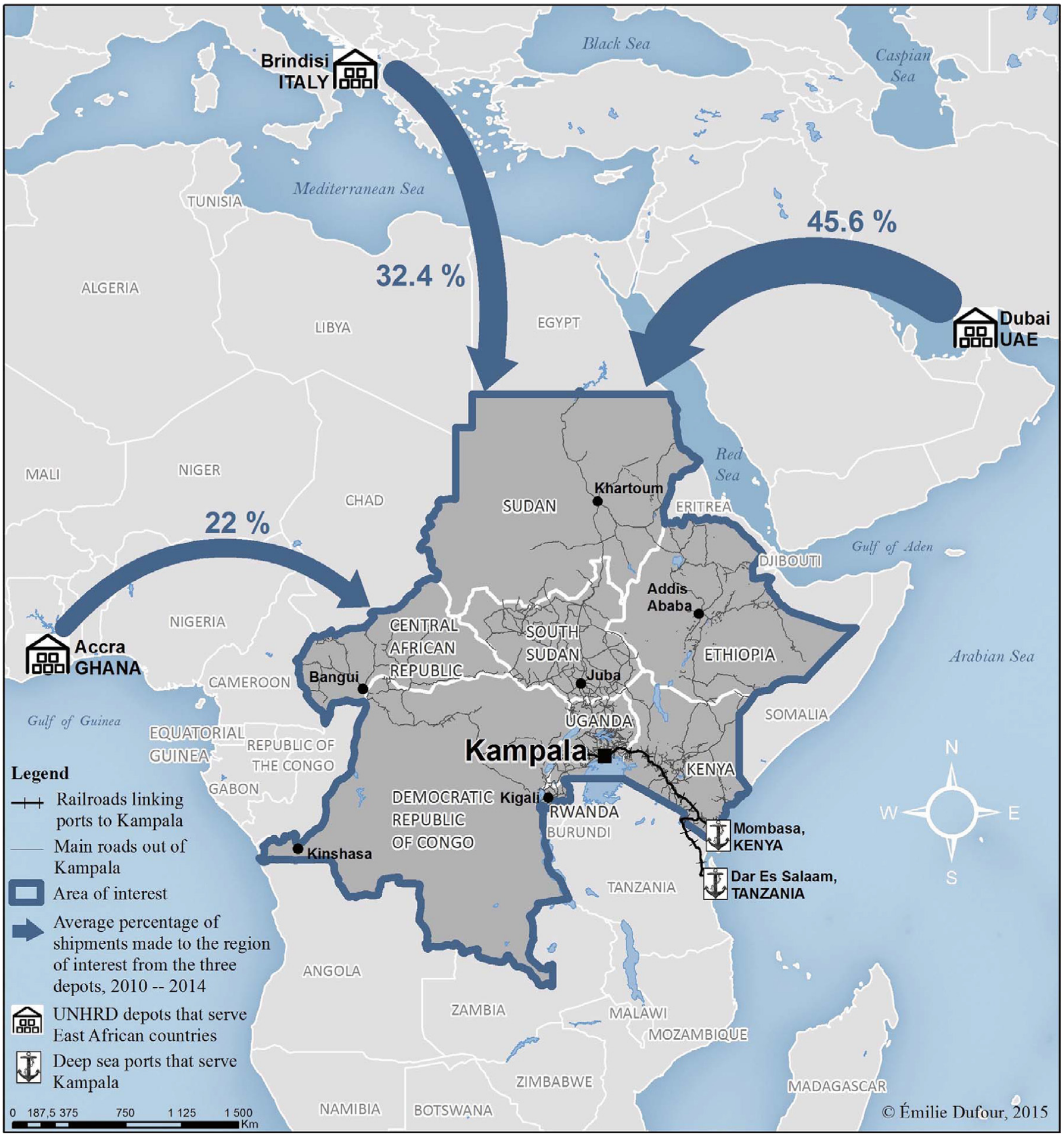

Fig. 3. Supply network of the area of interest.

Table 2
Summary of the potential location analyzes.

Potential location	Ease-of-doing-business	Corruption perception	Worldwide governance				LPI	WFP available storage capacity
			Political stability and violence	Regulatory quality	Rule of law	Corruption control		
	(rank/190)	(rank/175)	(percentile)				(rank/160)	(yes/no)
Bujumbura (Burundi)	155th	157th	8	13	11	12	107th	no
Djibouti (Djibouti)	168th	94th	55	28	29	48	154th	yes
Kampala (Uganda)	116th	140th	16	47	43	19	66th	yes
Kigali (Rwanda)	59th	49th	39	46	46	71	80th	no
Mogadishu (Somalia)	190th	175th	0	0	0	0	160th	yes

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at Kampala next to WFP warehouse was decisive in the UNHRD choice. Finally, Kampala is considered by the UNHRD to be one of the locations which is the least prone to disasters in this area.

While the main concern in this project for the UNHRD lies in the generation of transportation cost savings, we use delivery time as a guideline to determine which demand points can be reached within a specified time window. In the course of our field work, we collected information on the estimated delivery times to all East African demand points. The area of interest corresponding to the region covered by Kampala could then be defined in collaboration with the WFP Country Office in Kampala and with the UNHRD. In the WFP Kampala facilities where the RDC would be located, the maximal storage capacity is limited to ten 20-foot containers. Thus, even after the opening of an RDC in Kampala, the existing network would continue to cover the area of interest.

2.3. Research questions

This paper will answer the following research questions: (1) Should the UNHRD develop a supply chain structure with an RDC in Kampala to store some its white stocks and thus improve the efficiency of its response to humanitarian crises in East Africa? (2) Which items should be prepositioned at the RDC, and in which quantities? To this end, we first analyzed the UNHRD inventory management processes and we assessed the impact of adding an RDC to the existing prepositioning structure through the optimal solutions of two network flow models. We then determined the best prepositioning plan by conducting statistical analyses on several candidate solutions over a large number of realistic demand scenarios. In effect, we are solving a stochastic network flow problem heuristically.

3. Positioning of our research within the field of humanitarian logistics

Several papers in the field of humanitarian logistics have investigated questions relative to network design. Here we review some of the most relevant work and we position our contribution with respect to this literature.

3.1. Literature review

In a humanitarian context, organizations must invest in preliminary planning to ensure quick and efficient crisis response [33,56,63]. Our literature review focuses on this preparation phase, with an emphasis on network design and relief supply prepositioning. Given the focus of our paper, we first present papers that analyze the roles of humanitarian logistics service providers.

Logistics service providers are relatively new actors in the humanitarian field and only a few authors have studied the impact of their operations on relief supply chains [25,66]. Outsourcing supply chain management activities can be viewed as an innovative logistics model in the humanitarian field. The HLSP service offer is very similar to that of business 3PLs, which includes logistics activities such as procurement, inbound and outbound transportation, warehousing, inventory management, packaging and reverse logistics [3]. The benefits of using HLSPs are considerable in terms of costs reduction and supply chain performance improvement. Outsourcing some of these logistics activities also allows both companies and humanitarian organizations to focus on their core competencies. There exist, however, some differences between HLSPs and their commercial counterparts. First, a part of the HLSP function is to promote collaboration between the actors and to support the coordination of efforts during crisis responses. Second, the core mission of HSLPs is to provide high quality logistics services adapted to humanitarian needs while retaining their non-profit vocation. These differences may explain why most of the current HLSPs consist of divisions of major international organizations, rather than being independent entities like commercial 3PLs. Thus, organizations such as Médecins Sans Frontières, the WFP and the International Federation of Red Cross and Red Crescent Societies (IFRC), have already developed such divisions in order to conduct their logistics activities [51,66]. Nevertheless, some commercial 3PLs, such as ST Logistics Pte Ltd, offer public sector services dedicated to humanitarian assistance and disaster relief.

Bhattacharya et al. [7] have assessed the efficiency of transfer mechanisms in humanitarian supply chains. Their results stress the importance of coordination entities, such as the UNHRD, for the fluidity of resource transfers. Although it has been shown that HLSPs play a central role in coordinating logistics chains, these organizations have received little attention in the scientific literature. In their recent review of the role of the HLSPs, Vega and Roussat [66] have identified 26 papers discussing logistics providers and the cluster approach in the humanitarian context. The authors note that only four of these 26 papers focus on logistics service providers [51,29,13,1]. Schulz and Blecken [51] have analyzed three case studies to understand the opportunities of horizontal cooperation in humanitarian operations: these are the cases of the UNHRD (WFP), the RLUs (IFCR) and the HPC (ECHO). The authors have further compared the actual and potential benefits resulting from horizontal cooperation. Jahre and Jensen [29] have studied the potential of a cluster approach to facilitate supply chain coordination based on the case study of the United Nations Joint Logistics Centre, while Cozzolino et al. [13] have identified the humanitarian logistics processes where lean principles could be applied. These authors propose a conceptual framework, which was tested on the basis of the experience of the WFP response to the humanitarian crisis in Darfur. Jensen [31] has studied the humanitarian clusters' practices by comparing them with those of a commercial fourth-party logistics provider (4PL), while Abidi et al. [1] have assessed the potential value of a 4PL service in the humanitarian supply chain context. Nagurney et al. [38] have analyzed, by means of an optimization-system model, the design of a supply chain network for critical needs, considering the possibility of outsourcing some supply chain activities to decrease response time.

Mathematical models on prepositioning initially developed in the areas of location science, network optimization and inventory management have been adapted and used in humanitarian contexts. Caunhye et al. [9], Galindo and Batta [21] and Özdamar and Ertem [41] provide exhaustive surveys of operations research-based studies that have contributed to humanitarian supply chain management, while de la Torre et al. [15] and Anaya-Arenas et al. [4] summarize several contributions focusing on distributions networks in disaster response. Graß and Fischer [23] have reviewed the literature on stochastic prepositioning and location problems in the area of disaster management, which concern the type of problems more related to our work, such as determining the locations and capacities of the permanent or temporary infrastructures to store the prepositioned supplies, and deciding which supplies to preposition, where to preposition them, and in which quantities. Good decisions enhance preparedness and emergency response capacity by providing a higher availability of relief supplies [19], which improves supply chain agility and can mitigate the impact of a disaster. Nevertheless, several forms of uncertainties, such as the knowledge of future demand, can influence prepositioning planning [5,20,11]. Lately, many location and stockpiling problems have been treated using two-stage stochastic programming [49,46,32,67,2], where facility location and inventory decisions are taken in the first stage and the transportation decisions are determined in the second stage. Rennemo et al. [47] and Caunhye et al. [10] have combined routing and location decisions for disaster response and emergency supplies.

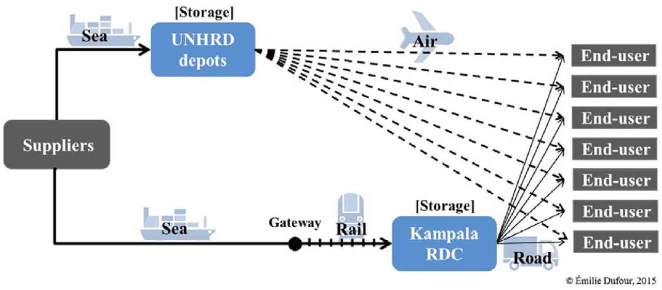

Fig. 4. Depiction of the proposed logistics service network.

In our case we want to evaluate the benefits of locating an RDC in Kampala as part of the existing network of the UNHRD depots. Moreover, the UNHRD will impose to its partners that ENFI requests to be shipped from this RDC must be carried out in full containers, and therefore routing decisions do not apply in this case. Instead of using a two-stage stochastic programming approach to consider uncertainty in future demand, we have developed a heuristic based on mathematical programming and simulation. This solution method allows solving large-scale instances efficiently, which is one of the important needs identified by Graß and Fischer [23]. We also aim to analyze the case of an international humanitarian organization using an operations research-based methodology tested on real data. Other interesting cases of empirically-grounded analytical modeling studies on prepositioning issues have been described by McCoy and Brandeau [36], Jahre et al. [30], Duran et al. [19], Stauffer et al. [54] and Besiou et al. [6], in the contexts of the UNHCR, CARE and IFRC supply chains.

Some authors have investigated network structures similar to that presented in this paper [14,48,53]. The multi-level networks considered by these researchers include a central depot that replenishes the subdepots in the network, but they differ from the network structure considered in our paper, where each level of depot is independently and directly replenished from the suppliers. This supply strategy offers a major advantage in a humanitarian context where disruption risks are high [26]. Moreover, as in Gatignon et al. [22], Duran et al. [18], Rancourt et al. [44] and Jahre et al. [30], we apply an operations research-based methodology to a case study, which enables the integration of real data as parameters in the mathematical models and can be used by the UNHRD to assist its decision making process. We also generate several random scenarios to capture the demand uncertainty, as in Balcik and Beamon [5], Rawls and Turnquist [45], Salmerón and Apte [49], Klibi et al. [32] and Acimovic and Goentzel [2].

3.2. Research contributions and organization of this paper

Our literature review reveals that the role and the impacts of the HLSPs have received little attention by the scientific community [13,24,66]. Here we combine simulation, network optimization and statistical analyses to assess the costs of prepositioning high-demand ENFIs in Kampala and to propose a robust solution. Our framework is simple and of general applicability. Simplicity is indeed cited as a model feature favoring its adoption by humanitarian organizations [64,50,12,44]. Our approach could thus be used to develop regional prepositioning strategies in other regions.

Our work is based on an actual case arising in East Africa and uses real data. Based on the conclusions of our research, the UNHRD is currently installing the recommended regional prepositioning site in Kampala. To our knowledge, the proposed network shown in Fig. 2, in which the depot and the regional distribution center are replenished independently from the suppliers, is the only existing prepositioning network with two independent levels available in a humanitarian context. Beyond yielding transportation cost reductions, as we will show, this network configuration also offers protection against disruptions because it contains two possible paths between the suppliers and the end-users.

The remainder of this paper is organized as follows. Section 4 provides a formal problem statement, mathematical models and a description of the methodology. Computational results and analyses are presented in Section 5, followed by conclusions, managerial insights and outlooks in Section 6.

4. Problem description, mathematical models and methodology

We first describe the problem in more detail before presenting two mathematical models and the solution methodology.

4.1. Problem description

In order to assess the potential improvement resulting from the addition of a regional prepositioning location, we need to compare the operational costs obtained by this new potential network with those of the current network. The existing network operates as follows. First, depending on the needs expressed by a partner, the order and purchase processes to the suppliers are handled by the UNHRD procurement department. The suppliers ship the relief items requested by the partner to a UNHRD depot. When a partner's demand occurs in East Africa, the UNHRD ships the material by plane to a gateway, and then by truck to the end-user. With the addition of a regional prepositioning depot, some storage activities will be displaced to the RDC and some high demand relief items will be sent by boat directly from the suppliers to the port of Mombasa (Kenya). The containers will then be transported to the RDC by train, where they will be stored until a demand occurs. The advantage of adding an RDC is to offer an alternative transportation mode for part of the demand by storing some relief items closer to the end-users. Fig. 4 depicts this proposed service network.

Following a decision made by the UNHRD, we only consider the white stocks in this study. There are relief items stored in the UNHRD network that remain the supplier's property until a partner purchases them. This restriction is motivated by the fact that prepositioning activities requires a large capital investment. Besides being categorized as white stocks, the 15 products selected for this study satisfy most of the following important criteria: (1) they are subject to a high regional demand; (2) they are non-perishable, a feature that allows an undetermined storage time; and (3) some are very heavy, which has an important impact on air transportation costs.

Because the containers will be kept outside, the storage conditions at the Kampala RDC were also analyzed in order to move adequate products toward the regional level. Kampala is located in a tropical climate region without large temperature variations. The average temperature is between 22 and 23 degrees Celsius. The area is also subject to relatively constant rainfalls throughout the year, with peaks during the two rainy seasons, which last from March to May and from September to November. Combining this information with that gathered from the suppliers, it was decided that three item types previously selected for this project should not be stored in the Kampala RDC. These are humidity-sensitive items such as the two types of mosquito nets (160 cm and 190 cm) and the wool blankets. Thus, a total of 12 products were initially considered to be moved to the Kampala RDC, out of 15 for the entire network.

The data collected in order to compute the model's parameters can be divided into two groups: the demand and the networks operation costs. The historical demand analysis helps us determine the shape of the distribution for each product at each East African

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delivery point, which is necessary to produce realistic demand scenarios. Since one must ship full containers, these demand data were aggregated and expressed in number of container loads, and because the demand is probabilistic, we generated 5000 random demand scenarios which were used as inputs to the model.

We then analyzed the transportation costs, which were divided into two categories: the costs relative to the current network operations, and those associated with the operations of the network with the Kampala RDC. The main challenge was to collect the cost data relative to Kampala RDC operations since this network does not yet exist. Note that the operation costs for both networks do not include storage costs since following interviews with the UNHRD and the WFP country office in Kampala, we were informed that the storage costs for the UNHRD depots are mostly borne by the host governments, while those relative to the Kampala facilities are assumed by the WFP. Nevertheless, we needed to consider other operating expenses in order to run the RDC model. These include the crane rental and the workforce salaries associated with the handling of containers on the Kampala site. Since the values of the demand and cost parameters are the results of different analyses, we explain in more detail in Section 5 how they were determined. In this section, we present two general model formulations for our problem.

4.2. Mathematical models

We consider a set of emergency supplies that must be prepositioned in the UNHRD network and are subject to high demand fluctuations. We use a directed graph $G = (V, A)$ to describe the supply chain network. The vertex set V is partitioned into $\{I, J, R, K\}$, where I is the set of suppliers, J is the set of depots excluding the RDC, the singleton R contains the RDC, and K is the set of end-users. The set A consists of arcs from the suppliers to the depots and the RDC, and from the depots and the RDC to the end-users. The set of 15 white stocks is denoted by P and is indexed by p. We denote by P' the subset of the 12 white stocks that can be stored at Kampala. We denote by c_{ij}^{p} the cost of shipping one container of product p from i to j.

The demand for a product can only be fulfilled by one prepositioning facility, i.e. one of the depots or the RDC. Each of the two networks compared in our study contains three uncapacited depots located at Accra, Brindisi and Dubai, since the facility storage capacities are not an issue in this case. The first network contains no RDC, but the second one contains an RDC located at Kampala, with a capacity Q equal to 10 containers. Let d_{k}^{p} denote the demand of product $p \in P$ at location $k \in K$. Since demand is stochastic, we will solve our models for 5000 random demand replications.

Let x_{ij}^{p} be an integer variable equal to the number of containers of product p shipped from i to j, and let x_{jk}^{p} be the quantity shipped from j to k. We have developed two models: Model 1 represents the existing network and Model 2 the proposed network.

Model 1: Existing network without the RDC

$$\text{Minimize} \quad \sum_{p\in P}\sum_{i\in I}\sum_{j\in J} c_{ij}^{p} x_{ij}^{p} + \sum_{p\in P}\sum_{j\in J}\sum_{k\in K} c_{jk}^{p} x_{jk}^{p}$$

$$\text{subject to} \quad \sum_{i\in I} x_{ij}^{p} = \sum_{k\in K} x_{jk}^{p} \quad p \in P, \quad j \in J \tag{1}$$

$$\sum_{j\in J} x_{jk}^{p} \geq d_{k}^{p} \quad p \in P, \quad k \in K \tag{2}$$

$$x_{ij}^{p}, \quad x_{jk}^{p} \geq 0 \text{ and integer} \quad p \in P, \quad i \in I, \quad j \in J, \quad k \in K. \tag{3}$$

Model 2: Proposed network with the RDC

$$\text{Minimize} \quad \sum_{p\in P}\sum_{i\in I}\sum_{j\in J} c_{ij}^{p} x_{ij}^{p} + \sum_{p\in P'}\sum_{i\in I}\sum_{j\in R} c_{ij}^{p} x_{ij}^{p} + \sum_{p\in P}\sum_{j\in J}\sum_{k\in K} c_{jk}^{p} x_{jk}^{p} + \sum_{p\in P'}\sum_{j\in R}\sum_{k\in K} c_{ij}^{p} x_{ij}^{p}$$

$$\text{subject to} \quad \sum_{i\in I} x_{ij}^{p} = \sum_{k\in K} x_{jk}^{p} \quad p \in P, \quad j \in J \tag{4}$$

$$\sum_{i\in I} x_{ij}^{p} = \sum_{k\in K} x_{jk}^{p} \quad p \in P', \quad j \in R \tag{5}$$

$$\sum_{j\in J} x_{jk}^{p} \geq d_{k}^{p} \quad p \in P\backslash P', \quad k \in K \tag{6}$$

$$\sum_{j\in J\cup R} x_{jk}^{p} \geq d_{k}^{p} \quad p \in P', \quad k \in K \tag{7}$$

$$\sum_{p\in P'}\sum_{i\in I} x_{ij}^{p} \leq Q \quad j \in R \tag{8}$$

$$x_{ij}^{p}, \quad x_{jk}^{p} \geq 0 \text{ and integer } p \in P, \quad i \in I, \quad j \in J \cup R, \quad k \in K. \tag{9}$$

In these models, the objective functions consist of minimizing the logistics costs associated with all the white stocks since it represents the major concern of the UNHRD in this case. Constraints (1), (4) and (5) are flow conservation equations, constraints (2), (6) and (7) ensure that end-user demands are satisfied, constraint (8) imposes the capacity restriction on the RDC, and constraints (3) and (9) define the domains of the decision variables.

4.3. Solution methodology

The two models were coded in C++ and solved by means of the optimization software CPLEX (version 12.6.2) over 5000 simulated scenarios of discrete biannual demands. The solution methodology is depicted in Fig. 5 , where the inputs are the simulated demand scenarios and the logistics costs, and the outputs are the results obtained by solving Models 1 and 2. Several analyses were conducted on the outputs. These include the computation of descriptive statistics such as the mean cost, the standard deviation, and the mean savings that can be expected by adding an RDC to the

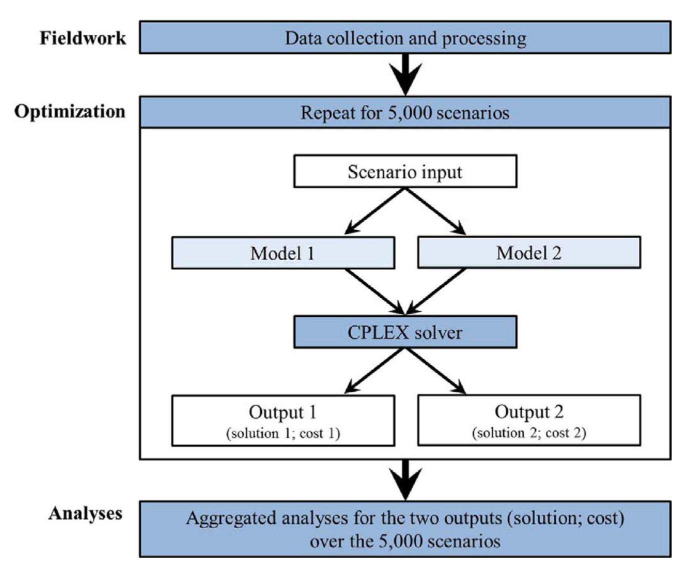

Fig. 5. Framework of the solution methodology.

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current network. We also assessed the impact of several parametric cost variations on the results. Finally, the detailed solutions allowed us to analyze which products should be prepositioned at the RDC, and in which quantities.

From a conceptual point of view, the problem of determining the best stock prepositioning solution within the proposed network is a two-stage stochastic optimization problem. The first-stage decision consists of determining which quantity of each product to store in Kampala, while the second-stage decision consists of determining the best distribution plan after the demand has been realized considering the decision made in the first stage. We have opted to solve this problem by means of a two-phase heuristic. The first phase determines the average savings obtained by optimally delivering the relief items within the proposed network over several demand scenarios, and then analyzes the results in order to retrieve a set of potential advanced prepositioning solutions. The second phase determines the best advance prepositioning solution by testing all potential solutions obtained in the first phase.

5. Computational results and analyses

We now present our computational results and analyses. In order to respect a confidentiality agreement with our partner, the demand data presented in this paper have been aggregated and the monetary values have been rescaled. The first part will explain how the data used to conduct our study have been collected and processed. The second part covers the data description. The demand scenarios will then be introduced, followed by the outputs of our analyses.

5.1. Data collection

Obtaining reliable data in a humanitarian context always poses several difficulties and is even more challenging when these relate to a distribution network that has yet to be partially constructed. The data were collected by the first author who conducted field studies in Italy, the UAE and Uganda, between June and November 2014. Fieldwork proved to be a crucial phase of this research project since it would have been impossible to gather all the necessary information without working closely with the United Nations staff and observing logistics operations at the relevant facilities.

The first field study was carried out in 2014 at the UNHRD and WFP offices in Rome. This first step allowed us to gain a good understanding of the UNHRD logistics processes as well as to obtain the procurement data and the historical data related to East Africa. These data cover the 2010 to mid-2014 period, for a total of nine six-month periods (semesters). They provide valuable information concerning the products, the suppliers and the demand characteristics for the area of interest. In addition, we had access to the LTAs, which are contracts between the suppliers and the UNHRD. Finally, extensive information about the positioning of inventories in the network was obtained. A second field trip at the UNHRD headquarters and at the Dubai depot, allowed us to complete secondary data collection concerning the functioning of current network. Specific information and data about the proposed network were then collected during our visit of the WFP facilities at Kampala, such as available capacity, inland transportation costs and the distribution network details. The data sources are summarized in Fig. 6. At the end of this fieldwork activity, some data were still missing, such as the transportation costs from the suppliers targeted in our study to the port of Mombasa (Kenya), which is the entry port used to reach Kampala by train. Some air shipping costs between the depots and the East African delivery points were also unavailable. We estimated these missing data by lodging information requests to a freight forwarder agency and a sea shipping company. Finally, the data points for the proposed network, which is not in operation so that costs of the LTAs are not yet available, were estimated by linear regression. Some details will be provided in Section 5.2.

5.2. Data description

The main parameters of our models are the demand, costs associated with the existing network, and those associated with the extended network including the Kampala RDC.

5.2.1. Demand data

The analysis of the UNHRD's historical data base provides an overview of the humanitarian aid shipped in East Africa. The large data bases contain many details such as shipping dates, volumes, product descriptions, final delivery points and logistics partners. Based on this information, we studied the shape of the demand in East Africa for the 15 white stocks targeted by this research, all of which can move in the supply chain, but only 12 of which

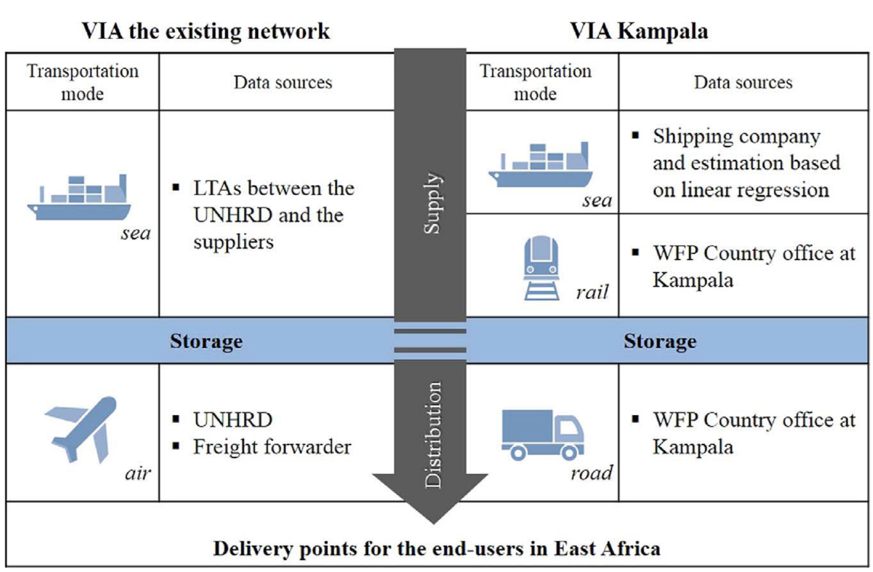
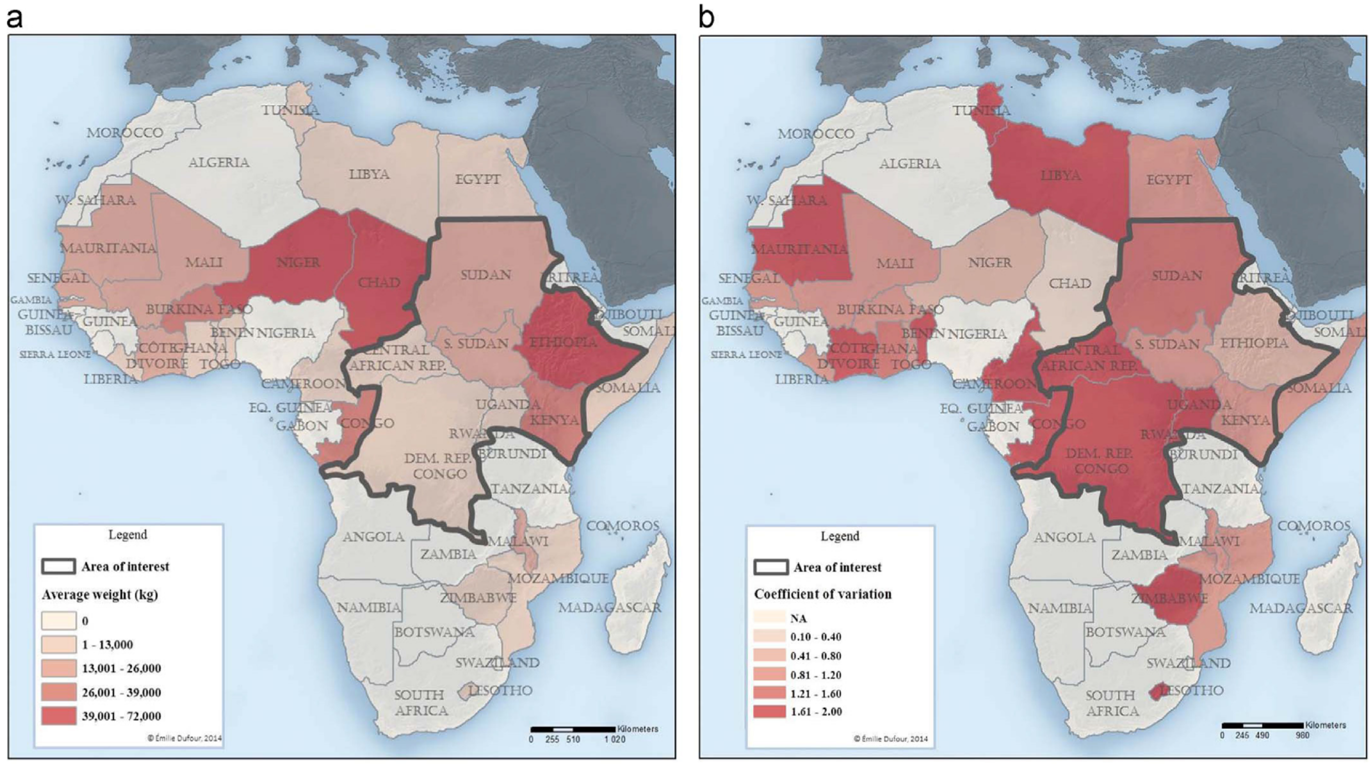


Fig. 6. Data sources.



Average weight of the demand for the 15 products studied (2010 – 2014).

Coefficient of variation of the demand for the 15 products studied (2010 – 2014).

Fig. 7. Characteristics of the demand distribution over Africa.

can be stored in Kampala. These white stocks are blankets, generators, kitchen sets, mosquito nets, mobile storage units (MSUs), prefab units, tarpaulins, tents and water tanks. Most of these products are heavy high-demand items. All these products are needed for displaced people. However, in the case of malaria, only mosquito nets are needed. In the case of droughts, water tanks, mosquito nets and sometimes MSUs (to prepare food) are needed. The maps of Fig. 7 show the mean demand (Fig. 7(a)) and the coefficient of variation (Fig. 7(b)) across Africa for each of the 15 products. In these maps, the area of interest is delimited by a dark gray line. It is interesting to note the wide variation across the territory. Two main observations can be made concerning the demand. First, some countries like Ethiopia have a high average distribution and a low coefficient of variation. This is mainly due to the constant food insecurity in that country. Second, other countries such as the Democratic Republic of Congo and Sudan exhibit a relatively low average and a high coefficient of variation. This can be mostly explained by the armed conflicts in these areas, which create uncertainty.

We have estimated the demand distributions on a biennial basis for each product and each delivery point. Because one must ship products in full containers, we have aggregated the historical demand by semester and assessed the number of containers requested for each product. To model demand distribution, we have opted for a discrete distribution fitting produced by the @Risk software [42], for each product and delivery point.

5.2.2. Cost of the existing network

The fieldwork allowed us to collect almost all data needed to define the operating costs of the existing network. Concerning the three supply depots used to cover East Africa, i.e. Accra, Brindisi and Dubai, we extracted the shipping costs from the LTAs. The

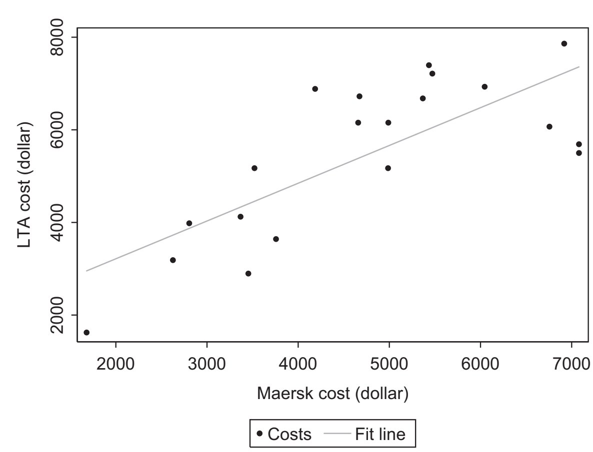


Fig. 8. Linear regression between the costs provided by Maersk and those from the LTAs (dollars); adjusted $R^2 = 0.5415$.

air shipping costs associated with deliveries to the end-users were partially provided by the UNHRD. However, to complete this information, we also consulted a local freight forwarder.

5.2.3. Cost of the proposed network

The costs of supplying Kampala were more difficult to obtain since the links between the suppliers and the port of Mombasa are non-existent in the current UNHRD network structure. To circumvent this difficulty, we requested information from Maersk, an international sea shipping company. In order to validate the costs of supplying Mombasa, we also lodged requests for two of the three depots of the existing network, Accra and Dubai. Note that since Maersk does not serve Mombassa from Brindisi, this route

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Table 3
Summary of the logistics cost parameters.

Parameters	Description	Existing	Proposed
$c_{ij}^p \quad p \in P,\ i \in I,\ j \in J$	Sea transportation costs	√	√
$c_{jk}^p \quad p \in P,\ j \in J,\ k \in K$	Air transportation costs	√	√
$c_{ij}^p \quad p \in P',\ i \in I,\ j \in R$	Handling costs, sea and rail transportation costs		√
$c_{jk}^p \quad p \in P',\ j \in R,\ k \in K$	Handling and road transportation costs		√

could thus not be included in the analysis. We found that the costs provided by Maersk were lower than those extracted from the LTAs. This gap can be explained by the fact that the costs in the LTAs include other components, such as the container handling fees and insurances. To obtain more realistic costs, we therefore used a simple linear regression model to estimate the LTAs costs of the proposed network: $LTA\ cost = \beta_1 + \beta_2\ Maersk\ cost + \epsilon$. The regression equation is $LTA\ cost = 1,583.84 + 0.8157\ Maersk\ cost$ as depicted in Fig. 8 , the adjusted R^2 coefficient is equal to 0.54 and β_2 is significant at a 0.001 level.

In the proposed network, after arriving at Mombasa the containers would be shipped by train to the Kampala facilities. The railroad directly links the port of Mombasa to the site of Kampala, which is why this transportation mode was selected. The WFP country office at Kampala provided the rail transportation rates for this link. We added to these costs the port fees and the handling costs for the reception of the container in the port. Moreover, the WFP country office provided the rates for delivering the containers by truck to the end-users for the delivery points targeted in the area of interest. Finally, others fees have to be taken into account in order to operate the RDC at Kampala. Indeed, it is necessary to rent a crane and to hire an operator to handle the incoming and outgoing containers. These costs were also included in the model. Table 3 summarizes the costs associated with the existing network and with the proposed network.

5.3. Generation of the input scenarios

We generated 5000 biennial demand distributions for each product and delivery point using the best fitted distribution extracted from the historical data. Fig. 9 depicts examples of the demand for two different products and distribution points. In each scenario, multiple products and demand points are considered and the number of containers thus varies between nine and 85, with a mean of 43.46 and a standard deviation of 10.04. We confirmed with the UNHRD that this is representative of the demand patterns in the region of interest. These scenarios were used to solve Models 1 and 2.

5.4. Analysis of the scenarios′ output

We analyzed the results of the scenarios′ outputs through aggregated data analyses. Descriptive statistics allowed us to evaluate the potential improvement yielded by the implementation of the Kampala RDC. Several sensitivity analyses were also conducted. We proposed a cost efficient and robust prepositioning solution at the Kampala RDC.

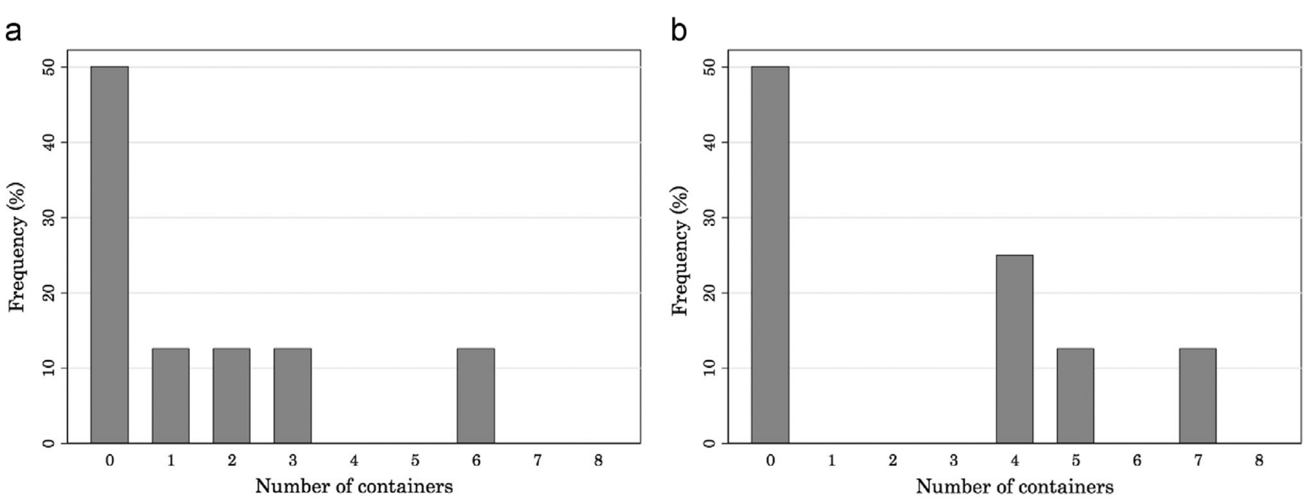
5.4.1. Cost improvement

The optimization results indicate that the proposed network is always less costly than the existing network. Table 4 shows that the addition of the Kampala RDC to the current network constitutes an efficient strategy for the reduction of operating costs. In this table, the monetary values have been rescaled but the percentage improvement is real. The improvement yielded by the proposed network represents an average cost reduction of 33.97%, with a standard deviation (STD) of 6.85%. This improvement ranges from 15.59% to 69.77% over the 5000 scenarios.

Fig. 10 shows that there exists a negative relationship between the total demand in number of containers included in a particular scenario and the percentage of improvement yielded by the introduction of the RDC. Indeed, since the capacity of the RDC is fixed at 10 containers, the proportional weight of Kampala decreases when the number of containers requested increases. We also observed that the more the RDC is used to send heavy products such as MSUs, the higher is the improvement.

5.4.2. Sensitivity analyses on the cost improvement

We conducted extensive sensitivity analyses in order to evaluate the robustness of the expected improvement obtained by adding an RDC and the solution of products to preposition. We solved the 5000 scenarios several times by letting the airfares and road transportation tariffs vary. The aggregated results of the cost sensitivity analyses are shown in Table 5, where the first line highlights the benefits of the proposed network compared with the existing network considering the original costs. We first tested the impact of an air transportation cost decrease. Indeed, for some of these rates, the costs were provided by an external source and in



Demand for prefab units at Addis Ababa.   Demand for MSU 10x24 (design 1) at Khartoum.

Fig. 9. Bar charts of the frequency of the requested number of containers per semester for two different products and distribution points.

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Table 4
Descriptive statistics of the costs, per semester, obtained for the existing and proposed networks.

Statistic	Existing network ($)	Proposed network ($)	Improvement (%)
Average	1,100,044	741,612	33.97
STD	289,201	252,623	6.85
Median	1,085,216	723,025	33.02
Min	239,557	95,505	15.59
Max	2,186,694	1,755,218	69.77

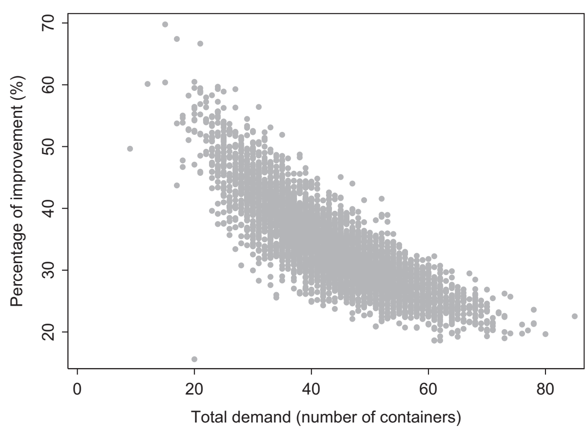

Fig. 10. Percentage of improvement obtained with the proposed network as a function of the total demand in number of containers across the scenarios.

this sense, they were most likely overestimated, which can provide an unfair advantage to the regional prepositioning. To avoid this bias, we conducted sensitivity analyses by solving instances in which the air transportation rates were reduced by 10%, 20% and 30%. Results of Tests 2–4 presented in Table 5 show that the improvement resulting from the use of the RDC remains significant (30.12%), even with a rate decrease of 30%. The same conclusion was reached when the road transportation costs were allowed to increase. Indeed, according to the information provided by the Kampala WFP country office, these costs are expected to increase in the near future. Therefore, we decided to conduct sensitivity analyses by increasing them by 5%, 10% and 15% (Tests 5 to 7). As shown in Table 5, the negative impact on the mean improvement on logistics costs compared with the base-case scenario (Test 1) is small even when the road transportation rates increase by 15% (it goes down from 33.97% to 33.33%). We have also tested a simultaneous variation of these two parameters (Tests 8 to 16). The last nine lines of Table 5 show the aggregated results of this analysis. We note that the improvement is high (29.27%) even in the worst scenario tested, i.e. a decrease of airfares by 30% combined with a 15% increase in the road transport costs. On the basis of these results we are confident that the proposed network with an RDC at Kampala should yield an important operating costs over a wide range of transportation costs.

5.4.3. Determining which products to preposition at the Kampala RDC

We have analyzed the nature of the products stored at Kampala by solving Model 2 for each of the 5000 scenarios, which enabled us to identify a robust prepositioning solution. Our solution is robust since it better responds to the demand over all scenarios, and it yields a smaller average cost than do the other solutions. Table 6 provides the distribution of the number of containers allocated to each of the 15 relevant products over the 5000 demand scenarios, as well as, the average, median and standard deviation of the number of containers required for each product at the Kampala RDC. These products are determined by the variables x_{ij}^{p} $(j \in R)$ in Model 2. For example, in 880 scenarios, one container of product 7 transits through Kampala in the optimal solution. As already mentioned, three of the 15 products (two types of mosquito nets and wool blankets, which are products 1, 5 and 6) have characteristics that prevent them from being stored at the RDC because the storage conditions cannot be controlled. Some products, such as generators, kitchen sets, family tents and water tanks, are also rarely stored in the RDC. These were therefore discarded as potential products to be prepositioned at Kampala. This left us with a reduced list of six products, which are highlighted in Table 6. These are the products for which the average number of containers transiting through Kampala was the largest.

We used the descriptive statistics on the distribution of the number of containers for the six products highlighted in Table 6 to extract 12 candidate storage solutions as a prepositioning strategy at the Kampala RDC. In these candidate solutions reported in Table 7, the number of containers of each product was determined by rounding up or down the average value of products 7–12 given in Table 6, while ensuring that the total was equal to the capacity of the RDC, which is 10 containers.

We then analyzed the cost efficiency of the 12 candidate solutions. To this end, each solution was used as an input in each scenario for the proposed network by fixing relevant x_{ij}^{p} variables $(j \in R)$ in Model 2, which corresponds to specifying the amount of each product prepositioned in Kampala. We then solved all scenarios with these fixed variables. The results obtained from this exercise are compiled in Table 8. The second column of this table reports

Table 5
Logistics cost improvements resulting from the sensitivity analyses.

Test	Variation in transportation costs		Descriptive statistics				
	Air (%)	Road (%)	Average (%)	STD (%)	Median (%)	Min (%)	Max (%)
1	0	0	33.97	6.85	33.02	15.59	69.77
2	−10	0	32.94	6.63	32.02	14.33	68.08
3	−20	0	31.68	6.36	30.81	12.81	66.01
4	−30	0	30.12	6.04	29.30	11.35	63.48
5	0	5	33.76	6.81	32.83	15.27	69.50
6	0	10	33.54	6.76	32.61	14.94	69.22
7	0	15	33.33	6.72	32.40	14.62	68.95
8	−10	5	32.94	6.62	32.02	14.33	68.08
9	−20	5	31.67	6.36	30.81	12.82	66.01
10	−30	5	30.12	6.04	29.30	11.35	63.48
11	−10	10	32.48	6.53	31.58	13.62	67.48
12	−20	10	31.16	6.25	30.32	12.17	65.34
13	−30	10	29.56	5.93	28.75	10.72	62.72
14	−10	15	32.25	6.48	31.36	13.27	67.17
15	−20	15	30.91	6.20	30.07	11.89	65.00
16	−30	15	29.27	5.88	28.48	10.40	62.35

Table 6
Distribution of the number of containers of each products transiting through Kampala in the optimal solution over the 5000 scenarios.

Products		Number of containers											Descriptive statistics		
		0	1	2	3	4	5	6	7	8	9	10	Median	Average	STD
1	Blankets	5000	0	0	0	0	0	0	0	0	0	0	0	0.00	0.0
2	Generators 16Kva	4970	16	7	4	2	0	1	0	0	0	0	0	0.01	0.2
3	Generators 45Kva	4992	5	3	0	0	0	0	0	0	0	0	0	0.00	0.1
4	Kitchen set	4979	12	4	4	1	0	0	0	0	0	0	0	0.01	0.1
5	Mosquito net, 160 cm	5000	0	0	0	0	0	0	0	0	0	0	0	0.00	0.0
6	Mosquito net, 190 cm	5000	0	0	0	0	0	0	0	0	0	0	0	0.00	0.0
7	MSU, 10x24 (design 1)	1491	880	722	727	542	326	183	70	44	11	4	2	2.71	2.0
8	MSU, 10x32	2903	843	639	390	176	36	11	1	0	1	0	0	0.85	1.2
9	MSU, 10x24 (design 2)	2388	826	775	409	289	174	99	30	6	4	0	1	1.30	1.7
10	Prefab. units	2177	634	580	581	535	403	48	40	1	1	0	1	1.66	1.8
11	Tarpaulin, 4x6m	2159	809	651	624	327	298	100	19	13	0	0	1	1.52	1.8
12	Tarpaulin, 4x60m	1217	760	822	734	608	448	254	101	38	10	8	2	2.40	2.0
13	Tent multipurpose	4996	3	0	0	1	0	0	0	0	0	0	0	0.00	0.1
14	Water tank, 10000lt	4810	89	51	30	15	4	0	0	1	0	0	0	0.07	0.4
15	Water tank, 5000lt	4705	156	94	38	4	2	1	0	0	0	0	0	0.10	0.4

Table 7
Candidate prepositioning solutions.

Products	Solutions											
	1	2	3	4	5	6	7	8	9	10	11	12
MSU, 10x24 (design 1)	2	3	2	3	3	2	2	3	3	3	3	2
MSU, 10x32	1	1	0	0	0	0	1	1	0	1	0	1
MSU, 10x24 (design 2)	1	1	1	1	0	2	2	1	1	1	1	1
Prefab. units	2	1	2	1	1	2	1	3	2	2	2	2
Tarpaulin, 4x6 m	1	1	2	2	3	2	2	1	2	1	1	2
Tarpaulin, 4x60 m	3	3	3	3	3	2	2	1	2	2	3	2
Total	10	10	10	10	10	10	10	10	10	10	10	10

the average cost improvement for each candidate prepositioning solution compared with the existing network over the 5000 scenarios. The last six columns report some descriptive statistics on the utilization of the containers stored in Kampala over the 5000 scenarios. The third column shows the average number of prepositioned containers requested and the last five columns show the percentage of scenarios yielding a utilized capacity at the RDC of at least 90%, 80%, 70%, 60% and 50%. We note that Solution 7 (highlighted in Tables 7 and 8) is superior to the other candidate solutions since it outperforms them in terms of logistics costs improvement and of utilized capacity over the 5000 scenarios. We therefore consider that Solution 7 is the most robust and efficient solution. We note that 26.61% of all scenarios use at least 90% of the RDC capacity when the products of Solution 7 are initially prepositioned at the Kampala RDC. On average, 7.43 containers are requested at the Kampala RDC in order to fulfill the regional demand. Our analysis also reveals that at least 70% of the RDC capacity is used in 72.55% of the scenarios. We have also analyzed the resulting operation costs. We note that an average improvement of 21.16% can be expected with the proposed mix of products to store at the RDC.

6. Conclusions, managerial insights and outlooks

This research was rooted in a case study of the UNHRD response operations in East Africa for the delivery of ENFI to their partners. In its 2014–2017 strategic plan [60], the UNHRD targeted the reduction of the operational costs of its network. As a contribution to this objective, we considered whether the UNHRD should modify its supply chain through the addition of a regional distribution center in Kampala in order to improve the efficiency of its response to humanitarian crises in East Africa.

Our methodology included four main steps. We first carried out field studies in Italy, the UAE and Uganda to define the problem and collect data. We then formulated the problem as a network flow model, with and without the inclusion of the proposed RDC. In the next step, several demand scenarios across East African delivery points were simulated to circumvent the problem posed by the unpredictability of the demand; a total of 5,000 scenarios were generated and solved by the optimization software for both networks. Finally, we analyzed the results and performed extensive sensitivity analyses.

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Table 8
Descriptive statistics on the efficiency of the candidate prepositioning solutions.

Candidate solution	Average improvement in logistics costs (%)	Average number of requested containers	Percentage of scenarios yielding an utilized capacity at the RDC of at least				
			90%	80%	70%	60%	50%
Solution 1	18.28	6.96	19.72	40.81	61.19	78.62	90.82
Solution 2	17.16	6.88	19.7	34.71	56.89	76.44	88.78
Solution 3	19.95	6.72	17.16	37.43	55.05	74.59	87.34
Solution 4	16.83	6.55	17.34	31.25	52.8	70.95	84.76
Solution 5	15.63	6.13	14.12	26.33	44.69	63.43	76.60
Solution 6	20.27	6.98	18.76	41.83	60.09	81.08	91.00
Solution 7	21.16	7.43	26.61	51.07	72.55	87.52	96.20
Solution 8	19.82	6.22	13.62	24.08	44.63	63.73	79.10
Solution 9	18.5	6.4	13.6	28.67	48.61	66.43	85.00
Solution 10	18.83	6.63	15.58	31.29	53.39	72.21	88.81
Solution 11	16.27	6.34	14.08	28.11	48.09	65.85	82.48
Solution 12	20.52	7.01	18.76	41.79	61.11	81.9	92.14

Our computational results demonstrate the positive impact on the network operational costs of adding the Kampala RDC. Indeed, over 5000 demand scenarios, the implementation of a Kampala RDC yields a mean improvement of 21% for the products considered in our study. A detailed analysis of the optimization results allowed us to determine which products should be prepositioned at Kampala.

The performance of the RDC is strongly linked to the regional context, which itself is subject to significant changes that may affect humanitarian aid flows over time. Our recommendation of which products to preposition on Kampala is based on the 2010–2014 data and is conjunctural. For example, many people are currently displaced from the Democratic Republic of Congo and of South Sudan, which means that large quantities of MSUs and tarpaulins are needed in the refugees camps located in the area of interest. In order to optimize the use of its RDC, the UNHRD has to periodically review the list of products to preposition at Kampala.

Besides being an efficient strategy, the implementation of an RDC entails minimal financial risks for the UNHRD. Indeed, the initial investments to establish the RDC are relatively low since the UNHRD will use the outdoor spare capacity available in the WFP facilities at Kampala. The UNHRD will also benefit from reduced transportation tariffs through the agreements passed by the WFP with the transportation companies. Another advantage in term of costs lies in the use of white stocks. Since these stocks remain the property of the suppliers during storage at the RDC, they do not entail acquisition costs for the UNHRD, and the risk is shared between the stakeholders. The use of the East African WFP network also facilitates the establishment of the RDC. Following our recommendations made in July 2015, the UNHRD has begun a progressive implementation of the RDC.

While this strategy yields an important cost advantage for the UNHRD's partners, these should consider two additional factors before opting to replenish from Kampala. First, the delivery times are longer from Kampala, varying from several days to several weeks for some destinations, which could negatively affect the partner's response time in emergency situations. In this case, it would make sense to replenish by air from the depots. Second, the partners must work with a minimum order size of one full container when they replenish from Kampala. This constraint may act as a potential barrier for the small and medium organizations that do not necessarily have the capital, the storage capacity or the need to acquire a large quantity of the same product. In this sense, the potential saving provided by the RDC is more accessible to the larger organizations.

Our study has demonstrated the efficiency of a regional prepositioning strategy in East Africa. Considering the improvement provided by the ten containers stored at Kampala, the UNHRD is now searching for a site with a larger capacity. Our solution methodology should allow the UNHRD to analyze other potential sites in order to extend its RDC network. Thus, the UNHRD has opened an RDC in Djibouti in January 2016 and is currently considering the possibility of opening another one in Duala to serve the Cameroon-Chad corridor.

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