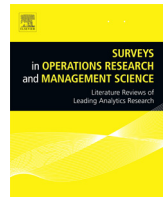




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## Review

## A literature review on inventory management in humanitarian supply chains

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## A B S T R A C T

In this paper, we present a review and analysis of studies that focus on humanitarian inventory planning and management. Specifically, we focus on papers which develop policies and models to determine how much to stock, where to stock, and when to stock throughout the humanitarian supply chain. We categorize papers according to the disaster management cycle addressed; specifically, we focus on pre-disaster and post-disaster inventory management. We evaluate existing literature in terms of problem aspects addressed such as decision makers, stakeholders, disaster types, commodities, facility types, performance measures as well as methodological aspects (i.e., types of policies, models, and solution approaches). We identify current gaps in the literature and propose directions for future research.

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## Contents

1. Introduction.....	1
2. Earlier literature surveys.....	3
3. Search methodology.....	4
4. Models for humanitarian inventory management.....	4
4.1. Pre-disaster inventory management.....	4
4.1.1. Problem aspects.....	5
4.1.2. Methodological aspects.....	8
4.2. Post-disaster and post-warning inventory management.....	9
4.2.1. Problem aspects.....	9
4.2.2. Methodological aspects.....	13
5. Conclusions and future research directions.....	14
Acknowledgments.....	15
References.....	15

## 1. Introduction

Every year, disasters affect millions of people. According to [1] database, 6873 natural disasters occurred in the world between 1994 and 2013, resulting in 1.35 million deaths and affecting 218 million people on average per year [2]. Moreover, the world has witnessed the deadliest disasters of the century over the last decade; the total death toll from the 2004 Asian tsunami, the 2008 Cyclone Nargis, and the 2010 Haiti earthquake was more than 500,000. The number of climate-related disasters such as floods, droughts, storms and heat waves are also on the rise, and the intensity of such events is not expected to decrease in the

future [3]. Furthermore, man-made disasters (such as conflicts, nuclear accidents, terrorist attacks) threaten the lives of people; for instance, the Syrian conflict, which started in 2011, has triggered the world's largest humanitarian crisis since World War II, killing more than 200,000 people to date and causing millions of people to be displaced [4].

Amid all the difficulty, people affected by disasters rely on life-saving assistance (such as food, shelter, water) from humanitarian organizations. Depending on location, timing, type and intensity of disasters, there may be significant differences in needs of victims and scale and scope of disaster responses. Nevertheless, a common objective for all relief operations is to access people in need and deliver aid on time. In other words, similar to the traditional supply chains, humanitarian supply chains must be designed to provide "the right supplies with the right quality at the right time in the right place to the ultimate customer" [5]. Effective logistics management is essential to achieve this objective. Humanitarian logis-

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tics involves procurement, warehousing, inventory management, transportation, and distribution functions, and is the most expensive part of disaster relief operations [6].

The importance of effective logistics management has been increasingly acknowledged in the humanitarian sector over the last years, and this increased attention has also found its counterpart in academia. The unique and challenging humanitarian environment (see e.g., [5,7–9]) have attracted many researchers to this field. As a result, the number of articles in Operations Research (OR) and Management Science (MS) focusing on humanitarian logistics has tremendously increased in the last decade. Several literature survey articles are also published, which examine the existing disaster management/humanitarian logistics (DM/HL) studies and evaluate the state-of-the-art from different perspectives (see Section 2). In this paper, we present a survey of OR/MS studies that focus on *humanitarian inventory management*, which highly affects the efficiency and responsiveness of humanitarian supply chains. Although some of the existing literature survey papers include discussions on inventory management, to the best of our knowledge, there is no study that particularly examines the policies and models developed for managing humanitarian inventories.

The fundamental questions of inventory management are the same for commercial and humanitarian supply chains, which are (i) *how much to order*, (ii) *when to order*, and (iii) *where to store* [10]. There is a well-established inventory management literature, which focuses on answering these questions for commercial supply chains. However, due to the unique characteristics of humanitarian settings, the policies and models developed for commercial supply chains may not be directly applied to manage humanitarian inventories [10]. Below, we summarize the distinct features of humanitarian inventories:

- **Objectives.** Improving customer service and decreasing inventory costs are important for both humanitarian organizations and business enterprises. However, efficiency is usually the most important objective in commercial inventory management, while satisfying beneficiary needs is always the utmost priority for humanitarian organizations. Whybark [10] considers humanitarian relief inventories as one form of “social” inventories, which “*serve broad social objectives as opposed to being used for the benefit of an individual*” [10]. Whybark [10] stresses the need for further research that investigates the criteria to use while making inventory decisions in disaster relief settings. While the benefits from keeping inventory can be usually converted to monetary measures in the commercial sector (e.g., lost profits), it is challenging for humanitarian organizations to quantify the benefits associated with serving people affected by disasters [10,11]. A critical criterion to consider in managing disaster inventories can be deprivation cost, which associates an economic value for human suffering due to lack of access to relief supplies [12].
- **Ownership.** Humanitarian relief inventories might have multiple owners such as governments and non-governmental/private organizations. Therefore, it is often difficult to have accurate information about the aggregate amount of stocks on-hand [10].
- **Demand.** There is a high level of uncertainty associated with timing, location, type and amount of demand in most humanitarian settings, which bring significant challenges in developing effective inventory policies [10]. Demand-related parameters are usually more predictable in commercial settings. Moreover, demand can be forecasted using historical sales data in commercial settings, whereas historical information for relief demand may not be available. Furthermore, since victims in a disaster area has no choice over the aid supplies, true demand for commodities may never become known [7]. Finally, when

a disaster occurs, demand must be immediately satisfied implying zero lead time requirements, while customers may be willing to wait for a reasonable amount of time in commercial settings.

- **Infrastructure.** The network infrastructure is generally reliable in commercial settings, whereas post-disaster network may be damaged and involve uncertainties. Furthermore, disasters may affect the power infrastructure in the affected regions, which may also prevent relief organizations from using advanced technologies to track and manage inventories. Business enterprises usually use technologies that support their decisions and operations with minimal or no interruption, and hence they usually have full inventory visibility.
- **Financial resources.** Humanitarian organizations collect most of the donations after disaster occurrences. Therefore, humanitarian organizations may not have financial resources necessary to keep and manage inventory. Moreover, some donations may be earmarked for certain operations and needs. Commercial organizations usually have less constraints in allocating budgets for inventory-related expenses.
- **Sourcing.** Humanitarian organizations may need to consider several issues while making sourcing decisions. For instance, purchasing supplies from local suppliers is usually preferred to support long-term economical development of the affected region. Giving equal opportunity to different suppliers might be an important concern, as well. Therefore, humanitarian organizations may not necessarily look for the most economical way to acquire relief supplies, which may affect ordering decisions and inventory management. Commercial organizations usually do not have such constraints preventing them from making the lowest cost acquisitions [11].

The OR/MS studies that address humanitarian inventory management develop new approaches (or adopt existing ones) to capture the unique aspects of the humanitarian environment. In this paper, we provide a systematic review of articles that present mathematical models for inventory management in humanitarian networks. In particular, we examine the papers which involve one or more of the following inventory management decisions: *where to stock*, *when to stock*, and *how much to stock*. These decisions may be of concern in different disaster management phases. We find that the existing studies that focus on pre-disaster inventory management generally address *long term pre-positioning decisions* (i.e., determining location and amount of stocks), while the studies on post-disaster (or post-warning) inventory management consider *short-term pre-positioning and inventory ordering* decisions. That is, according to our classification in this paper, pre-positioning decisions in the pre-disaster stage are generally made with no advance information or by only using historical data, while pre-positioning and ordering decisions in the post-disaster/warning stage are made once some information about a disaster become available. In this study, we review characteristics of the models developed to manage inventory in pre- and post-disaster/warning phases. The papers, which purely focus on facility location or routing/distribution decisions while assuming a fixed amount of inventory at the facilities, are not within the scope of this survey; interested readers are referred to other survey papers, which exclusively focus on distribution network design (e.g., [13]) and routing models (e.g., [14]) in humanitarian relief.

In Section 2, we provide a review of literature surveys on HL/DM and position our study. Section 3 presents our survey methodology. In Section 4, we present an in-depth analysis on characteristics of the studies that focus on pre-disaster and post-disaster/warning inventory management. Finally, we identify future research directions and present concluding remarks in Section 5.

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