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# Models and metrics to assess humanitarian response capacity

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ABSTRACT

The race to meet vital needs following sudden onset disasters leads response organizations to establish stockpiles of inventory that can be deployed immediately. These government or non-government organizations dynamically make stockpile decisions independently. Even though the value of one organization's stock deployment is contingent on others' decisions, decision makers lack evidence regarding sector capacity to assess the marginal contribution (positive or negative) of their action. To our knowledge, there exist no metrics describing the system capacity across many agents to respond to disasters. To address this gap, our analytical approach yields new humanitarian logistics metrics based on stochastic optimization models. Our study incorporates empirical data on inventory stored by various organizations in United Nations facilities and in their own warehouses to offer practical insights regarding the current humanitarian response capabilities and strategies. By repositioning inventory already deployed, the system could respond to disasters in the same expected time with a range of 7.4%–20.0% lower cost for the items in our sample.



## 1. Introduction

Capability to rapidly deploy life-saving commodities in response to natural disasters is vital. The humanitarian response capacity spans various actors and activities, which are often not coordinated. A common strategy government and non-government organizations use to improve humanitarian response is to pre-position stockpiles of critical commodities in various locations prior to disaster events. While increased inventory certainly improves response capacity, the incremental impact of continual stockpile deployments by various organizations is difficult to assess.

The reason is a complex system: dozens of organizations manage hundreds of distinct items in dozens of warehouses globally in order to respond to events that vary in location, type, and size. Thus, there are no sector metrics for humanitarian stockpile capacity, even though combined efforts across organizations determine the extent to which needs are met following a disaster. Moreover, there is no mechanism to influence numerous organizations' stockpile decisions toward system-wide improvement given inherent coordination challenges in the sector.

To more easily assess this complex landscape and guide decisions toward system improvement we propose new humanitarian logistics metrics based on stochastic optimization models. The metrics assess the quality of the humanitarian system according to various objectives (e.g., cost, time, need met, etc.). These numerical values help organizations understand how their isolated inventory decisions affect the response capacity for the system as a whole. Such evidence enables decisions that effectively weigh internal objectives (e.g., procurement and warehousing costs, organizational mission, etc.) with contribution to system capacity.

We evaluate our approach with a combination of proprietary data from the United Nations (UN), publicly available data from various sources, and expert opinion on parameter values. We show that the current allocation of inventory among the warehouses for which we have data can be improved significantly. By repositioning inventory already deployed, the system could respond to disasters in the same expected time with a range of 7.4%–20.0% lower cost for the items in our sample. Such efficiency gains translate directly into more humanitarian services for the same donation budget.

We show that coordination is increasingly important as the number of organizations deploying stockpiles grows. Organizations acting in isolation might optimally place inventory in the same location rather than deploy stock to serve more regions in a coordinated system. Fortunately our approach does not require explicit coordination, which is challenging to implement, since incremental

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decisions based on sector-wide metrics would improve system performance even if made independently.

We conduct sensitivity analysis to consider robustness to empirical data quality and to parameter value assumptions. Metrics and optimal decisions are robust for most parameter value assumptions. They are moderately sensitive to the empirical data used for the risk portfolio. The sensitivity analysis guides further efforts to collect data and calibrate the model for sector use.

The approach proposed in this paper addresses important gaps in the growing literature on performance measurement for humanitarian logistics. It summarizes dynamic empirical data from a complex system with a few intuitive metrics. The metrics are based on accepted modeling approaches yet extend beyond myopic outcomes of independent organizations to measure and improve sector-wide capacity. And most importantly, they guide system improvement without the need for explicit coordination.

## 2. Research design

This section characterizes the practical context of disaster response that motivates our analytical approach, described in section 3, and outlines the empirical research design we use to assess its potential. The section closes by positioning the research as an extension of established modeling approaches that fills a gap in the humanitarian metrics literature.

### 2.1. Context and motivation

Immediately following a disaster that outpaces community coping mechanisms, various outside organizations rush to provide life-saving commodities to meet health, water, food, shelter, or other needs for the affected population. The response is expedited by inventory prepositioned by these organizations, which could include government (local, regional, national, or foreign), non-government (NGO), military, or private sectors. The stock for this initial deployment could be centralized or deployed across several locations. For large-scale and/or urgent crises, organizations may choose to utilize stock in several locations and incur the additional cost of shipping farther to meet needs. In most cases, this initial push is intended to meet human needs within the first few days, followed by replenishment from strategic suppliers based on assessments of need in the affected community. Hence, the initial push is typically transported by air unless ground transportation offers better transit time from a nearby stocking point; sea shipping is rarely used for initial deployment. Our model considers both air and land modes to optimize distribution cost and/or time for the initial response to a sudden onset disaster.

Poor response to a widely publicized event pushes organizations to take tangible actions. Such actions often include increasing the size and/or number of locations for critical commodity stockpiles (typically skewed toward the nature of a recent event and not a broader risk portfolio). On the other hand, constrained fundraising and/or expiration of stockpiled items pushes organizations to reduce stock. As a result, numerous organizations are continually adjusting stockpile deployment.

These dynamic decisions are made independently for the same population of potential beneficiaries. Organizations do not have explicit incentives to coordinate; this can be exacerbated by lack of centralized data and visibility into needs and roles of the actors (Tomasini and Van Wassenhove, 2009). The result is a potentially chaotic response (Van Wassenhove, 2006). Furthermore, there is no central authority to enforce compliance to coordinated solutions, such as optimization of sector-wide stock.

Fragmented decision-making and limited transparency about response capacity make it difficult to assess, much less optimize, the combined level of preparedness for a region. As one manager at a large organization told us, a key unanswered question is “If we had one million dollars from a donor, what would we buy and where would we put it?”

### 2.2. Research questions and empirical study

To overcome coordination issues and improve system performance, we propose sector-wide metrics based on analytical models for disaster response capacity to inform and evaluate the dynamic, independent decisions of numerous organizations. The scope of these metrics and our analysis includes stockpile capacity for *rapid* response to sudden-onset disasters. We do not consider slow-onset disasters or ‘steady-state’ response. Items in these situations are more likely to be shipped by slower, less expensive transportation modes and/or from suppliers directly instead of being shipped rapidly from stockpiles.

We suggest that metrics could fill two gaps limiting coordinated decisions on stockpile capacity: (1) organizations lack evidence to evaluate system capacity, and (2) organizations lack guidance to operationalize system improvement. To close these gaps, our approach seeks to address two research questions:

1. What is the quality of current inventory positions across stockpile depots? (system assessment)
2. What is the value, positive or negative, of incremental change to the combined system? (decision support)

Dynamic answers to the first question provide effective evidence to motivate systemic actions by an individual organization and/or a coordinated group of decision makers. They also form the basis for more general insights regarding the value of stockpile capacity. Actions taken primarily focus on three decisions: (i) which items to buy; (ii) where to put these items; and (iii) stock transfers between depots. Proper application of answers to the second question will guide incremental change resulting from such decisions toward system improvement without the need for explicit coordination.

We use empirical data to assess the potential for these metrics to answer the questions posed. Despite the challenges of coordination, we found two data sources for stockpile inventory spanning multiple organizations in the humanitarian sector. First, inventory quantities and owners for the six United Nations Humanitarian Response Depots (UNHRDs) around the world, which offer space for organizations at no-cost or on a cost-recovery basis, are published dynamically online (United Nations, 2014). Second, several years ago the UN Office for the Coordination of Humanitarian Affairs (OCHA) conducted a “Global Mapping of Emergency Stockpiles” to track stock levels in various organizations’ warehouses; participation was voluntary and each organization provided its own data (UN Office for the Coordination of Humanitarian Affairs, (2014)). To our knowledge, our study is the only analytical assessment of those data. We analyze the combined sector capacity in these datasets across a broad portfolio of risk scenarios. As our research does not focus on disaster forecasting, we leverage a widely used historical database for our scenarios.

### 2.3. Relevant literature

Our work is mainly related to two streams of literature. The first stream utilizes mathematical optimization to pre-position disaster stockpiles. Our analytical approach is based on two-stage stochastic linear programs. Several authors have used such models to determine where to place inventory in the first stage in order to optimize the response in the second stage. The second stage of these