A Large Scale Systems Optimization Model for Distributed Warehousing: A Bilevel Programming Approach[1]

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ABSTRACT

The need for agile supply chains has altered distribution strategies; Solutions for optimizing the supply chain. Warehousing operations are moving from centralized toward hybrid centralized-distributed models as evidenced by current research strategy. This research is an attempt to extend this commercial concept to humanitarian relief operations (HUMRO) where a decentralized storage of goods and support equipment can be efficiently deployed in response to global disaster relief by governments or non-governmental organizations (NGOs).

INTRODUCTION

The elimination of many cross-border barriers to the movement of goods amongst many countries, in particular in Europe, has eliminated the need to establish distribution centers within individual countries. As a result, warehousing operations are moving from centralized toward hybrid centralized-distributed models such as the extended enterprise model which integrates all supply chain players and centralizes logistics controls. This commercial concept can be extended to humanitarian relief operations where a decentralized storage of goods and support equipment can be efficiently deployed in response to global disaster relief by governments or non-governmental organizations [4].

The focus of this paper is on an analytic framework for evaluating options for efficient allocating supplies, equipment and personnel. The presentation of this framework is important because it addresses how to assess these options in terms of the relevant programming costs while considering a novel approach to scenario planning. This formulation minimizes the facility operating, construction, and transportation costs associated with meeting the need of potential small and large operations. This concept is based on the notion that humanitarian relief is not only global, but also hierarchical and dynamic.

DECENTRALIZED WAREHOUSING LOCATION MODEL

In order to evaluate and select alternative warehousing options, we developed an analytic framework that uses a systems optimization model that assesses the cost and capability of

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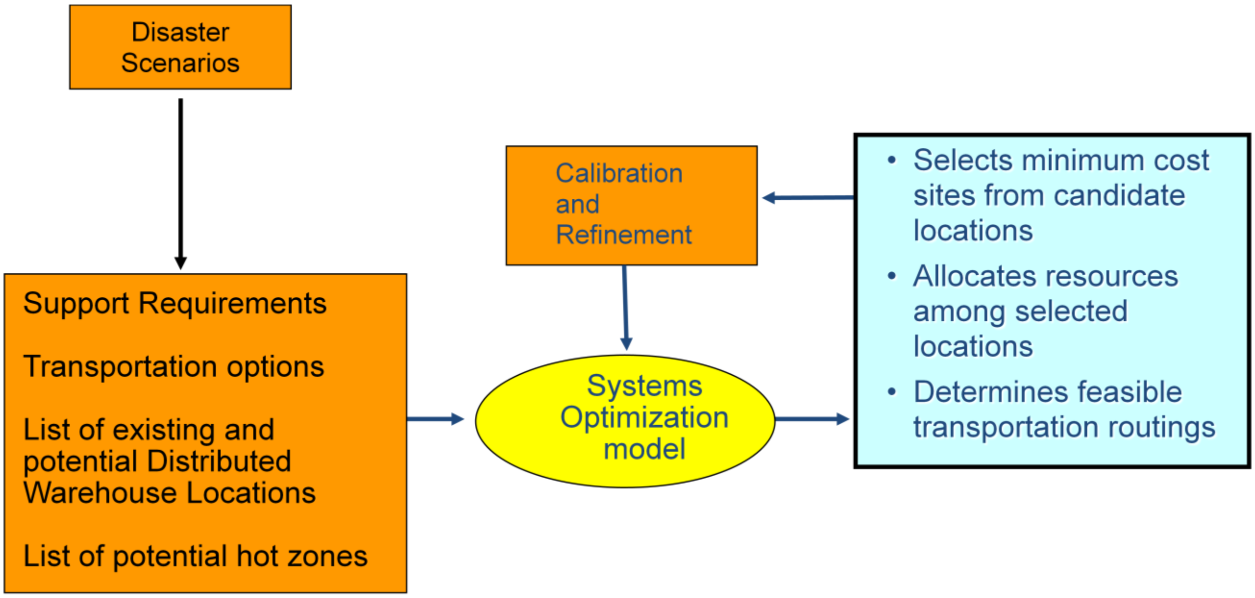
[1] This is an abbreviated version of the paper. The full paper is available from the authors upon request.

various portfolios of Decentralized Warehousing Location (DWL) for meeting a wide variety of global humanitarian operations. The primary approach is to minimize the overall system cost while meeting the operational need. The process examines the costs of alternative support options, for a constant level of performance against a variety of deployments, is an important process in the development of suitable programming and budgeting plans.

The overall analytical approach has several steps and is depicted in Figure 1. A diverse set of disaster scenarios such as tsunamis, earthquakes or floods that would stress the support system is selected. These operations would include different types and size of humanitarian operations from small-scale (small flood) or large-scale (Hurricane Katrina). These scenarios drive the requirements for resources, such as shelter, food or medicine. Some of these resources need to be stored in certain warehouses (DWLs) in order to expedite their distribution and transportation. Although it is difficult with any degree of certainty to predict the location and magnitude of the next disaster, we can limit the number of potential DWLs that provide the best option in meeting potential future disasters. The potential DWLs along with possible hot zones (Earthquake in California, Hurricane in Gulf States, etc) along with transportation options (e.g., allowing sealift or not) serve as the inputs to the optimization model.

The optimization model selects DWLs that minimize the warehouse operating and transportation costs associated with planned operations. The model also optimally allocates the programmed resources and commodities to those DWLs. The model computes the type and the number of transportation vehicles required to move the materiel to demand locations (hot zones). The result is the creation of a robust transportation and allocation network that connects a set of disjointed DWLs and demand nodes.

Figure 1: Analytical Approach



The final step in our approach is to refine and recalibrate the solution set by applying political, geographical, and vulnerability constraints based on current expert judgments of the environment. Thus, this step, since it is applied post-optimally and may force additional iterations, does enable reevaluation and reassessment of the parameters and options chosen.

The above framework was used earlier in solving the warehousing allocation of the US Air Force's combat support [1]. In the former problem, the system was managed centrally and therefore a single system optimization was sufficient in addressing many of issues and concern. There are other methods for centralized management of warehousing including spare-part management [5] but these methods also do not consider the hierarchical nature of the problem. In the current model, we must address the needs and requirements of various levels of decision makers from federal to state and local government to private NGOs. This additional constraint creates a new set of problem that cannot be addressed with a single optimization but rather we must rely on the so called multi-level optimization method. Simply put, the top-level decision maker may have limited control over all the decision variables (e.g., domestic use of the National Guard) and hence must respond to the local requirements and decision-making. This type of hierarchical decision process is called a duopoly and can be mathematically represented by an imbedded optimization model. In the next section, we will briefly introduce the concept of bilevel programming, which can be easily generalized and extended to multi-level model.

BILEVEL OPTIMIZATION

The bilevel programming problem (BLPP) is a mathematical model of the leader–follower game. In this game, the controls of decision variables are partitioned amongst two players: the leader and the follower. Each player seeks to optimize her objective function. The leader moves first by choosing a vector $x \in X \subset R^{n_1}$ in an attempt to optimize her objective function $F(x, y)$. The leader's choice of strategies affects both the follower's objective and decision space. The follower observes the leader's choice and reacts by selecting a vector $y \in Y \subset R^{n_2}$ that optimizes her objective function $f(x, y)$. In doing so, the follower affects the leader's outcome. It is important to realize the distinction between the bilevel programming problem and the common decomposition of large planning problems into multilevel problems). These methods are all concerned with breaking down a large math program into a number of smaller, more tractable units. A unique objective function is used to express the overall system goals. Separate solutions are obtained for each lower-levels and then combined in a master program to yield a complete solution. The basic distinction of this approach from bilevel programming is the assumption that a single objective function can be devised to accurately represent the upper-level as well as the lower-level goals. Even if this objective function can be decomposed, it is highly unlikely that a satisfactory weighing scheme can be developed to make it agreeable to all subdivisions. The BLPP can be formulated as follows

$$\min_{x,y} F(x,y)$$

$$\text{s.t.}$$

$$x \in X = \{x \mid G(x) \geq 0\}$$

where y solves,

$$\min_{z} \quad f(x,z) \text{s.t.}$$

$$g(x,z) \geq 0$$

$$z \in Y = \{y \mid H(y) \geq 0\}$$

Where G, H, and *g* are vector valued functions and *F* and *f* are real-valued functions of appropriate dimensions. There are many solution techniques to the above problem and we refer the reader to [2][3] and the references therein.

SCENARIO CONSTRUCTION

In this section we present potential scenarios that require the use of Decentralized Warehousing Locations (DWLs). In each region there may be several humanitarian missions, each with its own unique logistical characteristics. DWLs must have enough capacity and throughput to support not just the small missions but any large-scale operations as well. With the list of potential sites (e.g., Haiti) defined, it is next necessary to outline the *sequencing* and *recurrence* of those deployments. We chose to schedule the deployments and contingencies into a scenario comprising a five-year time frame. This number is arbitrary selected and can be adjusted if needed. To hedge against uncertainty, it is necessary to consider sets of potential scenarios (which we call *streams of reality,* or *timelines*) in order to identify a robust DWL posture. Given one timeline, we can use our optimization framework to identify an "optimal" DWL posture with respect to differing objectives, such as minimum cost, minimum deployment time, or minimum number of DWLs. Unfortunately, the truly optimal solution can only be computed if the future needs are known a priori. Therefore, we consider multiple scenarios and identify the *optimal* DWL postures for each stream individually. We then perform a *portfolio analysis* to identify DWL postures that perform well across every timeline and DWLs that provide robust solutions. The relative performance of this robust set of DWLs can be measured by comparing its performance versus the optimal solution for a given scenario. Ideally, multiple robust solutions should be identified to allow for other nonquantitative considerations (e.g., political constraints).

The scenarios were scheduled into five streams or timelines according to the following set of rules. Each timeline was designed to include two major operations in order to sufficiently size the facilities to support major humanitarian. Table 1 contains the specific sequencing of deployments for five different streams.

Table 1: Sequencing of Scenarios by Timeline

Year	Stream 1	Stream 2	Stream 3	Stream 4	Stream 5
1	Indonesia	China	Indonesia	South America 2	N. American Sub-continent
	Chile	Southern Africa	Horn of Africa	N. America	Central Africa
		East Timor		Chile	
2	Central Asia	Thailand	Central Asia	China	South America 1
	Thailand	West Africa	Liberia	Thailand	Horn of Africa
				Haiti	
3	Horn of Africa	N. American Sub-continent	Balkans	Pacific Rim	Southwest Asia
	Southwest Asia	Haiti	N. America	S. Africa	Chile
		Central Africa			
4	Thailand	Balkans	Chile	N. American Sub-continent	Pacific Rim
	N. America	North Africa	N. America	North Africa	Haiti
			N. America		
5	Southwest Asia	Indonesia	Southwest Asia	Indonesia	Southwest Asia
	North Africa	North Africa	Pacific Rim	N. America	East Timor
		Liberia	West Africa	East Timor	

CONCLUDING REMARKS

Our analyses show the costs and deployment timelines for various DWL options under different degrees of stress on resources while taking into account infrastructure richness, warehousing characteristics, distances, strategic warning (e.g., tsunamis versus earthquakes), transportation constraints, dynamic requirements and reconstitution conditions. These so-called "streams of reality" allow our model to measure the effect of timing, location and intensity of operational requirements on logistics resources and vice versa. Several of these streams (or *timelines*) are developed in order to account for the inherent uncertainties in future planning associated with each timeline. After the desired requirements in terms of combat support resources are determined, our optimization model selects a set of DWLs that would minimize the costs of supporting these various operations. This tool essentially allows for the analysis of various "what-if" questions and assesses the solution set in terms of resource costs for differing levels logistics capabilities.

The end result of this analysis is a portfolio containing alternative sets of DWL postures, including allocations of resources, which can then be presented to decision-makers. This portfolio will allow policymakers to assess the merits of various options from a global and strategic perspective.

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