Inventory Pre-positioning for Humanitarian Logistics

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Humanitarian operations are set in motion when human settlements are sufficiently impacted by natural disasters. Not only are hazards known to cause fatalities and economic disruptions (World Bank, 2006), but hazards also trigger significant population displacements. Four million people are rendered homeless annually as a result of natural disasters (EM-DAT, 2006); and homelessness in a post-hazard environment has been shown to be a precursor for diminished public health and increased morbidity (WHO, 2001). A rapid humanitarian response is expected to alleviate these harms. However, a United Nations-commissioned review of global relief operations reveals that lack of logistical coordination obstructs the flow of time-sensitive materials to the disaster theater, thereby delaying the recovery process (Adinolfi et al., 2005). The desire for a more responsive operation is a resonant theme. Preparedness, or measures taken before the onset of a disaster to facilitate logistics, is specifically cited as a top recommendation. This study evaluates one such preparatory measure.

Positioning of stocks at, or near, the locations where they will be used is thought to diminish the delivery lead-time. This study will first identify the scope of hazards and inventory types for which pre-positioning is appropriate, along with a brief discussion of the key measurement of global preparedness via positioning. Next, the model and research methodology used to identify optimal global positions will be reviewed, followed by a presentation of results. Finally, conclusions are drawn with respect to implementation considerations.

The Scope of Pre-positioning in this Study

This research examines strategic inventory pre-positioning as a method for minimizing delivery lead-time of humanitarian non-consumable aid. The study considers the scope of hazards for which swift humanitarian assistance is required (including earthquakes, floods, slides, volcanoes, waves, wildfires and windstorms) because they provide little advance notice. The scope of inventory is limited to non-consumable materials, because these infrastructure goods (such as tents, water filtration systems, medical equipment, tools and telecommunications) are typically flown into a disaster zone in the initial deployment waves; allowing aid workers to set up camp, begin assessment, administer medical aid, and provide shelter for displaced peoples. Moreover, these inventory types are suitable for pre-positioning because they are difficult to handle, costly to transport, and are often unavailable for procurement in remote regions (Lee, 1999).

In addition to the scope of hazards and inventory, five additional assumptions of the model are listed below:

- Forecasted homelessness is roughly proportional to demand of humanitarian non-consumable unit sets.
- Facilities are located at airports, thereby eliminating the need for ground transport.
- Delays other than air transit time, such as approval, picking, packing, loading and document generation, are constant or consistent across the range of disasters and geographies.
- Cargo-carrying aircraft are not restricted in range—rather, fuel capacity is infinite.
- The real network nodes and arcs are ignored; instead, aerial distance is the single criterion for calculating transit distance, which is assumed to be proportional to delivery lead-time.

Because pre-positioning reduces lead-time from warehouse to the disaster theater by shortening the total transit distance, the research identifies geographic locations for warehousing non-consumable inventory such that "per capital distance" is minimized.

This means that the global average distance from every person forecasted to be at risk of hazard-induced homelessness to the nearest facility is minimized under finite resource constraints. Minimization of per capita distance is thus advanced as the service objective in the relief context. Therefore sensitivity of per capita distance to optimal facility proliferation is measured to predict the impact of a strategic inventory pre-positioning policy.

The Quantitative Methods Applied

The facility location problems are formulated as geometric optimizations using "mean annual homeless" as the demand variable (extrapolated from data gathered over the past 25 years), and are solved using mixed-integer linear programs. An array of optimization formulations are framed together as an iterative algorithm. This means that each formulation is solved several times with incrementally fewer constraints to the number of facilities planned. Figure 1 is one such formulation. With each incrementally added facility, the configuration of positions and per capita distance are recorded. Each problem is constrained in various ways; some find center of gravity points for a given number of facilities, while others assume facilities in previous iterations are inherited in subsequent iterations. These formulations are designed such that decision-makers are given an understanding of how planning for various numbers of facilities can yield very different optimal results. Additionally, because the status quo condition impacts the performance of the predicted humanitarian supply chain, the research gathers insights into the system's sensitivity to initial conditions by taking into consideration the existing distribution centers for humanitarian goods.

Objective function:

$$\min \sum_{ij} d_{ij} H_j W_{ij} \quad \forall\, i, j$$

$$\begin{aligned} \textit{subject to}: \quad & W_{ij} \le Y_i \quad \forall i, j \\ & \sum_i Y_i = n \\ & \sum_j W_{ij} = 1 \quad \forall i \end{aligned}$$

Where:

i = facility candidate locations, with latitude and longitudinal coordinates (φ,λ)

j = center point for demand regions, with latitude and longitude (φ,λ)

$d_{ij} =$ geodesic distance from facility location *i* to demand point *j*

$H_j =$ The mean annual homeless as a result of natural hazards at region *j*

$Y_i \in \{0,1\} \quad \forall i$

$$Y_i = \begin{cases} 1 & \text{if facility exists at } i \\ 0 & \text{if otherwise} \end{cases}$$

$W_{ij} \in \{0,1\} \quad \forall i, j$

$$W_{ij} = \begin{cases} 1 & \text{if facility } i \text{ is assigned to region } j \\ 0 & \text{if otherwise} \end{cases}$$

(A facility is assigned by virtue of being the closest facility in terms of geodesic distance to a regional center point)

$n =$ The total number of global positions. It also indicates the iteration.

Figure 1: Example of the Least-constrained Formulation Type

Analysis of Demand and Optimization Problem Solutions

Analysis of global demand patterns, shown in Figure 2, indicates that a disproportionate majority of hazard-induced homelessness occurs in certain regions, notably South Central Asia and East Asia.

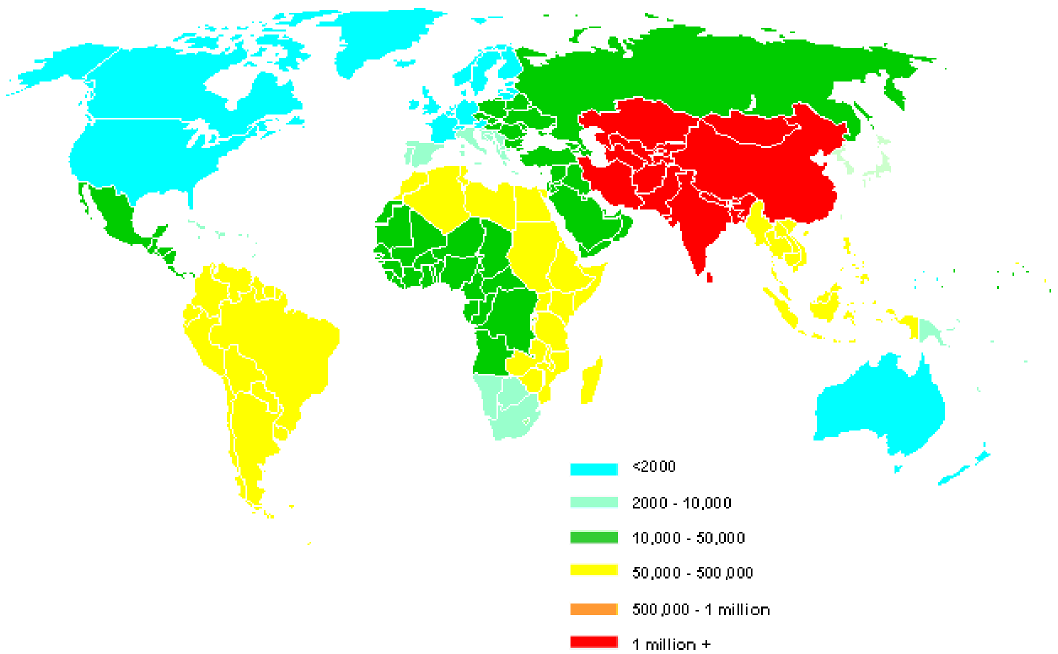

Figure 2: Geography of Annual Hazard-induced Homelessness

Coincidentally, these regions are the most populous on Earth. Because homelessness is shown to be highly correlated to population (95.6%), the data are manipulated to correct for population and the number of hazards in order to indicate the most fragile infrastructures. The correction is made by using the construct "number of homeless per hazard per number of residents". Using this measure, analysis reveals that Polynesia, Melanesia and Northern Africa are the regions least able to sustain the impact of natural hazards.

The facility location solutions impress upon the reader a view that additional positions located in South Central Asia and Eastern Asia would most benefit global humanitarian operations, followed by facilities in South America and Eastern Africa – not only because these regions are the sources of heavy demand, but also because of their geographic proximity to other regions with significant homelessness. Moreover, in order to meet a target service level of approximately a one hour average air transit time – disregarding approval, material handling and border delays – only six total facilities are required worldwide. Six facilities can be configured in four variants, each meeting service objectives. One of these is shown in Figure 3.

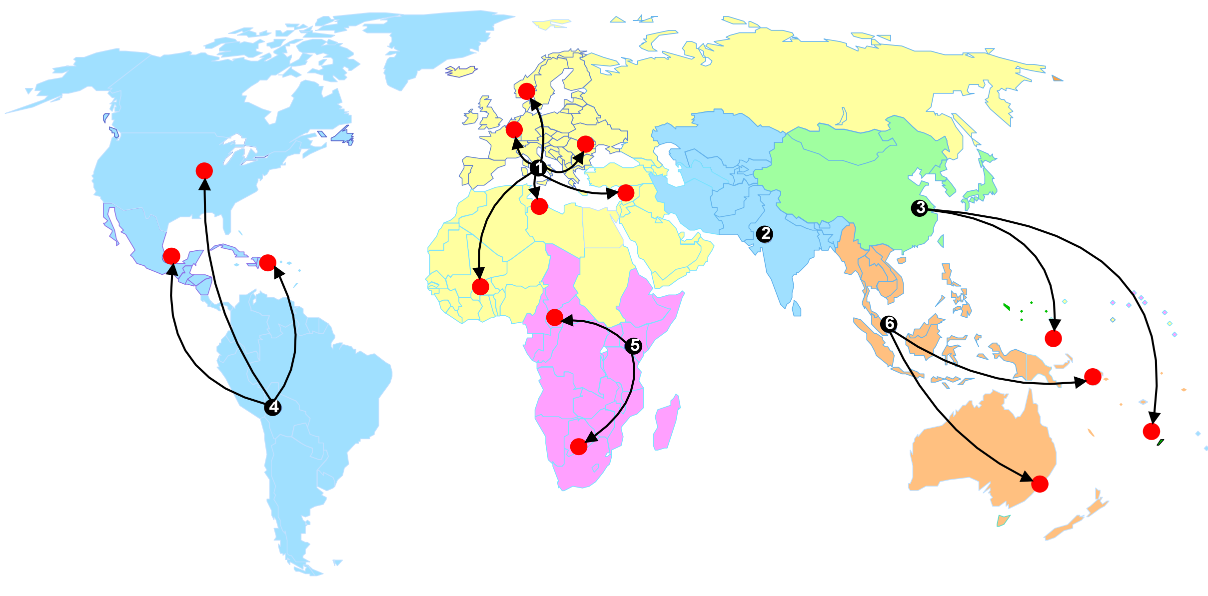

Figure 3: Six Optimally-located Global Facilities

An interesting discovery of this research is the absence of a behavior called "reconfiguration". Reconfiguration is exhibited when the positions within the set of optimal locations of previous iterations are absent from the set of optimal locations in subsequent, less constraining, runs. The model runs indicate that regardless of the number of planned facilities, optimal positions are retained. Therefore, humanitarian organizations may seek to add facilities incrementally rather than planning multiple facility locations at once. This is significant to facility planners implementing a pre-positioning policy because, according to the model, there is no reservation cost for locating facilities incrementally. However, conclusions drawn from the absence of reconfiguration in this study should be tempered because low-resolution spatial data was applied.

The study also captured the impact of facility proliferation on per capita distance. The following graph (Figure 4) illustrates this relationship in both the control case and the status quo case which considers the existing United Nations Humanitarian Response Depot location in Southern Europe.

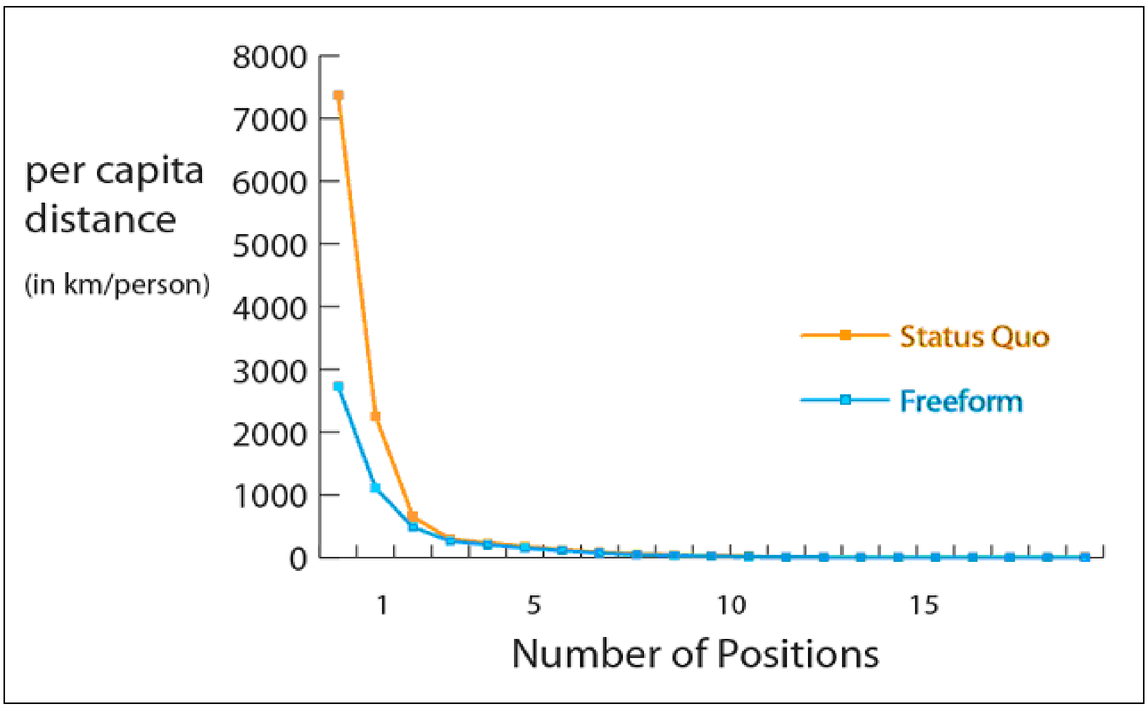

Figure 4: Global Distance per Capita Sensitivity to Optimal Facility Proliferation

The relationship is such that when five or more positions are taken globally, that the average distance from closest facility to people forecasted to be homeless as a result of natural disasters falls below 300 km/person. For cargo aircraft such as a C-5 Galaxy, IL-

76 or an An-225, this is typically less than 30 minutes flight time. Positions beyond the first six minimally reduce the per capita distance. Six is, perhaps, a suitable upper-bound for a performance-focused proliferation policy.

Recommendations for Policy-Makers

Although the measurements can be improved by increasing data resolution, and the delivery chain can be better modeled by including more sources of delay (such as approval, picking, packing, document generation, border delays, and camp setup), the optimal facility locations are unlikely to change significantly. South Central Asia and East Asia demand facilities to address humanitarian needs.

The argument for pre-positioning is compelling in light of performance metrics; however, evaluation of logistical strategies, especially network structure, requires other considerations; including facility overheads, staffing costs, procurement costs and inventory holding costs (all of which would increase under a facility proliferation policy). Moreover, complimentarity with systems, processes, and existing policies are equally important.

Humanitarian organizations generally do not capture inventory point-of-use data at the last node in the delivery chain because enterprise information systems have not yet been implemented. As such, *mean annual homeless* can be used as an indirect approximation for demand for pre-positioning-appropriate non-consumable items, until those information systems are fully established. Furthermore, *minimization of per capita distance from the nearest facility to forecasted people at risk of hazard-induced homelessness* may be a suitable objective for inventory pre-positioning because the real transit network is difficult to map, especially in light of rapid infrastructure development in much of the hazard-impacted world, and inherent last-mile uncertainties. Finally, the frameworks provided, including the optimization formulations and sensitivity algorithm can accommodate high-resolution geographical data to better facilitate facility location decisions of this kind.

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