Distribution Network Design For Humanitarian Relief Chains

Benita M. Beamon, Ph.D.

Burcu Balcik, Ph.D. Student

University of Washington
Industrial Engineering
benita@u.washington.edu
burcub@u.washington.edu

Overview

- Part 1: Introduction to Relief Chain Mgmt
  - Introduction/The Relief Mission Cycle
  - Comparison and Contrast: Humanitarian Relief Chains versus Commercial Supply Chains
  - Example Topics in Relief Chain Management
    - Procurement
    - Inventory Control
    - Last Mile Distribution
- Part 2: Distribution Network Design
  - Introduction and System overview
  - Problem Definition
  - Modeling Approach
  - Mathematical Model
  - Computational Results
  - Conclusions & Future Research

Introduction

- Humanitarian Relief Chain Management for Quick-Onset Large-Scale Emergencies
  - Does not focus on commercial supply of goods and services.
  - Has received little attention in the literature.
  - Is unique, due to:
    - The unpredictability of emergencies.
    - The stakes of adequate and timely delivery.
  - <u>Objective:</u> To respond rapidly to global emergencies by delivering appropriate supplies.

Introduction: How the Relief Chain Differs from the Commercial Supply Chain

- Zero (or approximately zero) lead times, dramatically affecting supply availability and distribution.
- High stakes (often life-and-death).
- Unreliable, incomplete, or non-existent supply and transportation information.
- Few established performance measurement systems (often ad hoc operations).
- Variable levels of technology availability.

Introduction: How the Relief Chain Differs from the Commercial Supply Chain

- External demand in many commercial supply chains: comparatively stable and predictable.

- External demand in the relief chain (supplies and people) are:
  - Lumpy: they occur in irregular amounts and at irregular intervals.
  - Suddenly-occurring: locations are usually completely unknown until the demand occurs.

Relief Mission Life Cycle and Relative Resource Requirements

Four distinct phases of the life cycle:

- **Assessment** –identify what is needed, based on disaster characteristics.
- **Deployment** - resource requirements ramp up to meet a need.
- **Sustainment** - operations are sustained for a period of time.
- **Reconfiguration** - operations are reduced, then terminated.

Relief Mission Life Cycle and Relative Resource Requirements

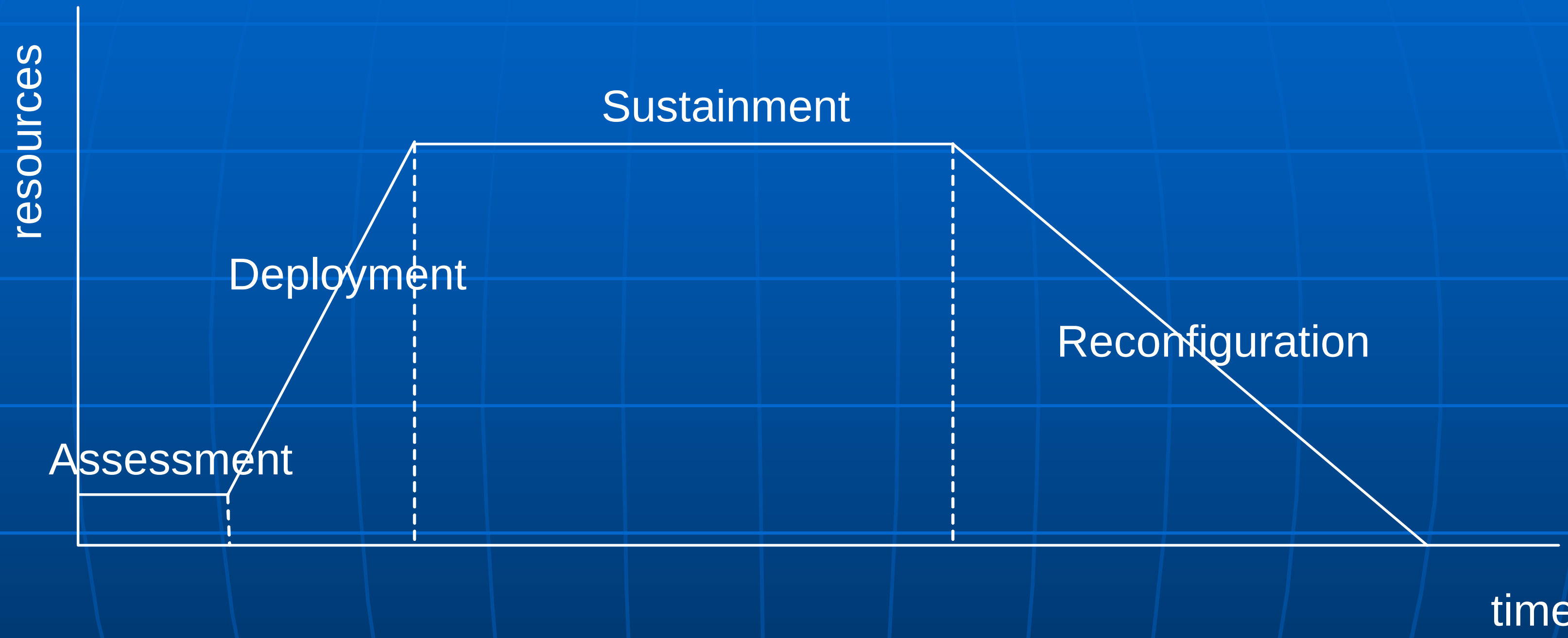

Figure 1. Relief Mission Cycle
[modified from Thomas (2002)]

Relief Mission Life Cycle and Relative Resource Requirements

- A relief organization will experience this life cycle each time they respond to a disaster.

- After the reconfiguration cycle of the relief mission another deployment cycle may occur related to the development effort (to rebuild infrastructure and ensure long-term stability in the region).

Comparison: Commercial Supply versus Humanitarian Relief Chains

	Commercial Supply Chain	Humanitarian Relief Chain
Demand Pattern	Relatively stable and predictable.	Unpredictable, in terms of timing, location, type, and size.
Lead Time	Determined by supplier-manufacturer-Dist. Center (DC) - retailer chain.	Approximately zero.
Distribution Network Configuration	Existing methods for determining the fixed locations and numbers of DCs.	Challenging due to the nature of the unknowns, and "last mile" considerations.

Comparison: Commercial Supply versus Humanitarian Relief Chains

	Commercial Supply Chain	Humanitarian Relief Chain
Inventory Control	Typically: inventory levels based on lead time, demand, and target customer service levels.	Challenging due to high variations in lead times, demands, and demand locations.
Information System	Generally well-defined, using advanced technology.	Information is often unreliable, incomplete, or non-existent.

Comparison: Commercial Supply versus Humanitarian Relief Chains

	Commercial Supply Chain	Humanitarian Relief Chain
Strategic Goals	Typically: to achieve high customer satisfaction and maximize profitability.	Minimize loss of life and alleviate suffering (increase donor funding).
Performance Measurement System	Traditional focus on <u>resource</u> performance metrics, such as maximizing profit or minimizing costs.	Traditional focus on <u>output</u> performance metrics, e.g., response time, ability to meet the needs of the disaster.

Example Topics in Relief Chain Management: Procurement

- Preference to procure locally.
- Highly varied and uncertain demands, lead times, holding costs.
- Transportation uncertainties.
- Direct suppliers versus owned warehouses?

[Balcik and Beamon (2005) “Distribution Network Design for Humanitarian Relief Chains”, in review]

Example Topics in Relief Chain Management: Inventory Control

If warehouses

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- Selecting reorder points and quantities, given high stakes supply and highly-varied and uncertain demands?

  [Beamon and Kotleba (2005), "Inventory Modeling for Complex Emergencies in Humanitarian Relief Operations", forthcoming in the *International Journal of Logistics: Research and Applications*.]

Example Topics in Relief Chain Management: Last Mile Distribution

[New Research: Beamon, Balcik, Smilowitz (NU)]

- Route uncertainties due to:
  - Infrastructure
  - Topology
  - Local politics
- Multiple commodities and transportation modes
- Multiple visits to each "demand" location
- Demand uncertainty (magnitude and location)

Part 2:
Distribution Network Design for Humanitarian Relief Chains

Recall: Part 2 Overview

- Introduction
- System overview
- Problem Definition
- Modeling Approach
- Mathematical Model
- Computational Results
- Conclusions & Future Research

Introduction

- As the effects of large-scale disasters become increasingly devastating, responding to these emergencies in the most effective manner to minimize the loss of life and suffering while maximizing the efficiency of relief operations becomes more important

- Non-governmental Organizations (NGOs) strive to meet immediate emergency needs by rapidly delivering the appropriate amount of goods, people and services to the affected regions

Introduction

- Achieving quick and effective response depends strongly on the design, planning and management of the structure and the processes of the relief (supply) chain
- The challenge for NGOs is to effectively plan and manage relief activities in an unpredictable environment
  - Scope, timing, location, type and resource requirements for a disaster are uncertain
- Quantitative tools and techniques that are widely implemented in commercial supply chains are rarely applied to humanitarian relief chains

Introduction

- The *structure of the distribution network* directly affects relief *costs* incurred throughout the relief chain as well as the *response time*

- The problems related to strategic configuration involve determining the best way to transfer goods to the demand points by selecting the appropriate distribution network structure

- The tactical level operations, such as *inventory planning*, *purchasing* and *transportation* are also highly dependent on the distribution network

Literature Review

- Existing literature on distribution network design problems is vast (see review by Klose and Drexel, 2005)
  - Only characteristics of commercial supply chain environment are considered

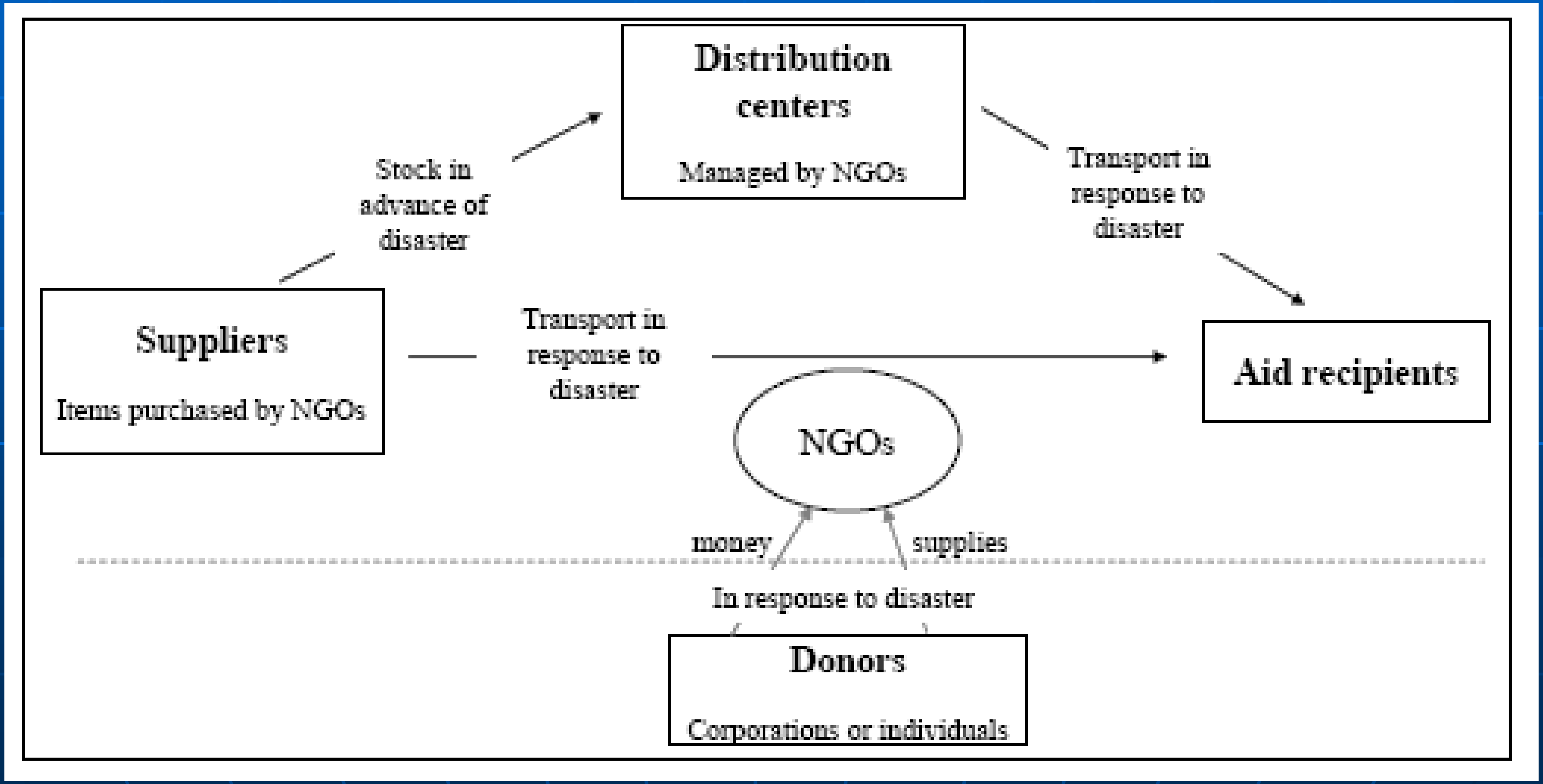
- Facility location problem for small-scale emergencies (medical emergencies, fires)
  - *Covering, P-Median, Center:*
    - Aly and White, 1978; Batta and Mannur, 1990; Belardo, et. al, 1984; Carson and Batta, 1990; Neebe, 1988; Serra and Marianov, 1998; Toregas et. al., 1971

Literature Review

- There has been limited research on distribution network design for quick-response large-scale humanitarian relief chains
  - Haghani and Oh (1996) consider operational transportation problems for a fixed distribution network
  - Jia et al. (2005) introduce various models for large-scale emergency medical services in response to terrorist attacks

System Overview

Flow of goods and funds in a relief chain for a natural disaster:



Problem Definition

- **Given**
  - Desired service levels for each group of items demanded in large-scale emergencies (whose location and impact are unknown)
  - Budgetary restrictions on fixed facility establishment costs, inventory costs, procurement costs and transportation costs,
- **Determine**
  - The best distribution network configuration for the relief chain (the number, location and the capacity of the DCs)
  - The associated distribution strategy for groups of items (which groups of items -and how much of them- should be directly distributed by the suppliers, and which should be stored and distributed through the DCs)

Modeling Approach

- The location, timing, type, and size of demand in relief chains are almost always unpredictable
- Discrete disaster scenarios (each defined by a disaster location-impact pair)

$p(s)$: probability of occurrence of a scenario

$$p(s) = p(m_s \mid d_s).p(d_s)$$

$p(d_s)$: probability of a disaster occurring in the region of scenario *s*

$p(m_s \mid d_s)$: fraction of disasters of impact m_s (e.g. low, medium, high) occurring in the region of scenario *s*

Modeling Approach

- Group relief items based on their similarity with respect to a common critical response time
  - Tier 1 items: critically needed in all emergency situations, such as *jerry cans*, *tarps*, and *blankets*
- *Expected demand* is estimated based on the population of the region of a scenario and the probabilities associated with the scenarios
- For simplicity, assume that the groups of items demanded at each scenario are identical

Modeling Approach

- There are a number of *suppliers*, whose locations are fixed and known
  - Each supplier can provide all types of items by shipping them directly to the affected region
  - When a disaster occurs, demand for supplies increases dramatically, and suppliers will often raise their prices in response
- A *specified coverage level* for all of the items across all disaster scenarios is ensured while minimizing the expected response time
  - Each scenario's demand is satisfied from either the DCs or the suppliers that have the ability to deliver the items within the desired response time

Modeling Approach

- Relief chain functions under financial constraints
- Consider the design of a distribution network with the objective of minimizing response time subject to a given operating budget

- Costs:
  - fixed cost of establishing DCs,
  - procurement costs (pre- and post-disaster)
  - inventory costs (change linearly with the size of DCs)
  - transportation costs (from suppliers and DCs to disaster regions)

Mathematical Model

s : index for scenarios
j : index for candidate DC locations
m : index for supplier locations
k : index for item groups

p_s : probability of occurrence for scenario s
h_{sk} : expected demand for item group k in scenario s (units)
t_{sjk} : time to satisfy the demand of scenario s for item group k from DC at location j (hours)
spt_{smk} : time to satisfy the demand of scenario s for item group k from supplier at location m (hours)

F_j : fixed cost of establishing a DC at location j ($)
g_k : cost of keeping one unit of item group k at a DC ($/unit)
c_{sjk} : unit cost of shipping one unit of item group k from a DC at location j to the disaster location in scenario s ($/unit)
v_{smk} : unit cost of shipping one unit of item group k from supplier m to the disaster location in scenario s ($/unit)
r_k : regular unit price of item group k before disaster occurs ($/unit)
u_{mk} : unit price of item group k at supplier m after disaster occurs ($/unit)

Mathematical Model

Cap_k : maximum allowed capacity of a DC for item group k (units)

B : expected operating budget ($)

S_k : service coverage time requirement for item group k

N_{sk} : set of candidate DCs that meet the service coverage time requirement for item group k in scenario s such that $N_{sk} = \left\{ j \mid t_{sjk} \le S_k \right\}$

M_{sk} : set of suppliers that meet the service coverage time requirement for item group k in scenario s such that $M_{sk} = \left\{ m \mid spt_{smk} \le S_k \right\}$

Decision variables:

f_{sjk} : fraction of demand for item group k in scenario s satisfied by DC at location j

sf_{smk} : fraction of demand for item group k in scenario s satisfied by supplier m

Q_{jk} : amount of item group k stored at DC j

$$X_j = \begin{cases} 1, & \text{if a DC is located at location } j \\ 0, & \text{otherwise} \end{cases}$$

Mathematical Model

$$\min \sum_{s} p_s \left(\sum_{j \in N_{sk}} \sum_{k} f_{sjk}.h_{sk}.t_{sjk} + \sum_{m \in M_{sk}} \sum_{k} sf_{smk}.h_{sk}.spt_{smk} \right)$$

Minimize the sum of the expected response times of items over all scenarios

st

$$\sum_{j \in N_{sk}} f_{sjk} + \sum_{m \in M_{sk}} sf_{smk} \geq 1 \qquad \forall s, \forall k$$

Demand of each item for each scenario is completely satisfied either through DCs or suppliers

$$f_{sjk}.h_{sk} \leq Q_{jk} \qquad \forall s, \forall j \in N_{sk}, \forall k$$

Amount stored at a DC is at least equal to the maximum demand it will face

$$Q_{jk} \leq Cap_k.X_j \qquad \forall j, \forall k$$

Restricts the amount of inventory stored at a DC

$$\sum_{j} fixed_j.X_j + \sum_{j} \sum_{k} Q_{jk}.(g_k + r_k) + \sum_{s} p_s.\left(\sum_{j \in N_{sk}} \sum_{k} c_{sjk}.f_{sjk} h_{sk} + \sum_{m \in M_{sk}} \sum_{k} (v_{smk} + u_{mk}).sf_{smk} h_{sk} \right) \leq B$$

$$0 \leq f_{sjk} \leq 1 \qquad \forall s, \forall j, \forall k$$

$$0 \leq sf_{smk} \leq 1 \qquad \forall s, \forall m, \forall k$$

$$X_j \in \{0,1\} \qquad \forall j$$

Requires that the cost of relief operations is less than the available operating budget

Data Set

- **Creating scenarios:**
  - Real world disaster data: Earthquake and tsunami disasters that resulted in at least 10 deaths over the last century
  - Projected grid lines onto the earth's surface and assumed that the demand locations are located at the centroid of each resulting grid box (162 locations)
  - Disaster impact level:

Disaster impact level	Historical deaths
Low	10 to 50 deaths
Moderate	51 to 100 deaths
High	101 or more deaths

  - Total number of scenarios is 295
  - The probabilities associated with the scenarios are estimated by occurrence frequencies of each scenario
  - Two groups of items are considered

Computational Results

- The results were obtained by using GAMS/XA
- Solution for the base case that satisfies relative optimality tolerance of 5% was obtained in 40 minutes (47,980 iterations)
- *Base case results*:
  - 15 DCs located
  - Demand for item group 1 for all scenarios is satisfied by DCs; DCs satisfy 47% of the demand for item group 2
  - *Inventory given in number of units:*

	inventory at the DC	
DC #	item 1	item 2
164	126,068	-
165	1,698,684	-
172	1,813,029	337,828
173	1,442,131	-
184	899,862	-

	inventory at the DC	
DC #	item 1	item 2
192	2,494,375	-
195	1,230,309	-
198	5,326,234	2,854,016
208	8,083,728	4,177,439
212	4,828,155	1,925,135

	inventory at the DC	
DC #	item 1	item 2
215	12,516,473	2,942,336
216	3,409,399	-
217	2,166,299	-
219	4,227,550	538,904
220	3,765,017	-

Sensitivity Analysis

- Computational experiments are designed to test the sensitivity of the distribution network model for changes in
  - available operating budget
  - transportation costs
  - variable DC operating costs
  - fixed DC location costs
  - supplier unit prices
  - supplier procurement time
- The effects on response time, fraction of items satisfied by DCs, and number and total size of DCs are investigated

Sensitivity Analysis

- Number and location of the DCs are primarily affected by *supplier procurement time* and *transportation costs*
- Distribution strategy to be followed for item group 1 is only affected by the *supplier procurement time*
- Amount of inventory to be stored at the DCs for item group 1 is sensitive to changes in *budget*, *transportation costs*, and *supplier procurement time*
- Distribution strategy and the amount of DC storage for item group 2 is sensitive to changes in *budget*, *transportation costs*, *variable operating cost of DCs* and *supplier procurement time*
- Solutions are insensitive to changes in *fixed DC location costs* and *supplier unit prices*

Conclusions

- Addressed a problem that was previously unavailable in the literature: distribution design and strategy for quick-response delivery in a humanitarian relief chain
- MIP model determines the location, number and size of DCs in the relief network as well as the distribution strategy for relief items to disaster locations
- Performed computational experiments on a variety of problem instances to investigate the effects of various parameters on response time, structure of the distribution network, and distribution strategy for the groups of relief items

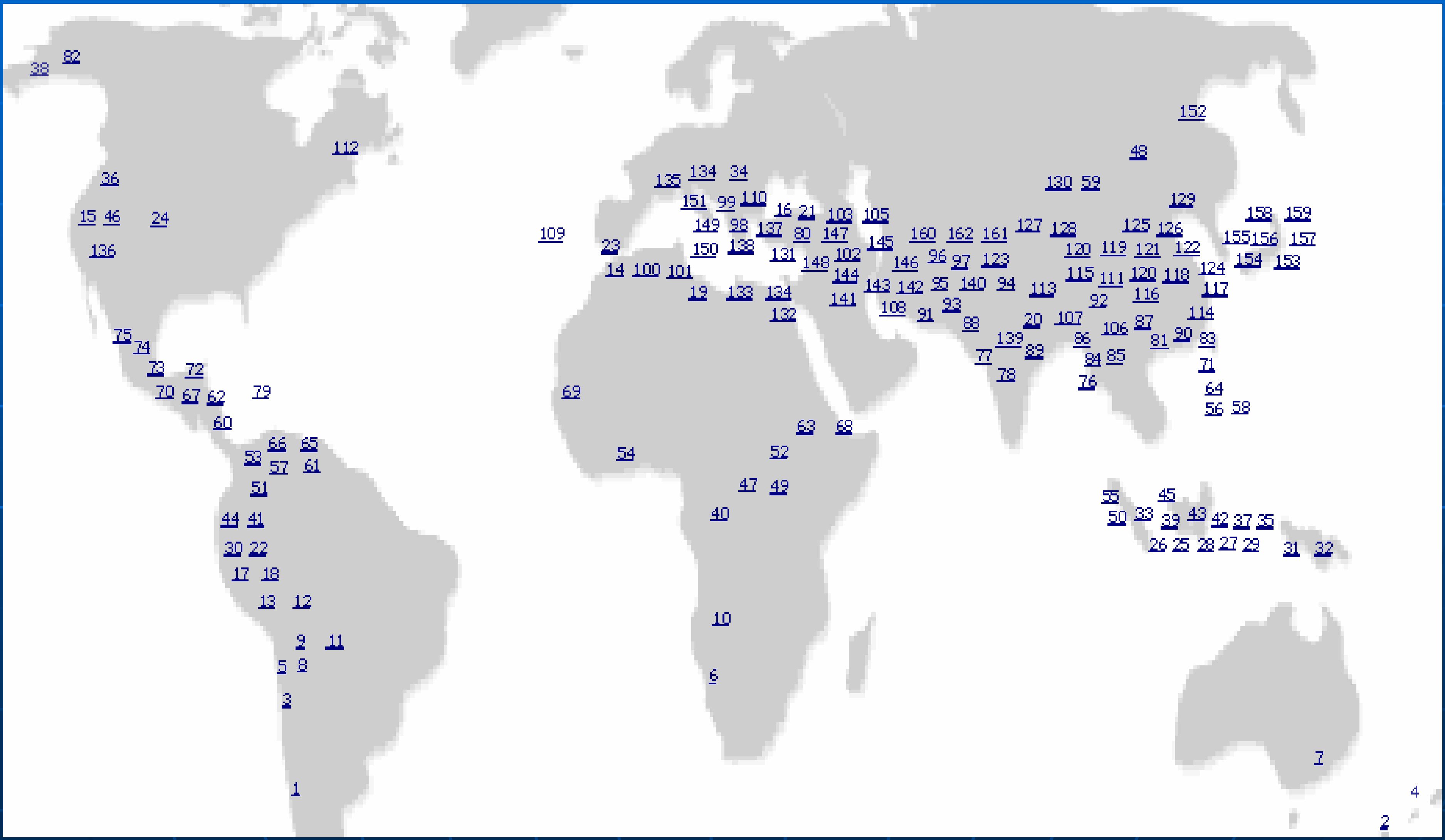
Future Research

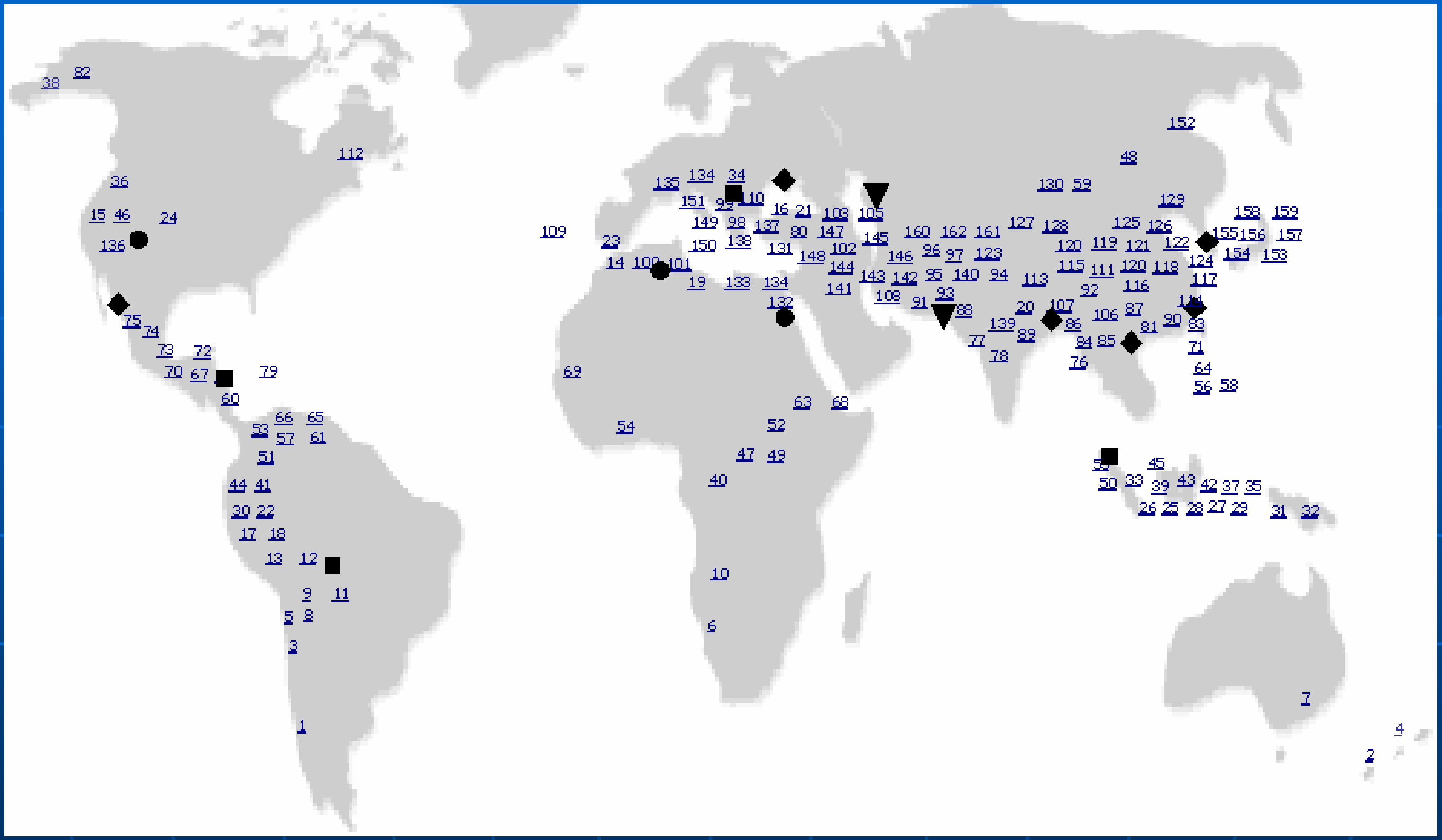
- We assume a single mode of transportation and identical DC candidates in terms of the availability of transportation modes
  - Consider availability and capacity of different transportation options
- We assume DCs and routes in the network are not affected by the disasters
  - Consider the possibilities of damage to some routes in the transportation network and reductions in DC service capabilities
- Explicitly model inventory problem in the relief chain (incorporating a more sophisticated inventory policy into the distribution network model would significantly increase the complexity of the model)

Thank You…

Questions 

DEMAND LOCATIONS





: DC with total capacity: 300,000-500,000 units
: DC with total capacity: 100,000-300,000 units
: DC with total capacity: 50,000-100,000 units
: DC with total capacity: 10,000-50,000 units