Data-driven optimization of OFDA’s disaster response capacity

Phase II – Workshop I

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Agenda

• Motivation & approach
• OFDAs current operations – model results
• Disaster portfolio adjustment methods
• Discussion & further work
Motivation
Introduction

Helping people the first days after a disaster with essential items

Disaster relief items in storage

Shipping items into disaster regions

Distributing items to affected population

All pictures from USAID News Photo and other US government sides
Inventory network

OFDA holds a strategic stockpile of key disaster response commodities to support people worldwide in crises situations.

Potential Inventory Locations

Research Questions

- How well does the current network perform against a portfolio of disasters?
- Should OFDA hold more or less inventory?
- Should OFDA redistribute inventory to improve performance, and if so, where should the inventory be located?
- How efficient is OFDA’s current prepositioning network based on existing costs and capacity?
- What alternative prepositioning strategies should OFDA consider considering cost and response time?
Model (i)

**Inputs**
- Risk portfolio
- Inventory portfolio
- Carrier portfolio
- Item/usage characteristics

**Model**
- Stochastic linear program (SLP)

**Outputs**
- System Assessment
- System Optimization
- Metrics

**Questions**
- How well does the current setting perform?
- Where to position inventory?
- What are recommended procurement strategies to reduce stockout risk?
- How much inventory to hold?
- How much budget to spend?
Model (ii)

Model assumptions

- Minimize time to respond to a portfolio of disaster scenarios.
- One disaster scenario is a random combination of resupply lead time and disasters.
- OFDA can only supply as much as they have in storage.
- OFDA must satisfy entire demand.
- OFDA can only spend their budget.
- OFDA can use different modes of transportation.

\[
\begin{align*}
\min_{y} & \quad \sum_{k} p^k \sum_{m} \tau_{i,j,k}^m \cdot y_{i,j,k}^m \\
\text{s.t.} & \quad \sum_{j} y_{i,j,k}^m \leq X_i \quad \forall i \\
& \quad \sum_{i} y_{i,j,k}^m = d_j^k \quad \forall j \\
& \quad \sum_{i} y_{i,j,k}^m \cdot c_{i,j,k}^m + \sum X_i \cdot s_i \leq B \\
& \quad y_{i,j,k}^m \geq 0
\end{align*}
\]
Disaster portfolio

- We use past disasters that OFDA responded to.
- We estimate a resupply lead time distribution from OFDA's past operations.
- We create a portfolio of disaster scenarios.
- One disaster scenario is a random combination of resupply lead time and disasters.
- Disaster scenarios are equally likely.
Disaster portfolio estimation process

1. Estimate a probability distribution from past shipments

2. Collect disaster portfolio

3. Draw scenario supply lead time
   e.g. 92 days

4. Collect disasters within lead time

5. Write disasters into a scenario

6. Draw scenario supply lead time
   e.g. 122 days

7. Collect disasters within lead time

8. Write disasters into a scenario
Total affected population

Initial estimation approach

- Our dataset of past responses includes the total affected population (TAP), which is the entire population in a disaster area.
- OFDA will carefully evaluate how many people they serve in a given disaster, considering, for example,
  - People’s needs
  - Capabilities/activities of other organizations
  - Inventory available at OFDA
  - OFDA’s mandate
- Similar to any insurance model, the size of the exposure matters for what the model recommends.
- We have to make assumptions, on how many people OFDA seeks to serve and how they decide to allocate scarce inventory.
Potential approaches to adjust TAP to OFDA’s business case

Targeted TAP estimation

- There are different ways to consider how many of a disaster’s TAP, OFDA seeks to address. For example:
  - Total cap: Any disaster larger than a threshold is capped at the threshold.
  - Scaling factor: All disasters are scaled down. Scale can be constant (e.g. 5%), or volume dependent (larger disasters are scaled down stronger than small ones).

Assumption inventory allocation rule

- OFDA decides, how much of their inventory they commit to different disasters in a disaster scenario.
- We have to capture this process; different options are possible, for example:
  - First come, first served.
  - Average allocation. OFDA provides the same volume to each disaster.
  - Proportional allocation. OFDA seeks to serve disasters in a disaster scenario according their proportional size across all disasters occurring in the lead time.

Target TAP cap
Cap at 200,000 TAP per disaster

Inventory allocation rule
Proportional allocation
Inventory locations - the balance metric

<table>
<thead>
<tr>
<th>Depot</th>
<th>Blankets</th>
<th>Buckets</th>
<th>Hygiene Kits</th>
<th>Kitchen Sets</th>
<th>Plastic Sheeting</th>
<th>Water</th>
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<tbody>
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<td>36,500</td>
<td>10,800</td>
<td>73,500</td>
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<tr>
<td>People served</td>
<td>183,750</td>
<td>183,750</td>
<td>125,000</td>
<td>182,500</td>
<td>540,000</td>
<td>183,750</td>
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<tr>
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<td>1.2</td>
<td>0.92</td>
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<td>0.54</td>
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</tbody>
</table>

Coefficient of Variation:

\[ CoV = \frac{\text{Standard Deviation}}{\text{Mean}} \]

Measures how balanced the inventory allocation is across the network.
Warehouse costs

Yearly warehouse costs

- Consider the total pallet costs per year (see right hand side).
- Turn into warehouse cost per item.

<table>
<thead>
<tr>
<th>Warehouse</th>
<th>Total per pallet per yr</th>
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<tr>
<td>Miami</td>
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<td>Dubai-K+N</td>
<td>$199.87</td>
</tr>
<tr>
<td>Dubai-UNHRD</td>
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<td>Pisa</td>
<td>$20.77</td>
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<tr>
<td>Subang</td>
<td>$24.55</td>
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Carrier portfolio assumptions

Comments
- OFDA currently uses (mainly) air freight.
- Truck and ship can be options to reduce costs.
- Lacking detailed data on modes of transportation, costs and capacity, we assume that at OFDA’s current inventory locations all three modes (air, truck, and ship) are available.
- In this analysis, we focus on air shipments as OFDA’s current mode of transportation.
- As the analysis proceeds we can adjust the carrier portfolio and conduct sensitivity analyses and/or eliminate modes of transportation.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Repositioning time</th>
<th>Travel time</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>6h</td>
<td>sphere distance / 600km/h</td>
<td>.5 $/km/kg</td>
</tr>
<tr>
<td>Truck</td>
<td>0h</td>
<td>min(Google API travel time, 100h)</td>
<td>.1 $/km/kg</td>
</tr>
<tr>
<td>Ship</td>
<td>12h</td>
<td>1.4 * sphere distance / 35km/h</td>
<td>.01 $/km/kg</td>
</tr>
</tbody>
</table>
Initial system evaluation

Given OFDA’s current operations*, how much more responsive can they become by optimally allocating inventory?

Results

- OFDA can improve responsiveness by up to 13% depending on product category
- The improvements are achieved through optimally allocating inventory throughout their network.

* Current inventory levels and allocation, only air shipments
Service and effectiveness metrics – hygiene kits

- Fraction of demand served (%): 0 → 100
  - 42

- Fraction of scenarios completely served (%): 0 → 100
  - 84

- Average time to deliver (h/unit): 0 → 20
  - 15.7
  - 18.1
  - -13%

- Average cost to deliver ($/unit): 0 → 20,000
  - 13,494
  - 16,729
  - -19%
Service and effectiveness metrics – water

- **Fraction of demand served (%)**
  - 0% to 100%
  - Current: 60%

- **Fraction of scenarios completely served (%)**
  - 0% to 100%
  - Current: 84%

- **Average time to deliver (h/unit)**
  - 0h to 20h
  - Current: 15.7h
  - Improvement: 17.4h (10% decrease)

- **Average cost to deliver ($/unit)**
  - 0$ to 800$
  - Current: 621$
  - Improvement: 725$ (14% decrease)
Optimal allocation decision – water

Where should OFDA reposition their inventory to become more responsive?

Results

- Results suggest that minimizing response times (air cargo), OFDA should allocate water inventory to Dubai and some to Pisa.
- Model is suggesting to consolidate inventory.
Optimal allocation decision for all products

Table: Optimal allocation for all products

<table>
<thead>
<tr>
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<th>Water</th>
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</thead>
<tbody>
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<td>68,218</td>
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<td>0</td>
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<td>Pisa, Italy</td>
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<td>5,282</td>
<td>1,600</td>
<td>2,641</td>
<td>3,000</td>
<td>5,282</td>
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<tr>
<td>Subang, Malaysia</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
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</tr>
<tr>
<td><strong>CoV</strong></td>
<td>1.57</td>
<td>1.57</td>
<td>1.59</td>
<td>1.57</td>
<td>0.6</td>
<td>1.57</td>
</tr>
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</table>

Results

- Table shows that OFDA should consolidate inventory in Dubai (and a minor share in Pisa).
- Except for plastic sheeting. We will provide intuition for why later!
Forcing allocations to Miami (and Subang)

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<tbody>
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<td>0</td>
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<td>0</td>
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<tr>
<td><strong>CoV</strong></td>
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<td><strong>0.94</strong></td>
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<td><strong>0.94</strong></td>
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<tr>
<td><strong>Cost change</strong>*</td>
<td><strong>+10%</strong></td>
<td><strong>+10%</strong></td>
<td><strong>+24%</strong></td>
<td><strong>+10%</strong></td>
<td><strong>+1%</strong></td>
<td><strong>+10%</strong></td>
</tr>
</tbody>
</table>

- Forcing some allocation to Miami reduces response times.
- It also substantially increases logistics costs!

*of forced Miami allocation relative to optimum
How much inventory should OFDA carry?
How much water should OFDA hold?

Considerations

- Trade off when increasing inventory: service level vs. total cost
- OFDA’s preferences? -> unclear
- We show service level vs. costs under different inventory scenarios to provide decision support.

Findings

- Figures to the right show service metrics for different inventory levels and total costs.
- A dot represents the service level vs. inventory or total cost resulting from response time minimization.
- Doubling (black) the current water inventory (red) increases service and cost.
Findings

- Given our assumptions on the relevant portion of TAP, OFDA should currently consolidate inventory of hygiene kits.
- As total inventory increases OFDA should diversify their inventory footprint and allocate more to Miami, Subang, and Pisa.
Optimal inventory levels: plastic sheeting

Service metrics vs. total inventory & average cost

Total Inventory

- Dubai
- Miami
- Pisa
- Subang

Warehouse absorption (share)
How to use the model? – The straight-forward approach

The steps

1. Agree on a target population per disaster that OFDA wants to address.
2. Learn from the resulting plots how much service you can expect, and what are the costs.
3. Choose an inventory level with acceptable service level and cost.
4. Consolidate or diversify according to the optimization.

Example – Hygiene kits

1. Target TAP of max 200,000 people per disaster for water.
2. 60% of scenario demand served and 84% of scenarios completely served at average cost of $621/unit.
3. Increase water inventory to 110k units to achieve 95% scenarios completely served at average cost of $602/unit.
4. Allocate 73% to Dubai, 16% to Italy and 11% to Miami.
Inferring a service level for water – an inverse approach for given CoV = 0.54
Inferring a target TAP

Finding the implicit target TAP

1. Assume distribution of inventory (CoV) and inventory level.

2. Calculate the optimal allocation and service metrics for varying target TAP.

3. Learn from the results what the implicit target TAP is and corresponding services and costs.

4. Choose an inventory level with acceptable service level and cost.

5. Consolidate or diversify according to the optimization.

Finding the implicit target TAP - assumed method to scale TAP: Cap
- target TAP cap @ 62,500 per disaster results in current Coefficient of Var = 0.54
Inferring a target TAP (cont.) – the resulting optimal allocation for water
The impact of supplier lead-times
What is the impact of lead times?

Considerations

- OFDA may be able to improve the supply lead times
  - improve ordering process
  - change suppliers
- OFDA has an option to procure through UNHRD with shorter lead times and, presumably, less variation in the lead times.
- We use the left-hand table to model a different lead time distribution to showcase its impact and cap it at 82 days.
Change to service and effectiveness metrics with more responsive suppliers – hygiene kits*

- Fraction of scenario demand served (%): 0 \(\Rightarrow\) 100
  - Current: 42
  - New: 50
  - Improvement: +19%

- Fraction of scenarios completely served (%): 0 \(\Rightarrow\) 100
  - Current: 80
  - New: 84
  - Improvement: +5%

- Average time to deliver (h/unit): 0 \(\Rightarrow\) 20
  - Current: 15.7
  - New: 15.7

- Average cost to deliver ($/unit): 0 \(\Rightarrow\) 20,000
  - Current: 13,480
  - New: 13,532
  - Improvement: +19%

*assuming current inventory levels, and current transportation operations (air only)
Evaluating the impact of different lead times
Impact of lead-time reductions

• Depending on how much inventory is in the system
  • Lower total inventory necessary to serve the same target TAP
  • Vice versa, with the same inventory higher fraction of people served and fraction of total scenario served.
  • cost reductions.
Next steps

• Verify inputs
  • Target TAP
  • Disaster portfolio
  • Lead time variations

• Conduct further analyses
  • Adding potential locations (e.g., Africa, Caribbean)
  • Additional modes of transportation
Disaster portfolio

Adjustment methods
Disaster portfolio

Our current approach

- Currently, we are using disasters that OFDA responded to in the past.
- This provides a good starting point.
- Of course, there is inherent uncertainty in OFDA’s activities.
- But, there are underlying factors that will influence where OFDA is active.
- The data set that we have is not capturing everything.

To ensure that our recommendation include potential changes to OFDA’s activities, we want to develop a methodology to appropriately adjust the disaster portfolio.
Consider the past to understand the future

How OFDA’s activities changed over the last decade...

- OFDA has been responding to more complex emergencies both in numbers of incidents and in TAP.
- OFDA has been responding to less natural disasters in TAP (and also in numbers of incidents).
- Complex emergencies focus in East/Central Africa (continuously) and in the last 3 years in the Middle East (EMCA).
- Natural disaster responses all over the world (East Asia, South Asia, LAC, EVA). Recently more focused on the Caribbean (LAC).
- Despite these trends and some focus, OFDA will evaluate emergencies as they occur and consider providing support.
Complex emergencies

The relevance of complex emergencies

- The number of complex emergencies increased from 2 to 7 incidents/a.
- The average size of complex emergencies increased from .5 to 11.5 million TAP.
- East/Central Africa and Middle East (EMCA) are main regions of activity.
- Recent activity in South/West Africa and East Asia/Pacific

This is an example for OFDA’s changing mandate!
Some of that is driven by unknown factors.
Other parts maybe more “predictable”.

We want to propose a method to flesh out the more predictable part.
Forecasting a Disaster Portfolio

Total Affected Population

- Likelihood of event
  - Develop a risk portfolio of disasters by determining the likelihood of such an event
  - Example: hurricane in the Caribbean

Other vulnerability of region

- Socio-economic
- Infrastructure
- Market capacity
- Population density
- Location
- Likelihood
Demand Forecast

Total Affected Population

Served Population

Consider organizational mandate and other organizations capacity

Commodity demand forecast

• Appropriate products to meet population needs
• Needs assessment
• Per capita / household parameters
• Time period
• Location
Risk Indices

• The INFORM Index uses different indicators to develop three main components which contribute to overall index: Hazard and Exposure, Vulnerability, and Lack of Coping Capacity
  • One or more of these indicators can be used to develop (i.e. only use select Vulnerability indicators)
• World risk index
  • Combination of exposure, susceptibility, adaptation and capacity of a country towards natural disasters.
  • Interesting approach to use statistical reports/indicators to estimate risks.

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>ISO3</th>
<th>Natural</th>
<th>Hazard</th>
<th>Hazard &amp; Exposure</th>
<th>Vulnerability</th>
<th>Lack of coping capacity</th>
<th>INFORM 2016</th>
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</thead>
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<td>Nepal</td>
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<td>Iran</td>
<td>IRN</td>
<td>6.7</td>
<td>1.4</td>
<td>4.6</td>
<td>2.9</td>
<td>5.6</td>
<td>4.4</td>
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<tr>
<td>Tanzania</td>
<td>TZA</td>
<td>4.0</td>
<td>1.1</td>
<td>2.7</td>
<td>5.7</td>
<td>5.2</td>
<td>5.5</td>
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Next steps

- Create a database with information from various risk management and early warning sources
  - Student class project underway
- Develop a methodology that can generate a disaster portfolio with available information
- Determine Total Affected Population using the combination of a futures disaster portfolio and organizational mandate input
Thank you for your attention!
Typical number of people served

Blankets

Hygiene Kits
Typical number of people served

- **Kitchen Sets**
- **Plastic Sheeting**
Inventory as insurance against a disaster portfolio

The intuition

- If OFDA seeks to minimize response time, the inventory allocation is driven by the distance of each warehouse location to the portfolio of disasters.
- But the total inventory level in the system matters as well!
- If there is little inventory in the system, OFDA should consolidate the inventory allocation.
- If there is a lot of inventory in the system, OFDA should diversify the inventory allocation.

A thought experiment

<table>
<thead>
<tr>
<th>Scarcity</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Inventory = 1</td>
<td>Total Inventory = 2</td>
</tr>
<tr>
<td>TAP = 1</td>
<td>TAP = 1</td>
</tr>
<tr>
<td>TAP = 1</td>
<td>TAP = 1</td>
</tr>
</tbody>
</table>

Potential disaster locations

Warehouse locations
Optimal inventory levels: blankets
Optimal inventory levels: buckets

Service metrics vs. total inventory & total cost

Total Inventory

- Fraction of scenario demand served
- First/last item served
- Coefficient of variation
- Warehouse allocation (share)
Optimal inventory levels: kitchen sets

Service metrics vs. total inventory & average cost

Total Inventory

- Fraction of normal demand satisfied
- Fraction of abnormal demand satisfied
- Weighted fraction completely satisfied
- Coefficient of variation

Warehouses allocation (share): Dubai, Miami, Pisa, Subang