Supply Chain and Logistics Problems for Emergent and Personalized Requests

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Overview

1. Thank you!
2. My Research Interests
3. Emergent and Personalized Requests
4. A model to determine proactive versus reactive strategy through the lens of military logistics
5. Other Research interests and applications
Fundamentally, I am a Modeler

- Develop **mathematical representations** of real-world systems and processes.
- Study the **structure** of the model and develop **solution approaches**.
- Use models to **study** and **understand** the **dynamics** and **properties** of the system and processes.
- Recommend **strategies** and **policies** that **optimize** performance measures.
Research Interests

• Development and use of analytical models to guide decision making in service industries.

• Primary focus on applying operations research methodologies to logistics challenges in:

  - Distribution Centers
  - Transportation
  - Healthcare
  - Military

• Emerging focus on:

  - Peer-to-Peer Resource Sharing Systems
  - Disaster Response
A **wide variety** of requests are made **with little warning** and are expected to be **fulfilled quickly** to a **number of different locations**.
Characteristics of Emergent and Personalized Requests

1. Occur as a random event in time.  
   (requests highly stochastic and time-varying)

2. Are highly personalized.  
   (variability in what’s requested, how it’s requested, and its delivery location)

3. To locations not necessarily known a priori  
   (distributed demand)

4. Are expected to be fulfilled quickly.  
   (short lead time expectations)
**Seabasing:** Maritime platforms are used for logistics, delivery, and at-sea transfer of cargo stored on ships.
Seabased Distribution Network Scenarios

Iron Mountain

Skin-to-Skin Replenishment

Tailored Resupply Packages

Policies & Vessels were Designed For

Emergent & Personalized Requests
<table>
<thead>
<tr>
<th>Demand-Level</th>
<th>Mission-Level</th>
<th>Vessel-Level</th>
<th>Individual-Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Characteristics</td>
<td>Pushed</td>
<td>Plannable</td>
<td>Emergent</td>
</tr>
<tr>
<td>Types of Requests</td>
<td>No requests, instead everything loaded is offloaded.</td>
<td>Bulk requests for standard items needed for replenishment.</td>
<td>Personalized requests on demand.</td>
</tr>
<tr>
<td>Handling Unit</td>
<td>Container, Vehicle, Pallet</td>
<td>Pallet, Case</td>
<td>Case, Piece</td>
</tr>
<tr>
<td>Key Performance Indicators</td>
<td>Maximize Storage Density and Product Assortment</td>
<td>Maximize storage density and minimizing transfer time of cargo between ships.</td>
<td>Responsiveness and Storage Density</td>
</tr>
<tr>
<td>Functional Requirements</td>
<td>Dense Storage</td>
<td>Dense Storage and Product Segmentation</td>
<td>Selective Offloading and Dense Storage</td>
</tr>
<tr>
<td>Type of System</td>
<td>Transportation System</td>
<td>Unit-Load Storage System</td>
<td>Order-Fulfillment System</td>
</tr>
<tr>
<td>Decision Problem</td>
<td>Knapsack Problem</td>
<td>Less-than-Truckload Loading and Routing</td>
<td>E-Commerce Order Fulfillment Problem</td>
</tr>
</tbody>
</table>
The Optimal Assortment of Items to Apply a Proactive Strategy
Submitted Manuscript
Tradeoff between Responsiveness & Additional Costs

**Proactive**
- Conduct some operations in advance.
- More agile and responsive
- No expedite or rush processes
- May increase inventory levels
- Extra space and labor costs
- Action in response to uncertain demand

**Reactive**
- Wait until demand materializes
- Time to respond longer
- Expedite options may be more expensive
+ Centralized pooling benefits
+ Action in response to known demand
Assortment of Items Tied Together via a Demand Profile

\[ g(i) = \omega i^{-\gamma} \]

\[ G(i) = \frac{i^{1-\gamma} - \gamma}{N^{1-\gamma} - \gamma} \]

\[ I_C = \{i \in \mathbb{R} : 0 < i \leq N \}. \]

Stochastic demand for the sets of items follows the ABC demand curve (Bender, 1981)

Unit costs have “economies of scale”

\[ C_i = \alpha + \beta i^\gamma \]

Higher demanded items \( \rightarrow \) lower unit costs
lower demanded items \( \rightarrow \) higher unit costs.

Two-stage item order-fulfillment cost functions

\[ C_i^1 = \alpha_1 + \beta_1 i^\gamma \]
Different values of \( \alpha \) and \( \beta \)
for some items \( C_i^1 > C_i^2 \)
and some other \( C_i^2 > C_i^1 \)
Research Questions

Given *multiple item types with skewed, stochastic demand and varying unit costs*:

1. Which items should be handled using a proactive strategy, rather than a reactive strategy?

2. What quantity of the items should be proactively handled?

Assumption: All demand fulfilled via either proactive or reactive strategy.
In Response to Tailored Resupply Packages a Proactive Strategy is to Prestage cargo on the flight deck

**Prestaging** involves retrieving and storing cargo on the flight deck of the supply ship in anticipation of requested demand.

Reduces time of transferring cargo for receiving vehicle

Requires additional costs
- Double handling cargo
- Extra labor
- Higher risk of damage/spoilage
the effort required to retrieve an item is Inversely Proportional to its Demand: 
\[ t_i \propto \frac{1}{D_i} \]
How Many to Prestage for Item $i$?  
(Quantity for the Initial Order $Q_i^*$)

The total payoff function for a prestaging policy $Q$ when demand of $x$ is realized

$$Z(Q, x) = \sum_{i=1}^{N} Z_i(Q_i, x_i)$$

Decomposed for each item $i$:

$$Z_i(Q_i, x_i) = \begin{cases} p_ix_i - C_i^1Q_i + v(Q_i - x_i), & Q_i \geq x_i \\ p_ix_i - C_i^1Q_i - C_i^2(x_i - Q_i), & Q_i < x_i \end{cases}$$

$$\max \Pi_i(Q_i) \equiv E[Z_i(Q_i, x_i)]$$

$$\Pi_i(Q_i) = (p_i-C_i^1)\mu_i - [(C_i^1-v)E(Q_i-x_i)^+ + (C_i^2-C_i^1)E(x_i-Q_i)^+]$$

The optimal prestaged quantity of each item $i$ ($Q_i^*$) can be found:

$$Q_i^* = \min\{Q_i \in W | F_i(Q_i) \geq CV_i\}$$

$$CV(i) = \frac{C_i^2 - C_i^1}{C_i^2 - v}$$

$$CV(i) = \frac{(\beta_2 - \beta_1)i^\gamma + \alpha_2 - \alpha_1}{\beta_2i^\gamma + \alpha_2 - v}$$
Properties of the Critical Value

$CV_i$ is a rational function of $i$

- Potential negative values due to negative marginal shortage cost  
  $CV(i) \in (-\infty, 1)$

- As the value of $i$ grows, $CV_i$ approaches a certain value

- $CV_i$ is a monotone function of $i$

$$Q_i^* = \begin{cases} 
F_i^{-1}(CV_i), & \text{if } 0 < CV_i < 1 \\
0, & \text{if } CV_i \leq 0 
\end{cases}$$

$$\lim_{i \to \infty} CV(i) = 1 - \frac{\beta_1}{\beta_2}$$
Critical Point & Proactive Candidates (CII)

\[\theta = \{ CV(\theta) = 0 \mid \theta \in I^c \}\]

\[\theta = \left( \frac{\alpha_1 - \alpha_2}{\beta_2 - \beta_1} \right)^{\frac{1}{Y}}\]

\[\begin{align*}
Q_i^* &\geq 0 \text{ for } i \in \text{ CII} \\
Q_i^* & = 0 \text{ for } i \notin \text{ CII}
\end{align*}\]

<table>
<thead>
<tr>
<th>(\beta_2 &gt; \beta_1)</th>
<th>(\beta_2 &lt; \beta_1)</th>
</tr>
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<tbody>
<tr>
<td>(\alpha_2 &lt; \alpha_1)</td>
<td>(\theta &lt; \text{ CII} \leq N)</td>
</tr>
<tr>
<td>(\alpha_2 &gt; \alpha_1)</td>
<td>(\text{ CII} \equiv I^c)</td>
</tr>
</tbody>
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Prestaging Problem:

Given fulfilling requested demand by prestaging an item requires additional labor efforts by the delivery ship, negative marginal shortage costs can occur.

\[ \gamma \] is the decision maker’s willingness to pay for responsiveness. \( \gamma \in [0,1] \)

**Overestimating**: Prestaging too many units, Extra Labor \((Q_i > x_i)\)

\[ C_i^O = t_i + u + r + m \]

**Underestimating**: Prestaging too few units, Low responsiveness \((Q_i < x_i)\)

\[ C_i^S = l - k - r + \gamma(t_i + u + l) \]
Lower Bound

Figure 5, a. prestaging area is located on the shortest path between the elevator and the transport point (case 2)  
   b. prestaging area is somewhere that requires additional efforts (case 3)

Table 1. Different recommendations for the lower bound with respect to three different conditions

<table>
<thead>
<tr>
<th>Case</th>
<th>$\beta$</th>
<th>$\delta = 1 - r - k$</th>
<th>$A_i$</th>
<th>$CV_i$</th>
<th>Recommendation</th>
<th>CII interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>$\leq 0$</td>
<td>$\leq 0$</td>
<td>$\leq 0$</td>
<td>No prestaging for $\forall i \in I$</td>
<td>$\emptyset$</td>
</tr>
<tr>
<td>2</td>
<td>$&gt; 0$</td>
<td>0</td>
<td>$&gt; 0$</td>
<td>$&gt; 0$</td>
<td>Candidate Items for Prestaging $i \geq 1$</td>
<td>$[1, U]$</td>
</tr>
<tr>
<td>3</td>
<td>$&gt; 0$</td>
<td>$&lt; 0$</td>
<td>$(-\infty, B_i)$</td>
<td>$(-\infty, 1)$</td>
<td>No prestaging for $i &lt; L$</td>
<td>$[L, U]$</td>
</tr>
</tbody>
</table>
Policy Recommendation for Imperfect Location Visibility

Candidate items for Prestaging $CIP \in [L, U]$

$$L = -NS + \frac{1}{2} + \sqrt{\frac{1}{4} - \frac{\delta + \alpha \gamma}{\gamma \hat{t}}} NS(1 + S)$$

$$U = -NS + \frac{1}{2} + \sqrt{\frac{1}{4} + \left(1 - q_T \frac{1}{\sqrt{(1 + \gamma)}}\right) NS(1 + S)}$$
Optimal Policies Vary Based on Level of Visibility

**With Perfect visibility:** Recommend pre-staging items that have the highest-likelihood to be demanded.

**With Imperfect visibility:** Recommend pre-staging items that balance the cost of search time with likelihood of being demanded.

**Managerial Insight:** Due to the presence of imperfect item location visibility, the recommended pre-staging policy is different than the one that is recommended with perfect visibility.
Contributions of our Research

• We contribute to the work on newsvendor models by considering and understanding the impact of negative marginal shortage costs on optimal policies for a set of SKUs connected through a demand profile.

• We prove structural results that determine which items should be considered as candidates for a proactive strategy and which items for a reactive strategy.

• We develop and study the structure of a pre-staging model, which we use to quantify the impact of “Perfect Visibility” versus “Imperfect Visibility” environments.

• We provide the optimal pre-staging policies for both environments, and provide insights into what factors impact these policy recommendations.

• Counter intuitive results shows that the candidate items suitable for proactive strategy are not necessarily the high-demanded items.

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Project Objectives

- Develop Seabased Logistics Models and Algorithms
  - to gain a better understanding of why seabased logistics operate in an uncertain environment
  - to quantify the impact on logistics performance of operating in a complex and uncertain environment
  - to analyze the trade-offs associated with different logistics system design and policy alternatives
  - to determine logistics strategies that support the transfer of vital sea-based resources to forces ashore that considers operating in an environment with imperfect visibility

Deliverables
Knowledge product to inform impact of imperfect information on the vitality of sea-basing logistics operations, and to inform direction for technology investments, strategies, and/or training.
Other Applications
Facility Logistics Applications

Facility Logistics

Principle: Store fast moving items in the most convenient locations

Consequently, the effort required to retrieve an item is based on the item’s demand and inventory profile

Unit Load Storage System

Slotting
Motivation for Future Research

Supply Chain Decisions
When making downstream decisions, the efforts within the facility are considered the same for all items (regardless of an item's demand or inventory profile)

Facility Logistics
The effort required to retrieve an item varies based on the item’s demand and inventory profile.
An Optimization-based Planning Tool for the Selection of Piece-level Order-fulfillment Technologies

• Automation Tends to be Used for:
  – Few, Very Fast-Moving SKUs (A-Frames)
  – Many, Slow-Moving SKUs (Picking Machines)

Ship-From-Store for E-Commerce Orders

• E-commerce orders are fulfilled from brick and mortar stores’ inventory

• Stores are designed for customer shopping experience; not for efficient order picking

“It took Ms. El Zein several tries to find a LeSportsac travel tote in the color "Journey," a diagonal zig-zag print. She says finding items with color names such as "magical" has also proved taxing.”

(Wall Street Journal, 2012)
Cost Parameters for Ship-from-Store:

1. **Company’s vision**
   - inventory pooling
   - responsiveness

   Independent of item type
   - Highly valued in-store customers
   - Reactive strategy can be costly

   **α-type parameter**
   - $\alpha_2 < \alpha_1$
   - $\alpha_2 > \alpha_1$

2. **Store Environment**

   **Depends on item type**
   - Store layout
     - If imperfect location visibility exists
   - Backroom
     - High backroom costs; dedicated storage

   **β-type parameter**
   - $\beta_2 > \beta_1$
   - $\beta_2 < \beta_1$
Four item-allocation policy

(1) What is the main reason for implementing a ship-from-store strategy?

(2) How is the item location visibility of the store?

(3) How high is the backroom cost of a particular store?
Emerging Research Focus

- Environments where a **centralized decision making process** recommends a course of action to **decentralized users**.
- Considering individual user behavior into optimization problems.

- Submitted NSF CAREER Proposal on how to match independent supply slots with demand requests in Peer-to-Peer Resource Sharing Systems.

- Awarded a National Academies of Science Gulf Research Fellowship for these ideas to Disaster Response Applications

- Hierarchical Command Structure of the DOD
- The future of work (machine-human interactions)
Uzma Mushtaque dissertation research is to incorporate cognitive decision heuristics, like information overload, as a context effect into discrete choice models by expanding the definition of representative utility such that it associates item utility with the ‘assortment-property’ of cardinality.

Incorporates theories and methods from the fields of recommender systems, cognitive science, and consumer choice theory, emphasizing the importance of incorporating human cognitive behavior into optimization models.

Hypothesis: If the central mechanism has a good model for individual human decision making, the recommendations made could be more likely to achieve less degradation of system performance and with higher levels of compliance and participation by supply users.
Questions, Comments, Concerns?

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