PNG: Effective Inventory Control for Items with Highly Variable Demand

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Robert Carroll, Office of Secretary of Defense
Founded in 1961 by Secretary McNamara under the Kennedy administration

“...to bring the best minds to bear on solving our government’s most complex management problems”
An Introduction to DLA
Jeffrey Curtis
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DLA’s Challenges

Customer
• Military operating environment is unpredictable
• Limited weapon system populations
• Unknowable human decision
• Uncertainty in maintenance programs
• Unpredictable failure patterns
• Highly variable demands

Supplier
• Low volume, highly specialized items are less attractive to suppliers than steady, higher volume business
• Diminishing manufacturing sources and material shortages
• These factors limit supplier base, limit supplier responsiveness
• Replenishment lead times are months and even years!

DoD inventory management has been a GAO high-risk area for 25 years.
A Shift in Segmentation

Need methods appropriate for each segment of inventory

- Infrequent demand
  - ~1.1 million items (76%)

- Frequent demand
  - High variability
    - ~285,000 items (20%)
  - Low variability
    - ~65,000 items (4%)
Technical Challenges

Infrequent Demand

- Items are mission-critical
- We can’t afford not to stock them
- So how do we decide when to order and how much?

Zero demand is the best forecast!
Technical Challenges

Frequent, Highly Variable Demand

Current process loses important information
New Approach

Key Elements

• Portfolio management
  – Target population outcomes (costs and risks)
  – Accept that individual outcomes cannot be predicted (“unforecastable”)
  – Aim for more “winners” than “losers”

• Actual demand transactions
  – No forecasting
  – No distribution fitting
  – No fixed empirical distributions

• Single integrated decision with simultaneous 3-way tradeoff
  – Customer service
  – Inventory
  – Buyer workload

We stopped forecasting and focused on outcomes
PNG Tradeoff Curves

Make single decision to fit business objectives

5% inventory $ reduction
22% wait time reduction
48% workload reduction

Pre PNG:
$435 M Inventory
14 Days Wait Time
54K PR/Year

Buyer workload
- 21k PR/yr (-60%)
- 24k PR/yr (-56%)
- 28k PR/yr (-48%)
- 37k PR/yr (-32%)
- 54k PR/yr (1%)
Solution Overview

Peak + Next Gen = PNG

Saves system downtime, saves money, reduces workload, and increases customer service
Peak

Solution for Infrequent Demand

- Order when inventory gets down to some % of Peak demand
- Order a quantity based on unit price

Min = (Price-based mult.) (Peak demand)
Max = Min + (Price-based order qty.)

How do we get good values for multipliers & order quantity?
Select best (M, Q) parameter set for each set of goals yields levels

Calculate metrics for each parameter set (1000s)
- customer wait time
- inventory value
- buyer workload

Generate 1000s of possible (M, Q) parameter sets for each price group

Run 1000s of simulations with randomized demand spikes for each (M, Q) parameter set

Run mixed integer program optimization

The Peak is the max required buffer of stock

\[
\text{min level} = (\text{price group multiplier}, M) (\text{max buffer size})
\]
\[
\text{max level} = (\text{price based order quantity}, Q) + \text{min}
\]
Innovations

Peak

- Reorder point that protects against affordable percentage of max demand, rather than based on forecast
- Portfolio management—acknowledge that we can’t be right on every item—aim for “more winners than losers”
- Stress testing each set of model parameters against many patterns of random demand spikes
- Sending simulation outputs to mixed integer program to find optimal parameters for wide range of metrics tradeoffs
Next Gen

Solution for Frequent, Highly Variable Items

- Compute objective function based on inventory investment, wait time, and procurement workload
- Solve the objective function for the best min/max values

Developed an objective function \( \sum c(s, S) \) that captures real-world messiness

How do we solve the objective function for min/max?

Real world does not conform to traditional distributions
Next Gen

Step by Step

1. Build Histograms for Inter-arrival time and Demand size

2.a. Compute inventory position probabilities for candidate min/max

2.b. Generate multiple sets of penalty factors for:
   - Backorders
   - Inventory $
   - Annual buys

3.a. For each set of penalty factors, build a cost function

3.b. Generate multiple sets of penalty factors for:
   - Backorders
   - Inventory $
   - Annual buys

4. For each cost function, perform an optimization to identify the min./max. for each item

5. Use simulation to independently stress test the solution to build trade off curves
Innovations

Next Gen

- Smoothed histograms capture emerging demand trends without over-reacting—no fixed empirical distributions
- Cost function built directly from the histograms and penalty factors, without distribution fitting or parameter estimation
- Reformulating cost function to fit a fast (abstract) search algorithm, and proving that our new function satisfied 3 conditions for search to work
- Modified cost function to serve items with large and small demands well
- Tradeoff curves built from independent simulation test of model parameter sets
**Project History**

1. **1st Problem Recognized:** Sparse Demand
2. **Developed 1st Risk Management-Based Approach**
3. **Abandoned Forecast-Based Approach**
4. **Developed Early Peak Algorithms**
5. **Initial Implementation of Peak**
   - **Barchi Prize at 2004 MORS Symposium**
6. **2nd Problem Recognized: Frequent, Highly Variable Demand**
7. **Developed Next Gen Algorithms**
8. **Testing**
9. **Peak + Next Gen = PNG Software**
10. **Developed Advanced Peak Algorithms**
11. **Testing**
12. **Next Gen Benefits Proven**
13. **PNG Implementation for DLA**
14. **Developed Next Gen Algorithms**
15. **Advanced Peak Algorithms**
16. **Barchi Prize at 2004 MORS Symposium**
Implementation Challenges

- Balancing the needs of all stakeholders
- Ensuring that all stakeholders had a voice
- Streamlining integration with monthly processes
Lessons Learned During Implementation

- Engage change agents to help shift the paradigm
- Communicate the strategic vision to the business
- Involve the customer early
- Provide training and communicate expectations
- Coordinate extensively with IT and functional experts for customized ERPs
Extension to the Department of Defense

“Perhaps the most significant change going forward is in demand forecasting. DoD is implementing a new forecasting methodology for inventory with demand patterns that are infrequent or highly variable. This initiative is producing improved materiel availability, decreased backorders, reduced procurement orders, and on-hand inventory results.”

Mr. Alan Estevez
Principal Deputy Under Secretary of Defense for Acquisition, Technology and Logistics

Written Testimony to the House Oversight and Government Reform Committee
February 11, 2015
PNG and DoD

Alan Estevez
Principal Deputy Defense Under Secretary for Acquisition, Technology & Logistics
Value to DLA and Department of Defense

...2 years later on affected items

- **↑ 4 points**
  - Material availability

- **↓ $600 million**
  - Excess on-hand inventory value

- **↓ 35 percent**
  - Recommended annual buys

- **↓ 70 percent**
  - Cancelled buys

- **↓ $127 million**
  - Estimated labor savings from unnecessary buys and cancellations over five years

- **↓ $2 billion**
  - Estimated savings in working capital over five years
PNG TRADEOFF CURVES

PNG and DLA
Jeffrey Curtis
Executive Director
Logistics Policy and Strategic Programs

• Right Items
• Right Time
• Right Amounts
Value to DLA and Department of Defense

...2 years later on affected items

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  Material availability

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Backup
Peak Math Notation

\[ N = \text{number of price groups, } (i = 1, \ldots, N) \]
\[ K = \text{number of candidate (m,Q) pairs for price group } i, (j = 1, \ldots, K) \]
\[ OH_{ij} = \text{average on-hand inventory value for parameter pairing } j \text{ of price group } i \]
\[ OH_{\text{base}} = \text{average on-hand inventory value for the baseline stocking policy} \]
\[ OH_{\text{scale}} = \text{scaling factor for average on-hand inventory constraint} \]
\[ PR_{ij} = \text{procurement workload for parameter pairing } j \text{ of price group } i \]
\[ PR_{\text{base}} = \text{procurement workload for the baseline stocking policy} \]
\[ PR_{\text{scale}} = \text{scaling factor for procurement workload constraint} \]
\[ WR_{ij} = \text{wait time for parameter pairing } j \text{ of price group } i \]
\[ WR_{\text{base}} = \text{wait time for the baseline stocking policy} \]
\[ WR_{\text{scale}} = \text{scaling factor for wait time constraint} \]

The parameters \( OH_{ij}, PR_{ij}, WR_{ij} \) are the outputs of a simulation model using Peak Policy to set levels, where the input is candidate pair \( j \) from price group \( i \).

\[ Variables: \]
\[ X_{ij} = 1 \text{ when } (m,q) \text{ candidate pair } j \text{ from price group } i \text{ is used; otherwise } 0 \]
Peak Math

- **Objective Function**

\[ \text{Min} \sum_{i=1}^{N} \sum_{j=1}^{K} OH_{ij} X_{ij} \]

- **Constraints**

\[ \sum_{i=1}^{N} \sum_{j=1}^{K} PR_{ij} X_{ij} \leq PR_{\text{scale}} PR_{\text{base}} \]

\[ \sum_{j=1}^{K} X_{ij} = 1, \forall i \]

\[ \sum_{i=1}^{N} \sum_{j=1}^{K} WR_{ij} X_{ij} \leq WR_{\text{scale}} WR_{\text{base}} \]

\[ X_{ij} \in \{0,1\} \forall i, j \]
Next Gen Notation

\( h = \) unit holding cost
\( K = \) administrative cost to place a replenishment order
\( \mu_s = \) mean inter−arrival time
\( \lambda = \) Lagrange multiplier or backorder penalty
\( E(BO) = \) expected backorders
\( E(OH) = \) expected on−hand inventory value
\( R(x) = \) renewal function of requisition sizes for a total quantity demanded \( x \)
\( S = \) requisitioning objective
\( s = \) reorder point
\( \Delta = S - s \)

Variables:
\( r(j) = \) renewal density of requisition sizes for a total quantity demanded \( j \),
\( G(y) = H(y) + P(y) \),
\( H(y) = \) the cost to hold on−hand inventory, and
\( P(y) = \) the cost of outstanding unit backorders.
Next Gen Math

• Objective Function

\[
c(s, S) = \frac{1}{M(\Delta)} \left\{ \frac{K}{\mu_a} + \sum_{j=0}^{\Delta-1} m(j)G(S - j) \right\} \\
= \frac{1}{M(S - s)} \left\{ \frac{K}{\mu_a} + \sum_{j=0}^{S-s-1} m(j)G(S - j) \right\}
\]

\(M(j)\) = expected time until the next order is placed giving starting inventory position of \(s + j\)

\(G(S - j)\) = short-term backordering and holding cost with inventory position \(S - j\)