PNG: Effective Inventory Control for Items with Highly Variable Demand

Dr. Tovey Bachman, LMI

Robert Carroll, Office of Secretary of Defense

LMI

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
Executive Director
Logistics Policy and Strategic Programs

DLA's Challenges

Customer

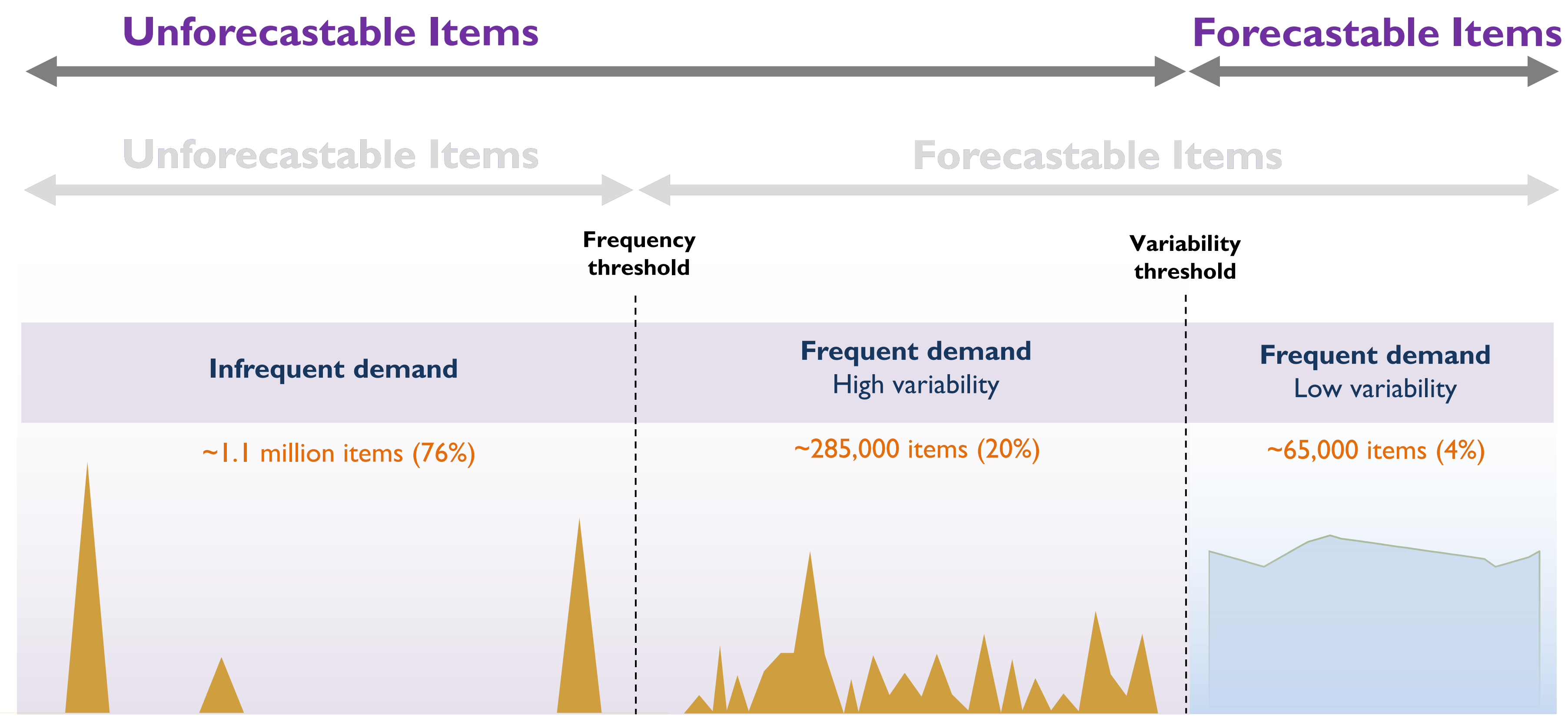
- Military operating environment is unpredictable
- Limited weapon system populations
- Unknowable human decision
- Uncertainty in maintenance programs
- Unpredictable failure patterns
- Highly variable demands

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



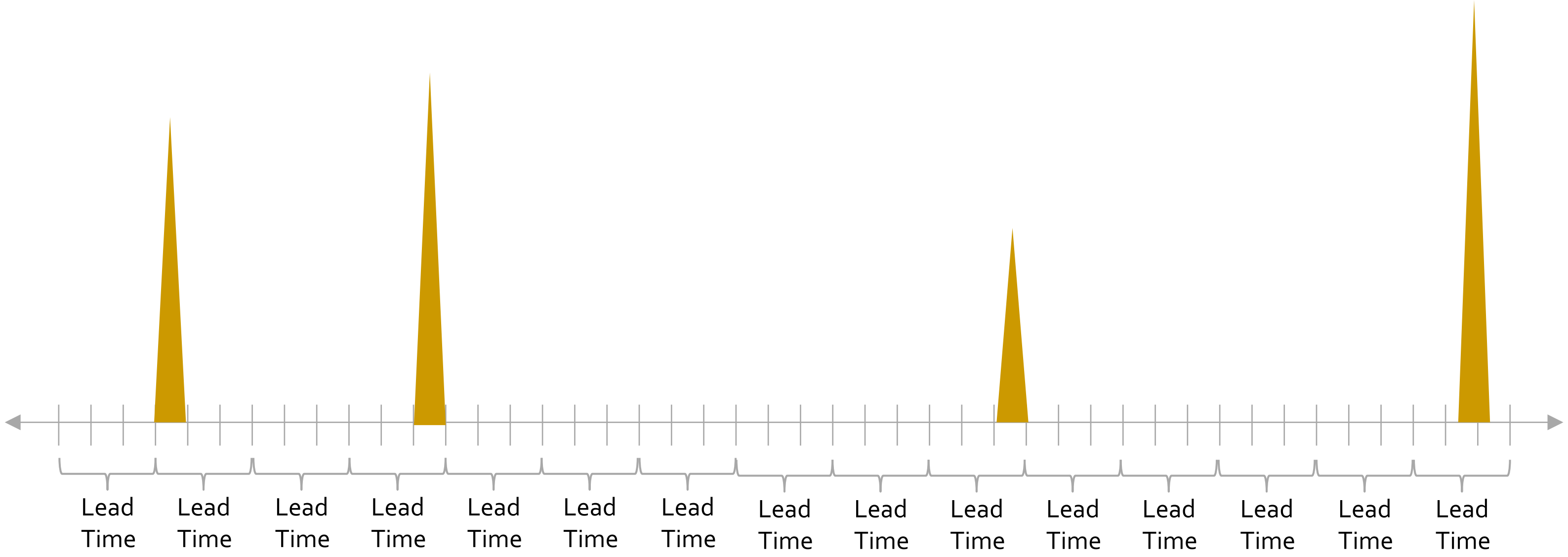
Need methods appropriate for each segment of inventory

LMI

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?

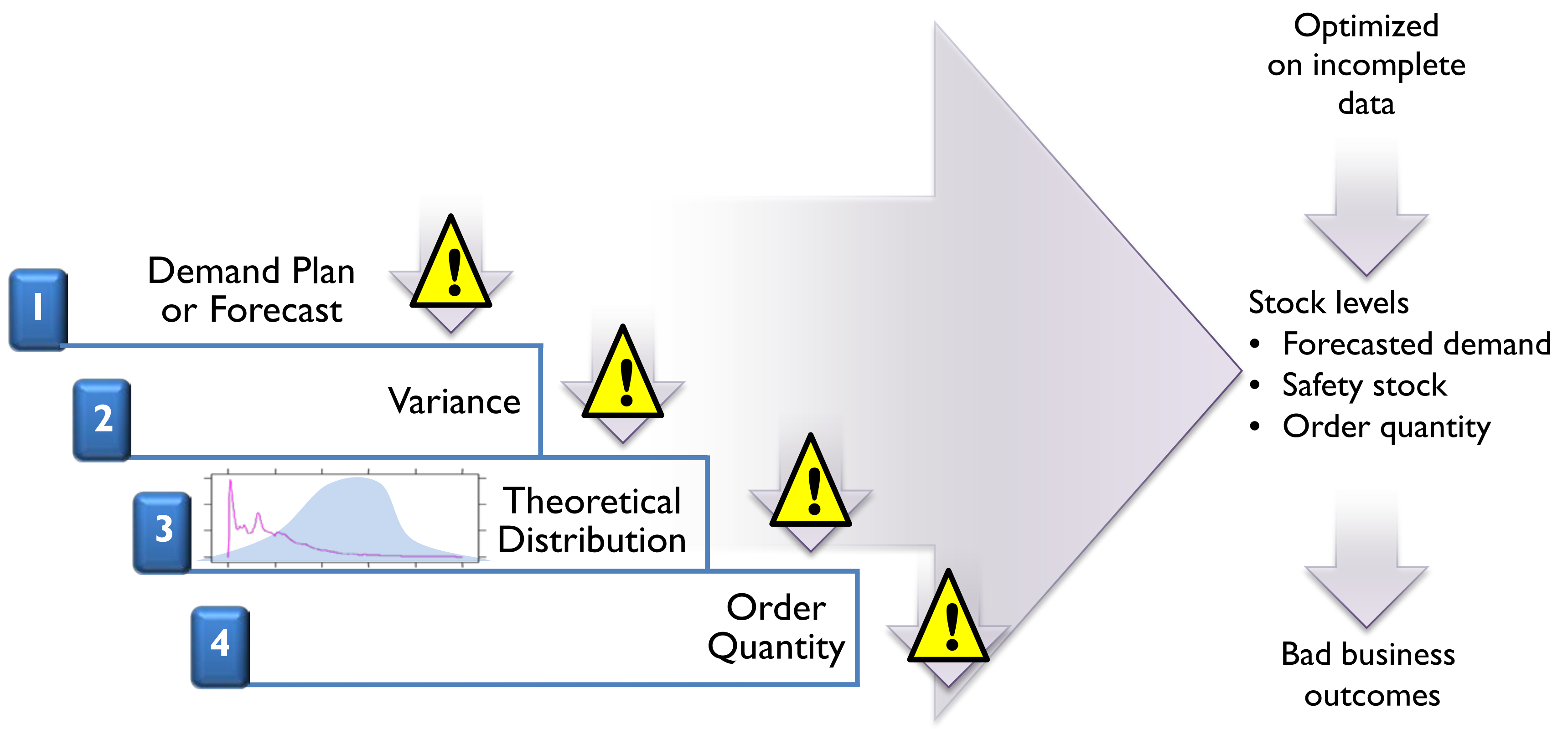


Zero demand is the best forecast!

LMI

Technical Challenges

Frequent, Highly Variable Demand



Current process loses important information

New Approach

Key Elements

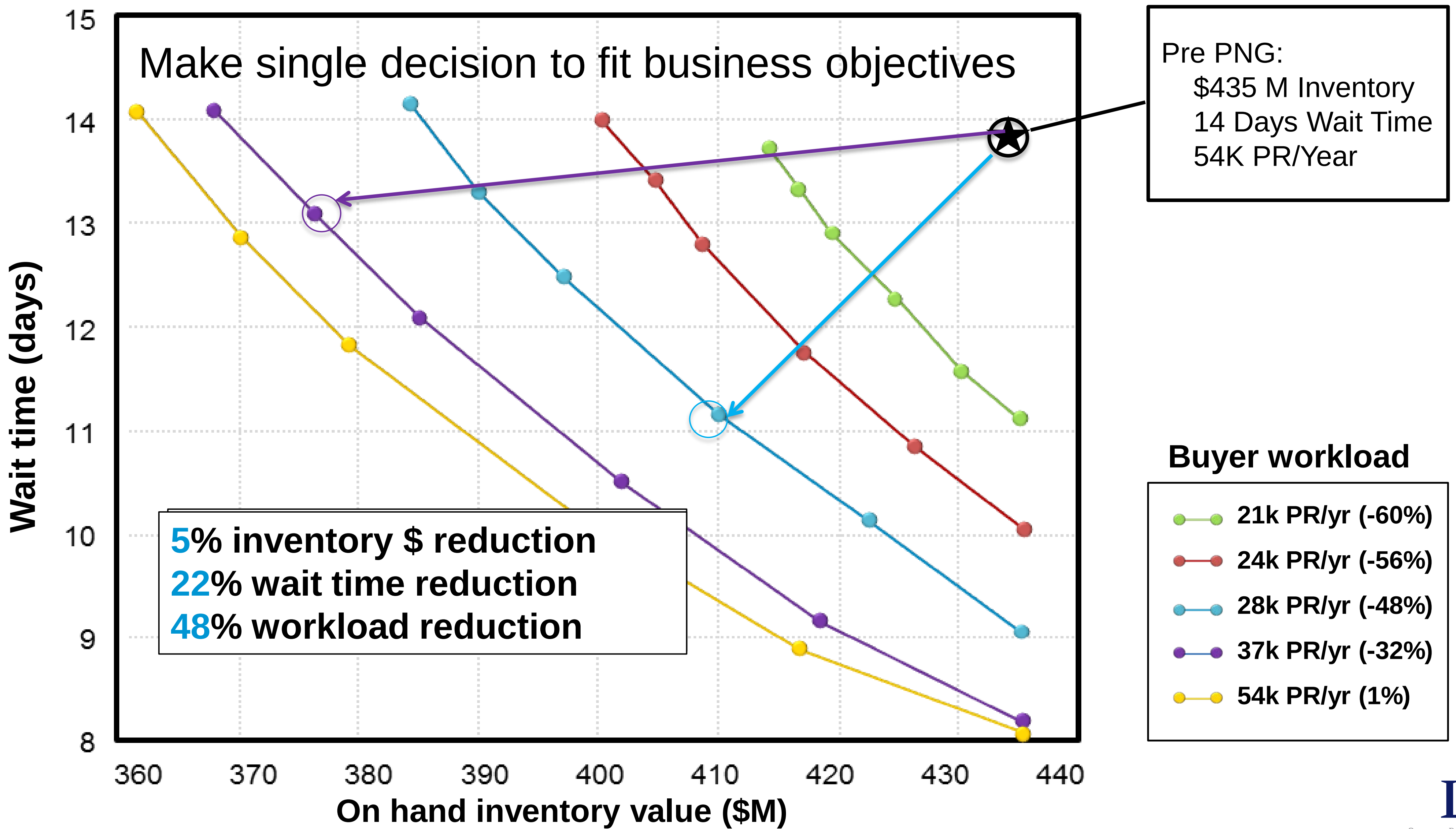
- Portfolio management
  - Target population outcomes (costs and risks)
  - Accept that individual outcomes cannot be predicted (“unforecastable”)
  - Aim for more “winners” than “losers”
- Actual demand transactions
  - No forecasting
  - No distribution fitting
  - No fixed empirical distributions

→ Evolving patterns

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

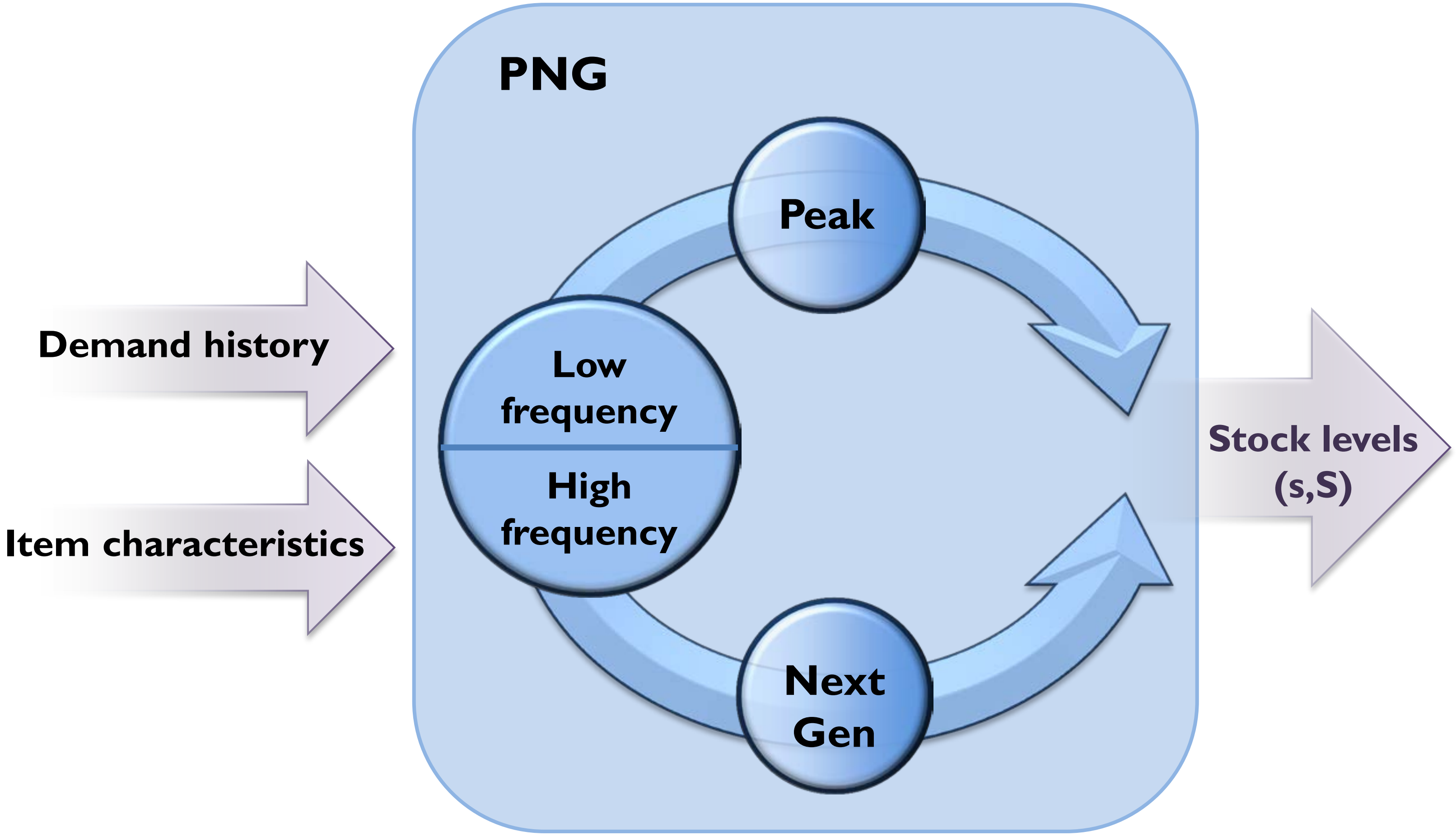
We stopped forecasting and focused on outcomes

PNG Tradeoff Curves



Solution Overview

Peak + Next Gen = PNG

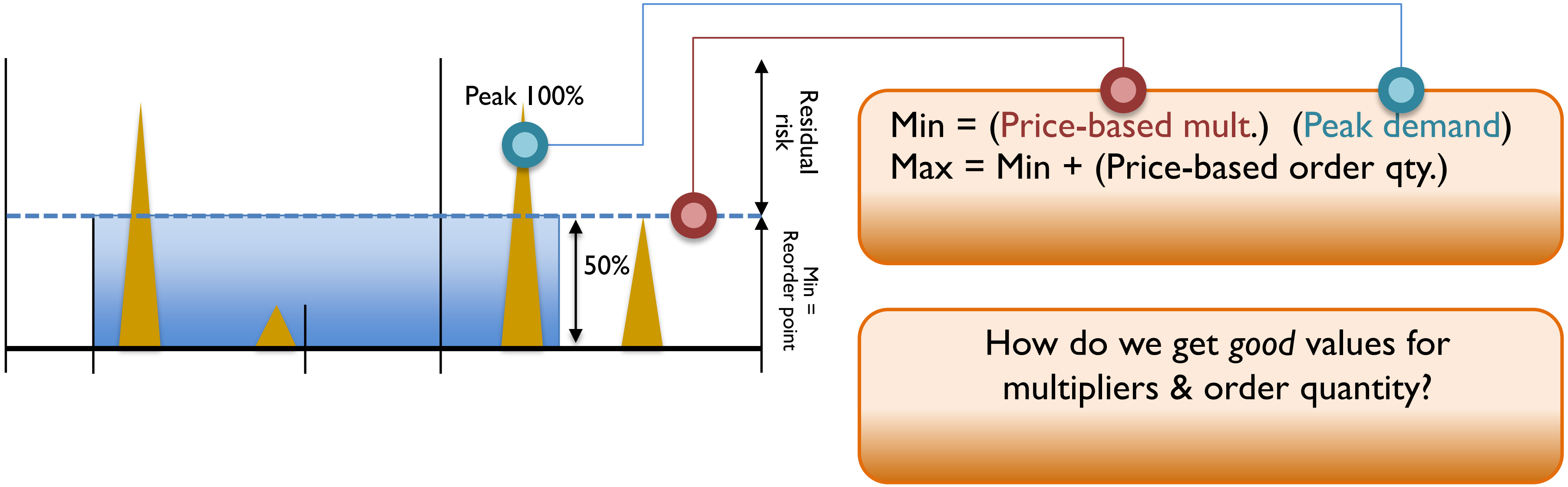


Saves system downtime, saves money, reduces workload, and increases customer service

Peak

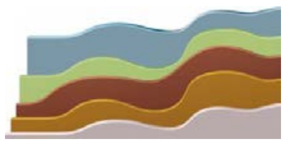
Solution for Infrequent Demand

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



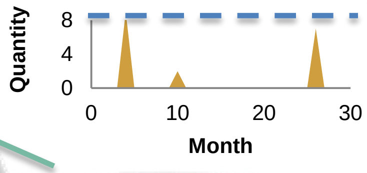
Peak

Step by Step



Identify 5-7 price groups

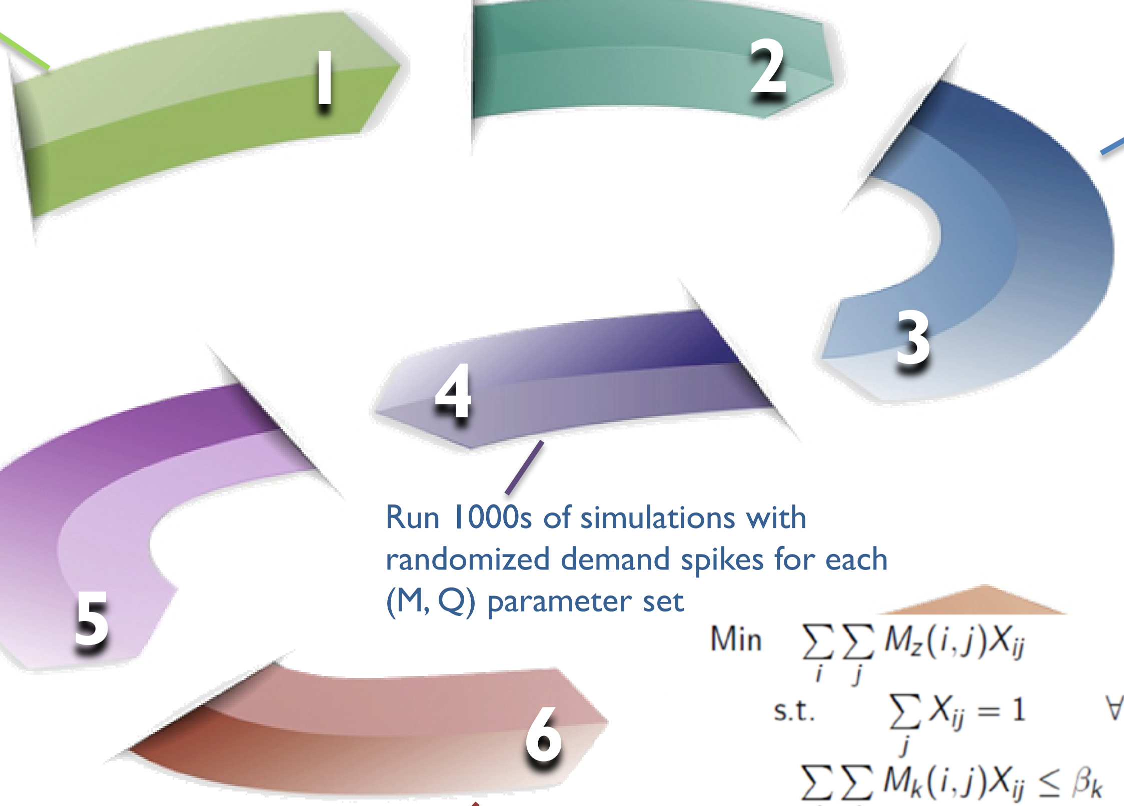
Determine Peak for each item



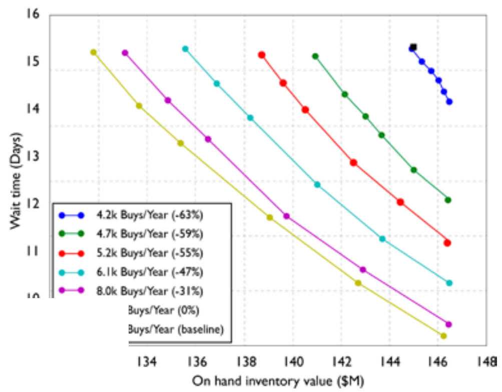
The **Peak** is the max required buffer of stock

min level = (price group multiplier, M) (max buffer size)

max level = (price based order quantity, Q) + min



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



Calculate metrics for each parameter set (1000s)

- customer wait time
- inventory value
- buyer workload

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

$$
\begin{aligned}
\text{Min} \quad & \sum_i \sum_j M_z(i,j) X_{ij} \\
\text{s.t.} \quad & \sum_j X_{ij} = 1 \qquad \forall i \\
& \sum_i \sum_j M_k(i,j) X_{ij} \le \beta_k \quad \forall k \\
& X_{ij} \in 0, 1
\end{aligned}
$$

Run mixed integer program optimization

LMI

Innovations

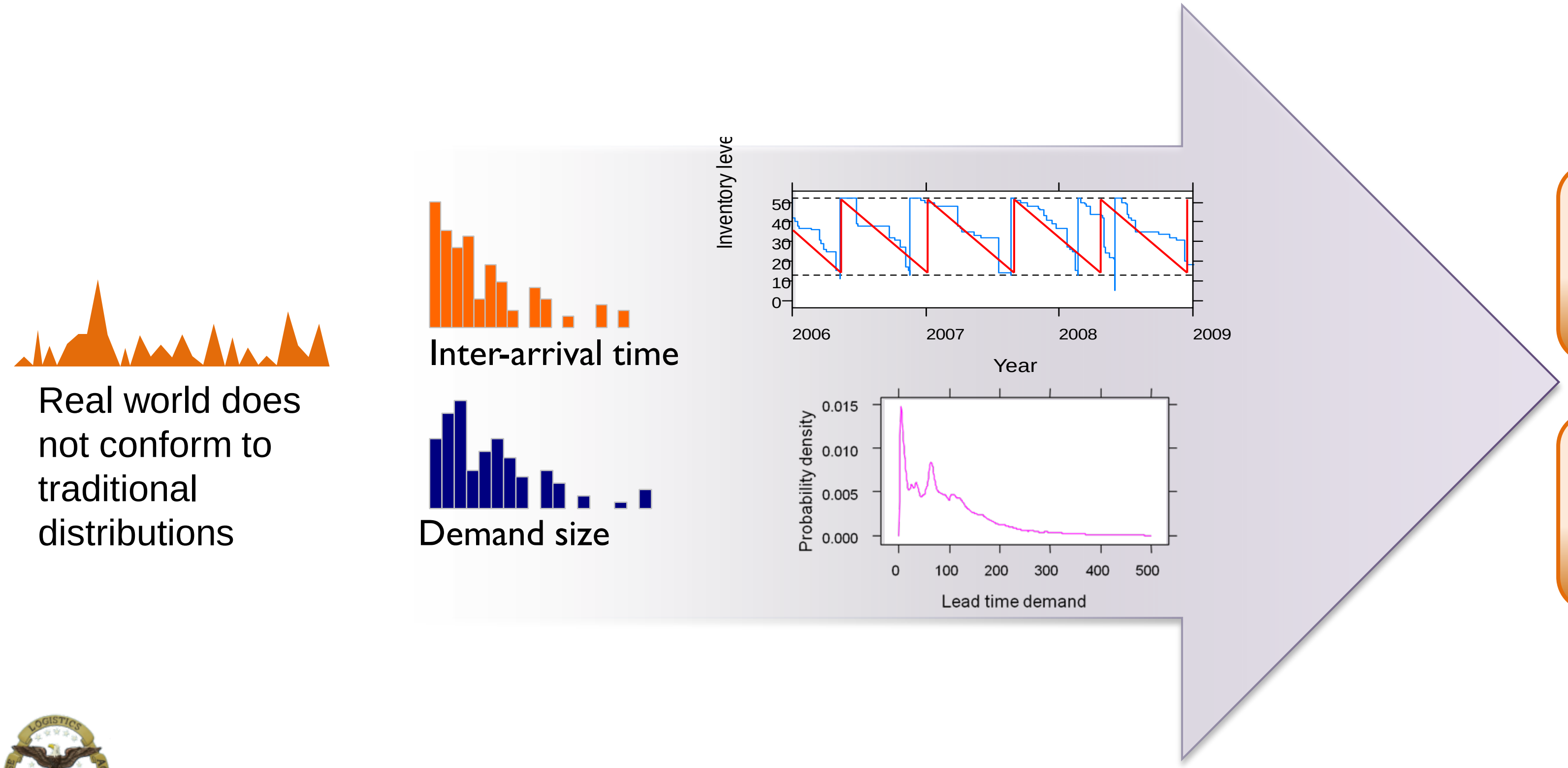
Peak

- 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



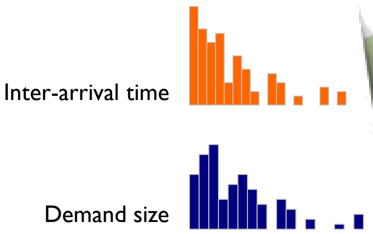
Developed an objective function $\sum c(s,S)$ that captures real-world messiness

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

Next Gen

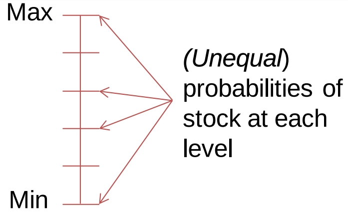
Step by Step

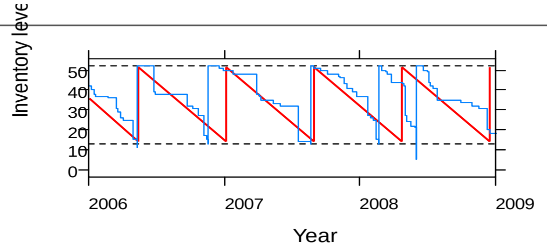
Build Histograms



1

Compute inventory position probabilities for candidate min/max

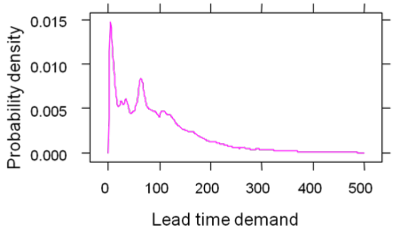




2.a

2.b

Compute leadtime demand probabilities



3.a

Generate multiple sets of penalty factors for

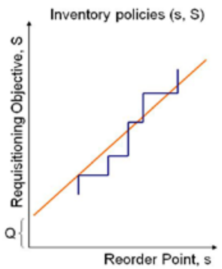
- Backorders
- Inventory $
- Annual buys

3.b

For each set of penalty factors, build a cost function

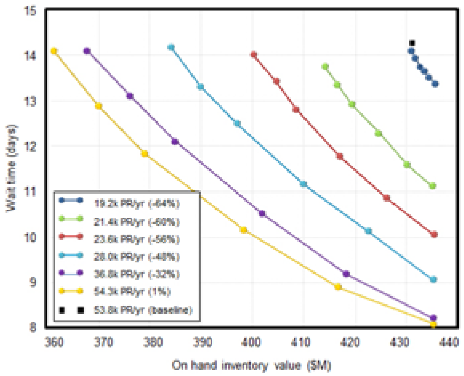
4

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

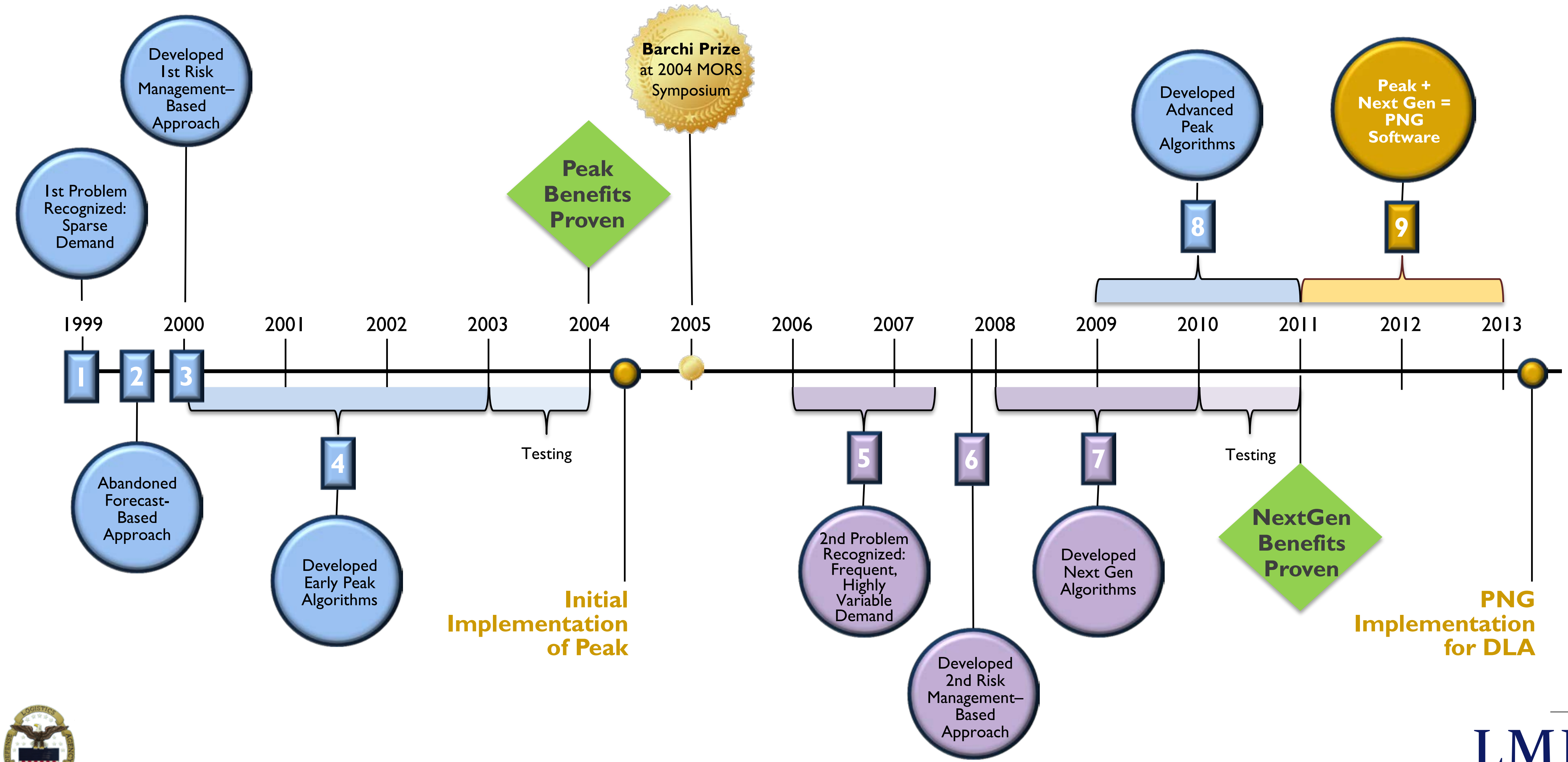


Innovations

Next Gen

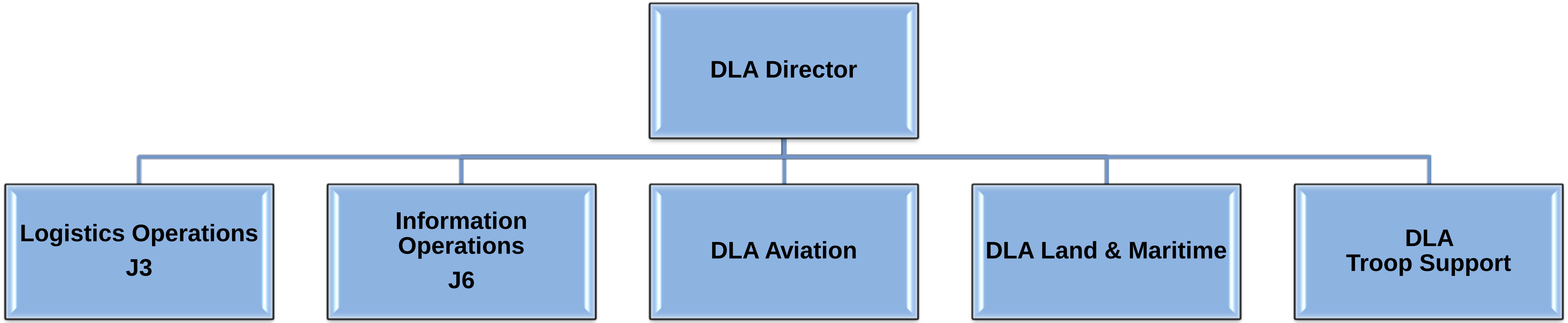
- Smoothed histograms capture emerging demand trends without over-reacting—no fixed empirical distributions
- Cost function built directly from the histograms and penalty factors, without distribution fitting or parameter estimation
- Reformulating cost function to fit a fast (abstract) search algorithm, 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



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*

LMI

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

Backup

Peak Math Notation

$N =$ number of price groups, $(i = 1, \ldots, N)$

$K =$ number of candidate (m, Q) pairs for price group i, $(j = 1, \ldots, K)$

$OH_{ij} =$ average on – hand inventory value for parameter pairing j of price group i

$OH_{base} =$ average on – hand inventory value for the baseline stocking policy

$OH_{scale} =$ scaling factor for average on - hand inventory constraint

$PR_{ij} =$ procurement workload for parameter pairing j of price group i

$PR_{base} =$ procurement workload for the baseline stocking policy

$PR_{scale} =$ scaling factor for procurement workload constraint

$WR_{ij} =$ wait time for parameter pairing j of price group i

$WR_{base} =$ wait time for the baseline stocking policy

$WR_{scale} =$ 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 :

$X_{ij} = 1$ when (m, q) candidate pair j from price group i is used; otherwise 0

LMI

Peak Math

- Objective Function

$$Min\sum_{i=1}^{N}\sum_{j=1}^{K}OH_{ij}X_{ij}$$

- Constraints

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

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

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

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

Next Gen Notation

h = unit holding cost

K = administrative cost to place a replenishment order

μ_a = mean inter – arrival time

λ = Lagrange multiplier or backorder penalty

$E(BO)$ = expected backorders

$E(OH)$ = expected on – hand inventoryvalue

$R(x)$ = renewal function of requisition sizes for a total quantity demanded x

S = requisitioning objective

s = reorder point

Δ = S - s

Variables:
r(j) = renewal density of requisition sizes for a total quantity demanded j,
G(y) = H(y) + P(y),
H(y) is the cost to hold on-hand inventory, and
P(y) is 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 $S - j$