Simulating Tomorrow’s Supply Chain Today: The Value of Flexibility in Supply Chain Design

Randolph L. Bradley
art2part@mit.edu
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System Description: The F/A-18E/F Supply Chain

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Wholesale

- Repairable Part Removed at Organizational Level
- Intermediate Level Repair at Naval Air Station
- Depot Level Repair
- Contractor Supply
- Replacement Repairable and Consumable Parts

Retail

- Stocking Policy determines Reorder Point and Order Quantity
- Fill Rate under uncertain demand determines fleet readiness
- Boeing (Wholesale) supports Demand from Navy (Retail) Maintenance

(1) Repairable Part Removed at Organizational Level
(2) Intermediate Level Repair at Naval Air Station
(3) Depot Level Repair
(4) Contractor Supply
(5) Replacement Repairable and Consumable Parts
Sources of Uncertainty: Stochastic Dynamic Forecasting

### Historical Data

<table>
<thead>
<tr>
<th>Period(t)</th>
<th>X(t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan-08</td>
<td>9.00</td>
</tr>
<tr>
<td>Feb-08</td>
<td>4.00</td>
</tr>
<tr>
<td>Mar-08</td>
<td>3.00</td>
</tr>
<tr>
<td>Apr-08</td>
<td>4.00</td>
</tr>
<tr>
<td>May-08</td>
<td>2.00</td>
</tr>
</tbody>
</table>

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### Exponential Smoothing of Historical Data

\[ X(t) = X(t-1)^a \exp(b + \epsilon(t)) \]

- **a**: 0.260 (SLOPE)
- **b**: 1.978 (INTERCEPT)
- **\( \epsilon(t) \)**: 0.379 (ERROR)
- **SES Forecast**: 8.99

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### Periodic Data Series for Consecutive Periods

Regression model for \( X(t) = aX(t-1) + \epsilon(t) \)

- **y**: 0.1419x + 4.523
- **R\(^2\)**: 0.0217

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### Paths of Additive Forecasting Model

\[ X(t) = X(t-1)^a \exp(b + \epsilon(t)) \]

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### Histogram of Stochastic Dynamic Forecast Error

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### Histogram of Expected Normal Values

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### PDF of the Regression Errors

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### Wholesale Demand Data

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### X\(^2\) Chi-Square Goodness of Fit Test
Fixed and Flexible Designs

- **Long Term Contracts & Jensen’s Inequality**: Evaluate fixed design (constant demand) vs. flexible design (variable demand)

- **Acquisition Policy**: Evaluate fixed design (periodic review policies) vs. flexible design (continuous review policy)

- **Flexible Designs**: Evaluate four stocking policies under variable demand
  - SPO Strategy by MCA Solutions
  - VMetric-XL by TFD Group/Systems Exchange
  - The Wilson Economic Order Quantity (EOQ) Model
  - Chief of Naval Aviation for Training (CNATRA) Heuristic

- **Exogenous uncertainties** – Not influenced by managerial decisions
  - Demand

- **Endogenous uncertainties** - Influenced by managerial decisions
  - Acquisition Policy
  - Stocking Policy

**Consider Flexible Designs for Contracting, Acquisitions & Stocking Policy**
Simulation Setup: Stocking Policy Simulator

**Supply Chain Data**

**Inventory Optimization**

**Stochastic Dynamic Forecasting**

Paths of Additive Forecasting Model $X(t) = X(t-1)^a \times \exp(b + \varepsilon(t))$

**Select Part**

(s,S) Order Point, Order-Up-to-Level

**Target Curve**

Cumulative Distribution Function (CDF)

**Hypothesis Testing**

**Simulation**

Fill Rate Histogram

**Visual Line of Balance**

**Line of Balance**

Wilson EOQ

**Supply Chain Management**

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Long Term Contracts & Jensen’s Inequality

$E[f(x)] \neq f[E(x)]$ if $f(x)$ convex function

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**Plan A**
- Fixed design (constant demand)

**Plan B**
- Flexible design (variable demand)

- The fill rate for average demand is 100%
- The average fill rate for all possible outcomes using uncertain demand is 92.7%

**NPV**
- For average demand: $\$5,422$
- Average NPV for all possible outcomes using uncertain demand: $\$5,975$

*INSIGHT: BASE LONG TERM CONTRACTS ON AN EXPECTED RANGE OF VALUES*
# Acquisition Policy

Plan A: Continuous review (flexible case)

Plan B: Twelve (12) month periodic review (fixed case)

Plan A: Current stocking policy!

Plan B: Annual budgeting cycle!

<table>
<thead>
<tr>
<th></th>
<th>Plan A (Continuous Review/ Flexible)</th>
<th>Plan B (Periodic Review/ Fixed)</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% Value at Risk (P10)</td>
<td>74%</td>
<td>59%</td>
<td>There is a 10% chance that fill rate will be as low as this amount</td>
</tr>
<tr>
<td>Mean</td>
<td>92.2%</td>
<td>80.3%</td>
<td>The expected value, with a 50% probability</td>
</tr>
<tr>
<td>10% Value at Gain (P90)</td>
<td>100%</td>
<td>100%</td>
<td>The VAG caps out at 100% fill rate</td>
</tr>
</tbody>
</table>

**Insight:** Acquisition Policy & Inventory Policy must be aligned.
Flexible Designs: Four Stocking Policies

Part Number: 5911804-1
CAGE: 99167
Nomenclature: BOOT, AIRCRAFT, MATER

- SPO Strategy by MCA Solutions: Inventory optimization model
- VMetric-XL by TFD Group: Inventory optimization model
- The Wilson Economic Order Quantity (EOQ): Classic inventory model
- Chief of Naval Aviation for Training (CNATRA): Lead time & demand heuristic

Stocking level recommendations:

<table>
<thead>
<tr>
<th></th>
<th>SPO Strategy</th>
<th>VMetric-XL</th>
<th>WILSON EOQ</th>
<th>CNATRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROQ</td>
<td>21</td>
<td>39</td>
<td>21</td>
<td>123</td>
</tr>
<tr>
<td>ROP</td>
<td>118</td>
<td>98</td>
<td>98</td>
<td>104</td>
</tr>
<tr>
<td>Stock Level</td>
<td>139</td>
<td>137</td>
<td>119</td>
<td>227</td>
</tr>
<tr>
<td>Safety Stock</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Flexible Designs: Fill Rate Evaluation

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**Cumulative Distribution Function (CDF)**
Part No. 5911804-1

<table>
<thead>
<tr>
<th>Fill Rate</th>
<th>SPO Strategy</th>
<th>VMetric-XL</th>
<th>WILSON EOQ</th>
<th>CNATRA</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% Value at Risk (P10)</td>
<td>74%</td>
<td>69%</td>
<td>63%</td>
<td>87%</td>
<td>10% chance NPV low as this amount</td>
</tr>
<tr>
<td>Mean</td>
<td>92% (Validation: SPO Strategy says 88%)!</td>
<td>87%</td>
<td>84%</td>
<td>96%</td>
<td>The expected value, w/50% probability</td>
</tr>
<tr>
<td>10% Value at Gain (P90)</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>10% chance NPV exceeds this amount</td>
</tr>
</tbody>
</table>
Flexible Designs: Net Present Value (NPV) Evaluation

Cumulative Distribution Function (CDF)
Part No. 5911804-1

Net Present Value (NPV)

<table>
<thead>
<tr>
<th>SPO Strategy</th>
<th>VMetric-XL</th>
<th>WILSON EOQ</th>
<th>CNATRA</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% Value at Risk</td>
<td>$4,990</td>
<td>$4,431</td>
<td>$4,484</td>
<td>10% chance NPV low as this amount</td>
</tr>
<tr>
<td>(P10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>$5,977</td>
<td>$5,461</td>
<td>$5,444</td>
<td>The expected value, w/50% probability</td>
</tr>
<tr>
<td>10% Value at Gain</td>
<td>$7,009</td>
<td>$6,531</td>
<td>$6,455</td>
<td>10% chance NPV exceeds this amount</td>
</tr>
<tr>
<td>(P90)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Business Rule: Stocking Policy with Lowest NPV s.t. Fill Rate Constraint
Conclusions

- **Long Term Contracts**
  - The average of all possible outcomes associated with uncertain parameters generally does not equal the value obtained from the average value of the parameters (Jensen’s Inequality)
  - Shift from basing long term contracts on average requirements, to an expected range of values.

- **Acquisition Policy**
  - The stocking policy should be in concert with the acquisition policy.
  - With an annual budgeting cycle, stock to a twelve (12) month periodic review policy.
  - This requires a large capital expenditure (CAPEX) for initial spares, due to the added twelve (12) months of pipeline inventory, and entails high holding costs.
  - Develop a financial business case for changing acquisition policy to (a) fund the “plus up” to achieve optimal stock levels, and (b) allow flexible funding for monthly buys.

- **Flexible Stocking Policies**
  - Reviewed four policies: SPO Strategy, VMetric-XL, Wilson EOQ, and CNATRA.
  - Multiple criteria - Fill Rate and NPV - must be considered together.
  - Select the stocking policy with the lowest NPV which achieves desired Fill Rate goal.

**BUSINESS RULE: STOCKING POLICY WITH LOWEST NPV s.t. FILL RATE CONSTRAINT**