Evaluating Inventory Segmentation Strategies for Aftermarket Service Parts in Heavy Industry using Linked Discrete-Event and Monte Carlo Simulations

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Advisor: Jarrod Goentzel
Sponsor: Heavy Industry

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Agenda

• Overview
• Hypothesis
• Methodology
• Data Analysis
• Simulating Baseline Strategy
• Simulating Alternate Strategy
• Stocking Policy
• Executive Summary
Overview & Hypothesis
The Persona of Heavy Industry

**Bernt A. Lilliestråle**

- Vice President, Shuttle Operation, Teekay Norway
- Teekay Petrojarl is a global leader in oil & gas shipping & offshore production
- Tech data, manuals, and standards often non-existent
- Focus on maintenance rather than maintaining data
- Small fleet
  - Five Floating Production, Storage and Offloading (FPSO) vessels
  - Two shuttle tankers
  - One storage tanker
- Knows his support challenges are systemic across heavy industry

“My biggest fear is that I have a ship down for maintenance, the part is somewhere in Teekay’s spares chain, and I don’t know it.”

– Bernt Lilliestråle
Definitions

• Customers want all their parts when needed...

• **Fill Rate**
  • Percent of parts shipped from stock on hand
  • Objective function of inventory optimization

• **Perfect Order Fulfillment (POF)**
  • Percent of orders shipped “on time and in full”

• **Order Fulfillment Lead Time (OFLT)**
  • Average time from order placement to customer receipt
  • Measures speed of service
  • OFTL as contractual metric = POF within delivery window
  • Modeled with simulation
Hypothesis: *The alternate ABCDE inventory segmentation strategy for consumable parts will outperform the baseline AB strategy when measured on Order Fulfillment Lead Time and inventory investment.*

**Baseline AB Inventory Segmentation Strategy**
- Group on price
  - A=Parts ≤ $2,000
  - B=Parts > $2,000
  - Min 50% Fill Rate

**Alternate ABCDE Inventory Segmentation Strategy**
- Group on annual use
  - A=Parts 80% Annual Use
  - B=Parts 15% Annual Use
  - C=Parts 5% Annual Use
  - D=$25 ≥ Parts > $1
  - E=$1 ≤ Parts
## Baseline AB vs. Alternate ABCDE Inventory Segmentation Strategies

### Baseline AB Inventory Optimization

<table>
<thead>
<tr>
<th>Unit Cost</th>
<th>Cumulative % Part Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 - $2</td>
<td>0%</td>
</tr>
<tr>
<td>$2 - $5</td>
<td>10%</td>
</tr>
<tr>
<td>$5 - $9</td>
<td>20%</td>
</tr>
<tr>
<td>$9 - $14</td>
<td>30%</td>
</tr>
<tr>
<td>$14 - $19</td>
<td>40%</td>
</tr>
<tr>
<td>$19 - $26</td>
<td>50%</td>
</tr>
<tr>
<td>$26 - $37</td>
<td>60%</td>
</tr>
<tr>
<td>$37 - $52</td>
<td>70%</td>
</tr>
<tr>
<td>$52 - $73</td>
<td>80%</td>
</tr>
<tr>
<td>$73 - $100</td>
<td>90%</td>
</tr>
<tr>
<td>$100 - $143</td>
<td>100%</td>
</tr>
</tbody>
</table>

### Alternate ABCDE Inventory Segmentation

<table>
<thead>
<tr>
<th>Part Count vs. Annual Use</th>
<th>Cumulative Annual Use (Demand * Unit Cost)</th>
</tr>
</thead>
</table>

### Table

<table>
<thead>
<tr>
<th>Segment</th>
<th>% Annual Use</th>
<th>% Part Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: ≤$2,000</td>
<td>37%</td>
<td>92%</td>
</tr>
<tr>
<td>B: &gt;$2,000</td>
<td>63%</td>
<td>8%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

### Table

<table>
<thead>
<tr>
<th>Segment</th>
<th>% Annual Use</th>
<th>% Part Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: 80% Usage &amp; &gt;$25</td>
<td>79%</td>
<td>7%</td>
</tr>
<tr>
<td>B: 15% Usage &amp; &gt;$25</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td>C: 5% Usage &amp; &gt;$25</td>
<td>4%</td>
<td>42%</td>
</tr>
<tr>
<td>D: $1&lt;Unit Cost≤$25</td>
<td>3%</td>
<td>30%</td>
</tr>
<tr>
<td>E: Unit Cost≤$1</td>
<td>0%</td>
<td>7%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Inventory optimization uses a “greedy algorithm” to select the lowest cost quantity and mix of parts achieving fill rate constraint.
Methodology
How much is enough?

Optimal # warehouse discrete event simulations

Sweet spot for warehouse discrete event simulation = 4 repetitions (+/- 1½%)

80% confidence interval similar from 4 to 21 iterations

Transactions in OFLT Window

Time

Sims vs. 80% Confidence Level Consumables Hi-Pri OFLT Jun-12

Sims vs. 80% Confidence Level Consumables Hi-Pri OFLT Dec-12

Sims vs. 80% Confidence Level Consumables Hi-Pri OFLT Jun-13

Transactions in OFLT Window

Transactions in OFLT Window

Transactions in OFLT Window

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Data Analysis
Empirical Shipping Delay Distributions

Average Shipping Delay (Days)

<table>
<thead>
<tr>
<th>Consumption Type</th>
<th>Average Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumable Parts High Priority</td>
<td>1.74</td>
</tr>
<tr>
<td>Consumable Parts Low Priority</td>
<td>1.94</td>
</tr>
</tbody>
</table>

*CDF = Cumulative Density Function
Simulating Baseline AB Inventory Segmentation Strategy
Baseline AB Inventory Segmentation for High Priority Consumables

Open orders at end of simulation cause phantom spikes…

Simulated ==>

Historical
Rightsizing Inventory for Consumable Parts
Baseline AB Inventory Segmentation Strategy

Optimal inventory with baseline AB inventory segmentation stock levels

- Optimal - Active: 40%
- Excess - Active: 26%
- Inactive: 14%
- Backorder Obligation: 0%
- Burned Down Years 1-5 - Active: 20%

Current Customer Inventory 100%

Identify Optimal Inventory

One-off Lay-in: 4%

Optimal - Active: 40%

Manage to Optimal Inventory: 44%
Simulating Alternate ABCDE Inventory Segmentation Strategy
Alternate ABCDE Inventory Segmentation for High Priority Consumables

Alternate ABCDE Inventory Segmentation
Baseline AB Inventory Segmentation

Note that stock levels assume Continuous Resupply!

Open orders at end of simulation cause phantom spikes...

Ostensibly* 50% confident of achieving metrics goal Aug 2013

*Must also address Stocking Policy: Continuous Resupply vs. Periodic Resupply
Rightsizing Inventory for Consumable Parts

Alternate ABCDE Inventory Segmentation

- Optimal - Active 28%
- Inactive 13%
- Excess - Active 40%
- Burned Down Years 1-5 - Active 19%
- Backorder Obligation 0%

Current Customer Inventory 100%

Identify Optimal Inventory

Optimal inventory with alternate ABCDE inventory segmentation stock levels

Manage to Optimal Inventory 36%
Stocking Policy for Baseline Stock Levels
Stocking Policy for High Priority Consumable Parts

<table>
<thead>
<tr>
<th>Continuous Resupply</th>
<th>30-Day Periodic Resupply</th>
<th>90-Day Periodic Resupply</th>
<th>360-Day Periodic Resupply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory Optimization Strategy Assumes Continuous Resupply</td>
<td>Spares Order Review Board Means 30 Day Periodic Resupply</td>
<td>Quarterly Acquisition Funding Means 90 Day Periodic Resupply</td>
<td>Annual Acquisition Funding Means 360 Day Periodic Resupply</td>
</tr>
</tbody>
</table>
Executive Summary
Executive Summary

• Simulation reveals tomorrow’s supply chain today
  • Resolves disconnects between models and measures
• Inventory segmentation improves service parts mix

<table>
<thead>
<tr>
<th>Segmentation Strategy</th>
<th>Date OFLT Goal Achieved</th>
<th>Inventory Investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline AB</td>
<td>Never</td>
<td>100%</td>
</tr>
<tr>
<td>Alternate ABCDE</td>
<td>Mar-2013</td>
<td>80%</td>
</tr>
</tbody>
</table>

• Successful spares chain execution requires aligned stocking, review, and acquisition policies