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Optimized Determination of Deployable Consumable Spares Packages

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### Optimized Determination of Deployable Consumable Spares Packages

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Optimized Determination of Deployable Consumable Spares Packages

Dr David Fulk
Dr Douglas Blazer
Mr Rob Kline
Abstract

This presentation will describe the new method the Air Force is using to compute deployment kits for consumable items (the spares required to support a deployed aircraft squadron. The Air Force has used the Aircraft Sustainability Model (ASM) for many years to compute and assess kits for reparable items. Over the past year, ASM was modified to account for the uniqueness of consumable items. This presentation will discuss how ASM computes the range (types of items) and depth (number of items) for consumable kits by minimizing the total number of backorders. We also analyzed different selection methods that filter certain types of items to determine which one performed the best when compared to actual deployment situations. Kits computed by this new technique were used in the CENTCOM area starting in January and some preliminary results will be provided.
Terminology

• MBS = Mobility Bench Stock (also called deployable bench stock)
• CRSP = Consumable Readiness Spares Package
• COLT = Customer-Oriented Leveling Technique
• ASM = Aircraft Sustainability Model
• CENTCOM = US Central Command
• AOR = Area of Responsibility
• MICAP = Mission Capability
• AEF = Aerospace Expeditionary Force
• ERRCD = Expendability/ Recoverability/Repairability/Cost Designator
• BS Flag = Bench Stock Indicator
• MPC = Maintenance Priority Code
• SPC = Stockage Priority Code
• DDR = Daily Demand Rate
• MIC = Mission Impact Code
• LI = Line Item
Overview

• Background
• ASM
• Filtering NSNs
• Follow-on Work
Overview

- **Background**
  - Deployable Consumables
  - CRSPs
- **ASM**
- **Filtering NSNs**
- **Follow-on Work**
Deployable Consumables

- Currently the US Air Force uses Mobility Bench Stocks (MBS) for deployments
  - User determined, Lack of formal process for defining
  - User maintained
  - No documentation
- Current deployments to US Central Command (CENTCOM) Area of Responsibility (AOR) have more MICAPs than desired
- For all these reasons, the AF is switching to using Consumable Readiness Spares Packages (CRSPs)
Using CRSPs

• AF changed its policy to use CRSPs rather than Mobility Bench Stocks (MBS)
  – Complete visibility of level and usage
  – Forced replenishment (demands recorded)
• Initial CRSP usage
  – Corrects some of the problems, but still lacks a formal process
• A standardized computation was still required
• So AF directed use of Aircraft Sustainability Model (ASM) for CRSP
  – Better support at less cost than MBS
  – Standardized tool
• Modifications were required to ASM for CRSPs and assistance in restricting the range was required to be cost-effective
Overview

• Background
• ASM
  – Standard ASM
  – ASM for Consumables
• Filtering NSNs
• Follow-on Work
What is the Aircraft Sustainability Model (ASM)

- ASM is a standard tool used in the Air Force to compute and assess reparable readiness spares packages (RSPs).
- ASM is a tool that illuminates the implications of a wide range of inventory (spare parts) decisions:
  - Initial sparing, replenishments, and deployments.
- Typical ASM implementations results:
  - Save 20 to 30% on your spares investment while maintaining system availability, or
  - Comparable improvements in system availability while maintaining spares investment level.
- These results achievable for many complex systems:
  - Aircraft, electronics, communications networks, ground vehicles, robots, spacecraft ...
A Relevant Measure of System Performance

• Aircraft availability
  – The percentage of “available” (mission capable) aircraft (i.e. not lacking any spare)
  – Example: An 80% availability rate means that 80% of the fleet is mission capable while 20% of the fleet is inoperable for parts

• The spares selection method
  – Choose spares that provide the greatest marginal improvement in aircraft availability per dollar
  – Benefit-to-cost ratio: The improvement in aircraft availability per dollar of inventory investment
Building an Efficient Shopping List

### Cost vs. Availability Curve

<table>
<thead>
<tr>
<th>Item (A,B,C...)</th>
<th>Unit cost $</th>
<th>Added end items per $10K</th>
<th>Total cost $</th>
<th>Availability rate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>6th A</td>
<td>1,600</td>
<td>0.388</td>
<td>101,600</td>
<td>66.67</td>
</tr>
<tr>
<td>11th B</td>
<td>2,300</td>
<td>0.352</td>
<td>103,900</td>
<td>66.69</td>
</tr>
<tr>
<td>2nd C</td>
<td>10,400</td>
<td>0.312</td>
<td>114,300</td>
<td>66.74</td>
</tr>
<tr>
<td>12th B</td>
<td>2,300</td>
<td>0.283</td>
<td>116,600</td>
<td>66.76</td>
</tr>
<tr>
<td>1st D</td>
<td>13,800</td>
<td>0.154</td>
<td>130,400</td>
<td>66.78</td>
</tr>
<tr>
<td>7th A</td>
<td>1,600</td>
<td>0.144</td>
<td>132,000</td>
<td>66.79</td>
</tr>
</tbody>
</table>

Shopping List

Dollars $ vs. Availability Rate %
Consumable ASM differences

• The model computes the least costly mix of consumables, which minimizes expected backorders, and treats all items as Line Replaceable Units (LRUs) with no cannibalization.

• The stockage “stopping rule” uses either a target Issue Effectiveness (IE) rate (instead of aircraft Not Mission Capable-Supply (NMCS)) or a budget constraint.
  – IE is defined as the projected percentage of consumable issues over the planning scenario.

• The model imports a special CRSP text input file derived from the Standard Base Supply System (SBSS) 7SC data, and allows the user to filter and delete inappropriate item records.
Consumable ASM Computation

ASM computes the spares requirements for the CRSP on an item-by-item basis, as well as providing some system-related summary outputs. The model develops a least cost CRSP for the user-specified IE target, where IE is defined as projected inventory fills over the wartime scenario.

\[
IE = 1 - \left( \sum_{i=NSN}^{\infty} EBOs_i \div \sum_{i=NSN}^{\infty} Pipelines_i \right)
\]

\[Pipeline_{NSN} = \sum_{Period}^{\infty} FH * TOIMDRW_{NSN}\]

where

- EBOs = expected backorders given the NSN’s authorized stock level
- Period = the wartime support period
- FH = wartime flying hours per day
- TOIMDRW = Historic demands divided by the historic flying hours (entered during import process).
Cost vs Issue Effectiveness

IE Rate vs. Cost

Run #6: RUN #6: Baseline - B52 BOTH: 6

Issue Effectiveness (%) vs Cost (1000)

IE Day 30
- - Solution
Overview

• Background
• ASM
• **Filtering NSNs**
• Follow-on Work
Determining the Range

- ASM determines the depth
  - That can be 0 or more
  - So it also determines range within the NSNs provided to it
- So what items to input to ASM?
  - Filtering out NSNs with little chance of use, means ASM is less likely to provide a level on a non-value added item
  - Makes the recommended CRSP from ASM more effective and/or efficient
- Evaluated alternative filtering (range restriction) rules
  - Compare performance with old mobility bench stock (MBS)
  - Examine effectiveness using deployed data
  - Consider Field Reparable (ERRCD XF or P) and Consumable (ERRCD XB or N)
Data Examination

- Using transaction histories from the deployed locations, we identified all NSNs that were used
  - Pulled all NSNs from the demand data for the 3 home bases and the SRDs at each
- Matching the results we identified NSNs **USED** or **NOT USED**
  - About 20-25% of the home station we used at the deployed location
- ERRCD, BS Flag, MPC, SPC, Total Pipe, Unit Price and DDR do not appear to be good predictors of future use
- MIC, Line Item (LI) Demands, and the mixture of them appear to be much better

<table>
<thead>
<tr>
<th>MIC</th>
<th>Not</th>
<th>Used</th>
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<tr>
<td>0</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>8636</td>
<td>2431</td>
</tr>
<tr>
<td>2</td>
<td>3829</td>
<td>1589</td>
</tr>
<tr>
<td>3</td>
<td>1071</td>
<td>180</td>
</tr>
<tr>
<td>4</td>
<td>1322</td>
<td>157</td>
</tr>
<tr>
<td>Blank</td>
<td>29</td>
<td>5</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>LI DMD</th>
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<th>Used</th>
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<tbody>
<tr>
<td>1</td>
<td>4028</td>
<td>242</td>
</tr>
<tr>
<td>2</td>
<td>2413</td>
<td>258</td>
</tr>
<tr>
<td>3</td>
<td>1555</td>
<td>253</td>
</tr>
<tr>
<td>4-6</td>
<td>2870</td>
<td>680</td>
</tr>
<tr>
<td>7-10</td>
<td>1799</td>
<td>733</td>
</tr>
<tr>
<td>11-20</td>
<td>1530</td>
<td>1052</td>
</tr>
<tr>
<td>21+</td>
<td>698</td>
<td>1147</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LI DMD and MIC</th>
<th>Not</th>
<th>Used</th>
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</thead>
<tbody>
<tr>
<td>LI DMD &lt;= MIC</td>
<td>5379</td>
<td>412</td>
</tr>
<tr>
<td>LI DMD &gt; MIC</td>
<td>9514</td>
<td>3953</td>
</tr>
</tbody>
</table>
The Suspects and Test Subjects

- Alternatives: Select by SRD and the following alternatives
  - Baseline: Current Mobility Bench Stock (MBS)
  - All: All items (All items for the weapon system)
  - Filter 1: XF and all Bench Stock (not just MBS) items
  - Filter 2: All Bench Stock plus MIC 1-2, SPC 1-3, DDR > 1/60, and some federal stock class (FSC) exclusions
  - Filter 3: User demands > MIC with FSC exclusions
  - XB/XF Sep: All XB and XF separately
  - Final: XB 30 day, XF 15 day separately

- Others were examined, but were significantly poorer and not reported here

- Bases/systems examined in the study:

<table>
<thead>
<tr>
<th>MDS / SRD</th>
<th>Base</th>
<th>Deployed Base</th>
<th>Deployed Period</th>
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</thead>
<tbody>
<tr>
<td>B-1B / ABA</td>
<td>Ellsworth</td>
<td>Andersen</td>
<td>Sep 05 – Apr 06</td>
</tr>
<tr>
<td>F-15E / ASH</td>
<td>Seymour-Johnson</td>
<td>Al Udeid</td>
<td>Jan 06 – Aug 06</td>
</tr>
<tr>
<td>F-16C / AKD</td>
<td>Hill</td>
<td>Balad</td>
<td>Jan 06 – Apr 06</td>
</tr>
</tbody>
</table>
Range and Depth Results

- This chart compares range and depth against the cost.
- 5 methods have much larger range (~2 times), and depth (~4 times) for less cost (~1/3 less).

These 5 have the best potential for increased performance at less cost.

**Stocking vs Cost, All 3 Bases**

- **Range**
- **Depth**

Current

Bench Stock
Computed Total IE Results

- This chart compares Total IE against the cost
- The same 5 methods have much larger IE (~4 times) for less cost (~1/3 less)
Usage Results

- These charts compare the cost versus
  - NSNs used and units covered
  - MICAP NSNs in the range and MICAP units covered
Initial Findings

- Several methods improve on current MBS
  - All, Filter 1, Filter 2, Filter 3, and Final all provide better support for less stockage costs
  - The “All” method provides slightly better results than the other 4, but has significantly more unused stock than the others
  - The Sep XB/XF is much more expensive because it is adding a significant number of XF items (see discussion later)

- All methods have some amount of SPC 5 stock
  - All the proposed methods have < 2% of the cost in SPC 5

- The results varied somewhat among the 3 bases
XF CRSP Stockage

- Unfair to compare to MBS which has no XF items
- XF items are used in contingencies
  - About 20-25% of the NSNs are the home station are used at the deployed location regardless of whether they are XB or XF
- XF items don’t compete well with XB in ASM
  - Higher cost and lower demand prevent stockage
  - 5% of the NSNs in this study are XF; but less than 0.5% of the NSNs in the range are XF for all the methods studied except XB/XF_Sep
- Reducing the length of time of the kit from 60 days to 15 days cuts the cost about in half
  - It has very little impact to the range, range used, and range used for MICAPs
  - It cuts the depth, units covered, MICAP units covered, and MICAPs avoided
Initial Re-supply Length Target

• All the runs to date used a 60 day initial re-supply target in ASM
  – Need to determine sensitivity to length and possibly other values
• Used only Filter 2 and Filter 3 for all 3 Bases for this analysis
• Lengths examined: 15, 30, 45, and 60
• Cost results
  – Steady growth in cost from $106K to $757K
Initial Re-supply Length - continued

- **Range and Depth**
  - Very little change in range (from 6087 to 6356 or 5147 to 5332)
  - Large, constant increase in depth (from 54K to 182K)
- **MICAP Coverage**
  - Constant increase range coverage – no major changes over the days
Initial Re-supply Length - continued

- Volume and Weight Results
  - Volume and Weight both decrease significantly as length of the kit decreases
  - 30 day kits are larger than the current bench stock while 15 day kits are slightly smaller

- Summary
  - Reducing from a 60 day kit could save significantly in cost
    - Small impacts to range and actual MICAP coverage
    - Large drop in depth
    - Many more partial units covered versus fully covered
  - Reducing the timeframe to no less than 30 days seems like a reasonable trade off of cost and performance
Issue Effectiveness (IE) Target

- All the runs to date used at 85% IE target in ASM
  - Previous work indicated that this was a “sweet spot” on the cost-performance curve
  - Need to determine sensitivity to IE and possibly other values
- Used only Filter 2 for all 3 Bases for this analysis
- Targets examined: 75, 80, 85, 90, and 95% targets
- Cost results
  - Exponential growth in cost for performance after 90%
  - Very little reduction in costs below 85%
IE Target - continued

- **Range and Depth**
  - Constant increase over the IE targets – no major jumps or slowdowns
- **MICAP Coverage**
  - Constant increase range coverage
  - Slow increase in MICAP units covered

- A range of 80-90% for IE target is good
  - Cost for performance is good
  - Maintaining the currently used 85% would save 14% over going to 90% IE target; but costs 5% more than going to an 80% IE target
  - 90% IE target uses about 14% more of the NSNs and covers about 7% more units demanded
  - 80% IE target uses about 15% fewer of the NSNs and covers about 8% fewer units demanded
Overall Recommendations

• Adopt “Final” method
  – Use Filter 2: All Bench Stock plus MIC 1-2, SPC 1-3, DDR > 1/60, and some federal stock class (FSC) exclusions
  – Run XB3 and XF3 run separately
  – XB3 run to 30 day target
  – XF3 run to 15 day target
  – Run all to an 85% IE target
Overview

- Background
- ASM
- Filtering NSNs
- **Follow-on Work**
Real World (AEF 5/6) Kits

- Computed 5 CRSPs as first live test of methodology
- Used in AEF 5/6 starting Jan 2007

<table>
<thead>
<tr>
<th>Base MDS SRD</th>
<th>ERRRC</th>
<th>Original</th>
<th>Bench Stock</th>
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<tr>
<td></td>
<td>Range</td>
<td>Depth</td>
<td>Cost</td>
</tr>
<tr>
<td>Ellsworth B-1 ABA</td>
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<tr>
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<td>XF3</td>
<td>23</td>
<td>47</td>
<td>$111,349.75</td>
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<tr>
<td>Pope A-10 AA1</td>
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<tr>
<td>All</td>
<td>1,192</td>
<td>15,378</td>
<td>$243,182.65</td>
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<td>XB3</td>
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<td>$24,701.24</td>
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<td>XF3</td>
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<td>101</td>
<td>$218,481.41</td>
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<tr>
<td>Langley F-22 A22</td>
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<tr>
<td>All</td>
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<td>32,818</td>
<td>$203,845.15</td>
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</table>
Real World (AEF 5/6) Kits continued

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<th>ERRC</th>
<th>Original</th>
<th>Bench Stock</th>
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<tr>
<td></td>
<td>Range</td>
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<td>Cost</td>
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<tr>
<td><strong>Mountain Home F-15E ASK</strong></td>
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<td>All</td>
<td>1,059</td>
<td>21,638</td>
<td>$193,975.28</td>
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<td>XB3</td>
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<td>$46,192.50</td>
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<td>52</td>
<td>107</td>
<td>$147,782.78</td>
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<td><strong>Cannon F-16 AKD, AKG, AKR</strong></td>
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<td><strong>TOTAL</strong></td>
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<tr>
<td>All</td>
<td>6,242</td>
<td>136,724</td>
<td>$1,237,188.33</td>
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<tr>
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<tr>
<td>XF3</td>
<td>185</td>
<td>406</td>
<td>$721,889.55</td>
</tr>
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- CRSPs provided 41% more range 183% more depth at 86% of the cost of mobile bench stocks
- CRSPs cover XF3 items
- Previous results show they should be more effective – this will be evaluated once sufficient data are available
Ongoing Research

- Measure performance of first set of CRSPs
- Where should the AF (build and) position CRSPs
- What is the employment concept?
- Determine how to assess CRSPs
- Are CRSPs needed after transition to sustainment operations?
- CRSP/COLT offset
- CRSP for Non-Airborne Assets
- Using Fleet-wide Demands
Summary

• AF transition to CRSPs should provide
  – More asset visibility
  – Visibility of levels and usage
  – Forced replenishment
  – A formal process for computations

• Research will allow for
  – More effective and efficient kits
  – Proper placement of kits

• Meet the wartime needs better than the system in the past without breaking the bank
BACKUPS
The System Approach to Inventory Management with the ASM

- Experience with the System Approach to Sparing
- ASM Implementation
- ASM Capabilities
- ASM Demonstration
- ASM Methodology
The ASM’s Core Capabilities

- Optimal spares requirements for a single aircraft type (reparable and consumable items)
- Multi-echelon (depot with different size bases) and multi-indenture (LRU/SRU) tradeoffs
- Steady state and/or dynamic scenarios
- Flexible with respect to resupply, maintenance (with or without cannibalization), and other parameters
- Common component considerations across different systems
- Multi-year spares and repair budgets
- Evaluation of existing spares mix
- Interface designed for complex spares analysis
Typical Spares Analyses

- **Initial Provisioning** – Estimate what spares requirements (cost of deliveries) for a specific period (months, quarters, years)
  - Aircraft delivery scheduled entered by period
  - Typically steady-state operations though can include a dynamic period
  - Total budget, year by year budgets, budgets by lead-time

- **Replenishment** – Estimate what spares requirements (cost of orders) by period (similar capability to initial provisioning)
  - Example: given existing assets, determines procurements in coming year.

- **Deployment Spares** – Estimate what spares needed if aircraft brought to new location (e.g., IRAQ)
  - Usually dynamic conditions with cannibalization

- **Evaluation** of spares mix by day over a dynamic period (availability and sortie generation).
ASM Users

- **US Air Force**
  - The standard model that generates wartime spares requirements and assessments Air Force-wide
  - Analyzes key policy issues
  - Supports the JSF and F-22 initial provisioning programs

- **Israel Air Force**
  - Re-engineered logistics support concepts
  - Initial provisioning

- **NASA**
  - Estimated spares budgets for Space Station life cycle
  - Evaluated shuttle spare parts performance
  - Performing spares analyses for Crew Exploration Vehicles
Experience with the System Approach to Sparing
Mathematical Modeling Group Experience

• US Air Force … over 25 years
  – Developed the standard models that now generate spares requirements and assessments Air Force-wide
    • Peacetime model (The Aircraft Availability Model - AAM)
    • Wartime model (The Aircraft Sustainability Model - ASM)
  – Analyzed key policy issues
    • Developed new policy for retention/disposal decisions with Financial/Inventory simulator (FINISIM)
    • Alternative spares distribution methods
    • Aircraft engine maintenance capacity
    • Demand forecasting
    • Policy impacts on budgets and capability
  – Support to the JSF and F-22 initial provisioning programs
Experience (Continued)
Theme: Systems Approach

• US Defense Logistics Agency Models ... 9 years
  – Developed new ordering policy for sporadic demand items with our financial/inventory simulator (FINISIM).
  – Developed a clothing and textile simulation model for policy analysis
  – Developed retention policy for excess inventory

• Israel Air Force ... 13 years
  – Re-engineered logistics support concepts
  – Initial provisioning
  – Depot repair prioritization

• NASA ... 8 years
  – Estimated spares budgets for Space Station life cycle
  – Evaluated shuttle spare parts performance
  – Performing spares analyses for Crew Exploration Vehicles
ASM Implementation:
Traditional Supply Support Ignores the Systems Impact of Sparing Decisions
The System Approach Explicitly Links Sparing Decisions to System Impacts
## Exemplar Benefits of the System Approach
(Sample results for aviation spares)

<table>
<thead>
<tr>
<th></th>
<th>Percent improvement of System over Item approach</th>
<th>Factors compared</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial provisioning</strong> (reparables)</td>
<td>30%</td>
<td>Cost savings for the same performance</td>
</tr>
<tr>
<td><strong>Annual Replenishment</strong> (consumables)</td>
<td>18%</td>
<td>Cost savings for same performance</td>
</tr>
<tr>
<td><strong>Depot repair</strong> (reparables)</td>
<td>40%</td>
<td>Backorder reduction for same cost</td>
</tr>
</tbody>
</table>
The System Approach:
(Marginal Analysis – Or Bang for the Buck)
ASM Capabilities
## F-22 Budget Computation Over Time

### Sequencing RBS Model Runs by year

<table>
<thead>
<tr>
<th>Year</th>
<th>CY 03</th>
<th>CY 04</th>
<th>CY 05</th>
<th>CY 06</th>
<th>CY 07</th>
<th>CY 08</th>
<th>CY 09</th>
<th>CY 10</th>
<th>CY 11</th>
</tr>
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<tbody>
<tr>
<td>Deliveries</td>
<td>Lot 1</td>
<td>Lot 2</td>
<td>Lot 3</td>
<td>Lot 4</td>
<td>Lot 5</td>
<td>Lot 6</td>
<td>Lot 7</td>
<td>Lot 8</td>
<td>Lot 9</td>
</tr>
<tr>
<td>Lot 4</td>
<td>LT&gt;=36</td>
<td>24&lt;=LT&lt;36</td>
<td>12&lt;=LT&lt;24</td>
<td>LT&lt;12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lot 5</td>
<td>LT&gt;=36</td>
<td>24&lt;=LT&lt;36</td>
<td>12&lt;=LT&lt;24</td>
<td>LT&lt;12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lot 6</td>
<td>LT&gt;=36</td>
<td>24&lt;=LT&lt;36</td>
<td>12&lt;=LT&lt;24</td>
<td>LT&lt;12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lot 7</td>
<td>LT&gt;=36</td>
<td>24&lt;=LT&lt;36</td>
<td>12&lt;=LT&lt;24</td>
<td>LT&lt;12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lot 8</td>
<td>LT&gt;=36</td>
<td>24&lt;=LT&lt;36</td>
<td>12&lt;=LT&lt;24</td>
<td>LT&lt;12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Budgets</strong></td>
<td><strong>Sum CY04</strong></td>
<td><strong>Sum CY05</strong></td>
<td><strong>Sum CY06</strong></td>
<td><strong>Sum CY07</strong></td>
<td><strong>Sum CY08</strong></td>
<td><strong>Sum CY09</strong></td>
<td><strong>Sum CY10</strong></td>
<td><strong>Sum CY11</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Order buys LT before

![Aircraft Delivered Over Time](image-url)
ASM Demonstration
Model Demonstration

- Model: Availability Computation
- User Interface
- User Generated Databases
- Previous Run Library
Demonstration: The System Approach with the ASM
ASM Methodology Details
Spares Management

• If failures, repairs, and transportation were deterministic, then there would be $P = \lambda T$ items in the resupply pipeline at all times, where $\lambda$ is the (daily) demand and $T$ is the resupply time.

• Then $[P]$ would be sufficient spares to avoid downed aircraft.

• So clearly one should aggressively manage supply chain velocity to minimize $T$, and design component reliability to minimize $\lambda$. 
But... THE REAL WORLD IS A SPECIAL CASE
Probabilistic Nature of Component Pipeline

• Suppose a reparable component is managed under \((s-1, s)\) resupply. Suppose demands are generated by a Poisson process with mean \(\lambda\) and \(T\) is the average resupply time. Then, under certain reasonable conditions, the number of items in the component pipeline is Poisson distributed with mean \(\lambda T\). (Palm’s Theorem)

• This can be extended to negative binomial demand distributions, and to non-stationary cases.
Overview of ASM Method

Demand Process → Pipeline → Backorders → Availability → Item Targets
Demands to Backorders

• Let the item pipeline (units in resupply) equals the daily demand rate times the resupply time

• Let $p(n)$ be the probability of $n$ units in resupply, and suppose there are $s$ spares. Then

• Probability of sufficiency = probability of no backorders

$$= \sum_{n=0}^{s} p(n)$$

• Expected backorders = expected unfilled demands

$$= \sum_{n=s+1}^{\infty} (n-s)p(n)$$
Poisson Probability Distribution
(Pipeline Mean = 4)

![Graph showing Poisson Probability Distribution with Pipeline Mean = 4]
Item Benefit/Cost Ratio
(As spares are added – unit cost $1)

<table>
<thead>
<tr>
<th>Spares</th>
<th>EBOs</th>
<th>Benefit/cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.00</td>
<td>0.95</td>
</tr>
<tr>
<td>1</td>
<td>2.05</td>
<td>0.80</td>
</tr>
<tr>
<td>2</td>
<td>1.25</td>
<td>0.58</td>
</tr>
<tr>
<td>3</td>
<td>0.67</td>
<td>0.35</td>
</tr>
<tr>
<td>4</td>
<td>0.32</td>
<td>0.18</td>
</tr>
<tr>
<td>5</td>
<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>6</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>7</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>8</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

The graph shows the increase in EBOs and benefit/cost as spares are added, with a unit cost of $1.
Aircraft Availability

- The probability an aircraft is not down for lack of an item
- In the simplest form, for a fleet of $T$ aircraft, with items $i = 1, 2 \ldots N$ with spares levels $s(i)$,

$$AA = \frac{N}{\prod_{i=1}^{N} \left(1 - \frac{EBO[i, s(i)]}{T}\right)}$$

- Where $EBO[i, s(i)]$ is the number of expected backorders for component $i$ with spares level $s(i)$. 
Marginal Analysis Optimization

- Let $f_i, i=1 \ldots N$, be real-valued functions with domain the non-negative integers. Let $C_i, i=1 \ldots N$, be positive real numbers. Suppose that each $f_i$ has decreasing differences:

$$\partial_i(s) = f_i(s) - f_i(s - 1) \quad \text{for all } n.$$

$$0 \leq \partial_i(n + 1) \leq \partial_i(n)$$

- Define sort values

$$V_i(n) = \frac{\partial_i(n)}{C_i}.$$
Marginal Analysis Optimization (continued)

- Form the ordered list of the $v_i(n)$ in descending order. Let $LC$ be any initial section of the list and let $C$ denote the sum of the costs in that section. Let $m_i$ be the largest index for $i$ appearing and $LC$.

- Then the vector $(m_i)$ maximizes $F = \sum f_i$ for cost $C$. 
## ASM Model Results

<table>
<thead>
<tr>
<th>Method</th>
<th>Range</th>
<th>Depth</th>
<th>Cost</th>
<th>Weight</th>
<th>Volume</th>
<th>Total EBO</th>
<th>Total IE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curr BS</td>
<td>3,227</td>
<td>44,223</td>
<td>$1,025.6K</td>
<td>4,065.8</td>
<td>309.4</td>
<td>158.5K</td>
<td>18.1%</td>
</tr>
<tr>
<td>All</td>
<td>7,614</td>
<td>191,379</td>
<td>$773.5K</td>
<td>28,310.8</td>
<td>2,147.8</td>
<td>29.0K</td>
<td>85.0%</td>
</tr>
<tr>
<td>Filter 1</td>
<td>6,158</td>
<td>179,366</td>
<td>$707.9K</td>
<td>19,821.4</td>
<td>1,269.0</td>
<td>36.8K</td>
<td>81.0%</td>
</tr>
<tr>
<td>Filter 2</td>
<td>6,356</td>
<td>182,145</td>
<td>$757.0K</td>
<td>23,578.2</td>
<td>1,897.1</td>
<td>34.5K</td>
<td>82.2%</td>
</tr>
<tr>
<td>Filter 3</td>
<td>5,332</td>
<td>175,980</td>
<td>$746.9K</td>
<td>23,832.2</td>
<td>1,924.0</td>
<td>37.5K</td>
<td>80.5%</td>
</tr>
<tr>
<td>XB/XF Sep</td>
<td>8,187</td>
<td>191,563</td>
<td>$3,417.1K</td>
<td>31,138.2</td>
<td>2,630.7</td>
<td>29.0K</td>
<td>85.0%</td>
</tr>
<tr>
<td>Final</td>
<td>6,362</td>
<td>99,797</td>
<td>$734.9K</td>
<td>11,103.7</td>
<td>736.2</td>
<td>20.5K</td>
<td>79.5%</td>
</tr>
</tbody>
</table>

- Results for all 3 bases together – 19,258 NSNs
  - Individual base results in backup
- Total EBO is based to EBO for all 19K NSNs, regardless of how many were in the range; rest have a level of 0
- Total IE is based on the Total EBO and is an model estimated value
## Results Compared to Actual Deployment

<table>
<thead>
<tr>
<th>Method</th>
<th>Range used</th>
<th>Range not used</th>
<th>Units Covered</th>
<th>Used Item EBO</th>
<th>Used Item IE</th>
<th>Range used - MICAPs</th>
<th>MICAPs avoided</th>
<th>Units Covered - MICAPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curr BS</td>
<td>1,755</td>
<td>1,472</td>
<td>24,631</td>
<td>94.0K</td>
<td>18.1%</td>
<td>509</td>
<td>777</td>
<td>7,562</td>
</tr>
<tr>
<td>All</td>
<td>2,455</td>
<td>5,159</td>
<td>52,635</td>
<td>12.3K</td>
<td>89.3%</td>
<td>681</td>
<td>1,166</td>
<td>12,397</td>
</tr>
<tr>
<td>Filter 1</td>
<td>2,229</td>
<td>3,929</td>
<td>51,117</td>
<td>13.7K</td>
<td>88.1%</td>
<td>613</td>
<td>1,084</td>
<td>11,327</td>
</tr>
<tr>
<td>Filter 2</td>
<td>2,257</td>
<td>4,099</td>
<td>51,370</td>
<td>13.5K</td>
<td>88.3%</td>
<td>622</td>
<td>1,092</td>
<td>11,384</td>
</tr>
<tr>
<td>Filter 3</td>
<td>2,143</td>
<td>3,189</td>
<td>50,764</td>
<td>13.7K</td>
<td>88.0%</td>
<td>608</td>
<td>1,089</td>
<td>11,183</td>
</tr>
<tr>
<td>XB/XF Sep</td>
<td>2,583</td>
<td>5,604</td>
<td>52,695</td>
<td>12.2K</td>
<td>89.4%</td>
<td>806</td>
<td>1,351</td>
<td>12,606</td>
</tr>
<tr>
<td>Final</td>
<td>2,244</td>
<td>4,118</td>
<td>37,327</td>
<td>7.4K</td>
<td>87.2%</td>
<td>655</td>
<td>980</td>
<td>10,952</td>
</tr>
</tbody>
</table>

- Results for all 3 bases together – 19,258 NSNs
  - Individual base results in backup
- Definitions for measures in backup
## ASM XF Results

<table>
<thead>
<tr>
<th>Method</th>
<th>XF Run Together with XB</th>
<th>XF Run Separately</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>XF Range</td>
<td>XF Depth</td>
</tr>
<tr>
<td>Curr BS</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>All</td>
<td>10</td>
<td>95</td>
</tr>
<tr>
<td>Filter 2</td>
<td>10</td>
<td>95</td>
</tr>
<tr>
<td>Filter 3</td>
<td>10</td>
<td>94</td>
</tr>
</tbody>
</table>

- Results for all 3 bases together – 1,021 XF NSNs
- Very little stocked when XF run with XB
- An increase in stocking of 10-20 times when run separately, for an increase in cost of 10-20 times
- Filter 2 removes many XF items due to the “DDR check” portion of that rule
- In all cases, the cost may be too much – look at alternatives
# XF Results Compared to Actual Deployment

<table>
<thead>
<tr>
<th>Method</th>
<th>Range used</th>
<th>Range not used</th>
<th>Units Covered</th>
<th>Used Item EBO</th>
<th>Used Item IE</th>
<th>Range used - MICAPs</th>
<th>MICAPs avoided</th>
<th>Units Covered - MICAPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>169</td>
<td>522</td>
<td>388</td>
<td>54</td>
<td>89.2%</td>
<td>140</td>
<td>219</td>
<td>313</td>
</tr>
<tr>
<td>Filter 2/60/85%</td>
<td>71</td>
<td>61</td>
<td>151</td>
<td>151</td>
<td>69.6%</td>
<td>65</td>
<td>123</td>
<td>193</td>
</tr>
<tr>
<td>Filter 2/30/85%</td>
<td>71</td>
<td>58</td>
<td>84</td>
<td>122</td>
<td>58.6%</td>
<td>65</td>
<td>86</td>
<td>157</td>
</tr>
<tr>
<td>Filter 2/15/85%</td>
<td>71</td>
<td>53</td>
<td>67</td>
<td>107</td>
<td>45.2%</td>
<td>65</td>
<td>66</td>
<td>127</td>
</tr>
<tr>
<td>Filter 2/15/90%</td>
<td>73</td>
<td>63</td>
<td>79</td>
<td>103</td>
<td>46.9%</td>
<td>67</td>
<td>68</td>
<td>140</td>
</tr>
<tr>
<td>Filter 3/60/85%</td>
<td>151</td>
<td>351</td>
<td>273</td>
<td>62</td>
<td>87.5%</td>
<td>129</td>
<td>206</td>
<td>293</td>
</tr>
<tr>
<td>Filter 3/30/85%</td>
<td>145</td>
<td>331</td>
<td>173</td>
<td>31</td>
<td>87.5%</td>
<td>124</td>
<td>135</td>
<td>242</td>
</tr>
<tr>
<td>Filter 3/15/85%</td>
<td>143</td>
<td>309</td>
<td>133</td>
<td>17</td>
<td>86.8%</td>
<td>122</td>
<td>101</td>
<td>203</td>
</tr>
<tr>
<td>Filter 3/15/90%</td>
<td>153</td>
<td>356</td>
<td>162</td>
<td>12</td>
<td>90.6%</td>
<td>130</td>
<td>119</td>
<td>222</td>
</tr>
</tbody>
</table>

- Results for all 3 bases together – 1,021 XF NSNs
XF Summary

• Reducing the length of time of the kit from 60 days to 15 days cuts the cost about in half
  – It has very little impact to the range, range used, and range used for MICAPs
  – It significantly cuts the depth, units covered, MICAP units covered, and MICAPs avoided

• Filter 3 is much more expensive than Filter 2, but saves more backorders
## Length of Kit Details

<table>
<thead>
<tr>
<th>Method</th>
<th>Length</th>
<th>Range</th>
<th>Depth</th>
<th>Cost</th>
<th>Weight</th>
<th>Volume</th>
<th>Total EBO</th>
<th>Total IE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curr BS</td>
<td>60</td>
<td>3,227</td>
<td>44,223</td>
<td>$1,025.6K</td>
<td>4,065.8</td>
<td>309.4</td>
<td>163.2K</td>
<td>15.7%</td>
</tr>
<tr>
<td>Filter 2</td>
<td>15</td>
<td>6,087</td>
<td>56,729</td>
<td>$107.3K</td>
<td>4,279.0</td>
<td>241.8</td>
<td>13.5K</td>
<td>74.7%</td>
</tr>
<tr>
<td>Filter 2</td>
<td>30</td>
<td>6,297</td>
<td>100,058</td>
<td>$263.9K</td>
<td>9,866.3</td>
<td>639.6</td>
<td>20.5K</td>
<td>79.5%</td>
</tr>
<tr>
<td>Filter 2</td>
<td>45</td>
<td>6,321</td>
<td>141,547</td>
<td>$496.5K</td>
<td>16,579.8</td>
<td>1,273.8</td>
<td>27.5K</td>
<td>81.3%</td>
</tr>
<tr>
<td>Filter 2</td>
<td>60</td>
<td>6,356</td>
<td>182,145</td>
<td>$757.0K</td>
<td>23,578.2</td>
<td>1,897.1</td>
<td>34.5K</td>
<td>82.2%</td>
</tr>
<tr>
<td>Filter 3</td>
<td>15</td>
<td>5,147</td>
<td>54,164</td>
<td>$106.1K</td>
<td>4,365.8</td>
<td>252.7</td>
<td>17.0K</td>
<td>69.5%</td>
</tr>
<tr>
<td>Filter 3</td>
<td>30</td>
<td>5,273</td>
<td>96,096</td>
<td>$261.1K</td>
<td>10,021.4</td>
<td>655.6</td>
<td>23.8K</td>
<td>76.5%</td>
</tr>
<tr>
<td>Filter 3</td>
<td>45</td>
<td>5,319</td>
<td>136,468</td>
<td>$491.0K</td>
<td>16,811.2</td>
<td>1,299.4</td>
<td>30.7K</td>
<td>79.1%</td>
</tr>
<tr>
<td>Filter 3</td>
<td>60</td>
<td>5,332</td>
<td>175,980</td>
<td>$746.9K</td>
<td>23,832.2</td>
<td>1,924.0</td>
<td>37.5K</td>
<td>80.5%</td>
</tr>
</tbody>
</table>

- Results for all 3 bases together
## Length of Kit Details

<table>
<thead>
<tr>
<th>Method</th>
<th>Range used</th>
<th>Range not used</th>
<th>Units Covered</th>
<th>Range used - MICAPs</th>
<th>Units Covered - MICAPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curr BS</td>
<td>1,755</td>
<td>1,472</td>
<td>24,631</td>
<td>509</td>
<td>7,562</td>
</tr>
<tr>
<td>Filter 2/15</td>
<td>2,119</td>
<td>3,968</td>
<td>25,600</td>
<td>573</td>
<td>10,269</td>
</tr>
<tr>
<td>Filter 2/30</td>
<td>2,192</td>
<td>4,105</td>
<td>37,323</td>
<td>596</td>
<td>10,837</td>
</tr>
<tr>
<td>Filter 2/45</td>
<td>2,221</td>
<td>4,100</td>
<td>45,516</td>
<td>612</td>
<td>11,067</td>
</tr>
<tr>
<td>Filter 2/60</td>
<td>2,257</td>
<td>4,099</td>
<td>51,370</td>
<td>622</td>
<td>11,384</td>
</tr>
<tr>
<td>Filter 3/15</td>
<td>2,010</td>
<td>3,137</td>
<td>24,313</td>
<td>557</td>
<td>10,148</td>
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<td>3,195</td>
<td>36,859</td>
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</tr>
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<td>3,198</td>
<td>45,023</td>
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<td>3,189</td>
<td>50,764</td>
<td>608</td>
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</tbody>
</table>

- Results for all 3 bases together – 1,021 XF NSNs
Length Summary

• Reducing from a 60 day kit could save significantly in cost
  – Small impacts to range and actual MICAP coverage
  – Large drop in depth
  – Many more partial units covered versus fully covered

• Reducing the timeframe to no less than 30 days seems like a reasonable trade off of cost and performance