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Innovative Techniques for Analyzing Incomplete Data to Improve Cost Estimates

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Introductions

Introduction

George Bayer

- Senior Director at Cobec Consulting
- Currently leads investment analysis consultant teams developing costs, benefits, and business cases for FAA acquisitions
- B.S. in Business Administration (Finance & English majors) from the University of Florida
- MBA in Corporate Finance from The University of Texas at Austin
- Project Management Institute (PMI) Project Management Professional (PMP)
- Over 20 years of Finance experience in capital investment valuation, forecasting & budgeting, cost estimation, benefits quantification, and business case development
- Developed discounted cash flow models in Investment Appraisal for major Power Generation capital investments at ConocoPhillips
- Evaluated major capital investments/acquisitions in the Business Case Group of Investment Planning & Analysis at the FAA

Introduction

Bryan Anderson

- Management Consultant and Programmer at Cobec Consulting
- B.S. in Economics and Mathematics from Augsburg College
- M.S. in Industrial & Systems Engineering from the College of Science and Engineering at the University of Minnesota – Twin Cities
- Over 8 years of experience in industrial engineering and systems engineering in the private and public sectors
- Active in ICEAA's Machine Learning Working Group
- Leading database development efforts for Cobec Consulting's Innovation Center

Government Capital Investments & Legacy Infrastructure

Government Capital Investments

- Federal Aviation Administration (FAA) and other civil agencies develop business cases to justify investment funding.
  - Focus on Cost -Benefit Analysis to justify investments
  - Brings private industry investment rigor to the agency for investment decisions
    - Identify the agency need
    - Why do we need to invest in this project?
    - What problem (shortfall) are we solving?
    - Who benefits and by how much? Benefits = FAA, airlines, public
    - Two types of investments – (1) new investment, (2) infrastructure sustainment
    - Quantify both costs and benefits for multiple alternative solutions
    - Develop legacy reference case (compare to alternative cost models, basis of cost avoidance)
    - Evaluate with Finance metrics – NPV, IRR, Payback, B/C Ration

Failure Analysis

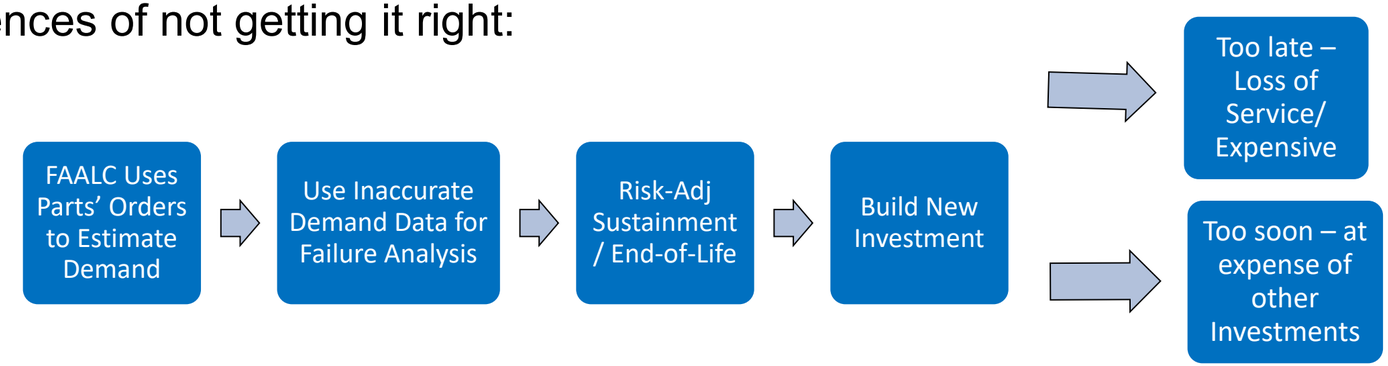
- Government Agencies – Large Infrastructure
  - Aging infrastructure programs need operational sustainment
  - When should we replace aging infrastructure programs?
  - Establish criteria by which to justify infrastructure replacement.
    - Historical and projected parts failures
    - Difficulty to procure replacement parts
    - System obsolescence
    - Risk of loss of service
  - Failure Analysis Answers:
    - What is vulnerable? Higher cost to sustain? Loss of Service?
    - Safety risk?
    - Sustainability – At what date can agency no longer sustain legacy system?
    - What parts are failing?
    - What is remaining inventory of parts, and how long will it last?
    - Are some old parts no longer manufactured and are difficult to procure? Consider lifetime buy.
    - How many parts must program procure to continue operation over lifecycle?
    - What is the total cost to sustain legacy system over lifecycle?

Infrastructure Investments

- **Infrastructure Investment Decisions**
  - Two Major Types of Government Investments – (1) infrastructure, (2) new capabilities
  - Approximately half of FAA business cases devoted to maintaining, improving, or replacing existing infrastructure.
  - To assess needs, timing of needs, & best spending of limited capital budgets, agency needs to:
    - Evaluate the condition of existing operations and services and their components,
    - Determine the logistics and spare parts sourcing requirements and availability,
    - Conduct an inventory analysis of spare parts' sustainment,
    - Evaluate the supply chain of the infrastructure sustainment operations,
    - Compare infrastructure investments to determine which is more urgent,
    - Evaluate each investment and portfolio against a constrained capital budget and determine best time to invest in each project to minimize opportunity costs and maximize efficiency. Why do we need to invest in this project?

Infrastructure Investments

- **Four Cost Estimation Considerations:**
  - **Cost to Sustain** – What is the cost of sustaining operations with existing operational expenses versus replacing aging infrastructure in the National Airspace (NAS)?
  - **Ability to Sustain** – At what point will continuing existing operations risk loss of service, or at what point will sustainment without significant investment no longer be feasible?
  - **Timing of Replacement** – When is the best time to invest new capital to replace existing infrastructure? Consequences of not getting it right:
    - **Investing Too Early**
    - **Investing Too Late**



  - **Cost/Benefit Analysis** – Justify capital investment – When do the costs of continued sustainment with increased parts failure or loss of service risk outweigh cost of replacement?

Data Driven Cost Est. & Business Cases

- **Data -Driven Estimates**
  - Cost estimates for government investments and acquisitions rely upon historical data, parametric data, and prior business cases to forecast cost.
- **Sustainment Business Cases & Legacy Case Cost Estimates**
  1) **Estimating End -of-Life**
     - How long can system be sustained without running out of parts?
     - Determine impact of EOL. Loss of Service? Impact to stakeholders?
  2) **Sustainment**
     - **Cost to Sustain** – Estimate cost to sustain legacy over program lifecycle.
     - **Further Investment** – If cannot be sustained over lifecycle, F&E investment required.
  3) **Cost Avoidance**
     - Cost of legacy case is baseline for comparison to replacement system/procurement.
     - Estimate of legacy case is estimate of costs that would be avoided if invest in replacement system. Usually, replacement system is cheaper to maintain.

Legacy System Sustainment Cost Drivers

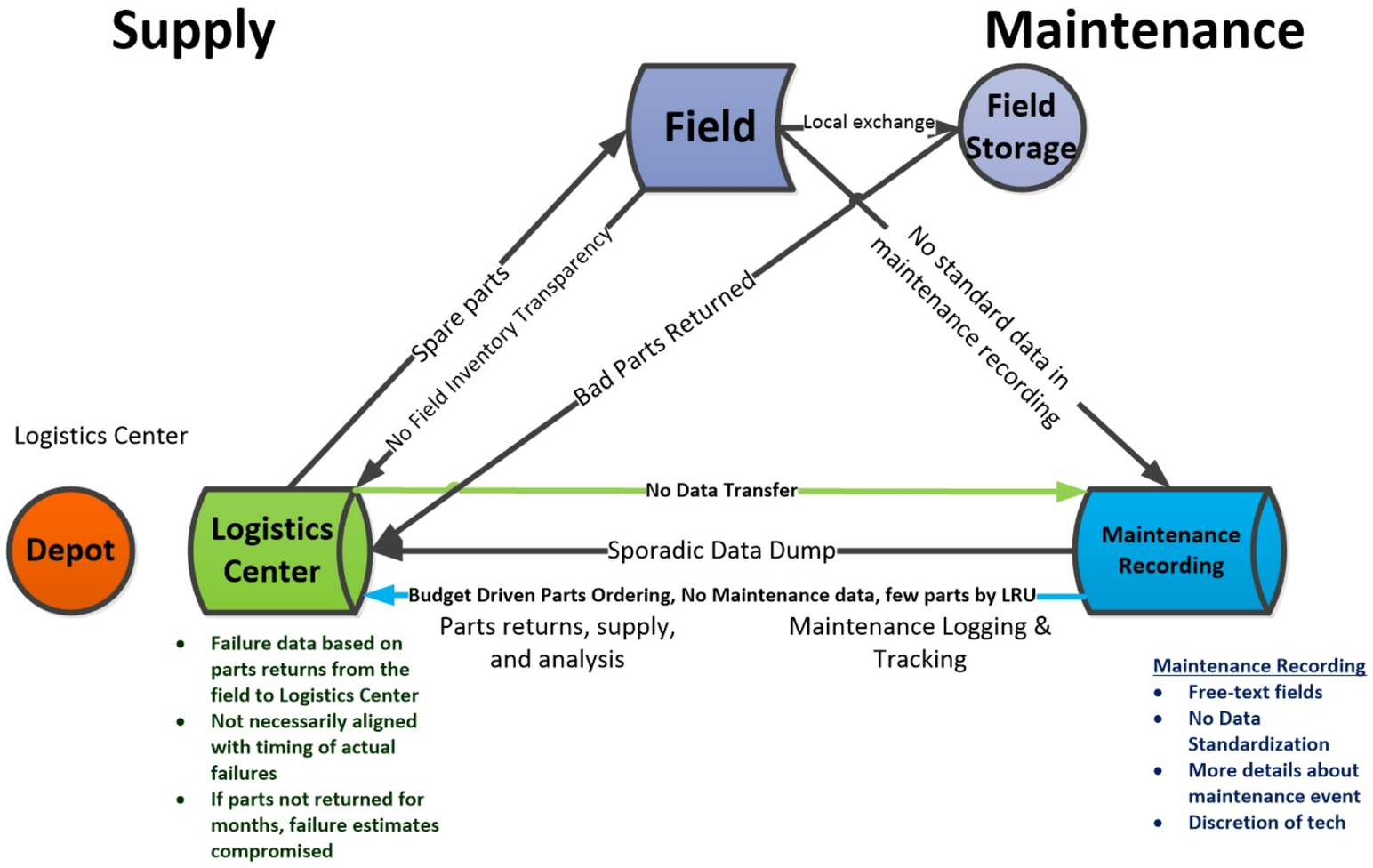
- **Legacy System Cost Driven by Parts/ System Failures**
  - Agency tries to estimate cost of legacy system sustainment and timing of replacing legacy infrastructure.
  - Legacy infrastructure system costs driven by estimates of failures over lifecycle.
- **Major Legacy System Sustainment Considerations:**
  - **Cost Per Maintenance Action**
    - Logistics and maintenance costs for each outage
  - **Labor**
    - Repairs in the field, preparation of field spares, tracking outages
  - **Analysis**
    - Investment Planning & Analysis (IP&A) oversight group use legacy system sustainability as a driver for investment decision timing
    - Historical failure analysis helps demonstrate new investment urgency and helps agencies decide in which business cases to invest based on need and timing

Legacy System Sustainment Cost Drivers

- **Major Legacy System Sustainment Considerations (continued) :**
  - **Parts Procurement, Storage, and Distribution**
    - **Procurement** – Critical Demand data drives procurement volume and operations costs to source replacement parts
    - **Storage** – Failures and parts demand drive inventory storage levels and cost
    - **Distribution** – Demand data used for "inventory readiness" and to repair right parts for distribution
  - **Time to Repair**
    - Calculate Mean Time Between Failure (MTBF) to measure parts demand and inventory depletion
  - **Ability to Source Parts & Manage Risk**
    - Some parts are customized; others no longer manufactured; some drive system end-of-life.
    - Agency manages parts sustainability risk by tracking parts procurement availability, cannibalizing parts, and making lifetime buys.
  - **Condition of Data for Analysis/ Assessments**
    - Is historical data accurate? What is the basis?
    - Analyze source data and assumptions for fidelity.

Government Supply Chain

Supply Chain Data Challenges for Failure Analysis



Government Supply Chain

- Challenges to data collection and data integrity
- Failure analyses have challenges with single source of data

Cost Estimating & Failure Analysis Methodology

Failure Analysis Methodology

Failure Analysis & System Sustainment Methodology

- Aging The cost team developed a standard methodology for estimating legacy system sustainment, including in-depth failure analyses by part and part type. This included examining procurement practices for each part at Logistics Center.

Failure Analysis Methodology

1. **Comprehensive Inventory of Systems and Parts**
   - Conduct audit of full list of system parts and the associated Lowest Replaceable Units (LRU) numbers.
   - Get initial inventory of parts in storage
2. **Parts Categorization**
   - Break parts supply into functional categories of parts (COTS, easy to procure, hard to procure, aging, custom for the FAA)
   - **Low Risk** – No procurement risk
   - **Medium Risk** – Supplier risk
   - **High Risk** – No supplier available
3. **Historical Demand** – Use Logistics demand data from parts returns to the Logistics Center to estimate historical demand.
4. **Trend Analysis** – Analyze historical demand data by part number (NSN) and check for failure trends.

Failure Analysis Methodology

Failure Analysis Methodology

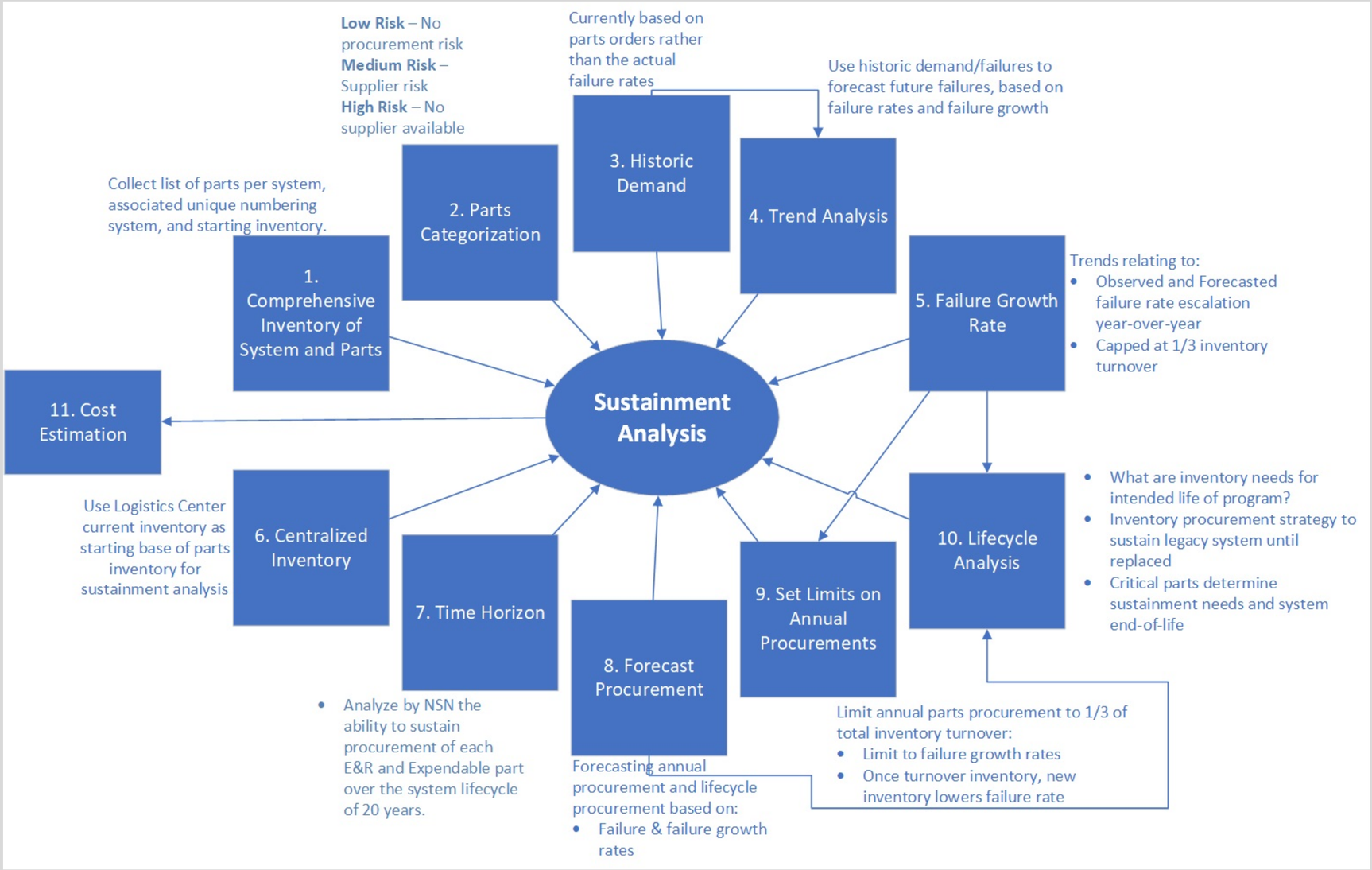
5. **Failure Growth Rate** – Estimate failure growth rate for each NSN based on trend analyses
   - **Growth Rate Regression** – Develop growth curves to refine growth rates to realistic sustainable levels using regression analysis – define three primary categories of growth for each NSN – zero growth, moderate growth, and high growth.
   - **Inventory Turnover** – Forecast growth rates for entire lifecycle with annual failure rate caps of full inventory turnover every three years for high failure rate parts.
6. Collect **centralized inventory** counts from the Logistics Center for Exchange & Repair (E&R) parts and a starting point for expendable parts
7. **Time Horizon** – Analyze by NSN the ability to sustain procurement of each E&R and Expendable part over the system lifecycle of 20 years.
8. **Forecast Procurement** – Forecast the annual inventory procurement of NSNs for each year using the demand forecast and appropriate failure growth rates.
9. **Set limits** on annual procurements, so growth rates cannot exceed a specific annual procurement level.
   - For this FAA project, we estimated that even with an aging infrastructure system, annual procurements and demand could not exceed total inventory turnover in a three -year period.
   - After total inventory turnover, failure growth rates would be reset to gradually escalate since old aging parts inventory were replaced.

Failure Analysis Methodology

Failure Analysis Methodology

10. **Lifecycle Analysis** – Finalize inventory procurement and sustainability forecast for entire business case lifecycle.
    - Assess current inventory levels deployed and at the Logistics Center
    - Compare this inventory versus standard demand levels
    - Compare these levels to full inventory needed to get to system end of life or next Tech Refresh
11. **Cost Estimation** –
    - **Procurement/Sustainment Cost** – Multiply annual inventory procurement volume by the unit cost of each spare part = Price X Volume
    - Forecast annual cost requirements to procure spares in legacy cost estimate.
    - **Corrective Maintenance** – Measure frequency of maintenance events by quantity of parts repaired by year and multiply by labor cost

Failure Analysis Methodology



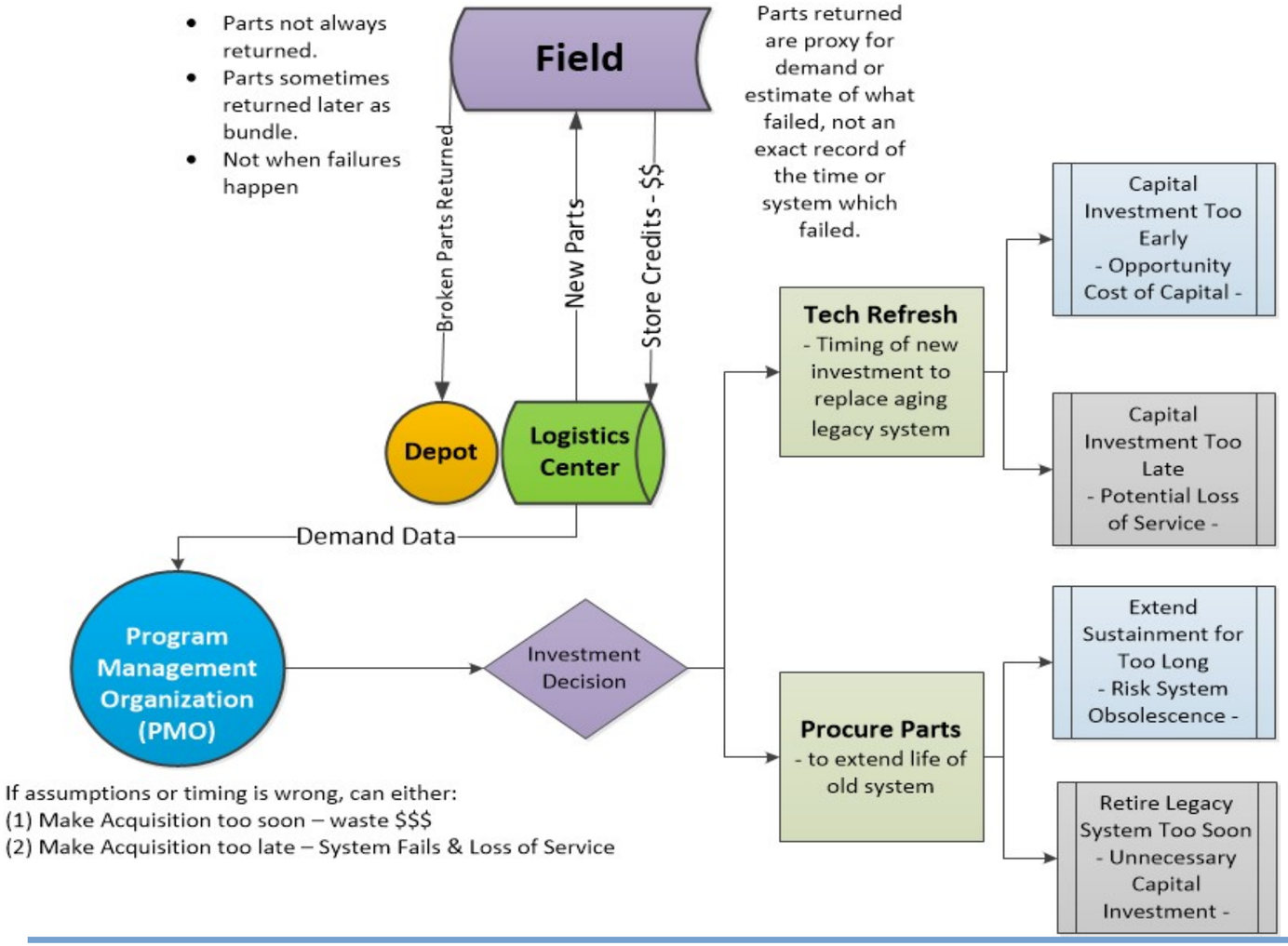
Impacts of Incomplete Data on Cost & Decisions

Impacts of Incomplete Data on Cost & Decisions

- **Legacy Investment Sustainment Analysis – FAA Air Traffic System**
  - Estimated sustainment of FAA system using Logistics demand data
  - **Source of Demand Data:** Parts orders/returns to Logistics Center
    - Source of data incomplete and imperfect match
    - Demand data from spare parts returns from field and parts orders is a proxy for demand
    - Parts not consistently returned or ordered at the time of failure leads to:
      1. Inaccurate timing of failure,
      2. Volatile year-to-year failure data,
      3. Choppy forecasting of failure data
  - **Impact:** Failure and cost analyses from imperfect historical data could result in poor timing of investment decisions
  - **Analytical Solution:** Need another source of data to add fidelity and context to business case analysis and sustainment analysis

Impacts of Incomplete Data on Cost & Decisions

Field Returns to Logistics Center – Proxy for Demand



Incomplete data can adversely impact (1) cost estimates and (2) investment decisions.

FAA Data Correlation Issues

2nd Source of Data Also Incomplete

- Adds context for each failure with notes from field at time of failure
- **Free text fields** – not standardized recording of systems or parts
- No means of searching across consistent parts numbers
- No correlation to "Lowest Repairable Unit" (lru) at Logistics Center
- **Logistics Center uses " lru "** – Lowest Repairable Unit
  - Repair E&R Spare Parts at FAA Logistics Center
  - Track using NSN and IFS unique numbering system
- **Maintenance System uses "LRU"** – Line Replaceable Unit
  - Track according to system field location and type
  - No correlation to NSN or IFS numbering system used at Logistics Center
- Only way to correlate failure with spare part number is for order requests in IFS and part returns
- **Budget -Based Ordering** – Little incentive to order parts at failure due to scarce "Store Credits"

FAA Demand Data Analysis

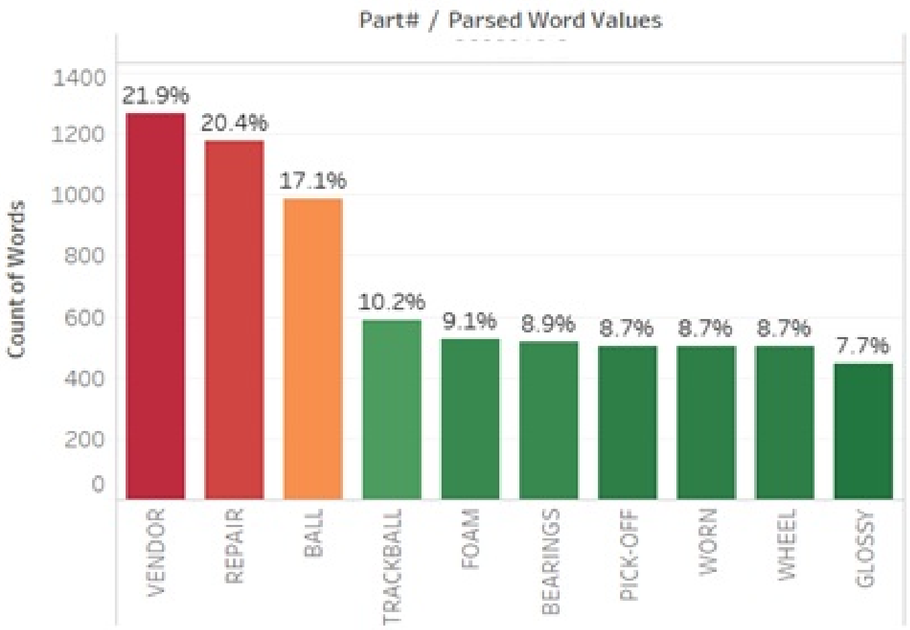
Demand Data Analysis – Context from "Free Text"

- **Challenge #1** – Need system to interpret text to correlate maintenance logging source data in free text to demand projections by part from Logistics Center
- **Challenge #2** – Dependent on order data since no recording of parts at failure
- **"Topic Analysis"**
  - **Topic Analysis** – Machine data technique that analyzes text for word clustering and related words. Modem part example: correlated counts, added context, "reset" versus "replace"
  - **Key Word Search** – Addressed Challenge #1 by searching for contextual words that had meaning or potentially described a part
  - **Word Descriptions** – Word Choice. "Timecard" example, "Clock," "CCA," word context of actions
  - **Intent** – Tried to understand intent. How did part failures correlate with part numbers.
  - Easier with single NSN/ IFS Number
  - Challenge to equate with parts orders due to "timing."

Topic Analysis, Key Words, & Counts

Used Word Variations, Queries, Topic Analysis to Refine Data Sets

- Word queries based on multiple variations – trackball example – “ball, ” “trackball,” “TRACK BALL,” “track,” “BEARINGS,” “WHEEL”
- Parsed out common words related to parts or actions
- Pivot table used to determine frequency counts and match popular words with words in component list
- Filtered for sentences that contain that word in free text
- Percentage of frequency captured and correlated with LRU and part numbers



Part#	Pivot Field ..	Trim Full Name	
A1234	BALL	BALL	DIA BLK G
		SS BALL	

Topic Analysis, Key Words, & Counts

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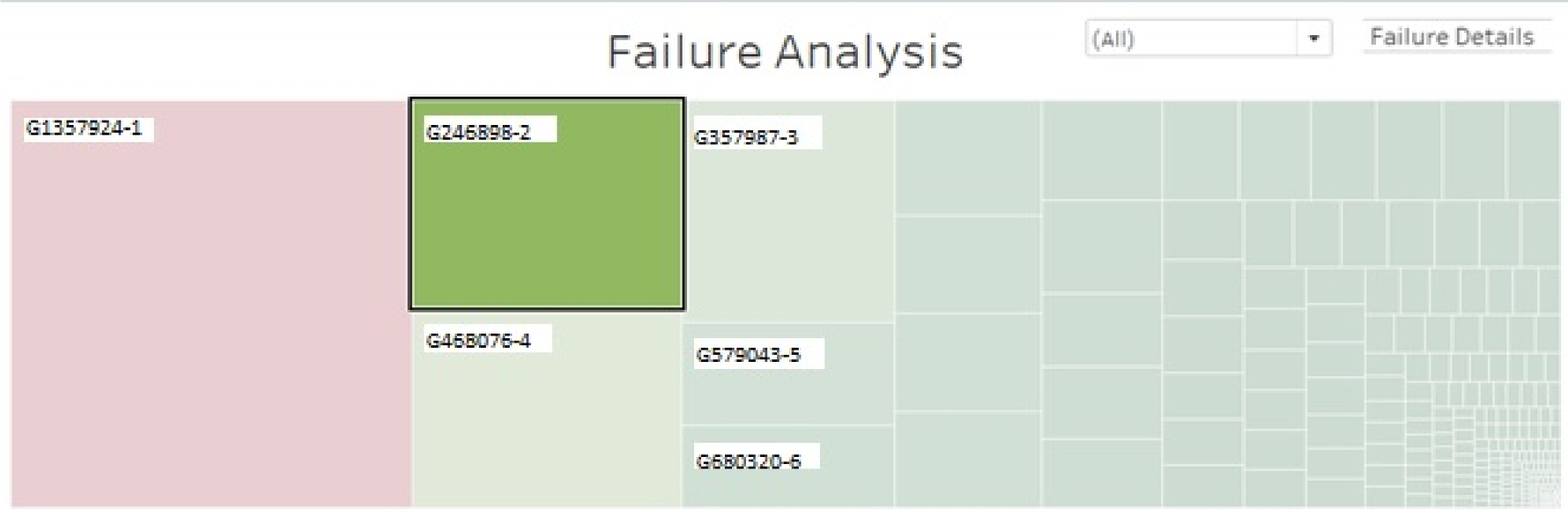
- Parsed out common words related to parts or actions
- Pivot table used to determine frequency counts and match popular words with words in component list
- Filtered for sentences that contain that word in free text
- Percentage of frequency captured and correlated with LRU and part numbers
- Chart shows frequency of part correlated with parsed words with most frequent as a larger block



Topic Analysis, Key Words, & Counts

Used Word Variations, Queries, Topic Analysis to Refine Data Sets

Fail Mode Listing

Failue Analysis

Part#	Parsed ..	Fail Mode	
G674371-3	BALL	TO VENDOR FOR REPAIR. WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS. G..	2
		BROKEN TOP LEFT CORNER NEAR THE MOUNTING HOLE, WORN FOAM PICK-OFF ..	1
		BROKEN TOP LEFT CORNER NEAR THE MOUNTING HOLE. WORN FOAM PICK-OFF ..	1
		EXCESSIVELY WORN FOAM PICK -OFF WHEEL AND BALL BEARINGS ON ALL THE U..	2
		EXCESSIVELY WORN FOAM PICK OFF WHEEL AND BALL BEARINGS ON THE UNIT. ..	2
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS ON ALL THE U..	22
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS ON ALL THE U..	32
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS ON ALL THE U..	12
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS ON ALL THE U..	6
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS ON ALL THE U..	2
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS ON ALL THE U..	30
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS ON ALL THE U..	2
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS ON ALL THE U..	2
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS ON ALL THE U..	10
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS ON ALL UNITS...	2
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL AND BALL NEARINGS ON ALL THE U..	2
		EXCESSIVELY WORN FOAM PICK-OFF WHEEL BALL BEARINGS ON ALL THE UNITS. ..	4
		EXCESSIVELY WORN PICK-OFF WHEEL AND BALL BEARINGS ON ALL THE UNITS. G..	6
		INTERMITTENT OUTPUT FROM SWITCH CARD. WORN FOAM PICK-OFF WHEEL AN..	2
		INTERMITTENT OUTPUT FROM THE SWITCH CARD. WORN FOAM PICK-OFF WHEE..	2
		INTERMITTENT SWITCH OUTPUT. SWITCHES ARE STICKY, LIQUID SPILLED ON TH..	2
		LEFT BUTTON DOESN'T FUNCTION. WORN FOAM PICK-OFF WHEEL AND BALL BEA..	2
		LOWER RIGHT CORNER IS BENT. WORN FOAM PICK-OFF WHEEL AND BALL BEARI..	1
		NO OUTPUT FROM EITHER AWITCH CARD OR MAIN PCB. BOTH CARDS ARE DEFEC..	2
		NO OUTPUT FROM EITHER SWITCH CARD 0R MAIN PCB. BOTH CARDS ARE DEFEC..	2
		NO OUTPUT FROM EITHER SWITCH CARD OR MAIN PCB. BOTH CARDS ARE DEFEC..	4
		NO OUTPUT FROM SWITCH CARD. NOTICED CORROSION ON PC CARD. WORN FOA..	2
		NO OUTPUT FROM THE `Y AXIS ENCODER. WORN FOAM PICK-OFF WHEEL AND B..	2
		NO OUTPUT FROM THE UNIT. WORN FOAM PICK-OFF WHEEL AND BALL BEARING..	2
		NO OUTPUT FROM THE UNIT. WORN FOAM PICK-OFF WHEEL AND BALL BEARING..	2
		NO OUTPUT FROM UNIT, WORN FOAM PICK-OFF WHEEL & BALL BEARINGS, GLOS..	2
		NO OUTPUT FROM UNIT. WORN FOAM PICK-OFF WHEEL AND BALL BEARINGS. GL..	2
		NO PUTPUT FROM EITHER SWITCH CARD OR MAIN PCB. BOTH CARDS ARE DEFEC..	2

- Chart Parsed out common words related to parts or actions
- Counts the number of times the same sentence or word grouping is found within the data
- This allows matching of word description to part number

Two Data Sources – Cost & Accuracy Impact

Impact of Using Two Incomplete Data Sources

- **1st Data Source**
  - Delay between Logistics spare parts orders or returns and actual failure
  - Dependent on parts orders to estimate demand
  - Data source alone impacts (1) spare part procurement volume, (2) timing of future capital investments
  - Cost models are (1) heavily risk -adjusted for legacy sustainment and (2) F&E investments happen sooner to avoid loss of service risk
- **2nd Data Source**
  - Interpret free text to equal part LRU
  - No data standardization
  - For some spare parts, topic analysis provides some correlation

Two Data Sources – Cost & Accuracy Impact

Impact of Using Two Incomplete Data Sources

- **Conclusion**
  - Two data sets even though each incomplete and reported at different time intervals added context and fidelity to failure analyses and business case projections for legacy sustainment
  - Reducing sustainment risk and increase accuracy of end-of-life date forecast
  - Reduced part procurement waste
- **Combined Data – 2 Sources – Cost Estimation Impact**
  1) **Reduction in Procurement Cost** – Reduced risk in failure/demand forecast for legacy part procurement
  2) **Reduction in Procurement Waste** – More accurate demand forecast allows leaner inventory and fewer parts left over after decommission
  3) **Acquisition Timing** – Capital Investment Timing improved by more accurate estimate of legacy system end-of-life
     - **Too Early** – Spend limited capital dollars on system that doesn't need it at expense of a system that does
     - **Too Late** – Risk loss of services with $ millions impact to NAS operations