Considerations for an Extended Framework for Interactive Epoch-Era Analysis

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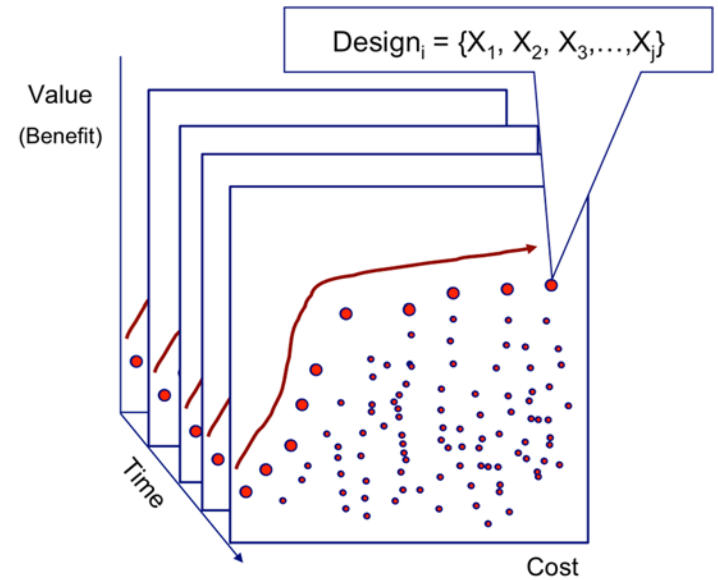
Outline

- Motivation
- Background
  - Epoch Era Analysis (EEA)
  - Value Sustainment
- Proposed Approach
- Interactive EEA Framework
- Case Study
- Summary

Motivation

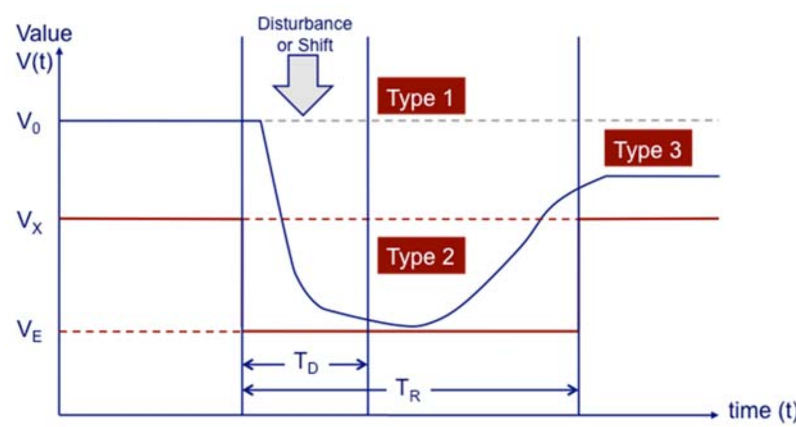
- **Development of resilient systems** identified by DoD as a strategic research priority [1]
  - Desire systems that maintain value (performance) over time relative to its cost in the presence of changing circumstances [2],[5],[6]
- **Systems Engineering processes** limited by how they handle these types of lifecycle uncertainty
  - Assumes that system/mission requirements and stakeholder needs are known / stable over time
  - Under-represents the impact of external factors
- **Epoch-Era Analysis (EEA)** considers the time varying needs of stakeholders and evolving contexts in which the system operates [7],[8], but also has limitations [9], [17]
  - **Data scale growth / complexity**: too much data to process
  - **Visualization:** high-dimensional data, difficult to visualize

Background



- **Tradespace exploration** tends to focus on system alternatives within a static context and needs[20]
- **EEA** explicitly considers the dynamic environment in which the system must sustain value to stakeholders[18],[19] and offers a more complete picture of dynamic system trades at the expense of a **large and complex data set**
- **Epochs:** periods of fixed context and needs
- **Eras:** sequences of epochs simulating a potential future lifecycle path experienced by the system

Value Sustainment – The ability of a system to minimize the impact of a shift in stakeholder needs, context or system state on system value through:
(1) the reduction of the likelihood or magnitude of a shift,
(2) the satisfaction of a minimally acceptable level of value during and after a shift,
(3) timely recovery*



*Adapted from: Richards, 2007 and Beesemyer, 2012;
Similarities with Jackson, 2013; (**Refs [3], [4,] [21]**)

Hypothesis and Proposed Approach

- **Problem Summary:** Need for **mature metrics, systematic frameworks and design applications** for comprehensive analysis of system value sustainment applied to large scale problems

- **Hypothesis:** An iterative design framework using EEA constructs that leverages interactive visualization will provide a more complete understanding of the dynamic environment in which the system operates while effectively controlling data scale growth and complexity

- **Objective:** Develop an iterative framework for exploring trades in needs/context/system and demonstrate via an interactive application

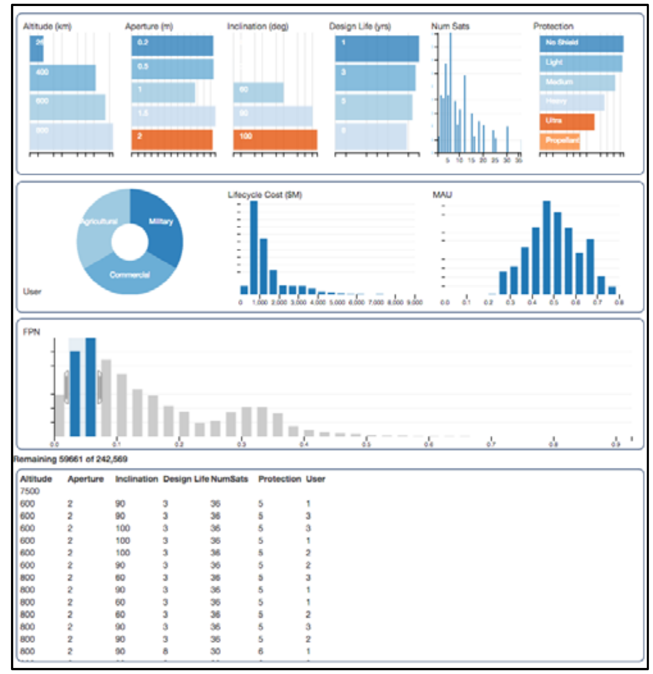
Visual Analytics

- Visual analytics can be applied to overcome issues created by bounded rationality and lead to improved decision making in system concept exploration
  - Improves productivity of cognitive effort[55]
  - Extends working memory[55][56]
  - Increased trust / confidence in decision[57]
  - Increased use of data for decision-making[57]

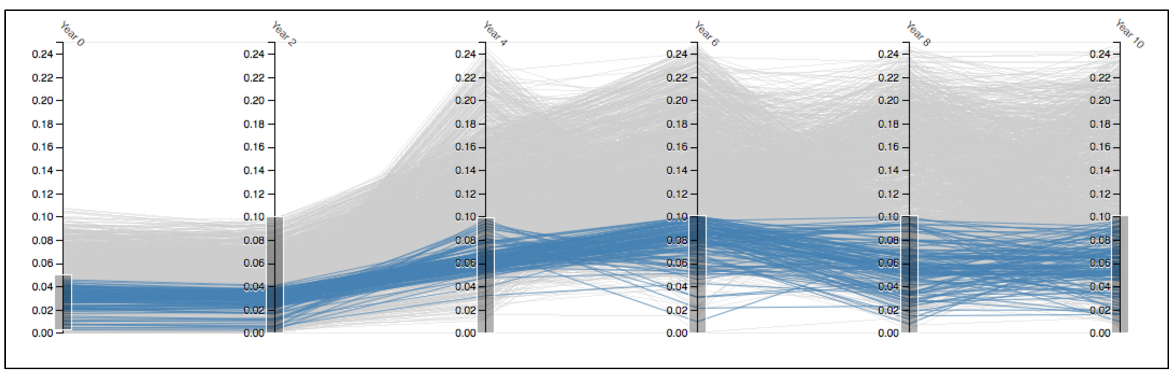
- Interactivity and data persistence between studies will enable deeper data exploration, and facilitate the development of user skills for anticipatory thinking

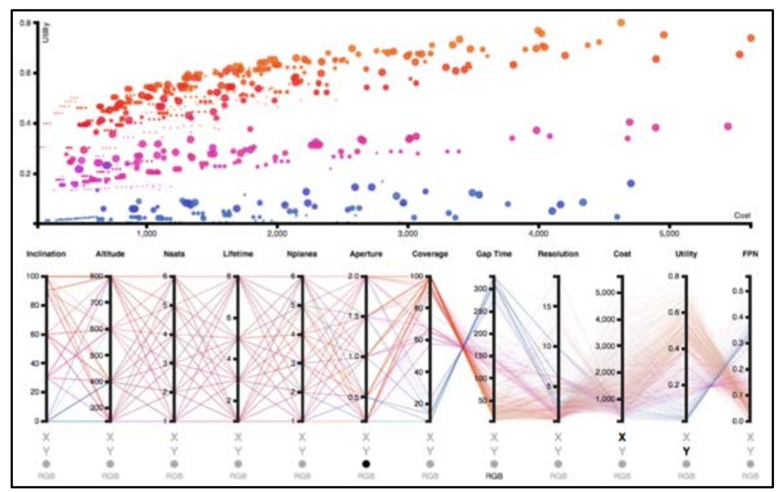
Interactive Applications

Computational Limitation	Solutions
Processing / Generation of alternatives	Parallel computing, Amazon EC2
Data handling and rapid query	Online Analytical Processing (OLAP) [16], Data Tiling, Crossfilter [53]
Visualization and Rendering	Multiple coordinated interactive visualizations[39],[40], Data Driven Documents (D3) [52]

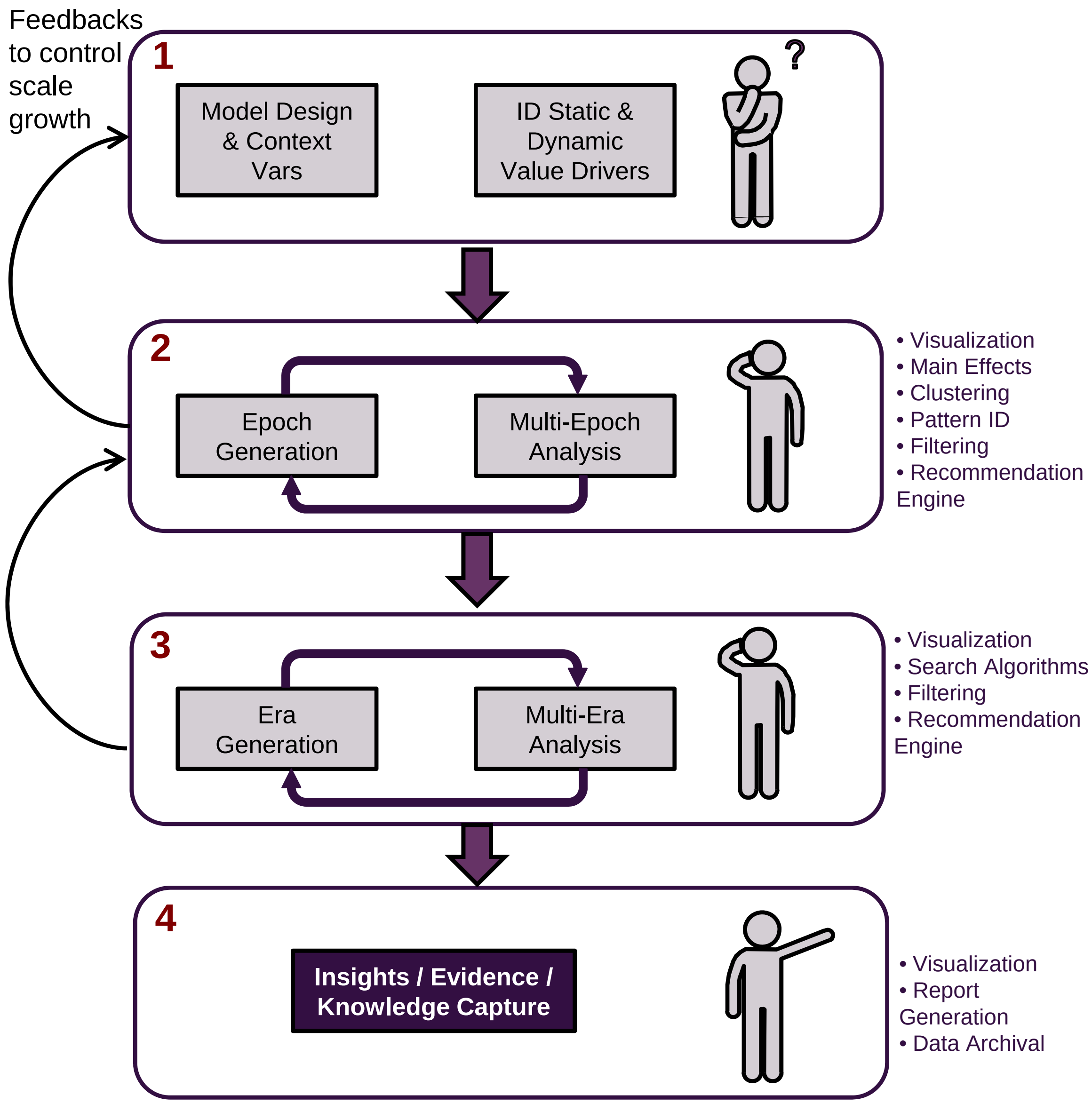


Screenshots from Interactive SE Applications





IEEA Framework

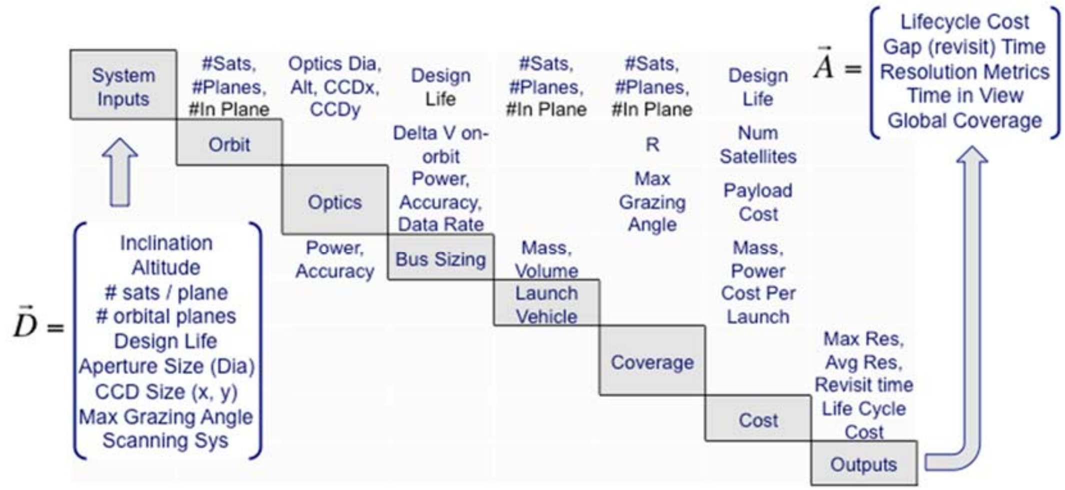


Curry et al., 2015 [24]

1. **Problem Formulation**
   a) Design/Performance
   b) Context/Needs
2. **Epoch Analysis**
   a) Design / Epoch Generation
   b) Multi-Epoch Analysis
   c) Identify designs/variables that necessitate further scrutiny
3. **Era Analysis**
   a) Era Generation
   b) Multi-Era Analysis
   c) Identify designs/variables that necessitate further scrutiny
4. **Knowledge Capture**
   a) Capture insights / evidence for dissemination
   b) Capture relevant results for use in future studies

Step 1: Problem Formulation

- **Problem Statement:** *To provide affordable, low-latency, high-resolution, near-continuous imaging of an arbitrary location on the Earth's surface* [23]



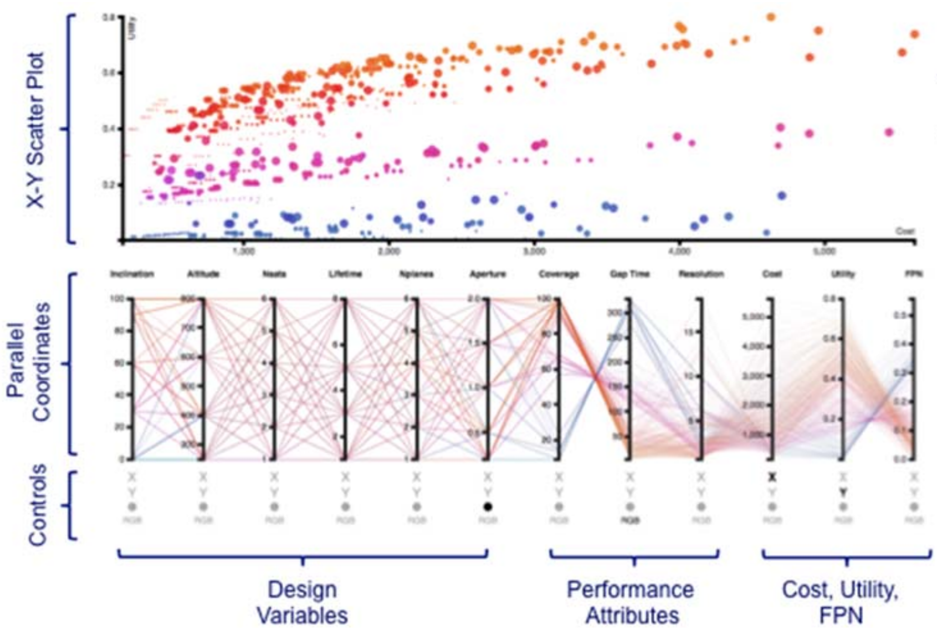
- Map problem statement to performance attributes:
  - Minimize lifecycle cost (***affordable***)
  - Minimize gap / revisit time (***low-latency***)
  - Minimize resolution (m/pixel) (***high-resolution***)
  - Maximize time in view (***near-continuous***)
  - Maximize global coverage (***arbitrary location***)

- Loss of satellites (ΔN_{sats}) within a constellation may degrade performance
  - **Endogenous vars**: Component reliabilities
  - **Exogenous vars**: Space debris
  - **Operational vars**: Replenishment rates

- User preference/needs is a function of performance attributes and are different for each stakeholder
  - Military User
  - Commercial User
  - Earth Science User

Step 2: Multi-Epoch Analysis

- DOE applied to generate inputs to parameterized system and context models
  - **Screening Test**
  - **Detailed Trade Study**
  - **Data Reduction**
- Design efficiency operationalized using **Fuzzy Pareto number (FPN)** [27]
- **Normalized Pareto Trace** (**fNPT**) evaluates the frequency that a design meets an FPN threshold [7]



Multi-Epoch Viewer Screenshot

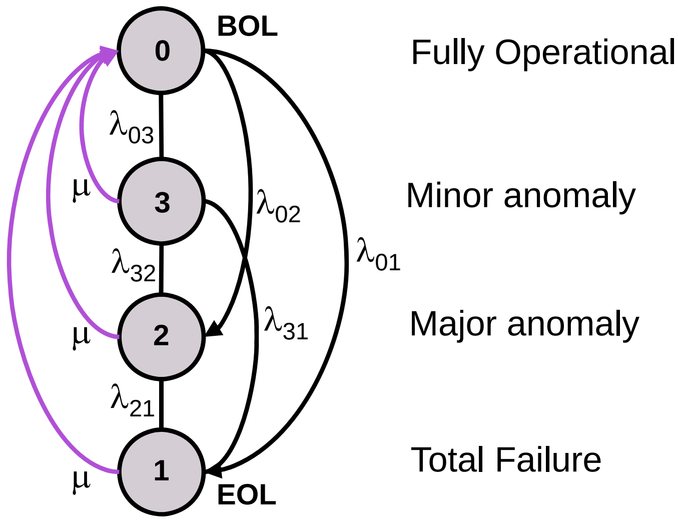
Design Variable	Levels
Altitude (km)	250, 400, 600, 800
Inclination (deg)	0, 30, 60, 90, 100
# Orbital Planes	1, 2, 3, 4, 5, 6
# Satellites / plane	1, 2, 3, 4, 5, 6
Design Life (years)	1, 3, 5, 8
Aperture Dia. (m)	0.2, 0.5, 1.0, 1.5, 2.0
Maneuvering Propellant	0, 1
Debris Shield	L, M, H

86,400 Designs

Epoch Variable	Levels
% of satellites w/ critical component failure	0, 20
% of satellites effected by **small** space debris	0, 10
% of satellites effected by **medium** space debris	0, 10
% of satellites effected by **large** space debris	0, 10
End User	Military, Commercial, Earth Science

3 Needs * 16 Contexts = **48 Epochs**

Step 3: Era Generation

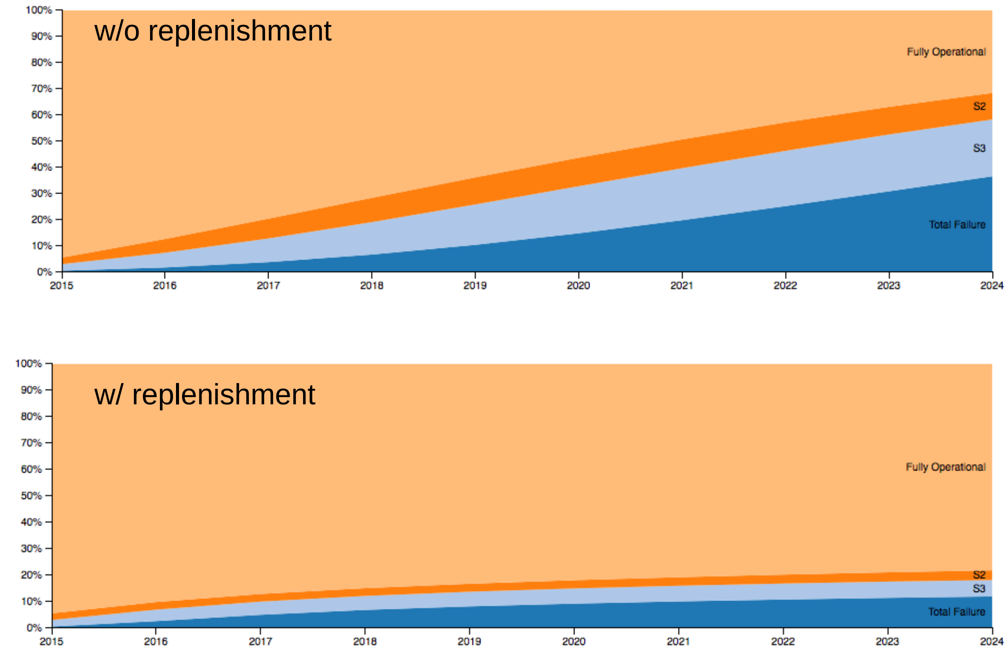


λ: transition to degraded state

μ: replenishment rate

Anomaly classes derived from **[12], [15]**

Failure progression over 10 years:

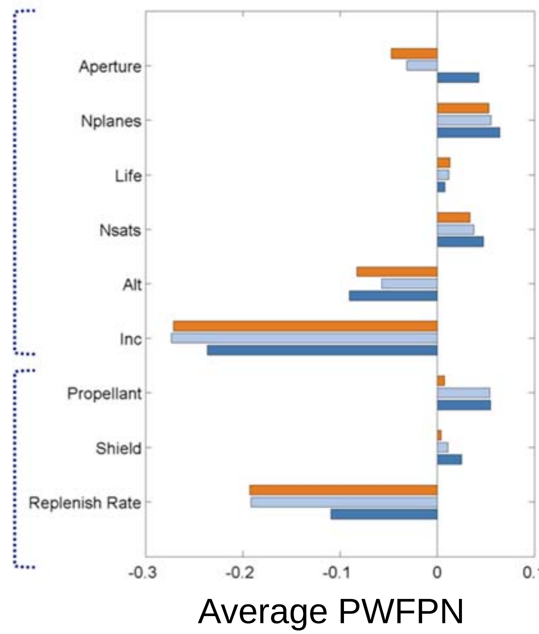


State progression visualization Screenshot

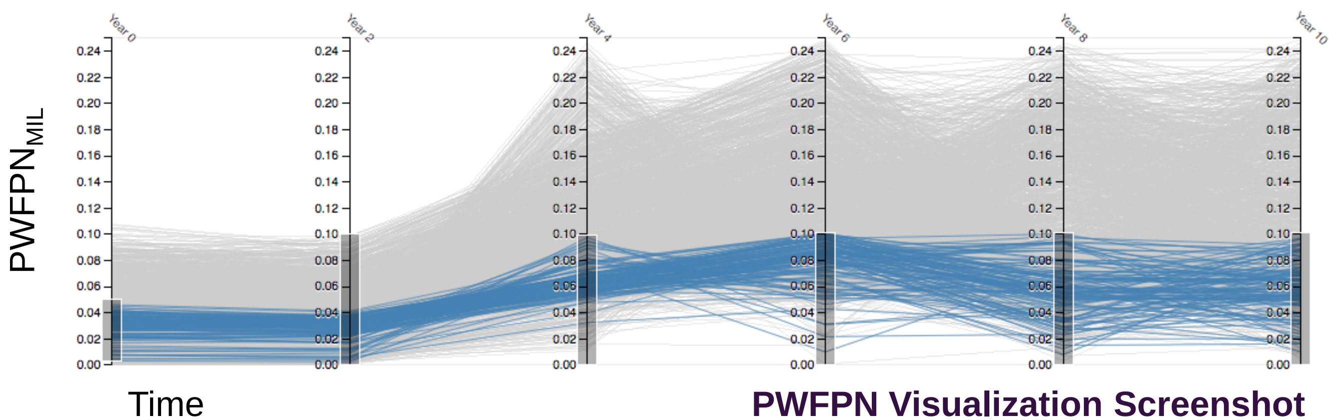
- An era is a time-ordered sequence of epochs which can be constructed by various methods (Narrative, Computational)
- Markov transition rates calculated from component failure rates and debris flux rates

Step 3: Era Analysis

- Performance at each time step can be evaluated as **probability-weighted FPN (PWFPN)**
- Remaining designs tend to suggest that the costs of shielding and maneuvering propellant outweigh the benefits to values sustainment
- Increasing risk aversion or uncertainty in probabilities might lead a designer to use options anyway



Probability-weighted FPN over 10 years:



PWFPN Visualization Screenshot

PWFPN $X = E(FPN)$

Average PWFPN $\overline{X} = \sum_{i=0}^{N} \frac{X_i}{N}$

Summary

- IEEA shows promise as a means for addressing ERS problems
  - Identifies systems that can sustain lifecycle value
  - Interactive visualization drives user engagement and improvements in the analytical experience

- Limitations and Future Work
  - Current example based on systematically pruning the decision space as we move forward
  - Risk aversion considerations
  - One query → One response

Questions?

References
&
Backup

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Visual Analytics

- "Adopters of interactive visualization achieve faster decision making, greater data access, and stronger user engagement, in addition to desirable results in several other metrics" (Aberdeen Business Analytics Survey, 2014)
    1) **70%** of interactive visualization adopters **improved collaboration and knowledge sharing**
    2) **64%** of interactive visualization adopters **improved user trust in underlying data**
    3) Interactive visualization users **engage data more frequently for decision making**
    4) Interactive visualizes are **150%** more likely than static visualizers to be satisfied with **ease-of-use of analytical tools**