Scenario Planning in Dynamic Multi-Attribute Tradespace Exploration

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Outline

- Motivation
- Background
- Scenario Planning
- Epoch-Era Analysis
- Case Application
- Results
- Future Work
- Implications
- Conclusions

Motivation

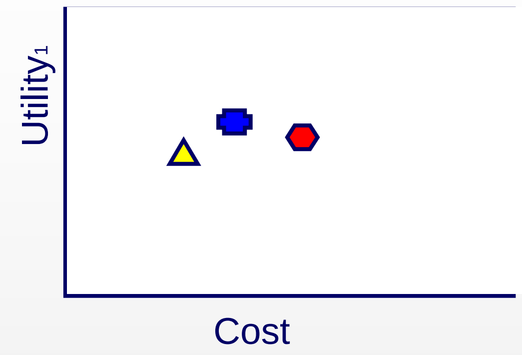
- Traditional front-end systems engineering methodologies typically assume static future contexts
- Complex systems have long time scales during which there exist many uncertainties about the future context

New methods that enable the evaluation of system value delivery in face of uncertain contexts are needed

(Ross and Rhodes 2008)

Background

- Traditional SE
  - Cost As Independent Variable
  - Few Design Points
  - Trades/patterns not clear



- Multi-Attribute Tradespace Exploration (MATE)
  - Parametric exploration
  - Thousands of designs

- Dynamic MATE
  - Tradespaces over time

 (Ross and Hastings 2005, Ross 2006)

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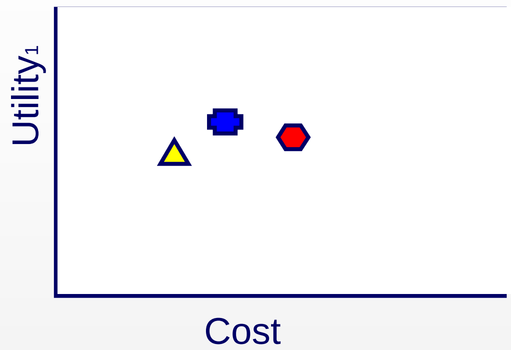

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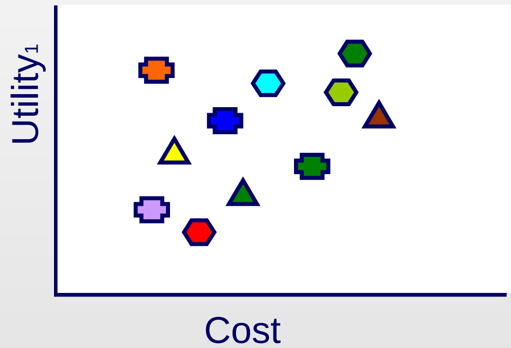

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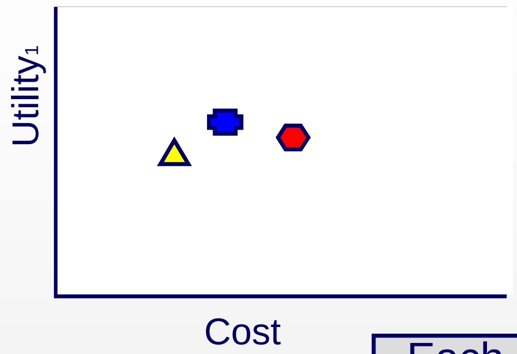

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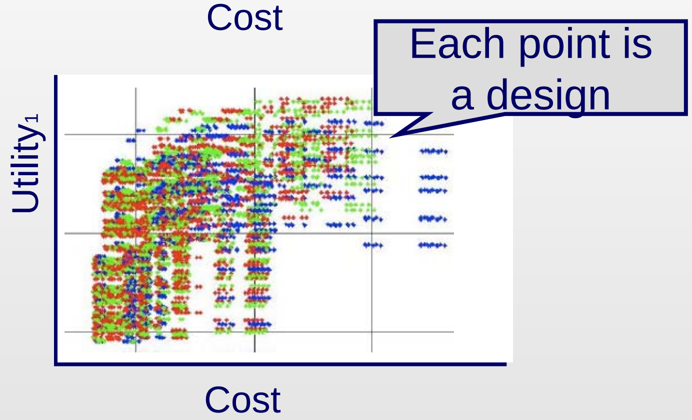

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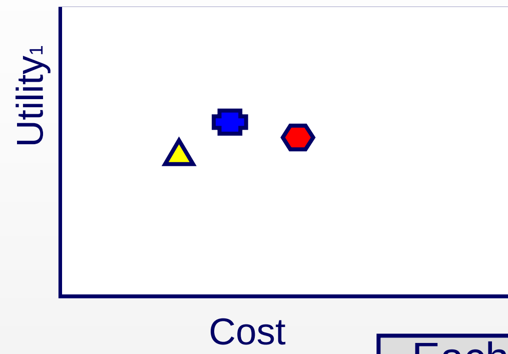

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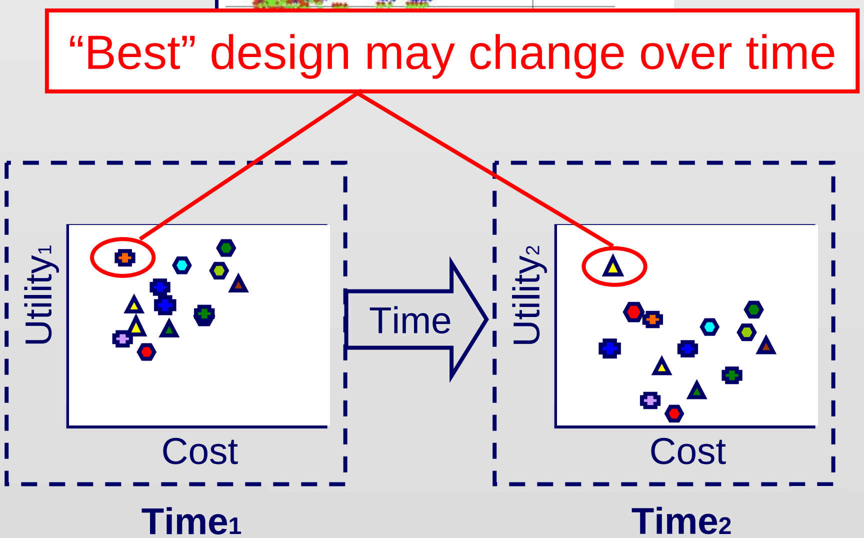

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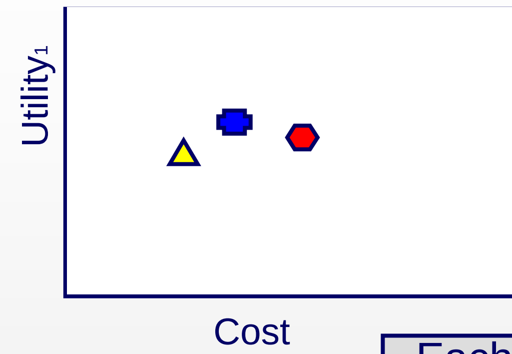

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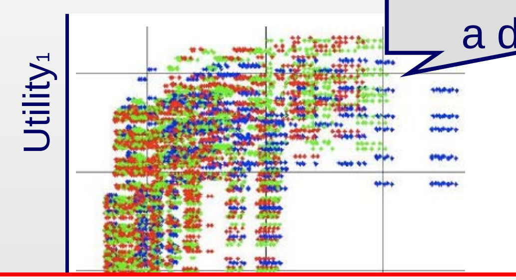
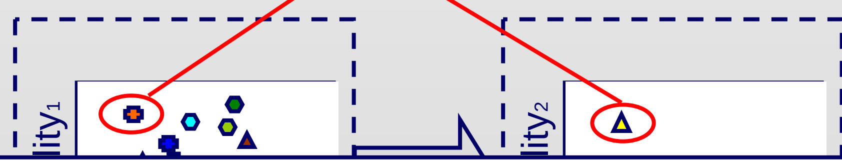


"Best" design may change over time

- Dynamic MATE



What are the factors that cause the "best" design to change over time?

How does one choose the "best" design?

Scenario Planning

- Scenario planning refers to a broad set of methods used to make strategic decisions

	Narrative	Computational
Description	Thickly-descriptive, Internally consistent	Parametric enumeration of future contexts
Pros	Compelling, more detail, plausible	Many futures, surface counterfactuals
Cons	Few future contexts considered	Computationally intensive

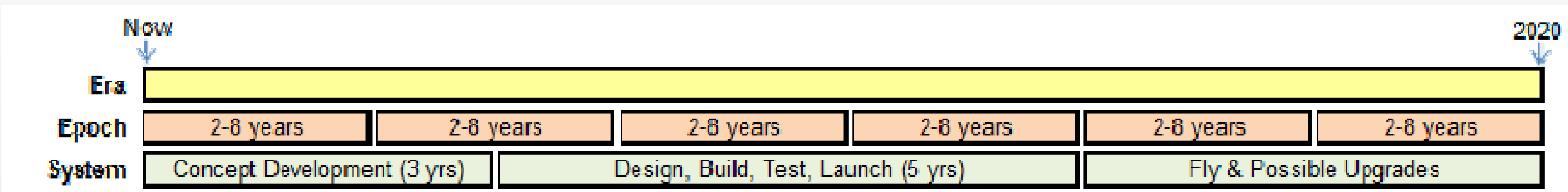
- Differing degrees of automation in computational scenario generation
  - Morphological
  - Expert systems

(Wack 1985, Ringland 1998, Eriksson 2002, Lempert et al 2003, Harries 2003)

Scenario planning allows strategic management of uncertain contexts

Epoch-Era Analysis

- System Development Lifecycle (SDLC) is a crucial organizing construct for managing system design activities, but does not facilitate management of uncertain contexts



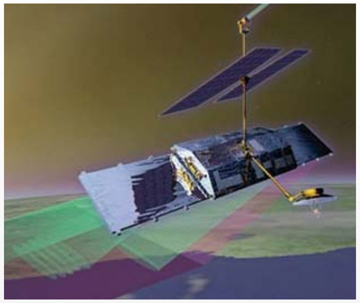
(Ross and Rhodes 2008)

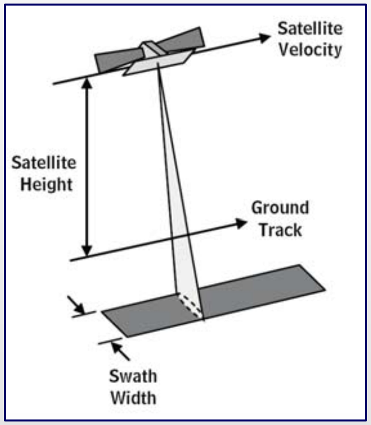
- Epoch
  - A period of time during which the context is static
  - Duration is determined by underlying dynamics of contextual factors considered
- Era
  - Spans the total lifecycle of a system
  - Constitutes an integrated set of epochs
  - Allows analysis of system evolution strategies

Epoch-Era Analysis provides a structured way to consider impact of context changes over the SDLC

Case Application: Satellite Radar (SR)

- Critical issue in national security space
  - Unique all-weather surveillance capability
  - Opportunity for impact given ongoing studies
  - Rich multi-dimensional tradespace
- Unit-of-analysis: SR architecture
  - Radar payload
  - Constellation of satellites
  - Communications network
- Articulated ***need*** for rigorous ***front-end systems engineering***
  - Uncertainties in future technology development, cost estimates, stakeholder needs, supporting infrastructures, and operational environments





(CBO 2007)

Case Application Goal

*To assess potential **satellite radar** architectures for providing the United States Military a global, all-weather, on-demand capability to **track moving ground targets**; supporting tactical military operations; maximizing cost-effectiveness; and **delivering value despite changes in context**.*

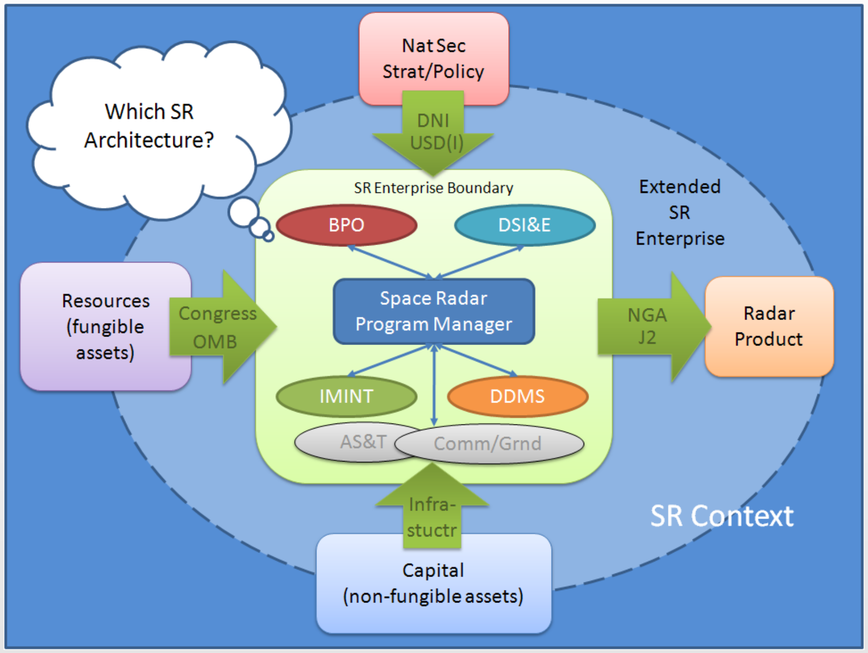
(CBO Report 2007)

Uncertainties Pervade Satellite Radar Enterprise

- Satellite Radar provides rich problem for SEAri to develop dynamic tradespace methodology
- Dynamics:
  - Policy
  - Funding
  - Infrastructure
  - Environment

DoD/IC stakeholders
changing tasking priorities

funding instability



dynamic environment

uncertain technology availability
uncertain ground/relay infrastructure

Given distribution of future uncertainties, how does satellite radar program manager select the "best" architecture?

(Ross et al 2008)

Step 1: Characterize the key exogenous uncertainties

SEAri Systems Engineering Advancement Research Initiative

Step 2: Epoch Enumeration

- Characterize plausible future context states (epochs)
- Initial set of 14 epoch variables identified
- QFD-like analysis led to a reduced set of 6 epoch variables
- Characterize levels for each variable
- Enumerate epochs to form the epoch sample space

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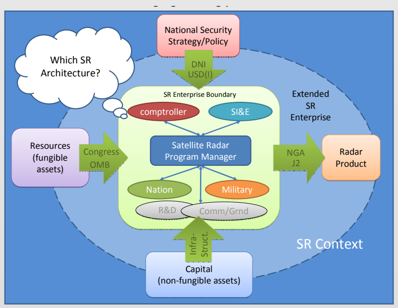


② Example of Two Epoch Variables

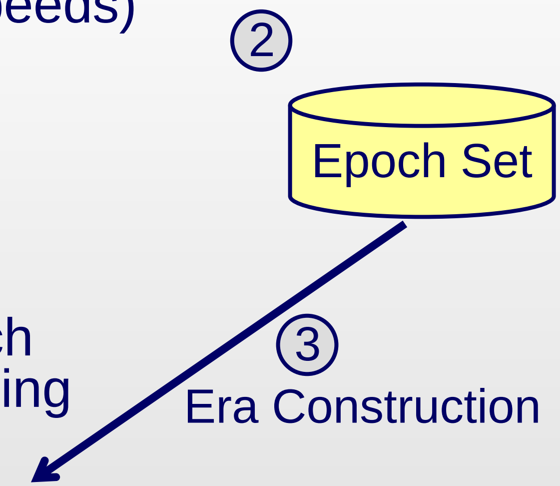
Exogenous Variable Category	Epoch Variables	Enumerated Range	Units/Notes
Capital	Technology Readiness Level – Radar Aperture	[1,2,3]	1=Small aperture 2=Med. aperture 3=Large aperture
Capital	Communication Infrastructure	[1,2]	1= Legacy comm. 2=Wideband comm.

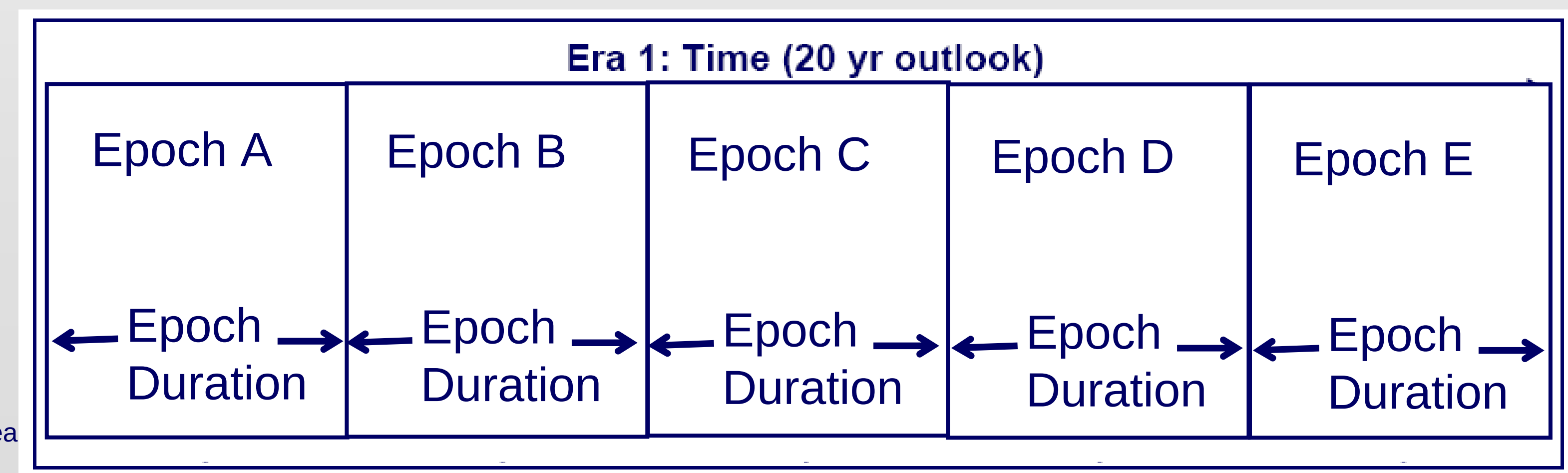
Epoch Set

648 Total Epochs

Step 3: Era Construction

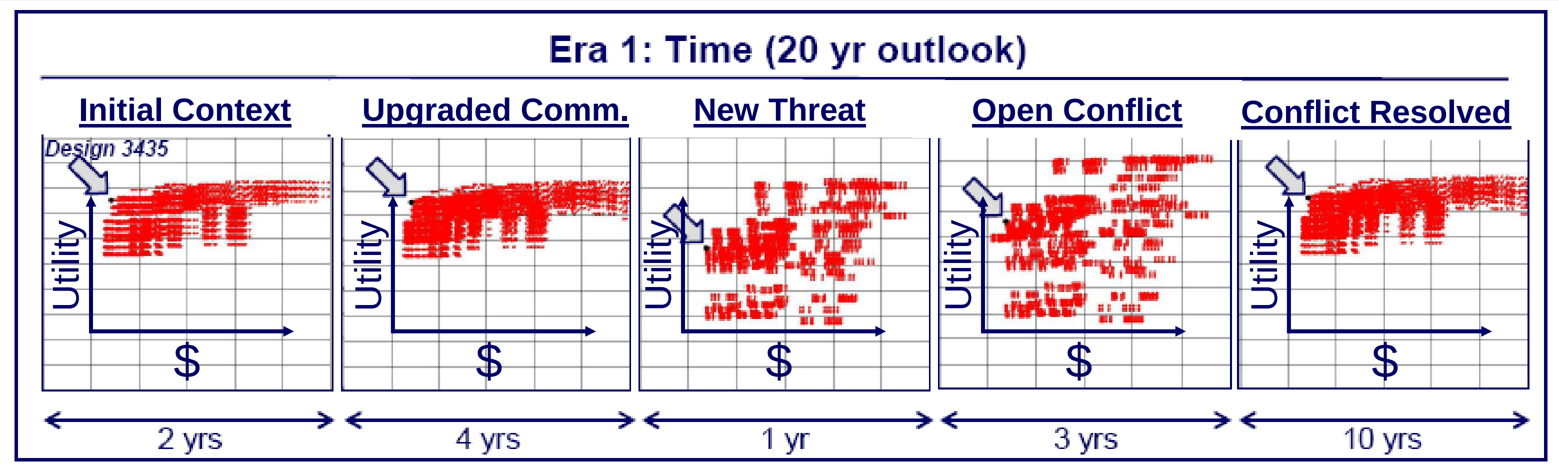
- Era construction involves four activities
  - Specify era duration
  - Characterize epoch durations (clockspeeds)
  - Establish epoch ordering logic
  - Construct Eras
- Satellite Radar Case:
  - 20 year era duration
  - Morphological approach used for epoch durations, transition logic, epoch ordering
  - 7 eras analyzed





Mobile Missile Scenario

- Epoch-Era Analysis with Multi-Attribute Tradespace Exploration enables the evaluation of system value delivery through changing contexts



- Design Point 3435 (arrow) retains value despite changing context

Implications

- 2007 Congressional Budget Office study assessed 4 satellite radar system design alternatives
  - Assumed two communication infrastructures
  - Equivalent to two discrete epochs
  - No consideration of system performance across changing contexts (eras)
- Our method assessed 23,328 system designs in each of 245 epochs
  - Independent ordering of the contexts
- 7 Eras were constructed, enabling evaluation of systems across context changes
  - Important feature for path dependent system strategies

This method reveals more information about complex socio-technical interactions, enabling decision makers to better assess design choices

Future Work

- Enterprise strategy
  - Empirical data collection and modeling techniques for socio-technical interactions such as the effects of resource constraints on program delays and multiple program (portfolio) decision analysis approaches
- Advanced epoch sampling
  - Empirical data collection and design-of-experiments techniques to more efficiently formulate & sample large sets of epochs
- Expert-systems era construction
  - Compare expert systems era construction to morphological approach, perhaps using Markov state transition model across wide range of epoch variables

Conclusions

- Scenario planning is growing in importance to systems engineering due to long system lifecycles and increasingly dynamic contexts
- Epoch-Era Analysis with Dynamic Multi-Attribute Tradespace Exploration enables the evaluation of system value delivery through changing contexts

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