Responsive Systems Comparison Method: Case Study in Assessing Future Designs in the Presence of Change

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Motivation

- System designers and architects often face changes in…
  - User needs
  - Available technologies
  - Political and technical contexts
- Classical "scenario analysis" can be too opportunistic, qualitative, or sparse
- Structured method needed for collecting information to characterize wide variety of possible futures
- Paper presents the initial work on Responsive Systems Comparison (RSC) Method

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RSC Process 1:
Value-Driven Design Formulation

Design-space:
Designer-controlled parameters that define a system concept

	Variable Type	Parametric Design Variable
DESIGN VARIABLES	Radar System Definition	Peak Transmitted Power
		Center Frequency
		Bandwidth
		Antenna Area
		Antenna Type
	Orbits	Altitude
		Constellation Configuration (inclination, Walker parameters)
	Satellite System Definition	Communication Link Type
		Tactical Communication Able
		Processing Power on-board
		Maneuver Capability
		Design for Servicing

Value-space:
Concept-neutral evaluation criteria specified by decision makers

	User Type (mission)	Attribute Name
ATTRIBUTES	Tactical data user (tracking)	Data Latency (tracking)
		Number Target Boxes
		Min. Detectable Target Velocity
		Min. Detectable Target Radar Cross-Section
		Target Acquisition Time
		Tracking Life
	Strategic data user (imaging)	Maximum Resolution
		Field of regard
		Number Targets Observed per Pass
		Revisit Frequency
		Geo-location Accuracy
		Data Latency (imaging)
	Programmatic "user" (schedule and cost)	Baseline Schedule
		Actual Schedule (under changing conditions)
		Baseline Cost
		Actual Cost (under changing conditions)

			ATTRIBUTES														
			Mission										Programmatics				
			Tracking						Imaging				Cost		Schedule		
	Variable Name	Definition Range	Minimum Target RCS	Min. Discernable Velocity	Number of Target Boxes	Target ID Time	Target Track Life	Tracking Latency	Resolution (Proxy)	Targets per Pass	Field of Regard	Revisit Frequency	Imaging Latency	Baseline Cost	Actual Costs (Era)	Baseline Schedule	Actual Schedule (Era)	Total Impact
	k Transmit Power	1.5 10 20 [KW]	9	9	9	3	1	1	9	9	9	0	1	9	9	9	9	96
	Bandwidth	.5 1 2 [GHz]	9	9	3	3	1	1	9	9	9	0	1	3	3	3	3	66
	Antenna Area	10 40 100 200 [m^2]	9	9	9	3	1	1	9	9	9	1	1	9	9	9	9	97
	na Type	Mechanical vs. AESA	9	9	9	3	3	1	9	9	9	1	1	9	9	9	9	99
	ellite Altitude	800 1200 1500 [km]	9	9	3	9	9	3	9	9	9	9	3	1	1	1	1	85
	Constellation Type	8 Walker IDs	0	0	1	9	9	3	0	0	3	9	3	9	9	9	9	73
	Comm. Downlink	Relay vs. Downlink	0	0	0	0	0	9	0	0	0	0	9	9	9	3	9	48
	Tactical Downlink	Yes vs. No	0	0	0	0	3	9	0	0	0	0	9	9	9	3	9	51
	Maneuver Package	1x, 2x, 4x	1	1	1	1	1	0	1	1	1	1	0	9	3	3	3	27
	Constellation Option	none, long-lead, spare	0	0	0	0	0	0	0	0	0	0	0	9	9	9	9	36

Design-Value Mapping (DVM):
Ensures alignment between Value-space and Design-space

Design-Value Mapping (DVM) Ensures Design Decisions Drive Value Delivery

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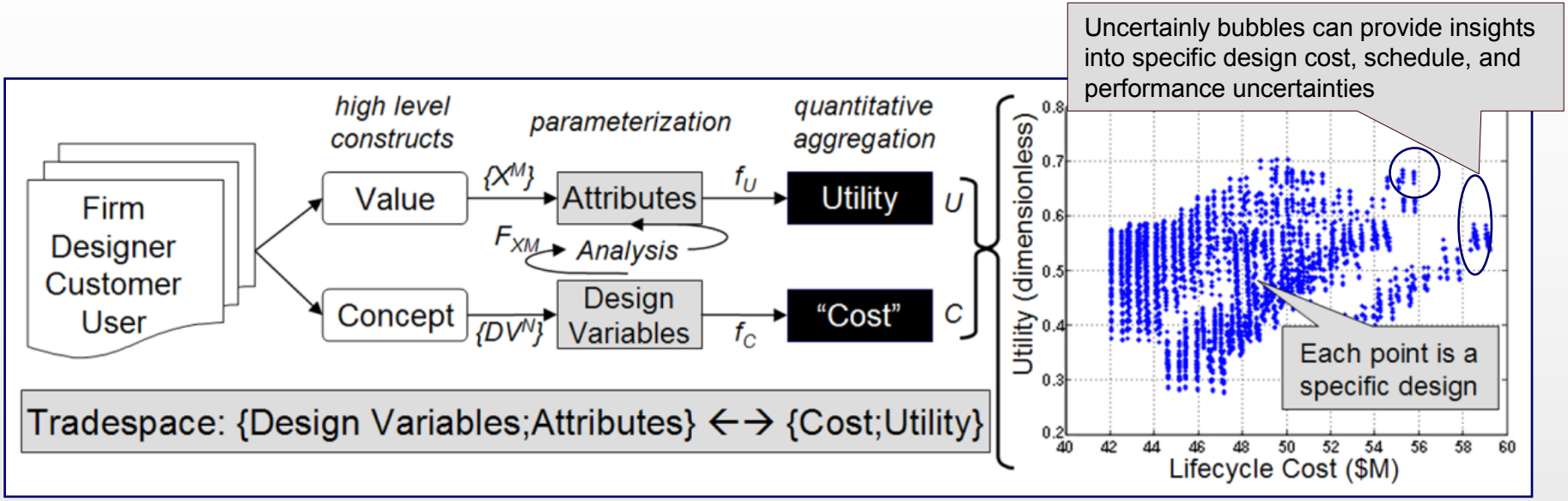
RSC Process 2:
Design Tradespace Evaluation



Compares system designs on a common, quantitative basis

- Uses computer-based models to compare thousands of designs
- Avoids limits of local point solutions
- Maps structure of stakeholder value onto design space
- Simulation can be used to account for design uncertainties (i.e., cost, schedule, performance uncertainty bubbles)

Design Tradespaces Provide High-level Insights into System-level Trade-offs. Detailed System-Level Design would follow-on Preferred System Concept Decisions

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RSC Process 3:
Epoch Development and Enumeration

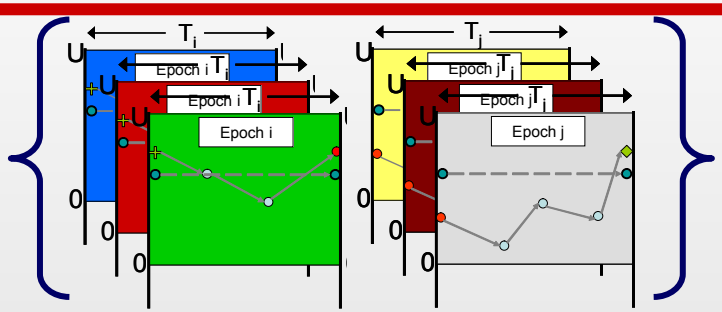
Definition of Epoch:

Time period with a fixed context and needs; characterized by static constraints, design concepts, available technologies, and articulated attributes (Ross 2006)

Define Epochs

Potential Contexts

Potential Needs



Construct Eras

Epoch Series

Dynamic Strategies

Parameterize Future Contexts for Design of Experiments Sampling of Scenarios

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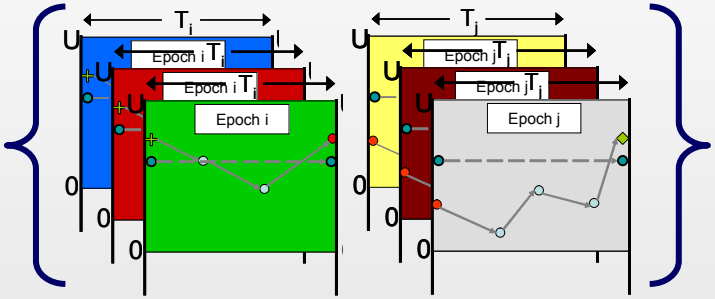
RSC Process 4:
Era Construction

Definition of Era:

System life with varying contexts and needs, formed as an ordered set of epochs; characterized by varying constraints, design concepts, available technologies, and articulated attributes

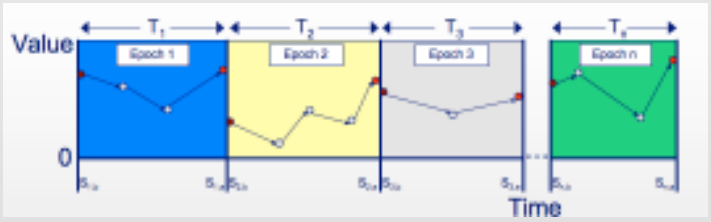
Define Epochs

- Potential Contexts
- Potential Needs



Construct Eras

- Epoch Series
- Dynamic Strategies



Discretization of Change Timeline into Short-run and Long-run Enables Analysis. Allows Evaluation of System Varying Performance over Possible Futures or Scenarios

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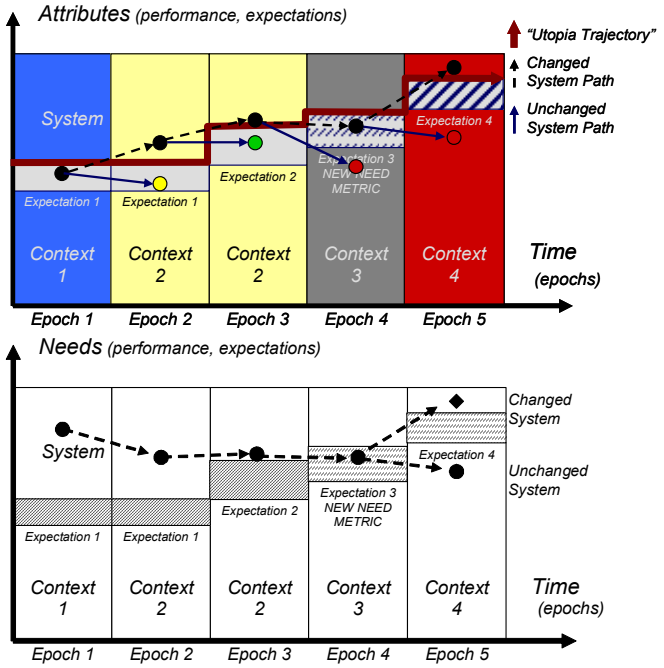
Using Eras to Generate System Evolution Strategies

Technical Goal: Develop time-based strategy for selecting designs that continue to deliver value to stakeholders across epochs

- Relevant metric: Minimized distance from "Utopia trajectory" of a design's performance in a given strategy



Trajectories across a system ***Era*** can be defined:

1. Set of expected Epochs
2. Strategy for selecting designs in each Epoch (e.g. min cost, max utility, etc.)

In RSC: Multiple Eras defined and system selection strategies compared to "Utopia trajectory"

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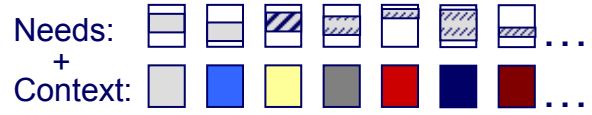
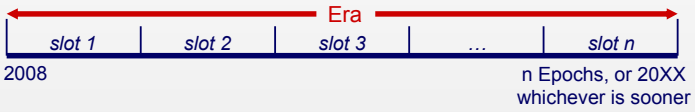
The Combinatorial Problem

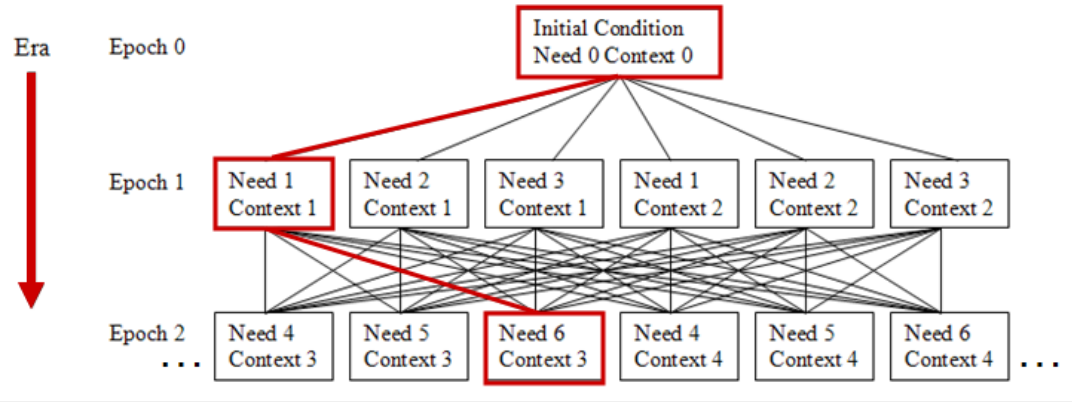
For generating a given *epoch:*

Needs:
+
Context:



…there are n "slots" in a given *era*





$N_{epochs1} = N_{contexts} * N_{needs}$ Number of distinct epochs for "slot 1" in era

$N_{epochs(total)} = (N_{contexts} * N_{needs}) * L_{era}$ Number of possible epochs for a given era

$N_{eras} = (N_{contexts} * N_{needs})^{Lera}$ Number of possible eras

Example with very small numbers:

If $N_{contexts}$=4, N_{needs}=3, L_{era}=4

$N_{epochs1}$=12, $N_{epochs(total)}$=48, N_{eras}=20736!!

Problem-space can grow more quickly than computational capabilities…

Possible solutions: clever enumeration, sampling strategies, leveraging symmetries and (in)dependence; intent of project is to confront this challenge

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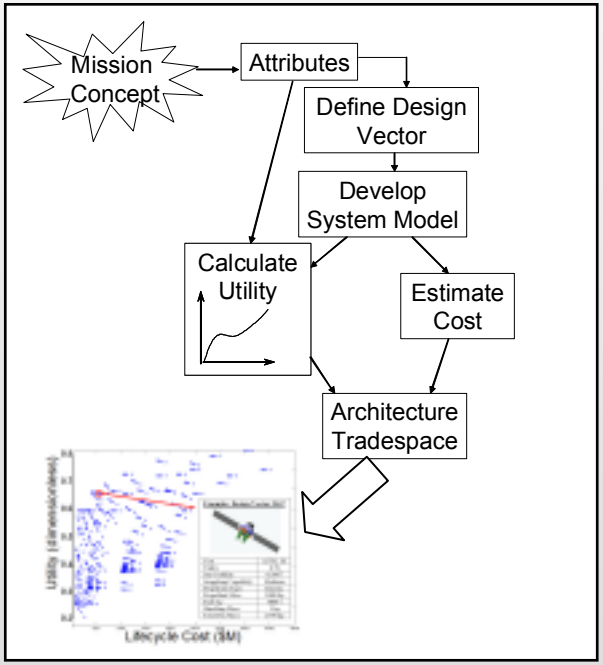
Satellite Radar System (SRS)

- Case study for developing method
- Used SRS Program Manager as key decision maker
- Process*
  - Identify key decision maker(s)
  - Scope the enterprise boundary
  - Determine key context variables
  - Interview decision maker(s)
  - Determine attributes
  - Determine design variables
  - Generate system model
  - Assess tradespace

Study state



*Team used Multi-Attribute Tradespace Exploration (MATE)

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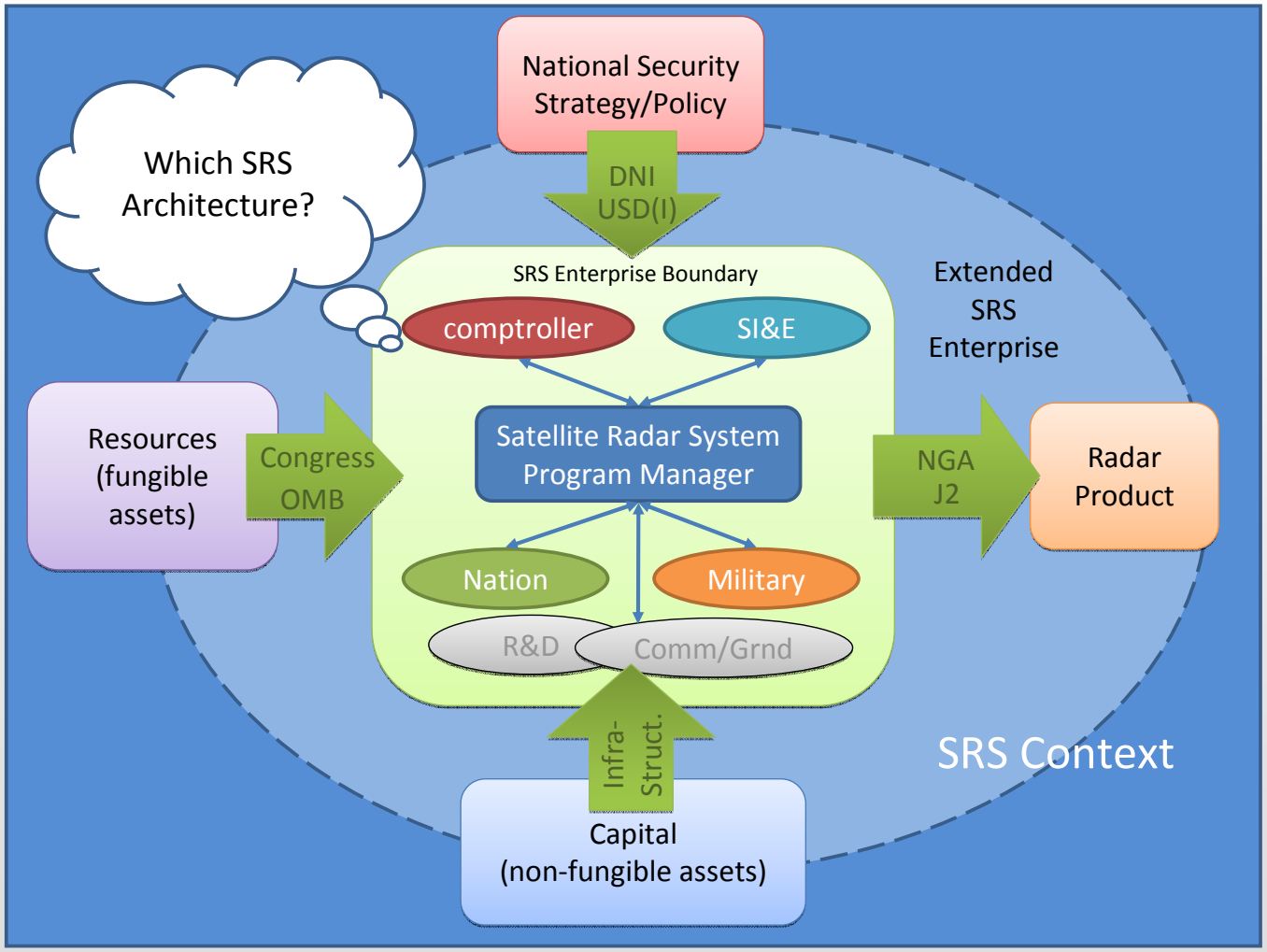
SRS Enterprise



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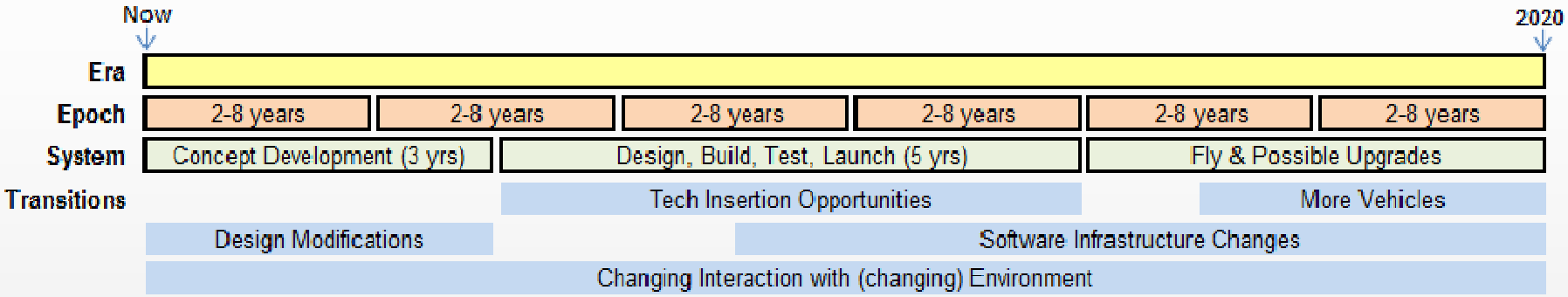
Structuring the Dynamic Context



- Each enterprise influence type has its own timescales for changing in the time period of interest
- System development itself has programmatic phases, whose duration may vary across system designs in a tradespace
- Epochs will need to be ordered in an era based on “rules” for allowable context transitions
- Boundary of analysis will help to encapsulate timescales

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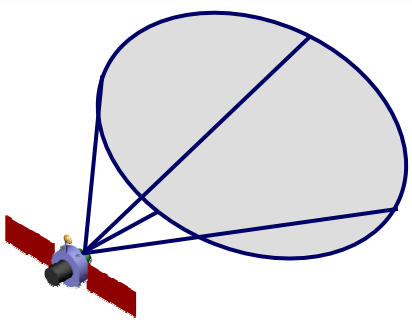
Bounding: Satellite Radar System

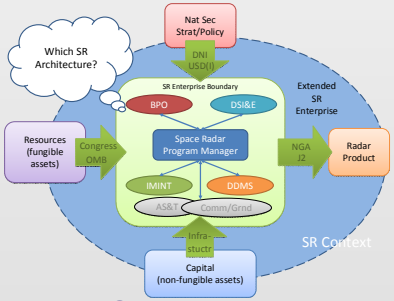


Exotic Technologies: Inflatables, Sails

Parabolic or AESA Antenna

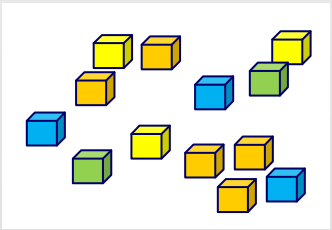
Schedule

Cost



Context Changes

Time Dynamic Strategies



Detailed Mission and Ground Models

Limited Horizontal Integration

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Attributes

Attribute: A decision maker-perceived metric that measures how well a *decision maker-defined* objective is met

	User Type (mission)	Attribute Name
ATTRIBUTES	Tactical data user (tracking)	Data Latency (tracking)
		Number Target Boxes
		Min. Detectable Target Velocity
		Min. Detectable Target Radar Cross-Section
		Target Acquisition Time
		Tracking Life
	Strategic data user (imaging)	Maximum Resolution
		Field of regard
		Number Targets Observed per Pass
		Revisit Frequency
		Geo-location Accuracy
		Data Latency (imaging)
	Programmatic "user" (schedule and cost)	Baseline Schedule
		Actual Schedule (under changing conditions)
		Baseline Cost
		Actual Cost (under changing conditions)

These attributes were elicited through semi-structured interviews with various stakeholders

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Design Variables

Design Variable: A designer-controlled quantitative parameter that reflects an aspect of a concept

DESIGN VARIABLES

Variable Type	Parametric Design Variable
Radar System Definition	Peak Transmitted Power
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	Bandwidth
	Antenna Area
	Antenna Type
Orbits	Altitude
	Constellation Configuration (inclination, Walker parameters)
Satellite System Definition	Communication Link Type
	Tactical Communication Able
	Processing Power on-board
	Maneuver Capability
	Design for Servicing

These design variables were generated through using the DVM to drive attribute value

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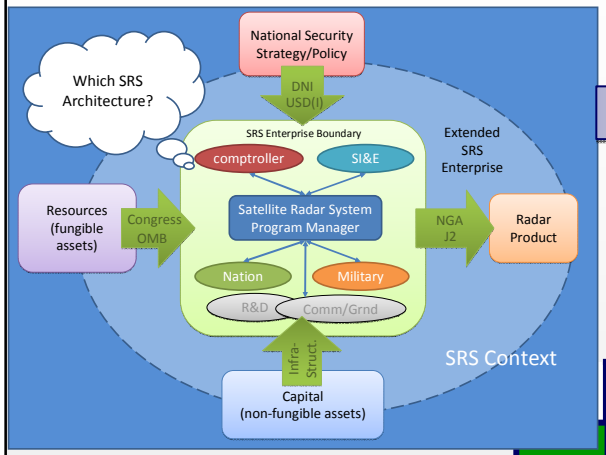
Epoch Variables



Enterprise scoping exercise informed the types of "epoch variables" encountered by program

EPOCH VARIABLES

Variable Type	Parametric Epoch Variable
Need Changes	Relative Priority change between different users/missions
	Target Radar Cross-Section
	Target Velocity
	Box Size
Available Infrastructure	TSAT communication system available
	Airborne Radar System available as complement
Technology Available	Antenna Mass per unit area and/or power
	Signal Processing Capability
	Efficiency of Spacecraft Subsystems (power in particular)
	STAP Technology available
Funding	Resource changes

Epoch variables allow for parameterization of some "context" drivers for system value

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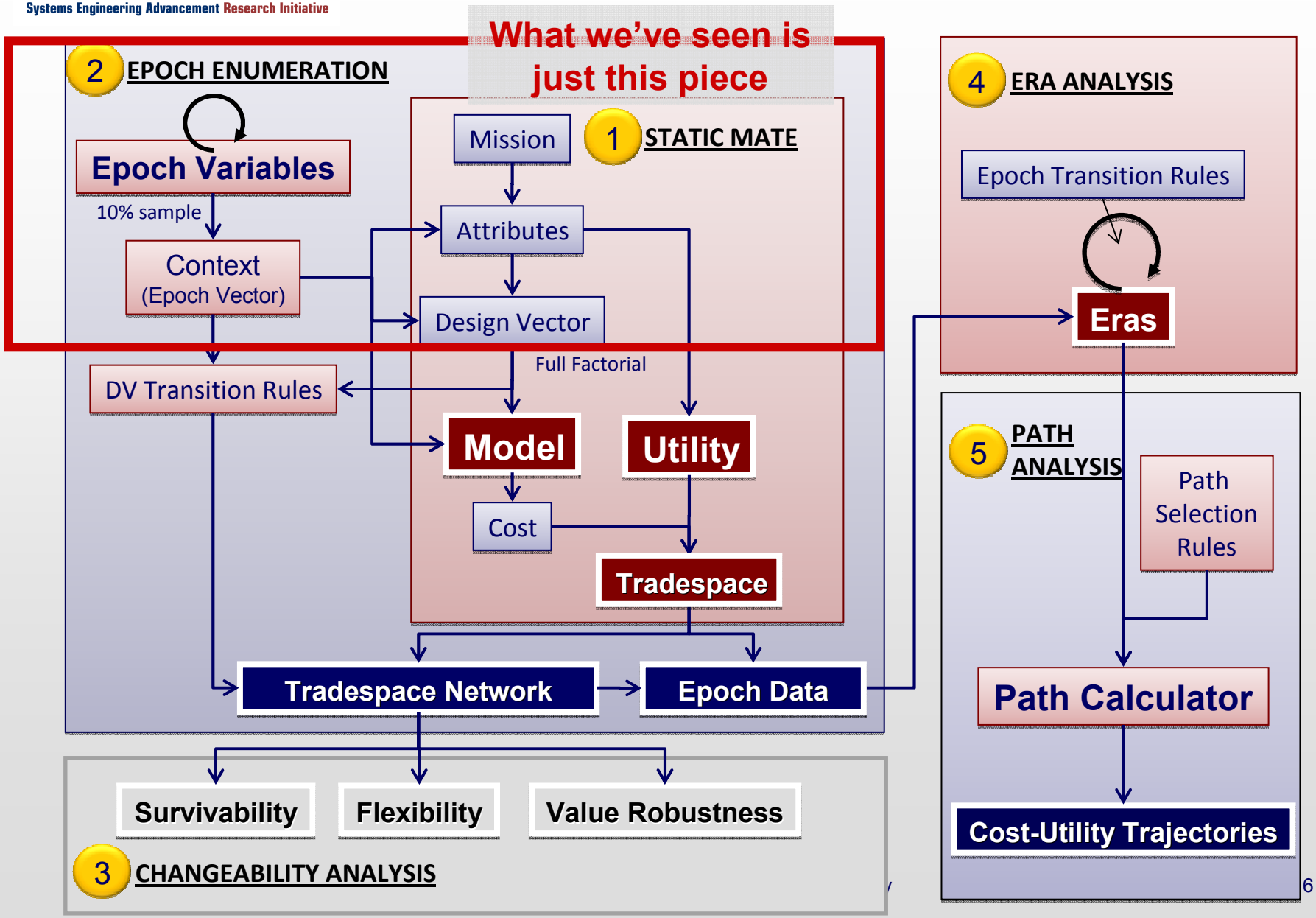
Overall Model Architecture



Anticipated Analytic Capabilities

Project continues through summer and coming fall, with tradespace modeling and dynamic analysis

Many Designs

Identify inconsistent expectations across stakeholders
Identify distribution of costs and benefits implications of designs
Identify cost and benefit tradeoffs across heterogeneous concepts

Changing Contexts

New technology
New concepts
Shifts in available SoS assets
Shifts in resource constraints
Shifts in policy
Disturbance threats

Changing Needs

New mission applications
New desired capabilities
Shifts in desired performance levels
Shifts in priorities of expectations
Shifts in stakeholders involved
New desire for “ilities”

Dynamic Strategies

Technology investment
System evolution
Dynamic SoS composition
Design for Changeability
Temporal resource allocation
Motivation for wargaming activities

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