SEAri Short Course Series

Course: PI.27s Value-driven Tradespace Exploration for System Design

Lecture: Lecture 8: Enhancing Systems Engineering Practice with Tradespace Exploration

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[PI.27s] Value-Driven Tradespace Exploration for System Design

Lecture 8
Enhancing Systems Engineering Practice with Tradespace Exploration

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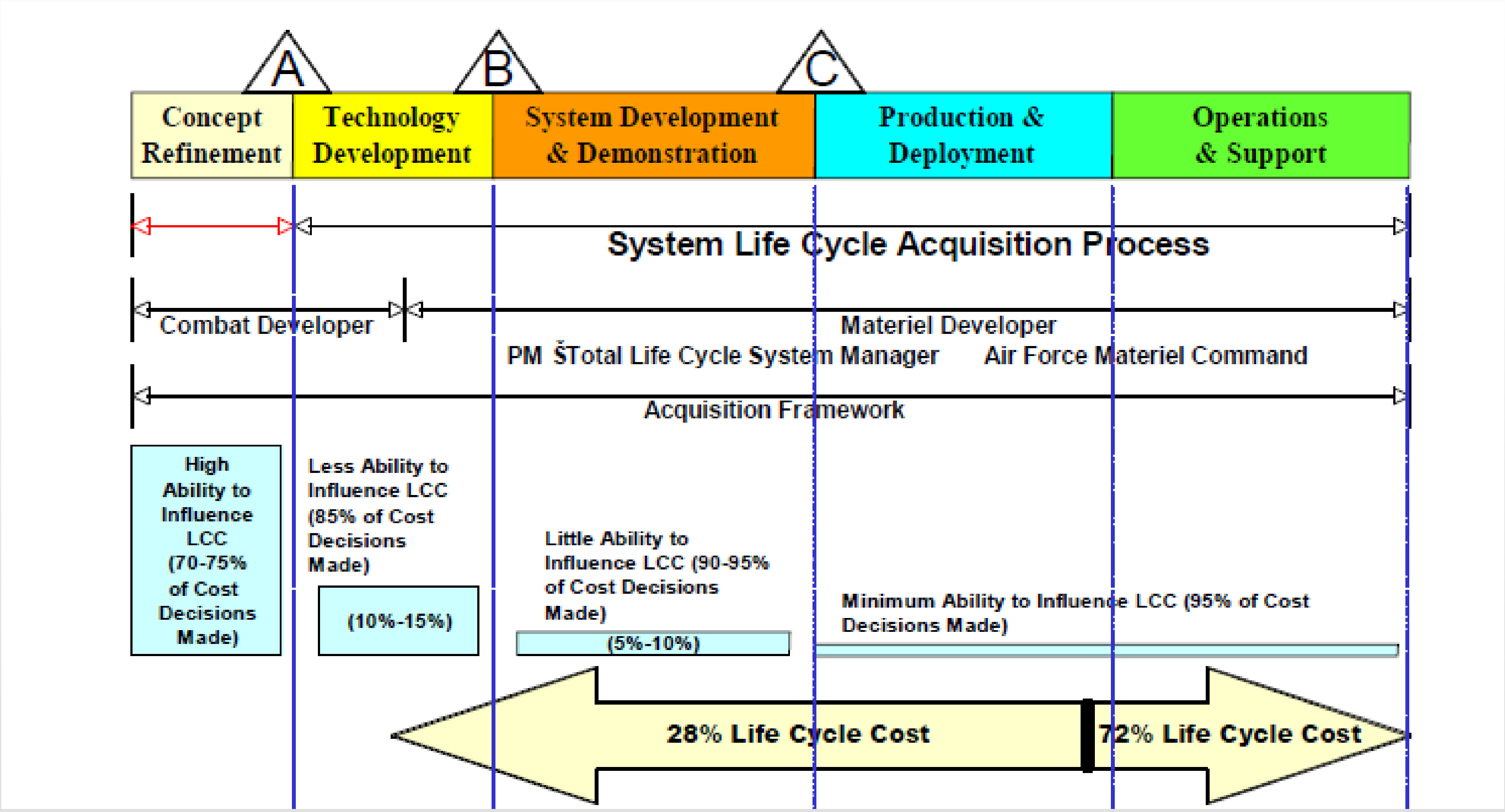
Outline

- Return on Investment of TSE
- Resources and Cost
- Alignment with Current Practices
- Socio-Technical Considerations
- MATE and ICE – example of integrating tradespace exploration with legacy approach
- Leadership Perspective

Potential for Significant ROI in Early Lifecycle Phase



SOURCE: R. Andrews, *An Overview of Acquisition Logistics,* Fort Belvoir, VA: Defense Acquisition University, 2003

Ability to Consider Alternative Concepts in Early Lifecycle

Modeling and simulation have become ever more central to the development of modern systems.

Unprecedented advances in digital processing have made <u>high-fidelity representation of systems and subsystems in computer models possible</u> from the simplest of systems to the most complex.

This has made it possible to <u>examine the projected performance of systems over wide excursions of design and environmental assumptions very early in the development process</u>, even prior to Milestone A.

NAE Report: Pre-Milestone A and Early-Phase Systems Engineering: A Retrospective Review and Benefits for Future Air Force Acquisition, 2008

ROI of Considering Alternative Concepts in Early Lifecycle

Many program managers fail to recognize the return-on-investment of planning for and using modeling and simulation up front in the systems engineering process, and therefore they reduce or eliminate the budget for modeling and simulation from their overall budgets.

A relatively minor up-front investment in modeling and simulation can actually reduce significantly the cost of the development program by identifying problems early and reducing both the time and the cost of full-scale testing.

Source: NAE Report: Pre-Milestone A and Early-Phase Systems Engineering: A Retrospective Review and Benefits for Future Air Force Acquisition, 2008

Recent Report Recommendation: Alternative Concepts in Early Lifecycle

How many alternatives need to be explored in the early lifecycle?

underachieving?

Pre-Milestone A/B Checklist

Concept Development

1. Have at least two alternative concepts to meet the need been evaluated?

   The purpose of alternatives is to stimulate thinking to find the simplest, fastest, and cheapest solution.

NAE Report: Pre-Milestone A and Early-Phase Systems Engineering: A Retrospective Review and Benefits for Future Air Force Acquisition, 2008

Resources Required for Tradespace Exploration

Budget	TSE is not free – there must be a budget to cover costs of the activity and enablers
People	TSE is an engineering activity and requires availability of skilled engineers
Infrastructure	TSE requires infrastructure – program Plan must include budget for software/computing resources, maintenance costs, etc.
Time	Good TSE requires access to key stakeholders so this time must be agreed to, planned, and scheduled
Commitment	TSE process must be carried out without sudden shortcuts that will lead to poor decisions (and blame on the TSE process)

Costs Incurred for Performing TSE

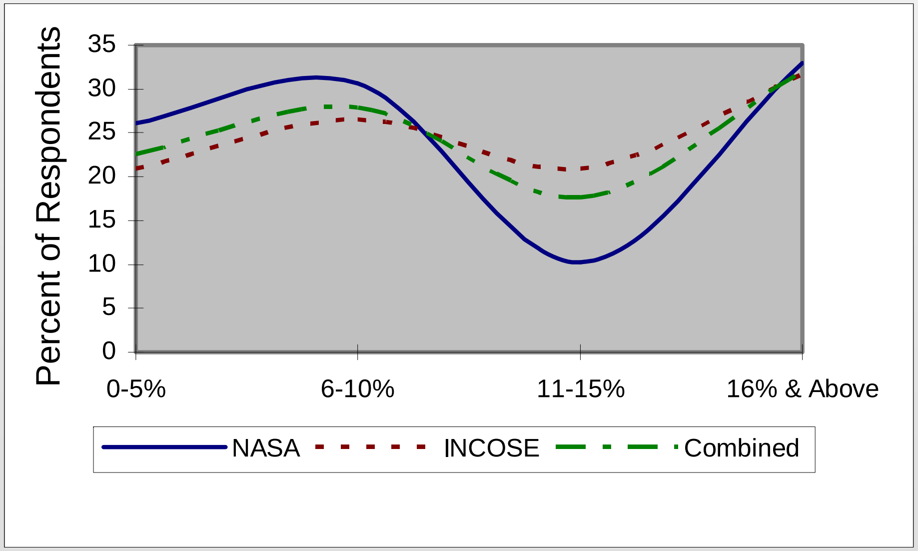
Costs include:

- Engineering labor costs
- Possibly training costs if first time/new staff
- Infrastructure: software, computing, etc.
- Costs to program for time of interviewed decision makers, etc.
- Costs for publishing and communicating results
- Costs for review sessions and follow-up

Cost of not performing tradespace studies are naturally greater – but lack of empirical evidence makes the justification of the investment difficulty

How Much Does It Cost?

- "Rule of thumb" – invest 10% or more of engineering budget in overall systems engineering activities (TSE is one)
- How much to invest in tradespace exploration depends upon:
  - nature of project
  - related uncertainty
  - criticality factors
  - precedence
  - available resources
  - and more…



Honour, 2004

Investing in Tradespace Exploration

- Can be difficult to convince program managers to invest adequate time and resources that are necessary to adequately perform tradespace studies
- Program cost and schedule pressures often drive looking only at current context or limit scope of tradespace
- Must deal with prevailing management perception *“Engineers will perform analysis until end of time unless stopped”*

Tradespace Exploration Scope

Value-driven tradespace exploration methods can be used to make better design decisions for all types of design problems

...designing a system of systems?

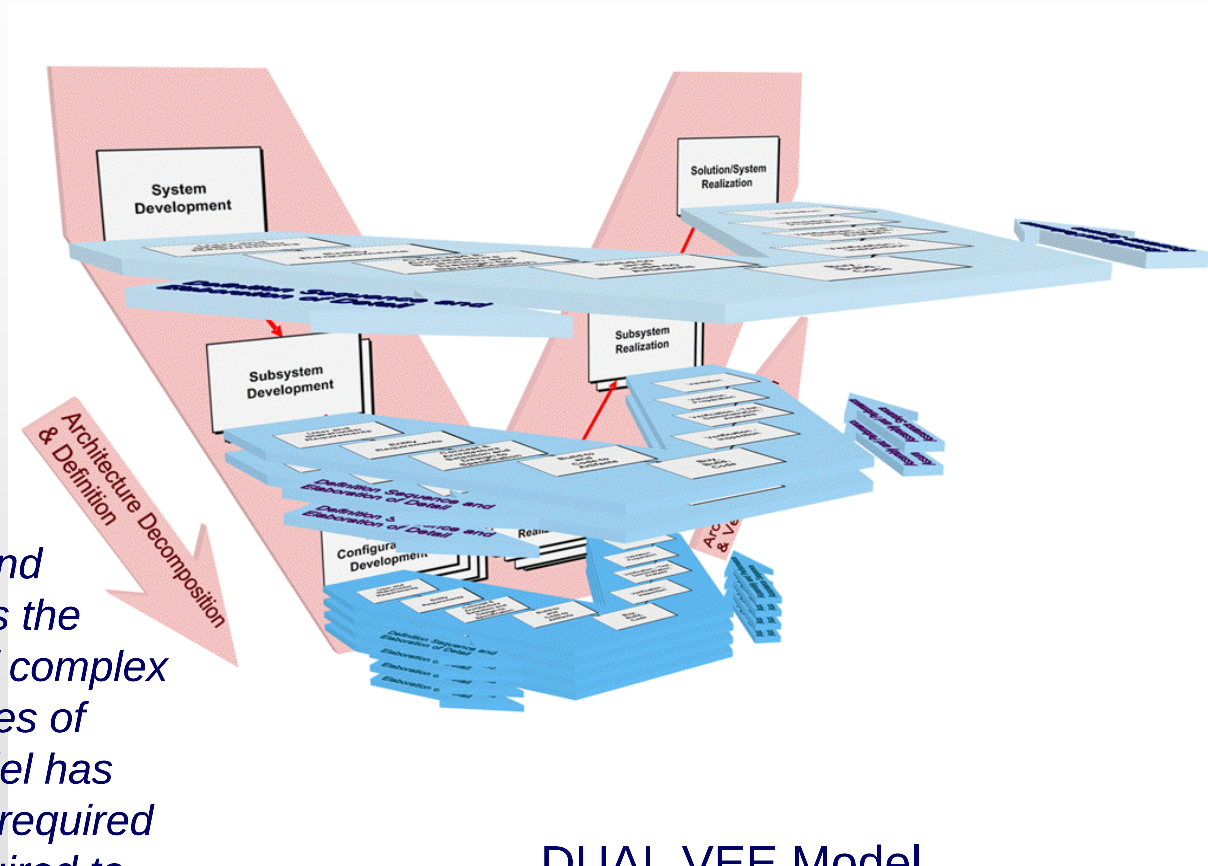
... designing product?

...a system?

Consideration must be given to level of abstraction and coordination of analyses

SEARI
Systems Engineering Advancement Research Initiative

Complex Environments Call for TSE at Multiple Levels of "VEE"



Development of systems and system of systems requires the concurrent development of complex architectures and the entities of those architectures. A model has been needed to depict the required multi aspect decisions required to ensure correct and progressive development of both architecture and entity baselines

DUAL VEE Model

Source: Forsberg and Mooz

Relationship to System Validation

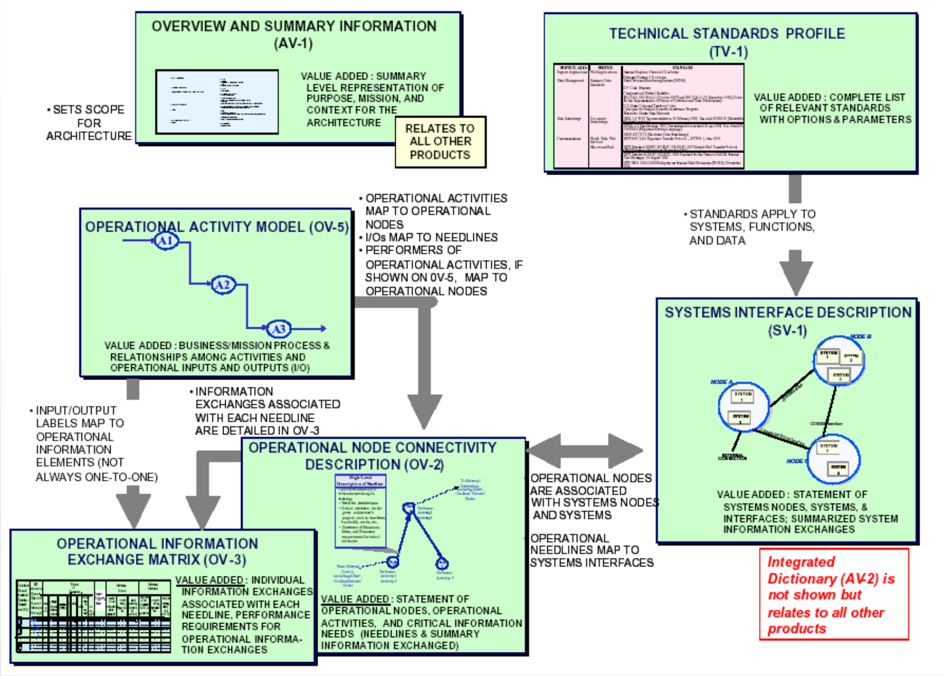
- Successful systems start the "validation" with stakeholders when design is still "on the back of an envelope"

- Tradespace exploration enables a better dialogue with key decision makers to enable early validation process

Architecture Frameworks (DODAF) TSE Creates/Informs Artifacts

Connects operational concepts and capabilities to technical architecture of DoD systems

- Improve acquisitions of major defense systems by providing a context for making resource allocation and trade-off decisions
- Aid interoperability and integration by ensuring systems fit into an integrated system-of-systems
- Conduct analysis
- Leverage complementary technologies
- Identify cost efficiencies



Originally intended as a communication tool

More descriptive, moving towards prescriptive

Where does TSE relate to CMMI process areas?

TSE relates to several areas of CMMI – TS and DAR being the most significant of these

Technical Solution (TS)

- An Engineering process area at Maturity Level 3

Purpose: The purpose of **Technical Solution (TS**) is to design, develop, and implement solutions to requirements. Solutions, designs, and implementations encompass products, product components, and product-related lifecycle processes either singly or in combination as appropriate.

Specific Practices by Goal

- SG 1 Select Product Component Solutions
  - **SP 1.1 Develop Alternative Solutions and Selection Criteria**
  - SP 1.2 Select Product Component Solutions
- SG 2 Develop the Design
  - SP 2.1 Design the Product or Product Component
  - SP 2.2 Establish a Technical Data Package
  - SP 2.3 Design Interfaces Using Criteria
  - SP 2.4 Perform Make, Buy, or Reuse Analyses
- SG 3 Implement the Product Design
  - SP 3.1 Implement the Design
  - SP 3.2 Develop Product Support Documentation

Process Areas
5.1 Causal Analysis and Resolution (CAR)
5.2 Configuration Management (CM)
5.3 Decision Analysis and Resolution (DAR)
5.4 Integrated Project Management +IPPD (IPM)
5.5 Measurement and Analysis (MA)
5.6 Organizational Innovation and Deployment (OID)
5.7 Organizational Process Definition +IPPD (OPD)
5.8 Organizational Process Focus (OPF)
5.9 Organizational Process Performance (OPP)
5.10 Organizational Training (OT)
5.11 Product Integration (PI)
5.12 Project Monitoring and Control (PMC)
5.13 Project Planning (PP)
5.14 Process and Product Quality Assurance (PPQA)
5.15 Quantitative Project Management (QPM)
5.16 Requirements Development (RD)
5.17 Requirements Management (REQM)
5.18 Risk Management (RSKM)
5.19 Supplier Agreement Management (SAM)
5.20 Technical Solution (TS)
5.21 Validation (VAL)
5.22 Verification (VER)

Where does TSE relate to CMMI process areas?

TSE relates to several areas of CMMI – TS and DAR being the most significant of these

Decision Analysis and Resolution (DAR)
Support process area at Maturity Level 3

Purpose: The purpose of **Decision Analysis and Resolution** (DAR) is to analyze possible decisions using a formal evaluation process that evaluates identified alternatives against established criteria.

Specific Practices by Goal

- **SG 1 Evaluate Alternatives**
  - SP 1.1 Establish Guidelines for Decision Analysis
  - SP 1.2 Establish Evaluation Criteria
  - SP 1.3 Identify Alternative Solutions
  - SP 1.4 Select Evaluation Methods
  - SP 1.5 Evaluate Alternatives
  - SP 1.6 Select Solutions

Process Areas
5.1 Causal Analysis and Resolution (CAR)
5.2 Configuration Management (CM)
5.3 Decision Analysis and Resolution (DAR)
5.4 Integrated Project Management +IPPD (IPM)
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Socio-Technical Considerations

Consider System Environment

	"Traditional" Environment	*"Newer Environment"*
Purpose	Development of single system to meet stakeholder requirements and performance	Evolving new system of systems capability by leveraging synergies of legacy systems
System Architecture	System architecture established early in lifecycle; remains relatively stable, TSE early	Dynamic adaptation of architecture as needs change requiring more continuous TSE
System Interoperability	Interoperability means integrating components and system to known external systems	Component systems can operate independently of SoS in a useful manner; interoperability more dynamic
System "ilities"	Reliability, Maintainability, Availability are typical ilities	Enhanced emphasis on "ilities" such as Flexibility, Adaptability, Composeability
Acquisition and Management	Centralized acquisition and management of the systems with well defined stakeholders	SoS component systems separately acquired, and continue to be managed and operated as independent systems; dynamic stakeholders
Anticipation of Needs	Concept phase activity to determine system needs	Intense concept phase analysis followed by continuous anticipation, ongoing TSE
Cost	Single/homogenous stakeholder group with stable cost/funding profile, similar measures of success	Multiple heterogeneous stakeholder groups with divergent cost goals and measures of success

Environment will shape who does TSE, when TSE is done, how TSE is done, where TSE is done, under what conditions TSE is done!

Co-located or Distributed Teams?

*At one time, __**many years ago, development of system capability was relatively simple**__ to orchestrate.*

The design and development of parts, engineering calculations, assembly, and testing was conducted by a small number of people. Those days are long gone.

Teams of people, sometimes numbering in the thousands are involved in the development of systems…

Source: Saunders, T., et al, System-of-Systems Engineering for Air Force Capability Development: Executive Summary and Annotated Brief, AF SAB TR -05-04, 2005

As a result, there may be multiple teams within a large program performing tradespace studies, leading to a planning challenge if there are interdependencies and relationships between the studies

Tradespace Exploration as an Activity in Distributed Enterprises

- Recent research studies have identified successful practices and lessons learned of collaborative distributed engineering teams
- Social and technical factors studied: collaboration scenarios, tools, knowledge and decision management, culture, motivations, others
- Even with the best technology infrastructure, the <u>issues of culture must be addressed</u>!

<u>Success Factor</u>: Invest in Up-front Planning Activities

Spending more time on the front- end activities and gaining team consensus shortens the implementation cycle. It avoids pitfalls as related to team mistrust, conflict, and mistakes that surface during implementation.

Cultural Differences in Concept Design Workforce

Linking Analysts and Architects

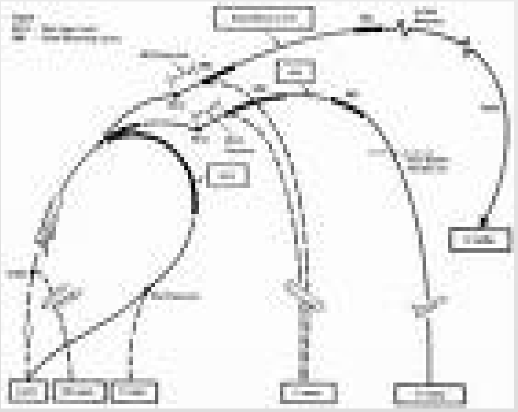
- Practice of conducting tradespace studies in the design of a system often occurs in two non-intersecting activities
- Leadership challenge to link the two activities and these two "cultures"

How can MATE be enhanced and applied so that it supports both architects and analysts?

What Architects Do…

WHAT ARCHITECTS DO

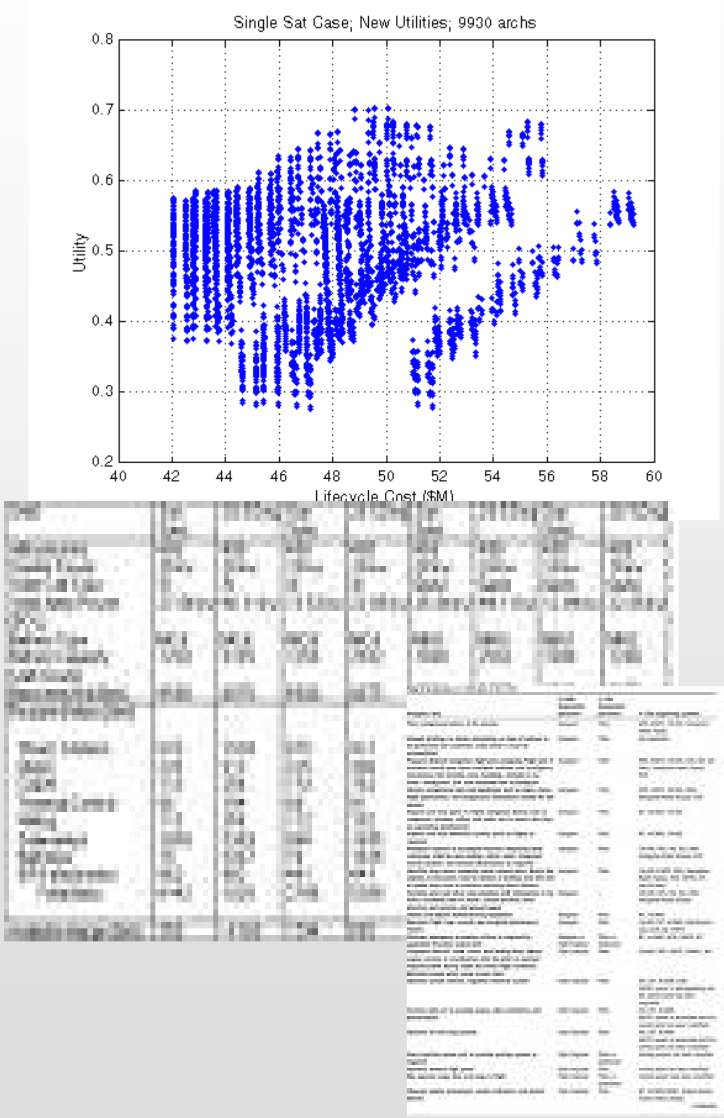
- Conceptual level through use of ‘storyboarding’ to define high-level scenarios
- Typically performed by system architects for purpose of defining system concepts and communicating with stakeholders in an effort to learn more about their needs, expectations, and preferences
- Outcome is usually a set of “cartoon-like” graphics, and narrative operational concepts or scenario descriptions



What Analysts Do…

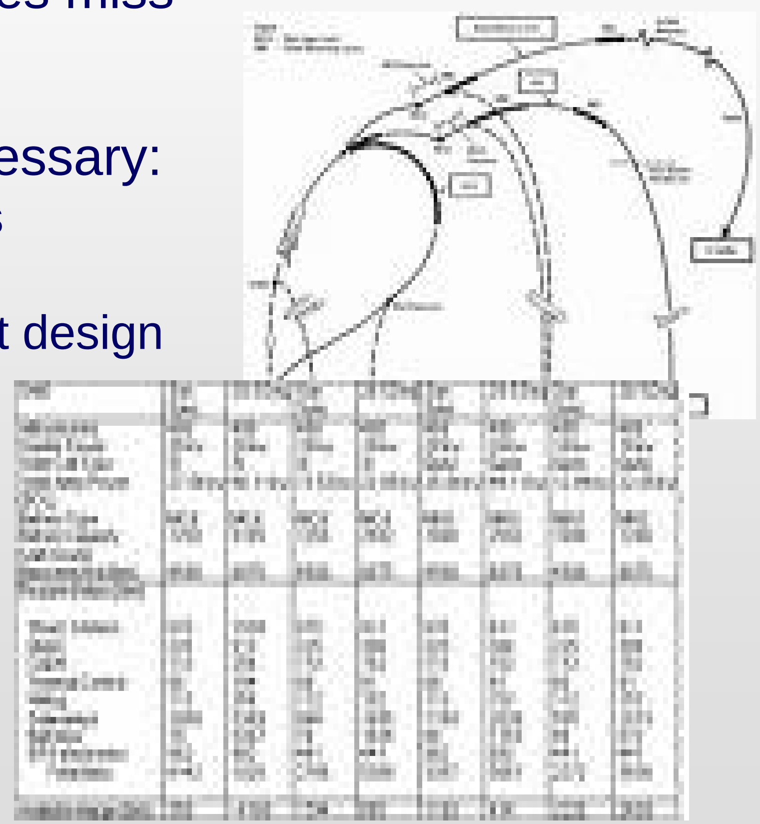
WHAT ANALYSTS DO

- Use deep analytic methods, usually modeling and simulation based.
- Activity is performed by technical specialists and analysts – often in separate organizational group
- Outcome in the form of a model and/or a highly technical report



Linking Architects and Analysis

- Shortfall of current approaches is that architecting and analysis are often somewhat independent
- Decoupled, these separate approaches miss the opportunities for fully informing architectural and design decisions
- Leadership interventions may be necessary:
  - Planning for integrated team activities
  - Asking the right questions in reviews
  - Use of enabling venues (e.g., concept design facilities)



Enabling Environment for Tradespace Exploration

While not necessary, tradespace exploration can be facilitated by availability of model-based environments

Physical collaboration venue can bring together relevant stakeholders

- Provides computing power and toolsets need to enact anticipation methods
- Enables effective display of complex data sets and analyses to facilitate communication

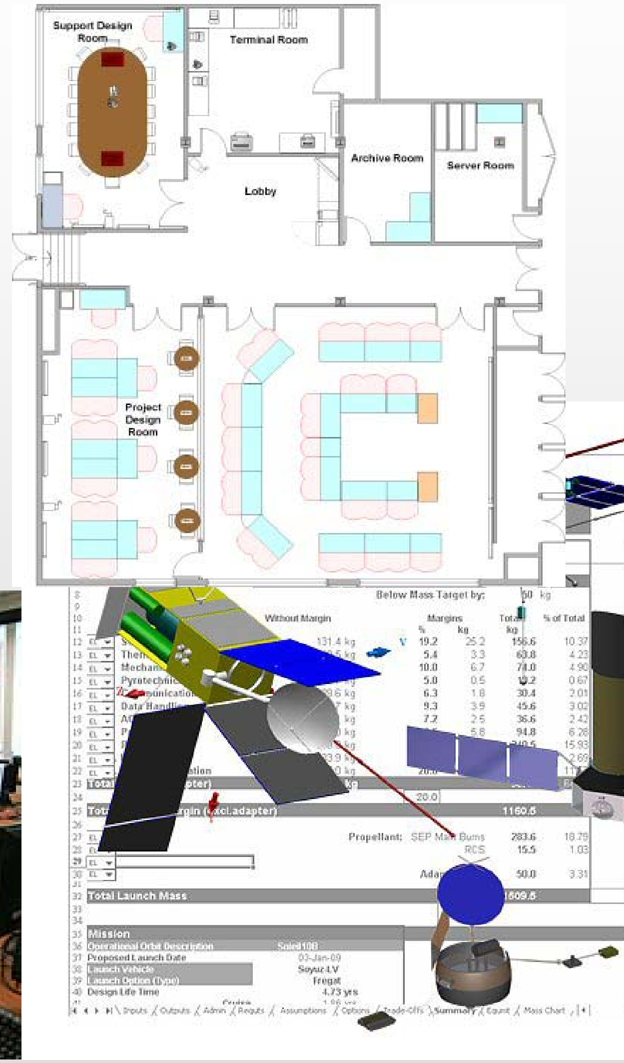
Tradespace exploration laboratories for creating models so that dynamic futures can be elaborated and their implications considered

We will discuss this further in Lecture 10…

Decade of Experience in Some Organizations in Using Integrated Concurrent Engineering Venues

Brings Together Architects and Analysts

Source: ESA



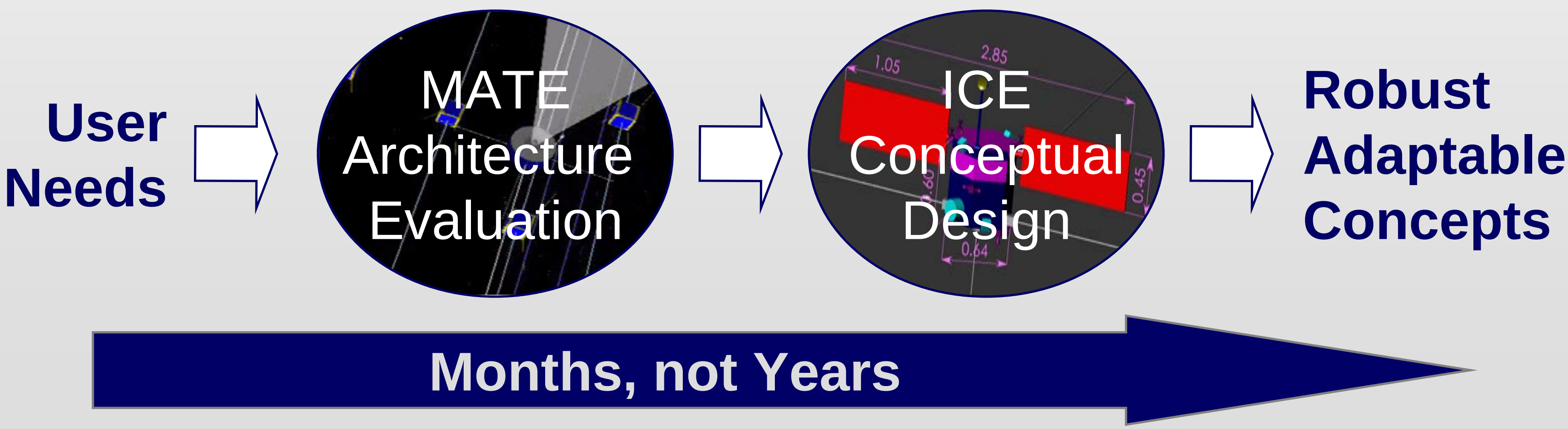
Integrated Concurrent Engineering is a systematic approach to integrated product development that emphasizes the response to customer expectations.

It embodies team values of cooperation, trust and sharing, in such a manner that decision making is by consensus, involving all perspectives in parallel, from the beginning of the product life-cycle.

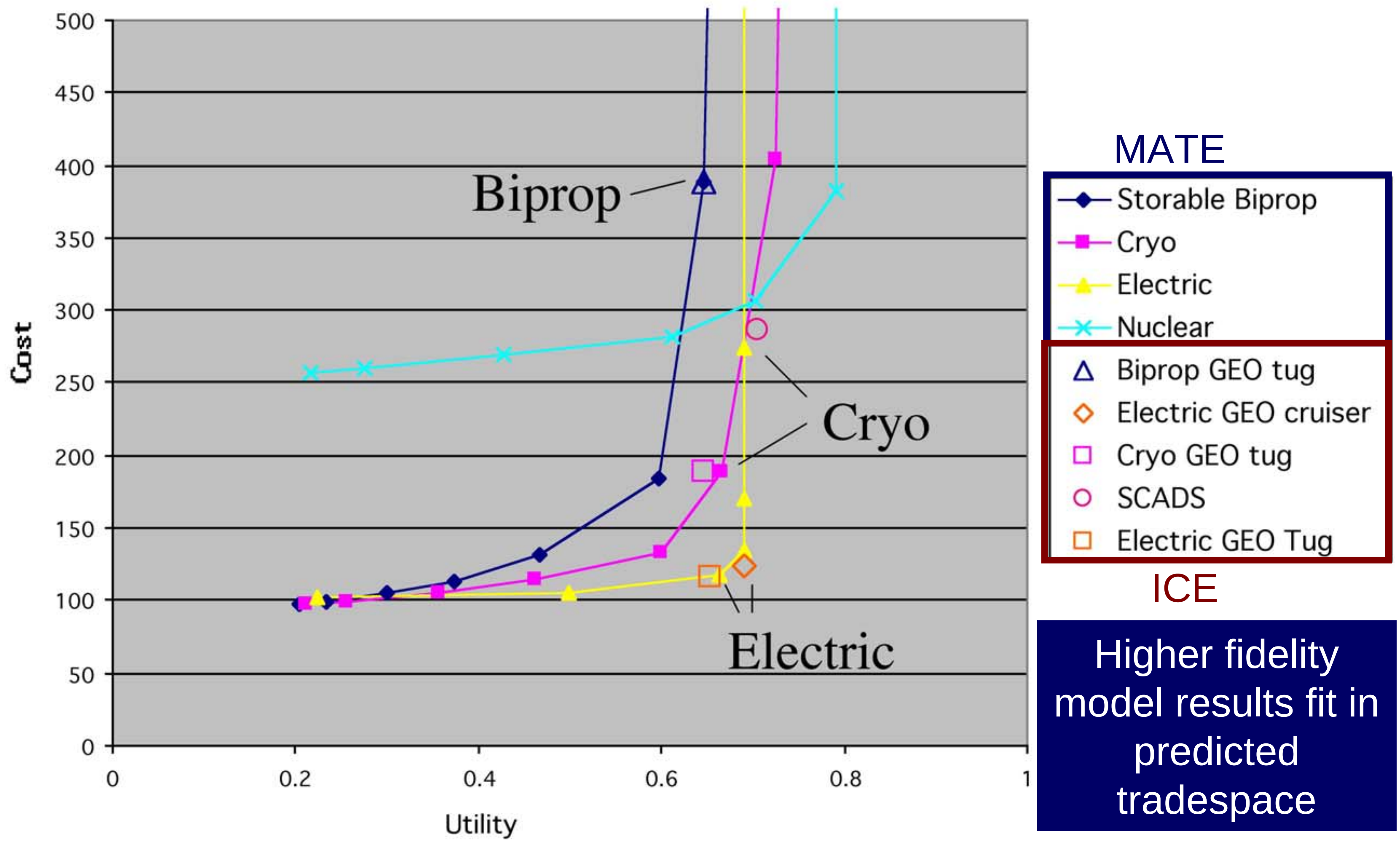
MATE with ICE Creates Synergistic Capability

- Linked method for progressing from vague user needs to conceptual/preliminary design very quickly
- MANY architectures, several/many designs considered
- Understanding trades allows selection of robust and adaptable concepts, consideration of policy, risk.

Previous deployment experiment showed benefits of combined MATE with ICE approach



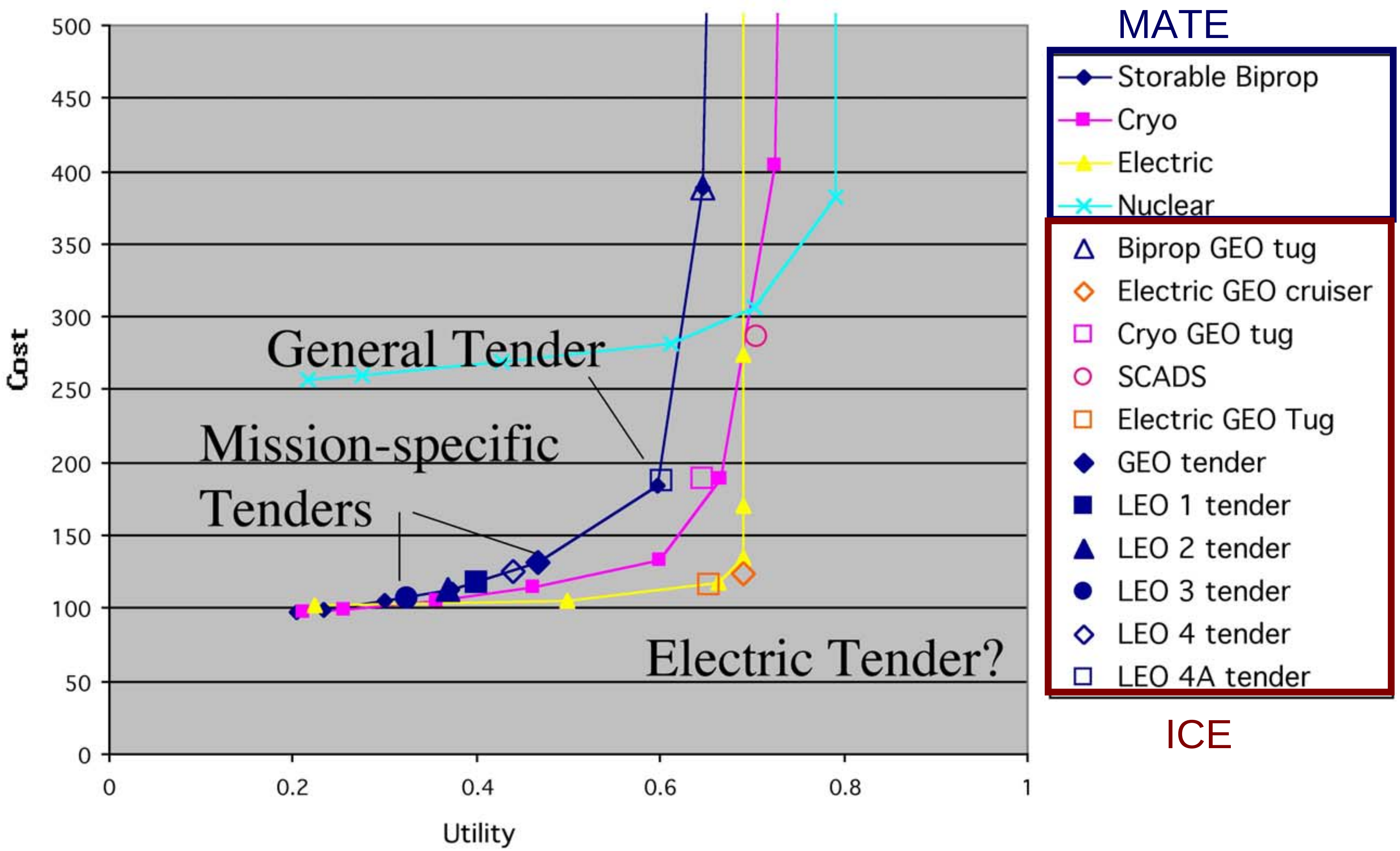
Tradespace Check - GEO Missions
ICE Results Plotted on MATE Tradespace



Higher fidelity model results fit in predicted tradespace

The GEO mission is near the “wall” for conventional propulsion

Tradespace Check - Tender Missions



The Tender missions are feasible with conventional propulsion

From the Leaders Perspective…

What if You Manage the Architecting and Design Effort? (slide 1 of 2)

Questions Program Leaders Should Ask …

- Were disconnects between perceived and actual preferences of decision makers identified and addressed?
- Were the impacts of the contexts (current and anticipated future) on the system adequately assessed?
- Did tradespace studies incorporate adequate interdisciplinary expert opinion and address diverse stakeholder interest?
- How have the architects and analysts collaborated to arrive at design selections?

What if You Manage the Architecting and Design Effort? (slide 2 of 2)

Questions Program Leaders Should Ask …

- Was analysis used to consider multiple concepts, and to drive the design selections?
- Were adequate technical feasibility studies conducted in the early stages of design (and how was "adequate" determined)?
- Was sufficient consideration given to the preferences of key decision makers?

Summary

- Investment in front-end has return on investment but still often obtain buy-in on its importance
  – TSE requires budget, people, infrastructure, time, commitment
- Tradespace exploration aligned with recommended good practices
- Complex systems/system-of-systems involve tradespace exploration throughout lifecycle
- Important to consider the socio-technical elements to ensure effective execution
- Leaders can enhance outcomes of tradespace exploration by asking the right questions