Systems Tradespace Analysis: Assessment of Current Capabilities and Future Directions

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Outline

• Background
• What is an ERS Tradespace?
• Tradespace Exploration Workshop
• Workshop Summary Points
• Tradespace Challenges
• Concluding Thoughts and Recommendations
ERS = Engineered Resilient Systems
- Transform system development process
- Effective, affordable, and adaptable systems
- Top 7 OSD S&T Priority for FYs 13-17

Tradespace Analysis Technical Thrust
- A key technology challenge within ERS
- Consider more alternatives, longer, across multiple and dynamic futures
- Current tradespace capabilities fall short

Tradespace Workshop held July 17-18, 2012
- Discuss desired capabilities
- Define gaps to begin prioritizing research
What Is An ERS Tradespace?

• A highly populated, multi-dimensional, combinatorial design space that cannot be visualized in all dimensions at once
  – More alternatives: generated earlier, kept longer, played out across multiple dynamic futures, while accounting for uncertainties

• Inputs and outputs are disparate, incompletely defined, and dependent, with non-linear relationships

• System behaviors are not predictable, and new behaviors emerge as initial conditions change

• Compromises required when trying to satisfy multiple objectives, from multiple stakeholders with independent perspectives

• Insufficiently explored with current practices
• Desired input from tradespace researchers on the challenges of performing tradespace exploration
• Discussed and shared knowledge in tradespace exploration processes, tools, theory, and application
• 40 participants from Academia, Government, Industry
  – Optimization, M&S, data visualization, complex systems, decision making, trade studies
• Held in conjunction with SERC workshop on Tradespace and Affordability; focus was “ilities”.
• Four critical capabilities
  – Broaden, Populate, Manage  – Search, Explore, Analyze
  – Link  – Act
• 36 research needs identified; 22 deemed near term (1-3 yrs)
**Scenario:** Tradespace explorers want to communicate interesting trends, features, and design compromises

**Problem Statement:** Tradespaces are established and explored ad hoc, contain insufficient or incorrect data for the decisions at hand, and are not navigated with intent to inform key decisions

**Current Capability:** Tradespace exploration performed informally using data that may not be viable for decision making

**Desired Capability:** Formal tradespace exploration process using data required for common decision types, for the purpose of supporting key decisions across the system lifecycle

**Near Term Needs:**
- Theories to classify types of decisions made by multiple decision makers across system lifecycle and hierarchy
- Knowledge management infrastructure linking decisions to evidence

**Out Year Needs:**
- Formal process for performing tradespace exploration
- Guidelines for defining necessary and sufficient tradespace exploration
**Scenario:** Decision makers draw conclusions using holistic system views and therefore want qualitative data such as risk, resilience, security, policy, and “ilities” in the tradespace

**Problem Statement:** Non-technical tradespace entries are difficult to articulate, predict, and scale, and therefore are typically suppressed or even ignored

**Current Capability:** Qualitative metrics are inconsistently assigned arbitrary ordinal rankings

**Desired Capability:** Early incorporation of qualitative factors in the tradespace, with quantified understanding of their impact on the system

**Near Term Needs:**
- Standard, formal, composable definitions
- Languages and tools for expressing, analyzing, and evaluating
- Models and relationships that quantitatively determine the impact of “ilities” on each other

**Out Year Needs:**
- Methods for trading qualitative factors

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**Tradespace Challenge 2:** Include non-quantitative factors and “ilities” in the tradespace

- Reliability: High
- Public Acceptance: Yay
- Policy Compliance: Full
- Resilience
- Reliability
- Risk
- Producibility
- Security
- Safety
- Integrates-ability

**Scaled System?**

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Scenario: Decision makers want real-time, dynamic tradespace engagement while they continually draw conclusions based on knowledge through exploration.

Problem Statement: Static tradespaces do not support changing preferences and inquiries, are repopulated slowly, and do not enable trust via interaction.

Current Capability: Tradespace snapshots presented upon request, inquiries are posed, tradespaces are supplemented, decision makers are summoned.

Desired Capability: A distributed, collaborative, real-time visualization environment that promotes trust through interaction with data.

Near Term Needs:
- Methods for communicating tradespace conclusions based on preferences and “viewing angles”
- Methods for logging search patterns and decisions

Out Year Needs:
- Normative and prescriptive approaches for interpreting, collapsing, and summarizing multi-dimensional spaces.
**Scenario:** Decision makers want to extend exploration of existing information into asking “what if” questions and then examine alternative futures

**Problem Statement:** Explosive growth in design and solution space limits the number of systems and operational contexts that can be explored

**Current Capability:** Scenarios minimally defined and not representative of future operations, real options, computational scenario planning

**Desired Capability:** Generate and evaluate multiple complex systems across multiple, dynamic life cycle futures, while accounting for emergent behaviors

**Near Term Needs:**
- Methods for classifying, modeling, propagating, and trading uncertainty
- Tools for rapidly assembling rich operational contexts for multiple stakeholders

**Out Year Needs:**
- Methods and tools for expressing alternative futures via dynamic and interactive visualization
**Scenario:** Human decision makers are presented with large, rich tradespaces from which to draw conclusions

**Problem Statement:** Decision makers do not know where to look, what to look for, when to look, or how to identify important features in a high-dimensional space

**Current Capability:** Evolutionary optimization algorithms for multi-objective problems in low-dimensional spaces

**Desired Capability:** Identify abstract and previously unknown objectives and constraints in the tradespace using search and classification algorithms

**Near Term Needs:**
- Effective and efficient search algorithms that can target selective regions
- Methods to apply optimization and machine learning methods to tradespace search

**Out Year Needs:**
- Approaches to filter and identify “interesting” areas of large tradespaces
- Mechanisms to guide search based on specified dimensions
**Scenario:** Decision makers want to progressively draw upon earlier tradespace knowledge during system development

**Problem Statement:** Later phase design decisions are inconsistent, incompatible, or infeasible with earlier decisions due to lack of retention of exploration sequences, decision rationale, and tradespace knowledge

**Current Capability:** New tradespace studies conducted with new data in each design phase or loosely linked to previous phases through transfer of personnel

**Desired Capability:** Persistent tradespace knowledge reused throughout the lifecycle

**Near Term Needs:**
- Methods for linking decisions: between stakeholders, throughout the lifecycle, and across the system hierarchy
- Empirical/historical based understanding of how decisions made through tradespace exploration have impacted programs

**Out Year Needs:**
- Methods for evolving the tradespace as information becomes available
Conclusions

• Current tradespace exploration capabilities are insufficient for envisioned ERS tradespace
  – Multiple complex systems across multiple dynamic futures

• Research areas identified that will enable the desired capabilities while addressing problems and challenges

• A tradespace is
  – Functional, perhaps even central to decision making
  – Visual and interactive
  – Dynamic over time
  – More than just a collection of points which each represent a design

• Consider the human aspects
  – Must compellingly communicate tradespace results
  – Social, psychological, and cognitive interaction with data