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Trade Space Exploration Throughout System Design

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Objective of our Trade Space Approach

- Support Trade Space Exploration
  - Artifacts, systems, system of systems, policies, plans, deterministic, stochastic
  - **Competing objectives (cost, performance, schedule, risk)**
  - Multiple decision makers

- Specifically: support decision making teams in exploring multi-objective trade spaces
  - Understanding the impact of requirements and constraints on cost and performance
  - Understanding how subproblems impact the total
  - Understanding how lower level uncertainties propagate
  - Identifying and resolving key “sources of tension” between stakeholders
  - Forming a group understanding of the problem
  - **Reaching a consensus decision on a solution**
  - Consolidate the choice

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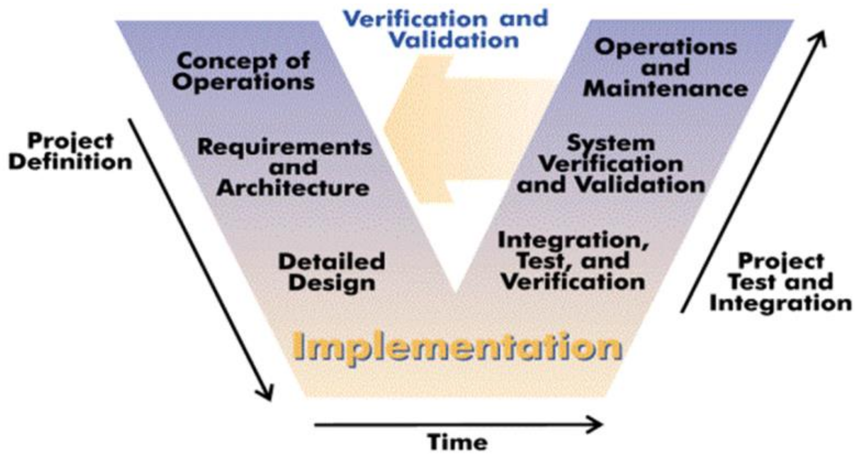
Systems Engineering

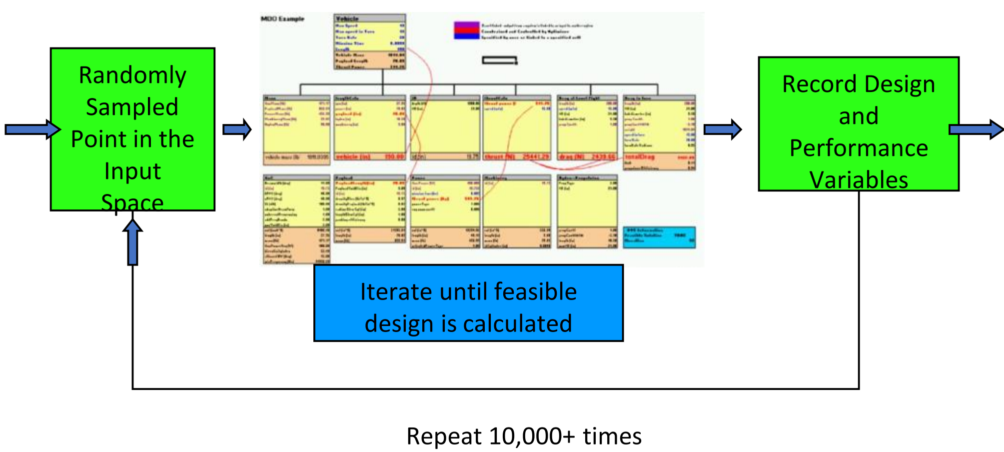


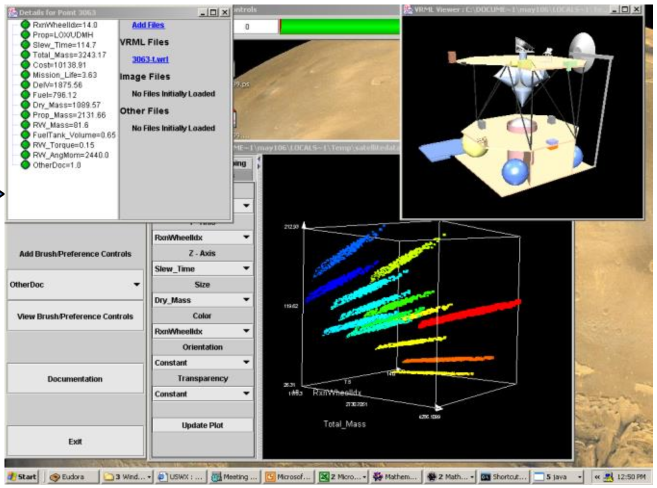
- Sponsor identifies system requirements from Concept of Operations
- Design agent flows down system requirements to derive subsystem requirements
- Subsystem designs independently created to meet requirements
- Prototype integrated, built, and tested
- Gaps identified from prototype and new requirements established

Traditional process is document oriented, time-consuming, expensive, and result in solutions that lack innovation and robustness

Trade Space Exploration – circa 2005

Build Models	Run Experiments	Explore
• Rule Capture • Dealing w/ Dependencies • Surrogates	• Focus on trade study of interest • Augment design with geometry and more	• Look for trends • Apply constraints • Visualize Pareto frontiers • Optimize





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Trade Space Exploration - Today

1. Identify sponsor, decision makers, subject matter experts, and tools and analysis models
2. Build/refine system model
   - Identify specific design question to be answered
   - Define current scope of technology options to explore
   - Connect/constrain subsystem models to best answer question
   - Identify gaps in analysis capabilities
3. Explore trade space resulting from system model
   - Generate a “consideration” set of observations of trade space
     - Design of Experiments on system model
     - Evaluate System Model at selected potential designs
4. Analyze design set from trade space
   - Visualize and Summarize results
   - Identify impact of technology options on system performance
   - Refine system model to further explore best technologies
5. Build, integrate, and test prototype(s)

Iterate, adding details to support building of prototype(s)

Identify Stakeholders

- Form the team
- Define the problem and scope
  - What is the purpose of the system?
  - What are the constraints on the system?
- Establish metrics for system requirements and constraints
  - What are the Key Performance Parameters (KPPs)?
- Gather tools and resources that are available
- Identify gaps – acquire/develop needed tools and information

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Build System Model

- Define the question to be answered **then look at the tools that are available**
  - The question is NOT what is the best design
  - The question IS what are the best set of technologies to consider for the design

- Enable "Apple-to-Apples" comparisons of alternative technology solutions

- Pick the right fidelity models to answer the current question
  - Fidelity should be sufficient to distinguish between potential technologies
  - Higher fidelity models do not guarantee better results – better to have models with similar fidelity
  - Desire is to rapidly generate a large set of potential designs – a trade space to explore

- Connect subsystems to evaluate system performance metrics
  - Subsystem models may consist of mathematical relationships, discrete choices on known quantities, or a combination of the two
  - Connect subsystem models to evaluate in a single pass or minimize number of closed loops

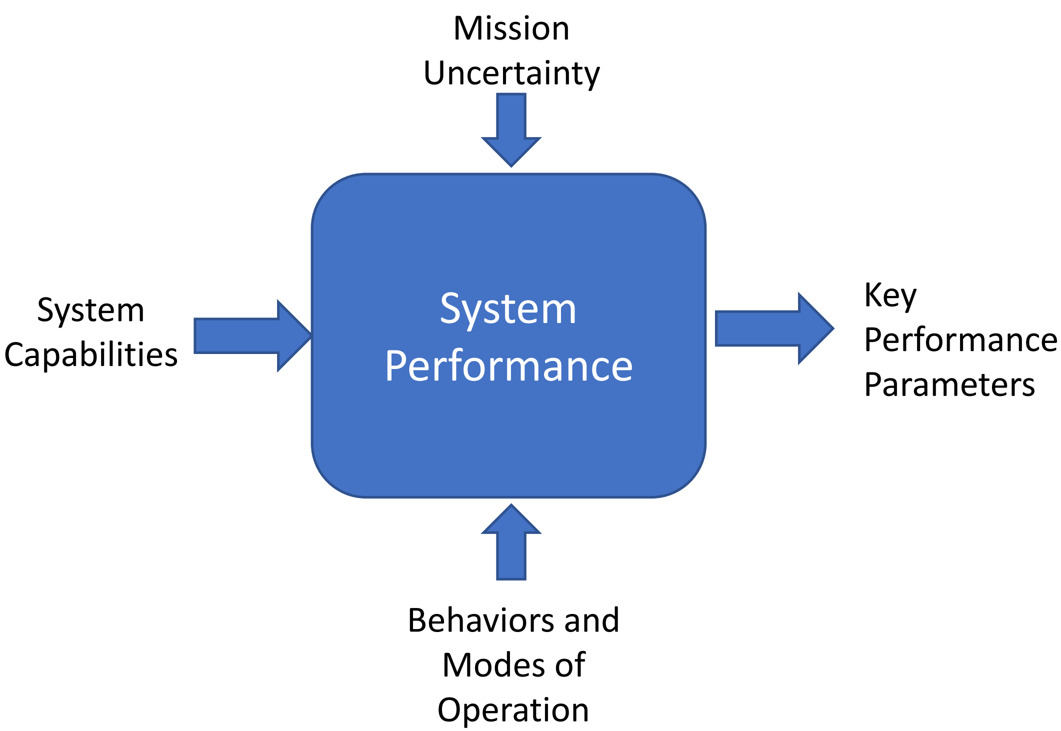
- Minimize constraint enforcement in system model
  - Allow max and min constraints to be violated
  - Simplifies execution – minimizes the number of closed loops
  - They can be imposed during post analysis – lets decision-makers understand the impact of setting requirements and constraints at certain values/levels

Concept of Operations

- Explore the space of system capabilities and concepts of operations

- Include Mission uncertainties to understand the impact of external system constraints an unknown missions have on performance

- Establish baseline CONOPs and system capability requirements to take into next phase



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Requirements and Architecture

Typical Underwater Vehicle Layout

Major Subsystems

- Autonomy & Control
- Payload
- Energy Storage
- Energy Conversion
- Propulsion
- Control Surfaces

Highly coupled system

System Properties/Capabilities

- Length
- Diameter
- Displacement
- Center of Buoyancy
- Weight
- Center of Gravity
- Outer Hull Shape
- Max/Min Speed
- Range
- Maneuverability

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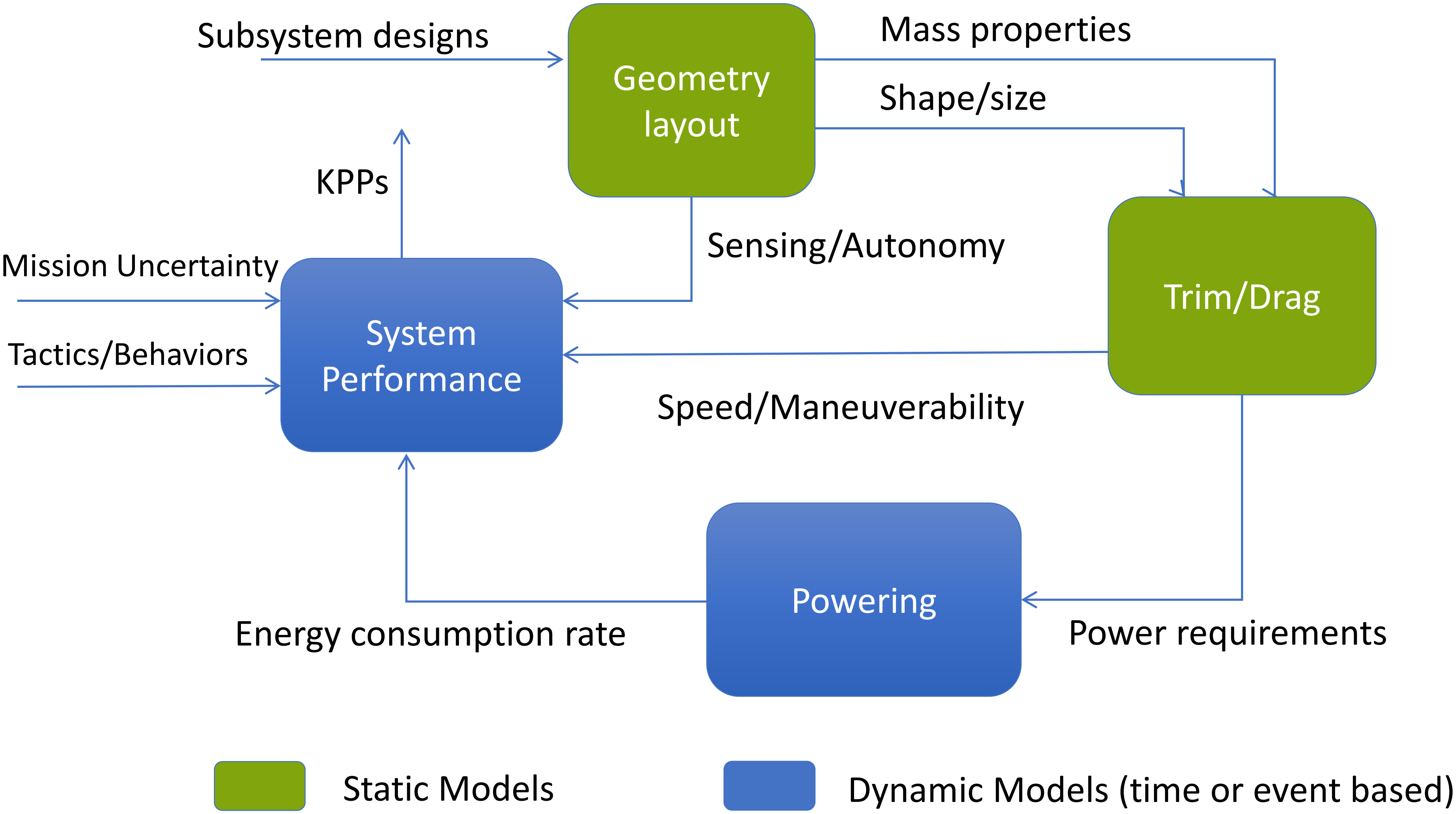
Detailed Design

- Replace subsystem performance predictions with detailed analyses/actual measurements
- Trade studies are focused on quantifying the current state of design
  - Managing sources of uncertainty
  - Understanding impact of under/over-performing subsystem designs
- Integrates the results of subsystem tests into system level performance estimates to verify requirements
- Quantify Reliability, Maintainability, Availability, and Cost

Implementation and Testing Iterations



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Conclusions

- ARL has been developing MBE tools and methods over the past 15 years
- Demonstrated their value on many recent programs
- The methods have proven effective aiding decision makers
  - Give insight into the impact of making a decision
  - Models include all of the complexity in a highly coupled system design throughout design process
- Every system is different – don't expect the same models to work effectively across programs – the process does work
- More important than tools and process is PEOPLE
  - Good listeners, thick-skinned, open-minded, and don't run down rabbit holes