THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

STEVENS INSTITUTE of TECHNOLOGY
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ART-016

Integrated Mission Equipment (IME) Architecture Process for Vertical Lift Systems

Sponsor: CCDC / AvMC

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12th Annual SERC Sponsor Research Review
HOSTED VIRTUALLY ON: November 18, 2020
www.sercuarc.org

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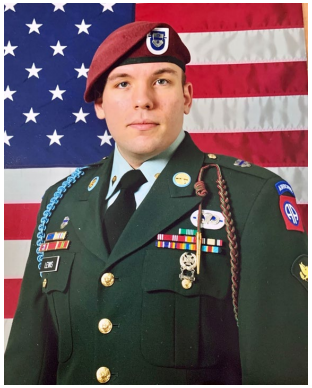

Andrew Thelen

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The Goal

Enable rapid integration of flight capable technology in a manner that is sustainable over the lifecycle of a platform, system, or component.

The Problem

A Comprehensive Architecture is Needed

- "To a large extent, the Military Services develop military systems through independent procurements using a unique set of program requirements implemented by a single vendor." (Comprehensive Architecture Strategy)
  - Often result in ad-hoc architectures that are the result of technical design decisions
- A process is needed that incorporates program business objectives

Need to Represent Business Objectives

- When program business objectives (which may vary from program to program) are identified as important they take the form of "desirements" or other weaker forms.
- Desirements are not treated as "equals" to performance requirements
  - Non-functional requirements are not included as normative requirements in typical requirements documents [Kazman 2000].
  - Desirements are often not defined in a common way
  - Leads to inconsistency between programs
  - Not verified/validated

Interoperability
Upgradeability
Maintainability
Etc.
→ Desirements

Operational and Performance Concerns

- Mission capability
- Performance
- Budget Non-Dependent
  - What can it do (reinforcing effects)
  - What does it enable (complimentary effects)
  - What needs does it satisfy (warfighting functions)
- Expressed often by the system

Business and non-Functional concerns

- Operation and Sustainment
- Future Cost and Schedule
- Update, Upgrade, Interoperate
- Budget Dependent
  - How often (operational tempo)
  - How many places (force structure)
  - How long (appropriations)
- Generally, time dependent
- Expressed often in the system's connections with other systems ie its Architecture

Business Objectives not Achieved Rigorously

- Non-functional requirements only achieved in an uncoordinated manner.
  - Long lead times, cumbersome improvement processes, limited hardware reuse, lack of software reuse…
- Combined with the extensive testing and airworthy qualification requirements, these factors have begun to affect the ability of the military community to deploy new capabilities in a timely manner to the Warfighter [Baldwin 2016].

Project Background

Business Objectives are Important to U.S.

- Government has had an initiative to acquire Systems with a Modular Open Architecture (MOSA) since 1995.
- Formed to help address larger strategic level business concerns on:
  - operation and sustainment costs
  - the time needed to field capabilities
  - the system's ability to interoperate across a range of DoD and non-DoD systems
  - the update and improvement of those capabilities over time.
- Requires low-level design decisions before a system has been selected.

Decision Making in the Army - Mission Command

- In higher levels of the Army, Mission Command is the preferred method to manage complexity in dynamic and uncertain environments
- Mission Command is a stakeholder value preference model used to direct a decision-making process
- It combines a centralized stakeholder intent with a decision execution at the lowest level of a hierarchy that will resolve an issue
- Used to execute the Commander's Intent

The Ideology Exists

- The existence of Mission Command highlights that the ideology needed to implement a comprehensive architecture strategy exists.
- The methods have not been identified or formed to implement the ideology in architecting to enable decision making that is consistent with the stakeholder, including their business objectives.

Project Objective

Our Mission

- Assist the Integrated Mission Equipment (IME) team in maturing the Comprehensive Architecture Strategy (CAS) approach by researching and developing methods for consistently applying CAS across multiple programs.
- Employ our expertise in systems engineering theory and practice, particularly the use of expressed preferences to guide decision making and mathematical alignment of contract incentives to carry this guidance across to industry.

Anticipated Impact

- We expect this architectural process to transition what has been an ad hoc method that is very dependent on “heroic designers”, into a more scientifically rigorous, repeatable, and reliable methodology.
- Prevent the “Vendor Lock” phenomena.
- Increase the reuse, upgradeability, expandability, and sustainability of developed and acquired systems
- Improve the interoperability of Army systems as a whole and with the Joint Force
- Increase the rate of innovation and the number of providers in the industrial base

Prior Army Work

Current Approach

- Document and manage Business and Technical Objectives
- Establish Key Business Drivers (KBDs) and the highest priority Quality Attributes in the form of Key Architectural Drivers (KADs) that are expressed in the Business Objective Requirements (BOR)
- Establish the elements of Performance and Capability that will be influenced by the architecture and express those elements through Technical Objective Requirements (TOR)
- Non-technical requirements are managed and contracted with the same rigor as a system's functional and performance requirements

Documentation Forming Current Foundation

- Common Architecture Strategy (CAS) paper
  - High level concept document
  - Defines the problem and provides a common language
- Architecture Derivation Method (ADM)
  - Describes the methodology and general process to derive and architecture from a set of stakeholder concerns
- Architecture Derivation Process
  - Detailed process document outlining step-by-step process
- ADW
  - A worksheet that holds coupling relationships for the ADM
- Governance Plan
  - Outlines the maintenance and communication of the various layers of architecture

Research Plan

Research Plan

- Long Term Goal: Provide a validated and rigorous systems architecture process based on evidence and theory from a broad collection of disciplines applied to a system of systems context.
  - Verify the intent of CAS.
  - Analyze CAS as a transformational system in a complex environment.
  - Make recommendations for improving the effectiveness of CAS itself.
  - Better integrate CAS with the acquisition and engineering environment.
  - Improve the transition of CAS into wider usage.

Research Plan

2 Years

- 3/20-10/20 — Exploration and Problem Definition
- 10/20-11/21 — Methods Identification and Recommendations
- 12/21-3/22 — Findings Dissemination and Training

Research Plan

- Four key topics concerning preferences are investigated: Elicitation, Representation, Communication, and Execution.
- The research is identifying current capabilities of a broad collection of fields including engineering, psychology, business, and marketing for implementation into CAS.
- Approaches based on evidence and have been rigorously validated in their previous contexts will be implemented in CAS, with the approaches' theoretical and validation limitations characterized within this new context.

Stakeholders

ELICITATION

Statements & Desires

REPRESENTATION

Preferences

COMMUNICATION

Structure & Incentives

EXECUTION

Decision Making

Exploration and Problem Definition:

Rigor in Systems Architecting

Rigor in Systems Architecting – Question

- To identify rigorous methods, we must first understand what rigor currently exists in systems architecting.
- The current method for solving architectural problems is a combination of mathematical models and heuristics.
- Heuristics are used when there is no way to mathematically model the problem at hand.
- *Where do these heuristics come from?*
- *What evidence exists that shows a heuristic is a trustworthy tool?*

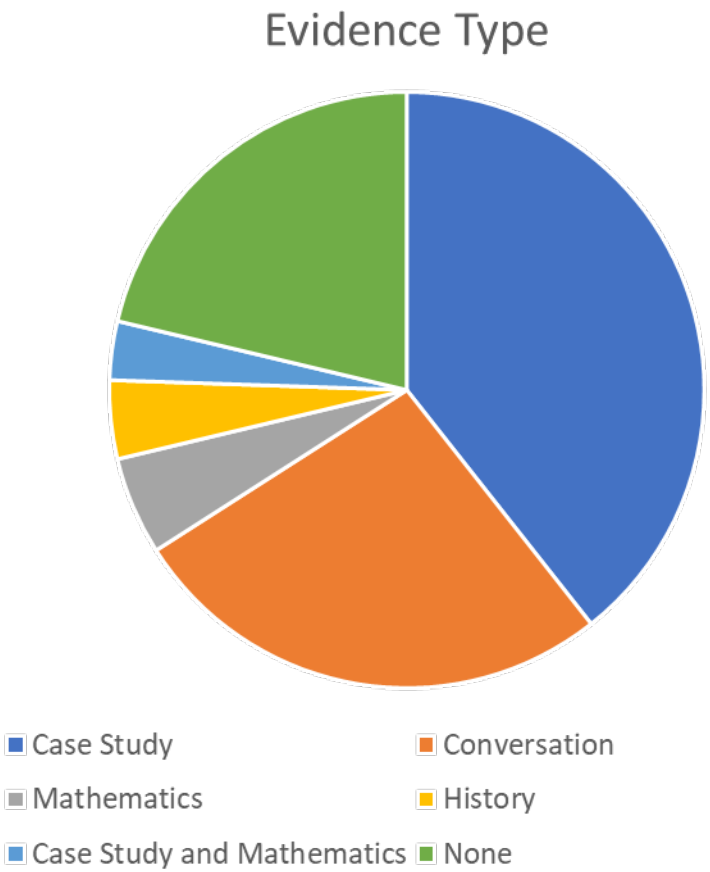
Rigor in Systems Architecting – Methodology

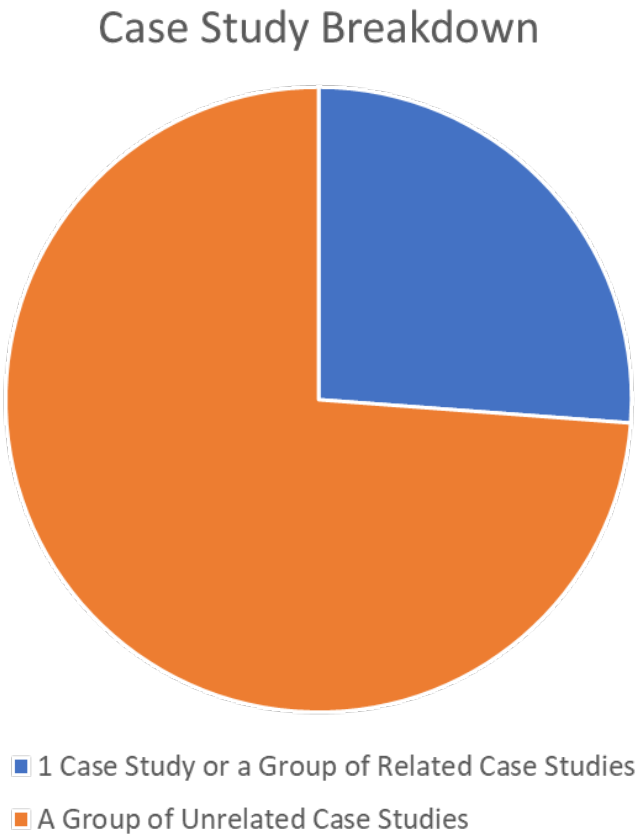
- Collect heuristics from primary Systems Architecting texts to form a database
  - "The Art of Systems Architecting" by Maier and Rechtin
  - "Augustine's Laws" by Augustine
  - "Systems Architecting" by Rechtin
  - "System Architecture" by Crawley, Cameron, and Selva
  - Main source of heuristics in the database is the appendix in the Maier and Rechtin book and Augustine's Laws
- Identify evidence used to support heuristics
- Categorize evidence and the architecture process they reference.

Rigor in Systems Architecting – Methodology

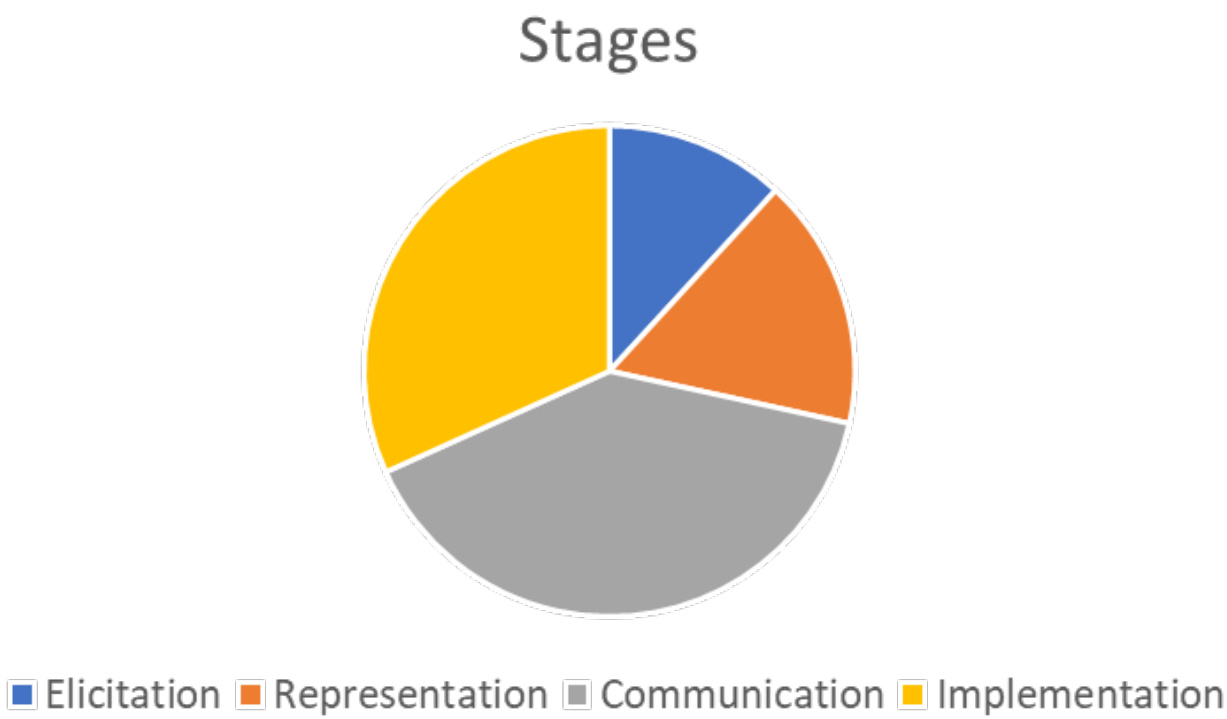
- Evidence supporting heuristics
  - results of tracing citations
- Evidence coding
  - Case study (or multiple case studies), mathematics, history, conversation, or no further evidence found from given references.
- Additional Coding
  - Part of the architecting process heuristic relates to
  - Systems vs Architecting
  - General vs Domain Specific

Rigor in Systems Architecting – Preliminary Results





Rigor in Systems Architecting – Preliminary Results

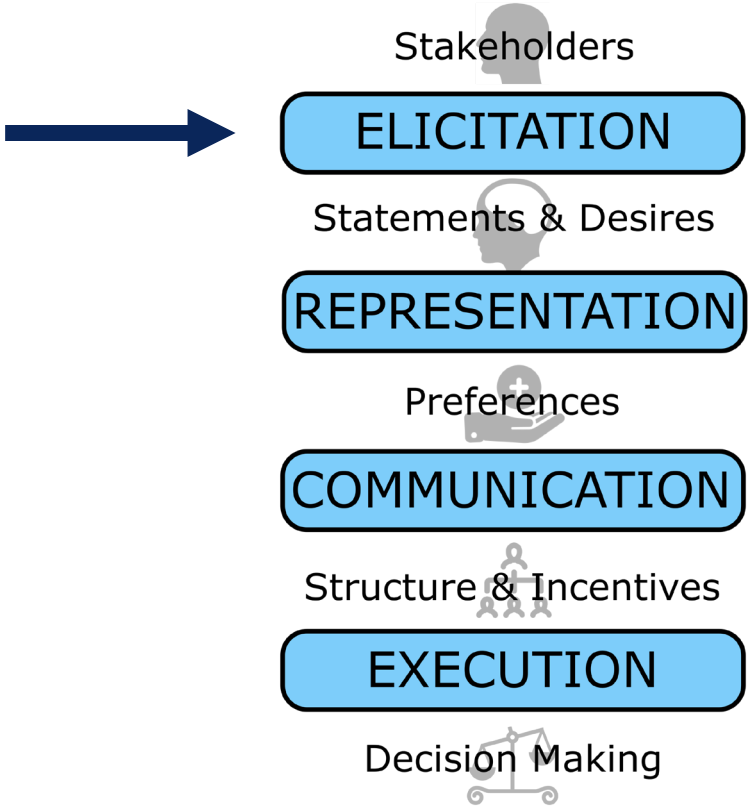


Rigor in Systems Architecting – Preliminary Results

- The basis for much of Systems Architecting lacks rigor.
- A “start from scratch” approach may be necessary.
- Adoption from other disciplines may be beneficial to provide grounding to methods.
  - Assumptions and contexts must be understood

Exploration and Problem Definition:

Elicitation of Preferences



Current Methods to Elicit Stakeholder Preferences

Current Methods	Problems	Search Areas for Rigorous methods
Scenarios, Document Analysis, & Workshops	-Does not capture full risk preference -Highly subjective -Not Falsifiable	Engineering Design Psychology Marketing

Elicitation of Preferences – Challenges

- Many of the current approaches used in design engineering and marketing may not be easily adapted for Architecting/Systems of Systems
  - Surveys
  - Conjoint Analysis

If you were in the market for your next vehicle and these were the only alternatives, which would you choose?

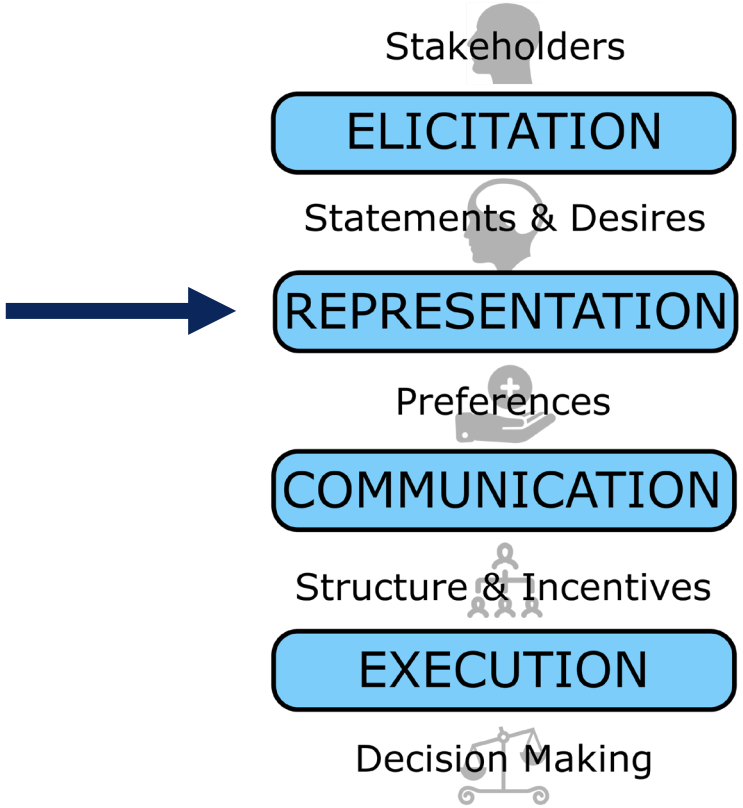
Brand:	Ford	Chevy	Ford	Dodge
Type:	SUV	Truck	Truck	Truck
Engine:	V6, 3.6 liter	V8, 5.7 liter	V8, 4.2 liter	V8, 4.8 liter
Price:	$36,599	$42,999	$42,999	$45,999
	Selected	Select	Select	Select

Elicitation of Preferences – Next Steps

- Identification of approaches from Psychology, Marketing, Design Engineering, Systems Engineering
  - Characterize assumptions and context
- Select and Adapt approach into CAS
- Implement and Demonstrate

Exploration and Problem Definition:

Representation of Preferences



Current Methods to Represent Stakeholder Preferences

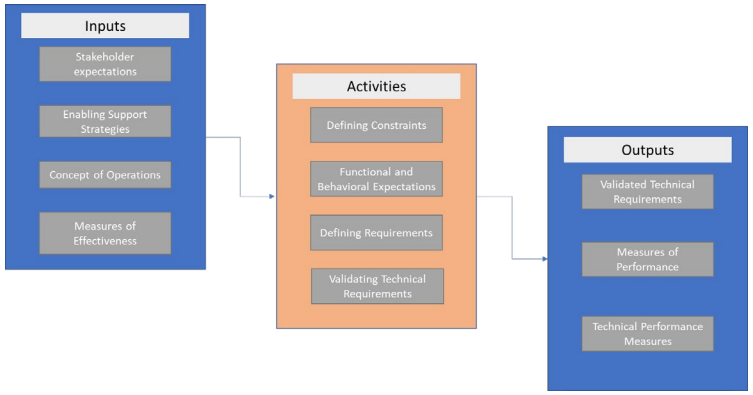
Current Methods	Problems	Search Areas for Rigorous Methods
Documented Statements and forum results are used with forcing functions and heuristics to write requirement statements	-Relies on un-Validated coupling Heuristics to drive process -Does not communicate risk & temporal preference -Leads to limited exploration of design space	Value-Driven Design Multidisciplinary Design Optimization Value-Based Requirements

Representing Preferences - Questions

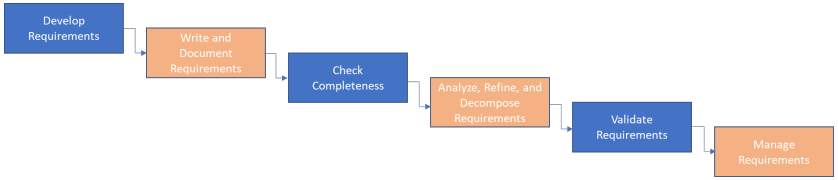
- The most common representations of preferences are requirements, assessments, requests for proposals, and objective functions
- *What are the processes currently used to form these common representations of preferences?*
- *Are Value-Based Requirements applicable?*

Representing Preferences – Processes

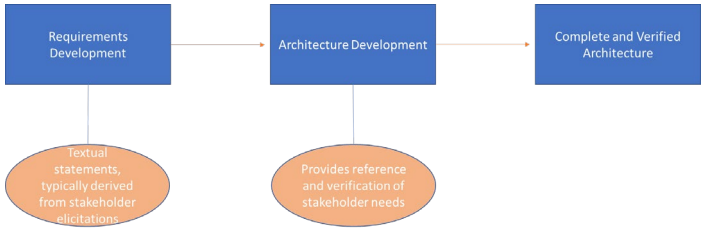
- NASA Requirements Process



- DAU Requirements Process

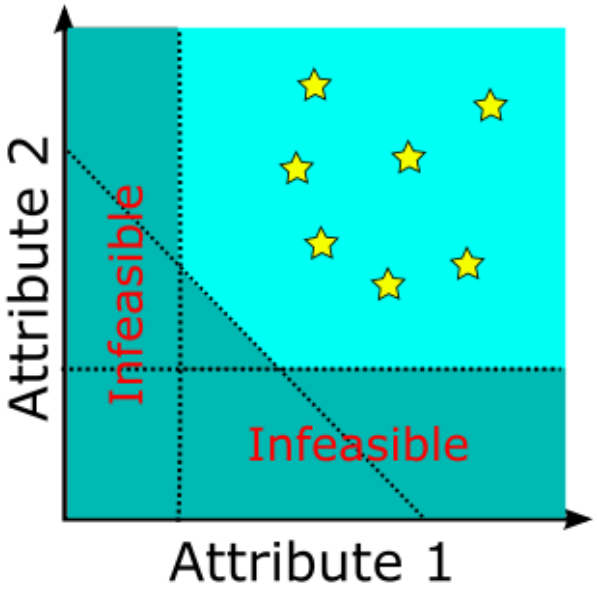


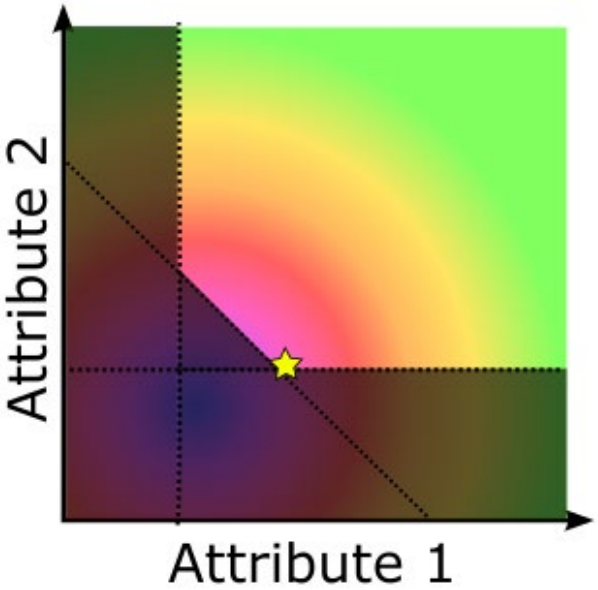
- SEBoK Requirements Process



Representing Preferences – Requirement Challenges

- Community does not have an agreed upon requirements formation process
- Limited information communicated through traditional requirements





Representing Preferences – VBRE

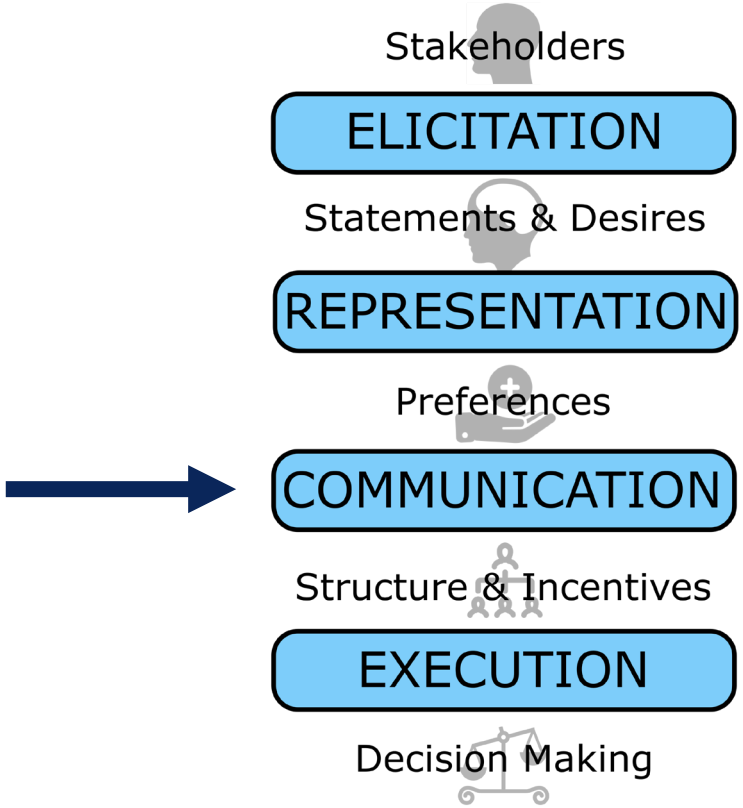
- Value-Based Requirements Engineering (VBRE)
  - Based on the concept of economic value during the requirements engineering process.
- "Traditional" requirements engineering techniques lack the forethought of products being economically valuable.
- VBRE experts suggest beginning with discussion of system requirements; this allows for a thorough understanding of the project and an improved commercial understanding.
- Value-based requirements tend to contain future integration and update potential that business-oriented requirements formation lacks.

Representation of Preferences – Next Steps

- Identification of approaches from Value-Driven Design, Requirements Engineering, Multidisciplinary Design Optimization
  - Characterize assumptions and context
- Select and Adapt approach into CAS
- Implement and Demonstrate

Exploration and Problem Definition:

Communication of Preferences



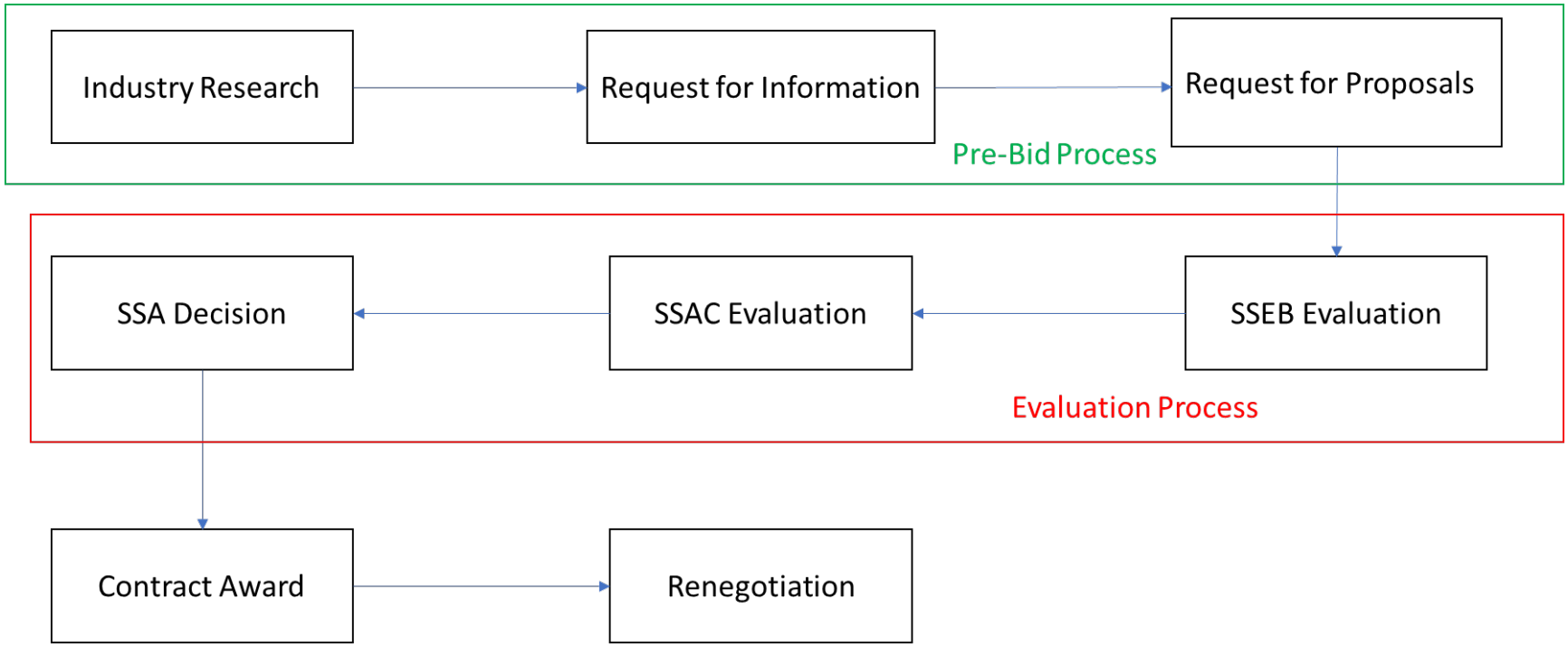
Current Methods to Communicate Stakeholder Preferences

Current Methods	Problems	Search Areas for Rigorous Methods
Internal to organization -Requirements Flow down -Centralized Decision making	-Relies on un-Validated coupling Heuristics to drive process -Does not communicate risk & temporal preference -Leads to limited exploration of design space	Value-Driven Design Multidisciplinary Design Optimization Value-Based Requirements
External to organization -Requirements driven Contracts	-Susceptible to the Most Plausible Liar strategy -Insufficient level of context to direct decisions optimally	Objective function centered contracts

Communicating Preferences - Questions

- Communication of preferences throughout the organization and contractors enables consistent and informed decision making.
- Contracting is essentially a game, capable of being manipulated using mechanism design.
- *What game theory tools can be used to improve the communication of preferences within and outside of an organization?*

Communicating Preferences – Contracting Process



Communicating Preferences – Mechanism Design

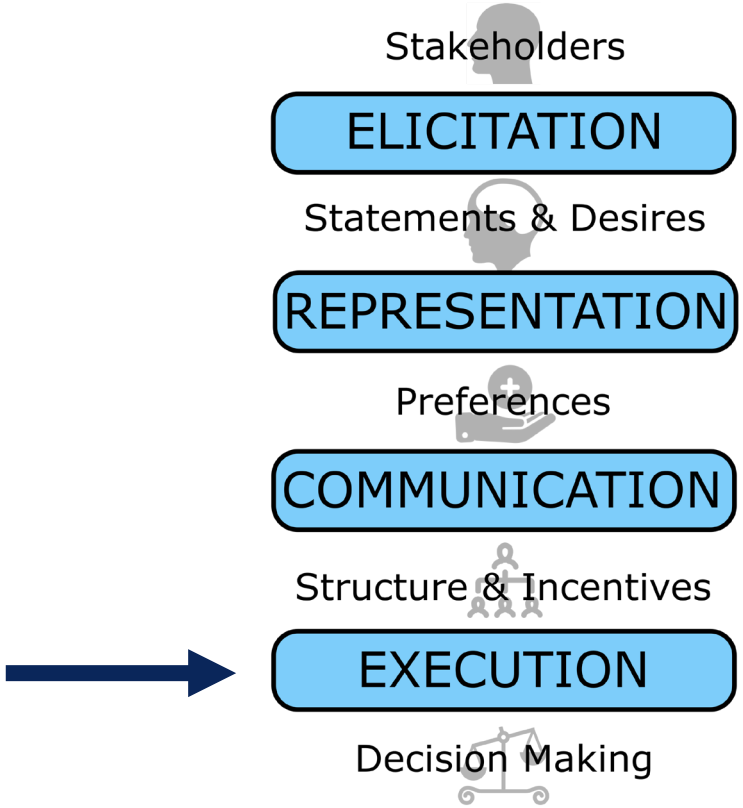
- RFP establishes a feasible region, but government preference is not sufficiently defined.
- The winner of the acquisition will be the contractor who can feasibly say they will produce the best product, the most plausible liar.
- Mechanisms can be derived that ensure that the contractors will always do better if they truthfully report the quality of their solution, making the acquisition incentive compatible.
- Acquisition methods used for Army Acquisition
  - Lowest Priced Technically Acceptable; Best Value; Tradeoff Process

Communication of Preferences – Next Steps

- Identification of approaches from Value-Driven Design, Requirements Engineering, Multidisciplinary Design Optimization, Value-Based Requirements
  - Characterize assumptions and context
- Select and Adapt approach into CAS
- Implement and Demonstrate

Exploration and Problem Definition:

Execution of Preferences



Current Methods to Execute Design decision using Stakeholder Preferences

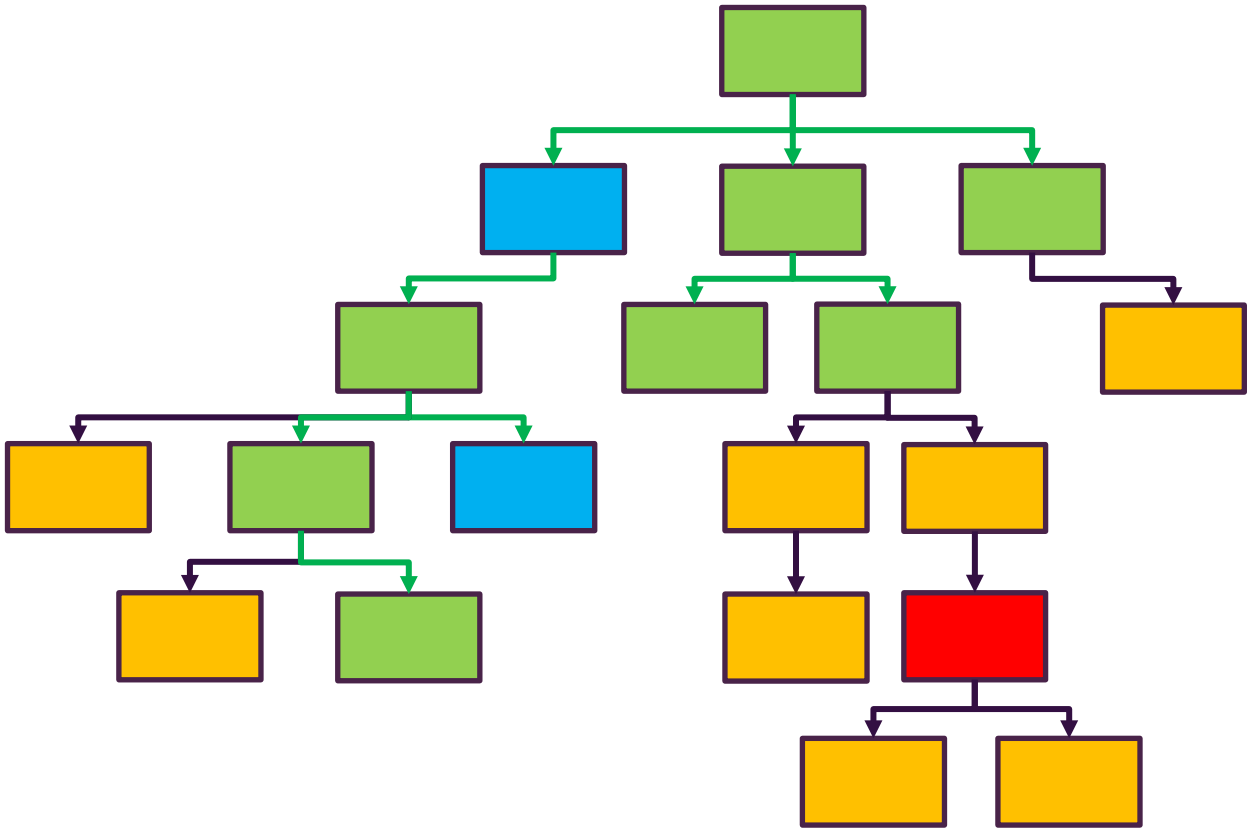
Current Methods	Problems	Search Areas for Rigorous Methods
The system is decomposed into platforms and variants and the requirements are used to create a bounded feasible region and design choices are executed therein	-Beyond satisfying a requirement there is insufficient context to explore the design space -Is unable to resolve tradeoffs inside and outside the feasible region - Both risk and time preferences are implicitly communicated - Decisions of where and how to decompose system are ad hoc	Military Decision Making Process Value-Driven Design Multidisciplinary Design Optimization Software Engineering

Executing Preferences – Software Architecture Questions

- In what fashion should architecture be developed?
- Is there a specific structure, pattern, or order by which the architecture should be developed?
- Is system modularity and rapid production feasible via the CAS structure? If so, how could they be implemented and how does it affect the CAS architecture at each level?
- How do you choose the right architecture design for your system? How does that reflect the system design? How do system design decisions affect architecture decisions?

Executing Preferences – Software Arch. Background

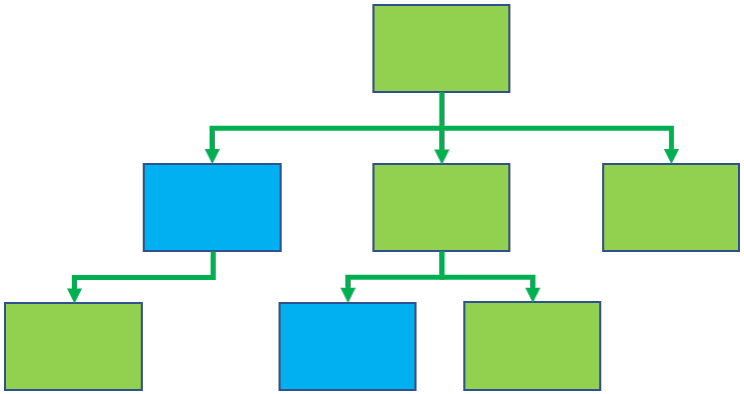
- Family of Systems Architecture



Green – Kernel Architecture Pattern
Orange – Target System Architecture (Kernel Pattern included)
Blue – Architecture Pattern in Domain Design
Red – Architecture Pattern in System Domain

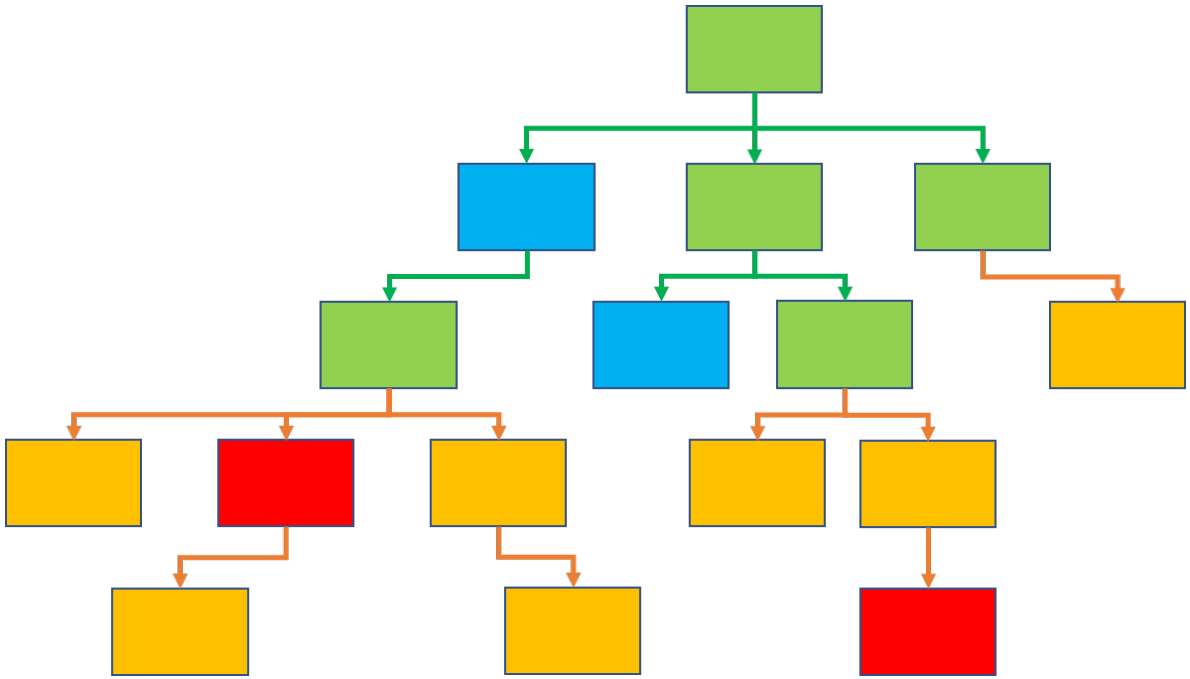
Executing Preferences – Application to CAS

- Reference Architecture



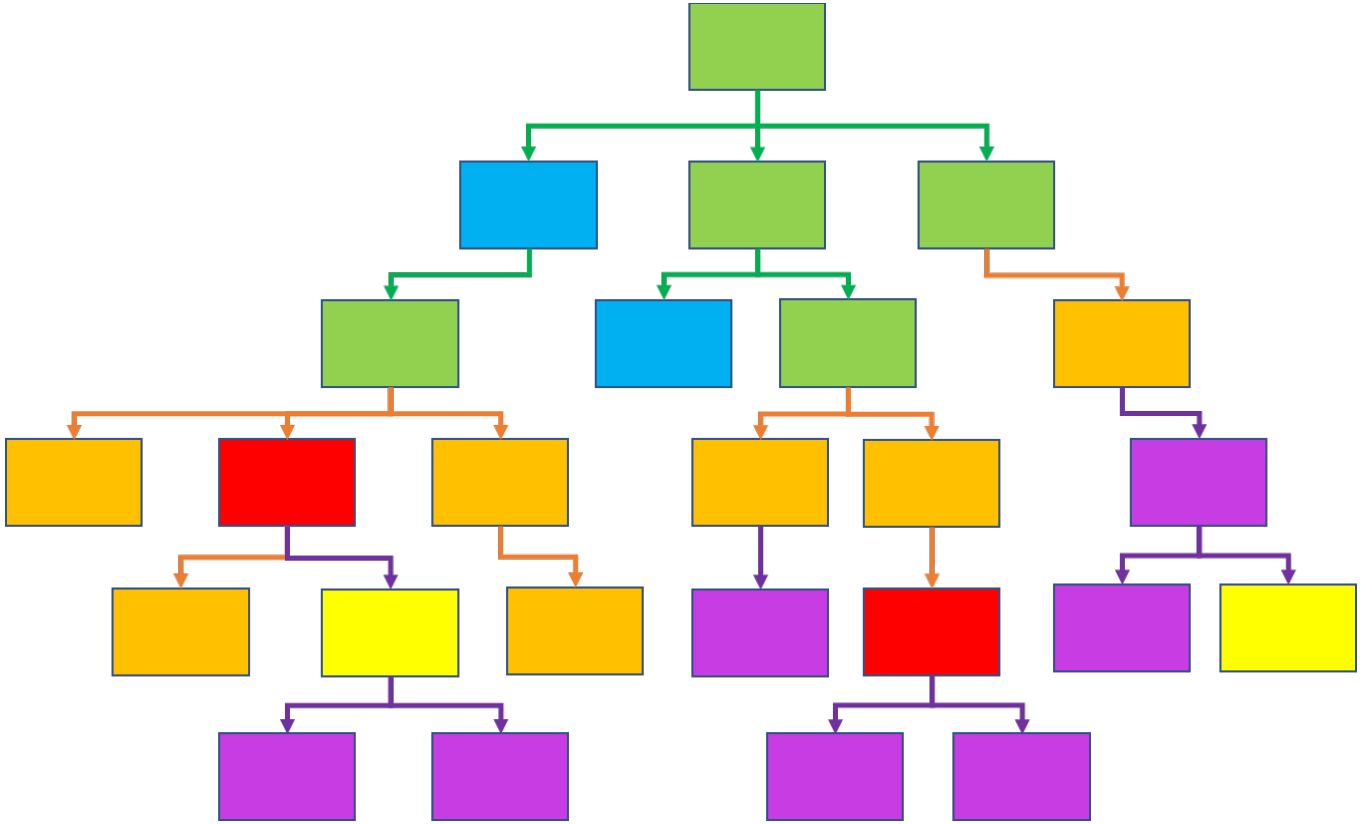
Executing Preferences – Application to CAS

- Objective Architecture



Executing Preferences – Application to CAS

- System Architecture



Executing Preferences – Software DevOps Background

- Involving both the Development (Dev) and Operations (Ops) teams of a project, keeping everyone working with the same tools, resources, and schedules
- Rapid/frequent development, testing and release
  - Moves the project along faster
  - Less code to integrate = less time integrating = more time to develop new code
  - Easier to determine what could be breaking code/system[5]
  - Less time spent fixing issues = more time to develop new code
  - Newest software is always up and running
  - Easier to roll back to previous version if fewer changes have been made between releases = less rollback time = time to develop code

Executing Preferences – Software Patterns and Tactics

- Patterns - dictate general architectural decisions, not the implementation of the architecture.
  - Contains general theory, problem description, context, solution, rationale, application, advantages, disadvantages, some previous instances/examples of use, and similar patterns
- Tactics - design decisions that implement quality attributes and other requirements.
  - No uniform documentation
  - Some papers have made possible documentation outlines for tactics but they have yet to be implemented
  - Tactics are very specialized so it is much more complicated to create such documentation

Executing Preferences – Product Families

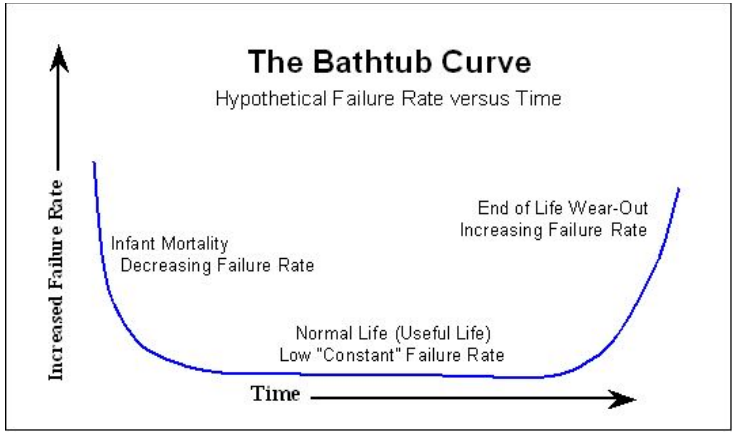
- Examine and identify the best ways to group and categorize systems.
- Examine the best ways to create commonality within the product family so that there's enough variation in the systems for them to serve in different roles and purposes, but not so unique they are hard to design and produce.
- Product families are a group of products that share common characteristics. It is important to identify these characteristics and define the relationship between them because it streamlines the ability to make a family of products with a diversified profile of variations that can also be easily produced.

Executing Preferences – Demonstration

- Tanks of the WWII era were chosen because the plethora of tanks created during the second world war generated a large amount of valuable data for design, production, and performance.
- Identify and evaluate the characteristics of design, production, and performance of variants within a family of tank models, and to also examine the evolution of these characteristics from one model of tank to the next model.
- Data Available and mathematics/physics models are simple

Representing Preferences – Models for Demonstration

- Cost Estimation Models
  - Analogous, Parametric, Engineering Build Up
- Success Models
  - $P_{ss} = P_{Available} \cdot P_{Survival} \cdot P_{Kill}$
- Reliability and Maintainability Models



$$MTTR = \frac{1}{\mu}$$

$$M(t) = 1 - e^{-\mu t}$$

$$Repair\ Rate = \mu$$

Reliability: $R(t) = e^{-\lambda t}$

Failure Rate: $h(t) = \lambda$

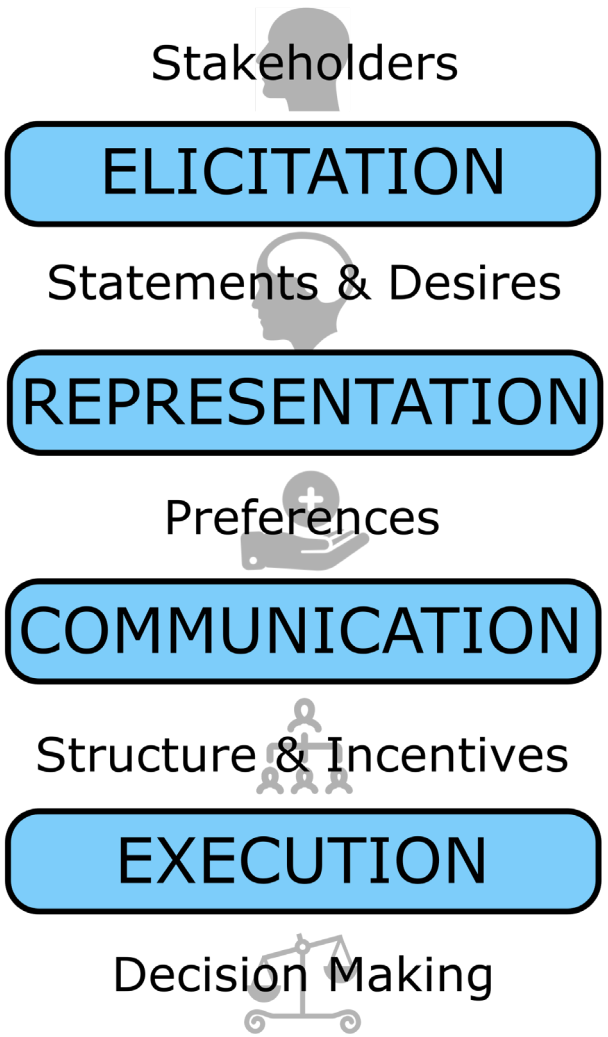
Mean: $\frac{1}{\lambda}$

Execution of Preferences – Next Steps

- Identification of approaches from Military Decision Making Process, Value-Driven Design, Multidisciplinary Design Optimization, and Software Engineering
  - Characterize assumptions and context
- Select and Adapt approach into CAS
- Implement and Demonstrate

Conclusion

- Exploration task has defined the problem landscape
- Next steps
  - Identify current capabilities of a broad collection of fields including engineering, psychology, business, and marketing for implementation into CAS.
  - Select approaches based on evidence and that have been rigorously validated in their previous contexts to implement in CAS, with the approaches' theoretical and validation limitations characterized within this new context.



Thank You