A Few Words First

Audio Connection –Please mute phone (*6 toggle) –or your GM left-side name

Phone connections may be muted during presentation. Put questions in chat box.

Upcoming Meetings:

- March 11: Chapter Social – Gruet Winery
- April 8: Joshua Salinas, SNL – Requirements Modeling
- May 13: Mary Compton, SNL – Applying MBSE

CSEP Courses by *Certification Training International:*

Course details(with more locations and dates)
Upcoming Course Schedule (somewhat nearby):
2020 June 1-5 | San Diego, CA
2020 Sep 28-Oct 2 | Austin, TX
Chapter SEP mentors: Ann Hodges alhodge@sandia.gov and Heidi Hahn hahn@lanl.gov

And now - introductions

Enchantment Chapter Monthly Meeting

4:45pm – 6:00pm MT

A Definition Abstraction and Implementation (DAI) Process for System-of-Systems Engineering

Abstract: The design, development, and planning of a System-of-Systems (SoS) is a difficult task as it involves several systems, organizations, and complex dynamics between the constituent elements of the SoS. These multitude of factors make SoS difficult to comprehend and model, and SoS solution synthesis becomes a challenging endeavor. Research and development of SoS Engineering (SoSE) processes to account for complexities involved in the design, management, and operations of the SoS has been an active area of research in Systems Engineering and significant progress is made in advancing the state-of-the-art of SoSE in the past decade. In this presentation, we will first review the current practices in SoSE—identifying their common themes and gaps—and then present a three phased SoSE process called the Definition-Abstraction-Implementation (DAI) process. The DAI process draws upon our decade long SoSE experience and critical lessons learned from a variety of government, industry, and academic SoS engagement experiences. The end goal of this work is to provide a domain-agnostic SoSE approach which incorporates both qualitative reasoning and quantitative analytics to create knowledge artifacts needed to support effective analysis for design and evolution of an SoS.

Download recording from the Library at www.incose.org/enchantment

NOTE: This meeting will be recorded

Speaker Bio

Dr. Ali Raz is a Visiting Assistant Professor at Purdue University School of Aeronautics and Astronautics where his research interests are in system-of-systems, systems engineering, and information fusion. Dr. Raz also hold a temporary faculty appointment with the U.S. Navy Naval Surface Warfare Center at Crane, IN. Prior to joining Purdue University, he worked as a systems engineer for Honeywell Aerospace in Albuquerque, NM and Phoenix, AZ. He holds a Bachelor and Master of Science in Electrical Engineering from Iowa State University, and a Ph.D. in Aeronautics and Astronautics from Purdue University. He is a co-chair of International Council of Systems Engineering Complex Systems Working Group and a Certified Systems Engineering Professional (CSEP). He is also a senior member of the American Institute for Aeronautics and Astronautics (AIAA) and a senior member of the Institute of Electrical and Electronics Engineers (IEEE).

A Definition Abstraction and Implementation (DAI) Process for System-of-Systems Engineering

Presenter: Dr. Ali K. Raz

Co-Contributors
Navindran Davendralingam, Shashank Tamaskar,
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Motivation and Summary

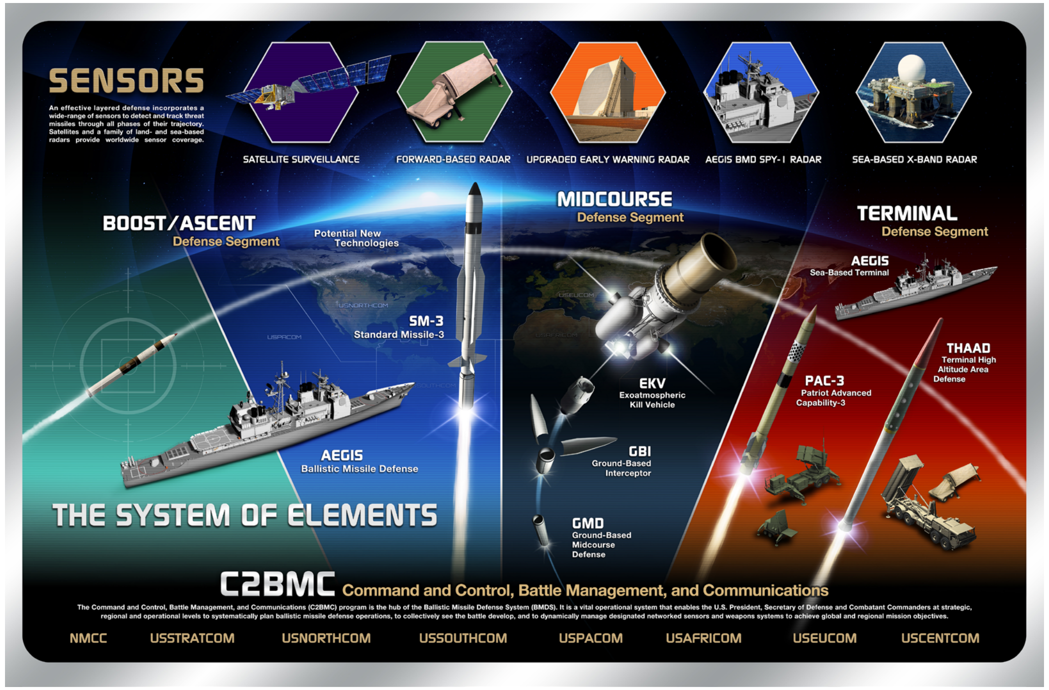
- **System-of-Systems Engineering (SoSE) Challenges:**
  - Multiple independent heterogeneous systems
  - Various multi-layered networks
  - Organizational policies and incentives, compartmentalized information

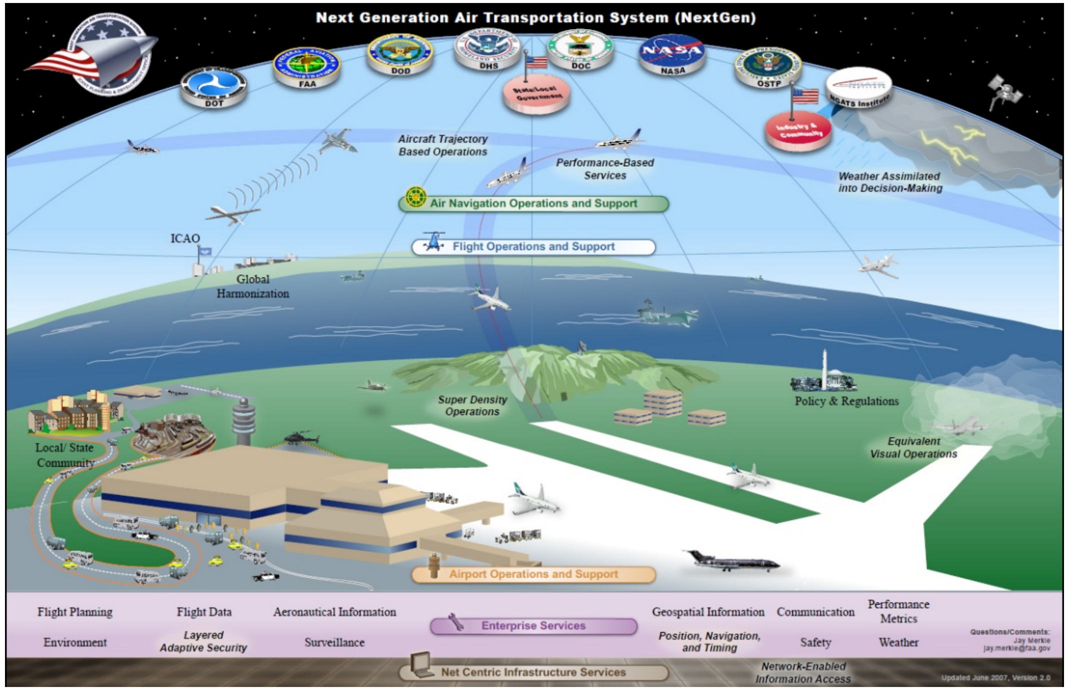
- Need a comprehensive approach to model SoS, comprehend the design space, and synthesize practical SoS solutions

- **Contributions of this work:**
  - A three-phase SoSE process called DAI: **D**efinition, **A**bstraction, **I**mplementation
    - A domain agnostic process for end-to-end SoSE
    - From concept formulation to qualitative and quantitative analytics

Introduction to SoS and SoSE

Systems of systems (SoS) are large scale concurrent and distributed systems that are comprised of complex systems





System-of-Systems Engineering (SoSE) is integrating complex independent systems to engineer novel capabilities

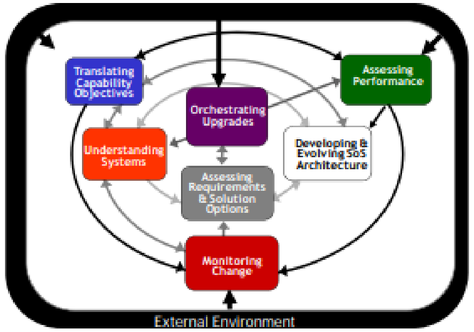
Literature Review and SoSE Approaches

- From Systems Engineering (SE) to System-of-Systems Engineering
  - SE focus is on developing independent complex systems
  - DoD Guidance on SoSE:
    - Adapt SE practices for SoSE but…

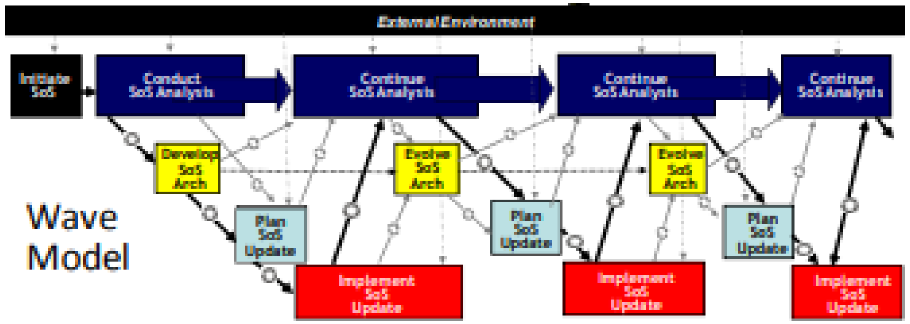
    "…the guide raises issues for awareness which may need to be addressed by systems engineers doing SoS work, but it does not provide practical advice on the issues."

  - SoSE is a major shift from SE:
    - ***"abandoning myths of total control"*** (Sage and Cuppan)

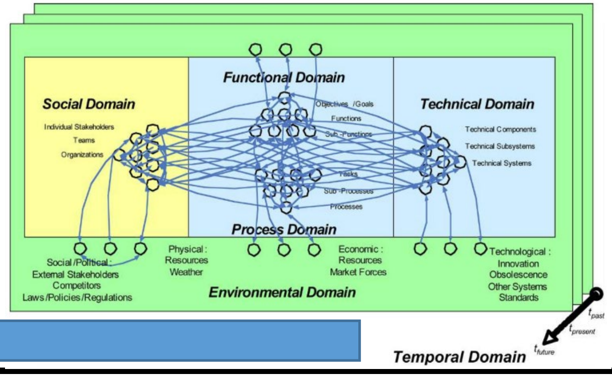
Trapeze Model



Wave Model



Engineering Systems Multi-Domain Matrix (ES-MDM) process



SoSE Approaches

Gaps in Literature and Need for a SoSE Process Model

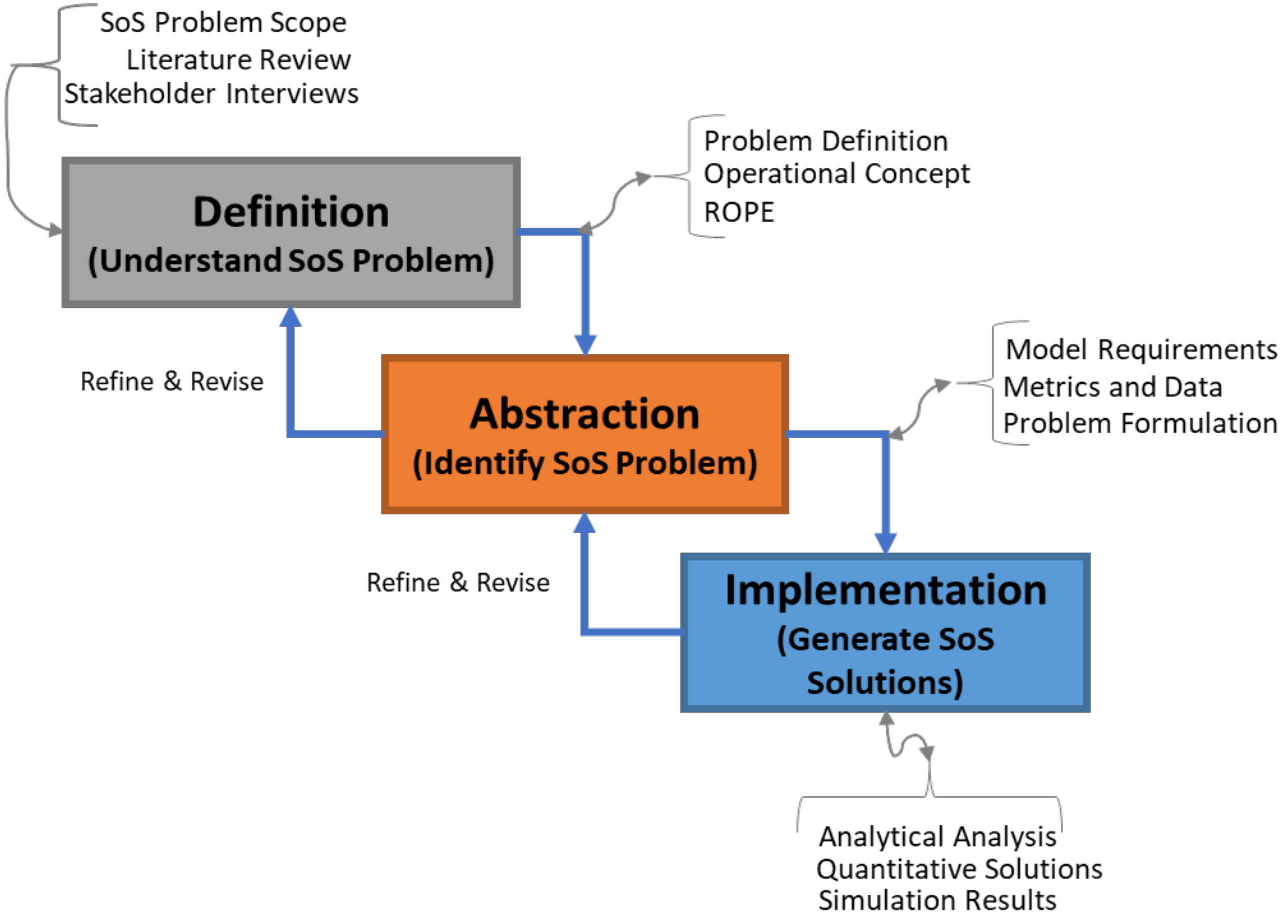
- Current SoSE methodologies largely provide high-level processes and guidance that are aimed at orchestrating activities for a particular domain (defense, transportation etc.)

- The SoSE processes that aim to be domain-agnostic, emphasize defining knowledge artifacts and contexts that may not be easily constructed and replicated

- No Support in current methods to address pertinent questions, e.g.,
  - *What are knowledge artifacts that are needed when the intent of the SoS evolution is to innovate?*
  - *What are artifacts and processes are needed to address the high degree of uncertainties associated with such types of evolutionary intent that projects far into the future?*
  - *How can SoS solutions be effective given that end solutions may be adopted only on a voluntary basis at the local level?*

The DAI (Definition-Abstraction-Implementation) Process

- Builds on prior *proto-method* by DeLaurentis
  - Explore SoS space across multiple dimensions
  - Frame relational contexts between constituent SoS artifacts in different dimensions
  - Guide SoS problem definition and development (are you asking and solving the right SoS question?)
  - Map feasible & practical SoS solutions



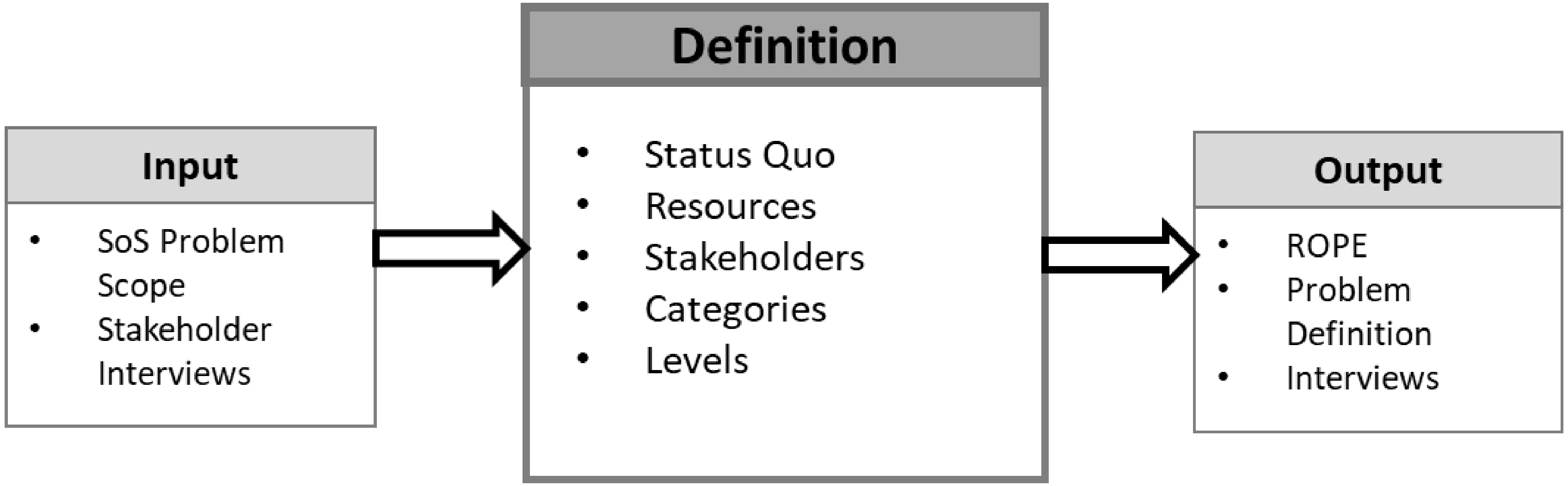
Preliminary Phase: Problem Scope and Time-Scales

- **SoS Purpose and Problem Scoping**
  - **Fully Specified Evolution**
    - Clear objectives of SoS evolution
    - Clear understanding of current systems
    - E.g., upgrading a sensor for Air & Missile defense
  - **Exploratory Evolution**
    - Multi-domain uncertainties and ill-defined spaces
    - Long-term innovation path
    - E.g, future of passenger and cargo mobility in air transportation system
  - **Hybrid Evolution:**
    - A combination of fully specified and exploratory evolution.

SoS Time-Scales

SoS Time Horizon	Features	
	Purpose	SoS problem space
Short Term	Immediate evolution	Structured, complex but quantified uncertainties. Short term solutions favor lower uncertain solution
Mid Term	Blend of short-term and long-term needs.	Blend of defined and high uncertainties for subsets of SoS
Long Term	Strategic Innovations	High multi-dimensional uncertainties in prediction. Both aleatoric and epistemic uncertainties driven by time

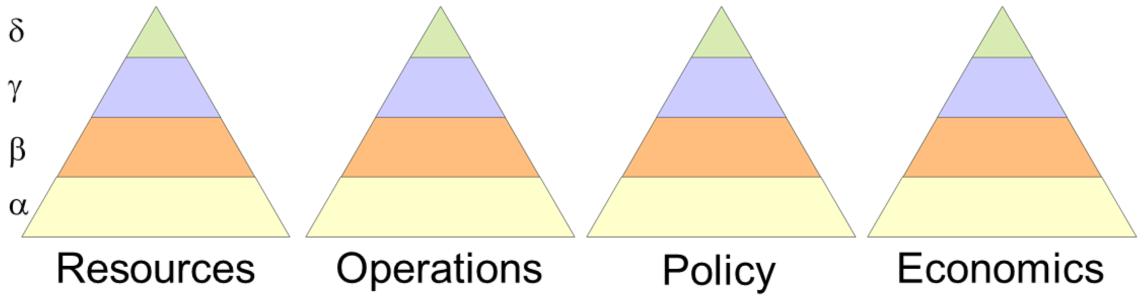
Definition



- Objectives:
  - Understand SoS problem space, and identify key elements including barriers
  - Construct the ROPE table (next slide)

Resources, Operations, Policy, Economics (ROPE)

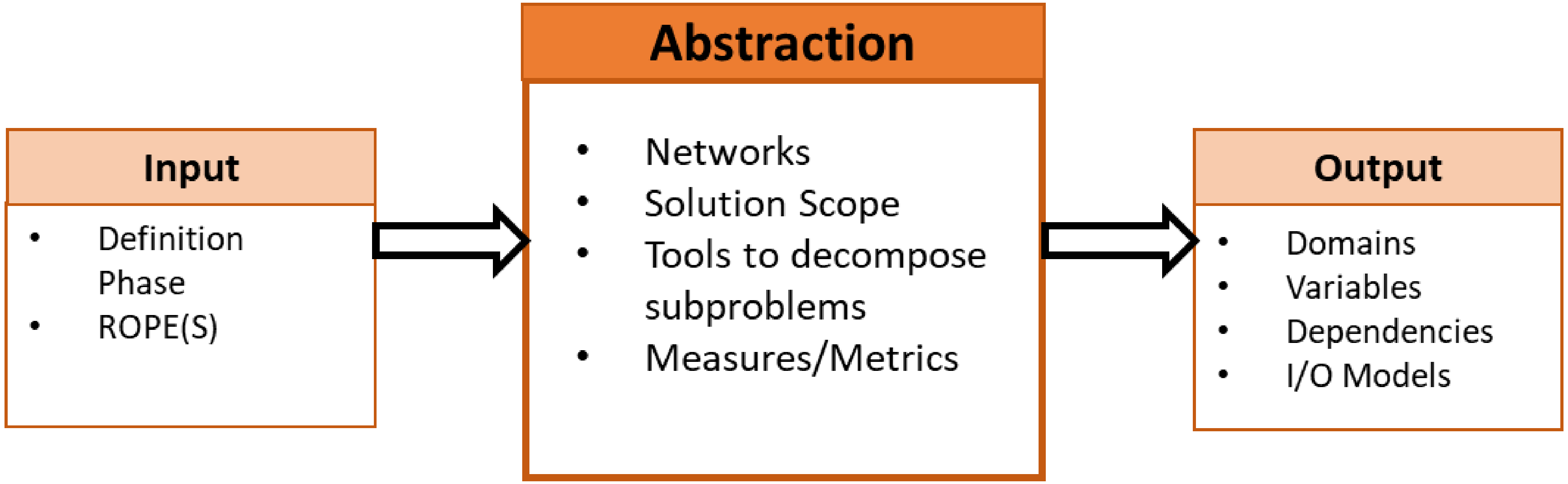
SoS Hierarchy & Categories



A flexible framework allows the various systems, contexts, hierarchy and interrelationships to be identified and described

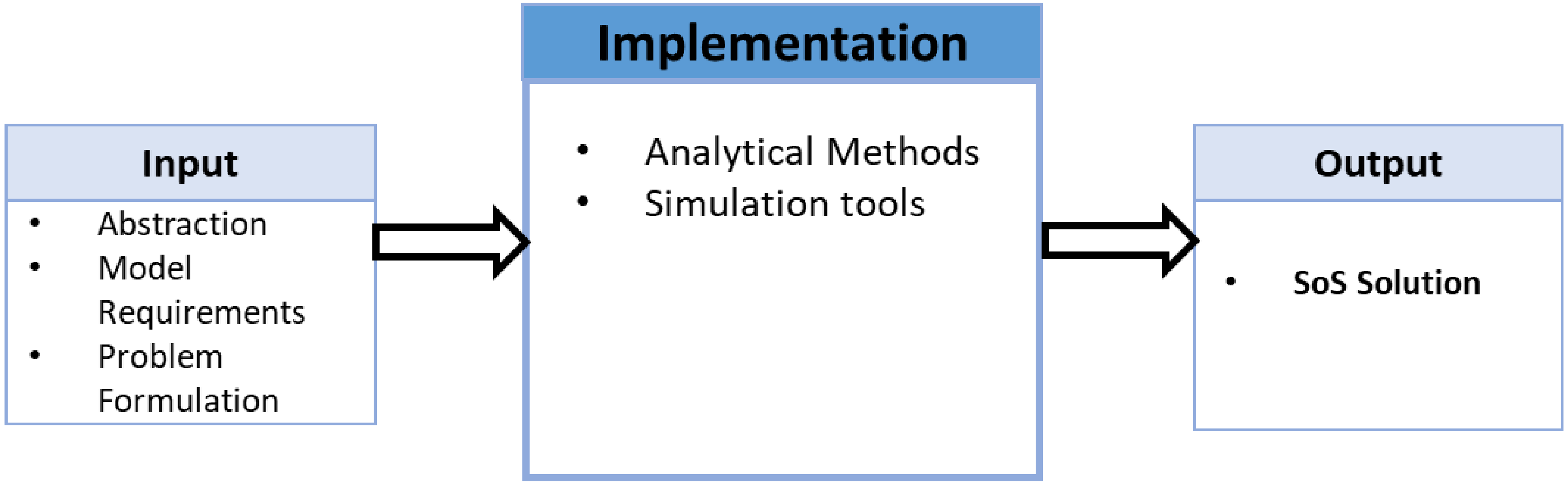
	Resources	Operations	Economics	Policy
α	Vehicles & infrastructure (e.g., aircraft, truck, runway)	Operating a resource (aircraft, truck, etc.)	Economics of building/operating/ buying/selling/leasing a single resource	Policies relating to single-resource use (i.e., no. of attendants per passenger for vehicle type)
β	Collection of resources for a common function (an airport, etc.)	Operating resource networks for common function (e.g., airline)	Economics of operating/buying/ selling/leasing resource networks	Policies relating to multiple vehicle use (i.e., local airport noise policies)
γ	Resources in a transport sector (e.g., air transportation)	Operating collection of resource networks (e.g., commercial air Ops)	Economics of a business sector (e.g., airline industry)	Policies relating to sectors using multiple vehicles (FAA certification, safety, etc.)
δ	Multiple, interwoven sectors (resources for a national transportation system)	Operations of Multiple Business Sectors (i.e., operators of total national transportation system)	Economics of total national transportation system (All Transportation Companies)	Policies relating national transportation policy
ε	Global transportation system	Global operations in the world transportation system	Global economics of the world transportation system	Global policies relating to the world transportation system

Abstraction



- Objectives:
  - Identify SoS level inputs, outputs, and metrics
  - Map variables between sub-domains (inter-dependencies)
  - Circumvent a natural tendency to tailor an SoS problem formulation to fit pre-conceived implementation methods

Implementation



- Objectives:
  - Generate SoS solution via applicable methods
  - Balance complexity of solution with technical and programmatic tractability

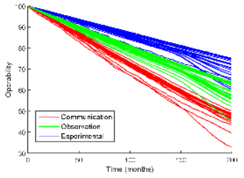
Example of Implementation Methods (1)

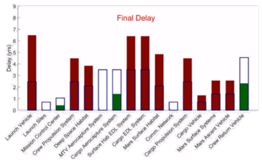
Purdue Analytic WorkBench (AWB)

System Operational Dependency Analysis (SODA)
System Developmental Dependency Analysis (SDDA)

Assess impact of technical and schedule dependencies

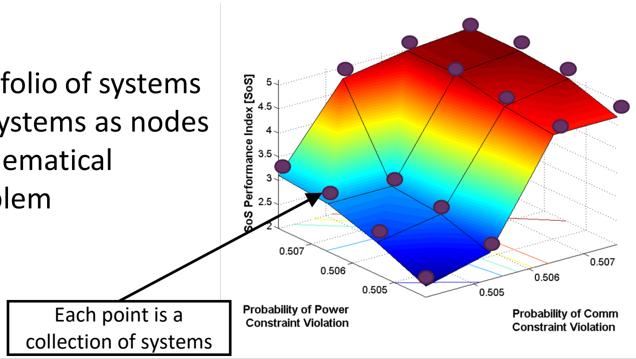
- Which systems are critical to SoS performance? SoS risks?
- What is the impact of partial/total system failures during operations?
- What is the impact of development delays in an interdependent network?





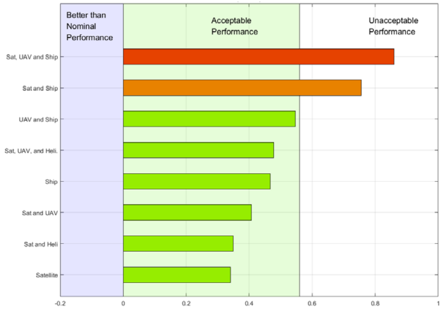
Robust Portfolio Optimization (RPO)

- Treat SoS as a portfolio of systems
- Model individual systems as nodes
- Represent as mathematical programming problem



System Importance Measures (SIMs)

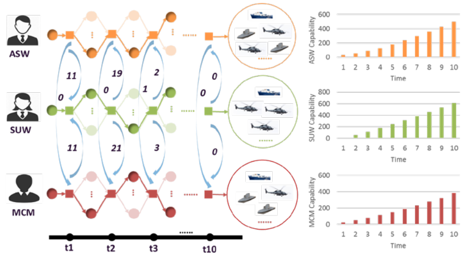
- Rank the constituent systems based on their *resilience significance*
- SoS resilience map highlights strong and weak points
- Iteratively use design principles to update SoS until desired resilience is achieved



Multi-Stakeholder Dynamic Optimization (MUSTDO)

Dynamically contracting across an enterprise

- How do we optimize multi-stage acquisitions in SoS development?
- How do we coordinate planning between local and SoS-level stakeholders?

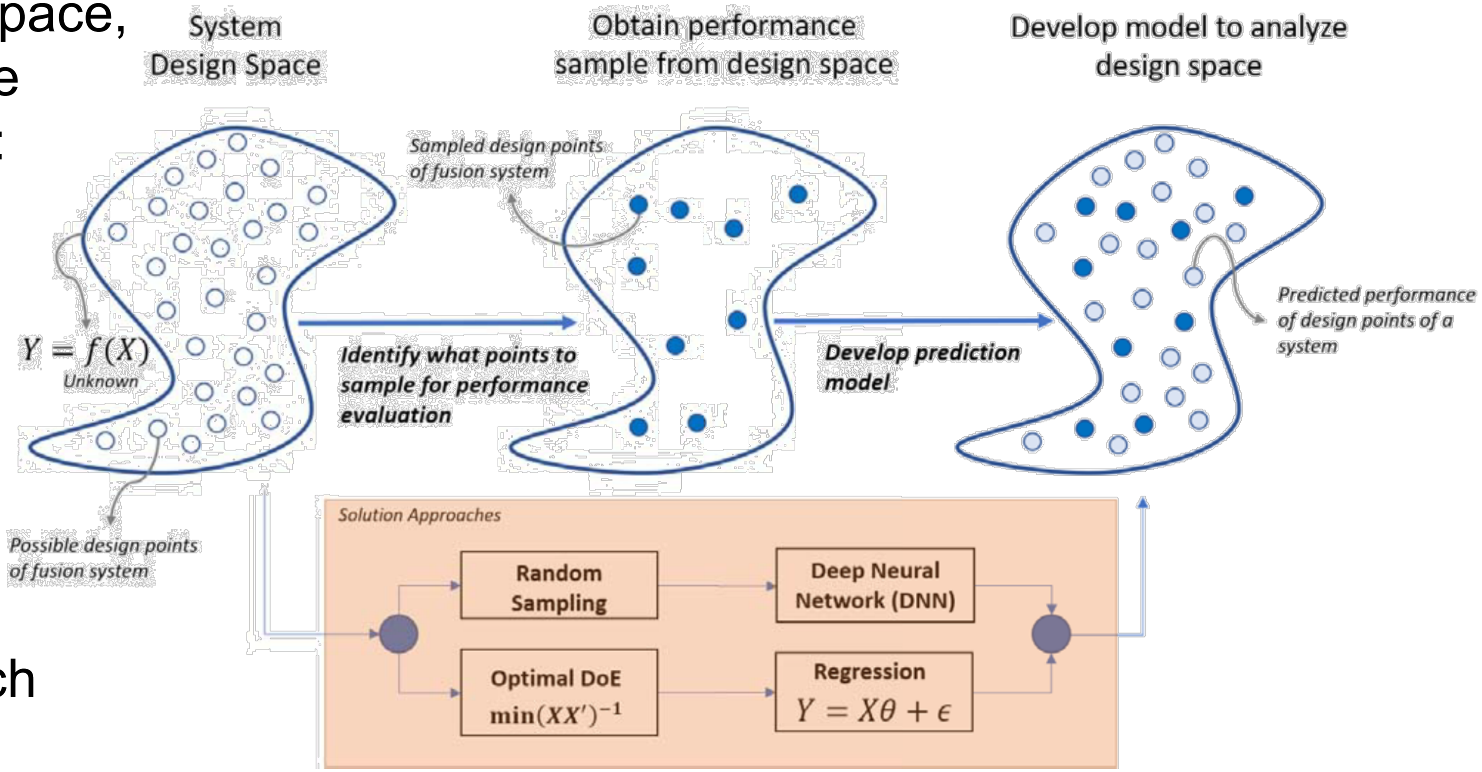


- Set of tools to assess impact of interdependencies.
  - **Domain agnostic**
  - **Each tool touches a different aspect of SoS. Tools specific for SoS features, but not for a single application**
  - **Identifying the appropriate tools serves as first step to bridge the abstract approach with specific application**

Example of Implementation Methods (2)

Machine Learning to Reduce Complexity

- When complexity is due to large design space, but a form can be found for representative equations of the behavior of components:
  - Sample points to evaluate performance (can be done with DoE)
  - Develop a prediction model, usually with Deep Neural Network
  - Use model to predict performance of other design points
- Interactions between variables identified and quantified with this approach



DAI Challenges from Various Research Engagements

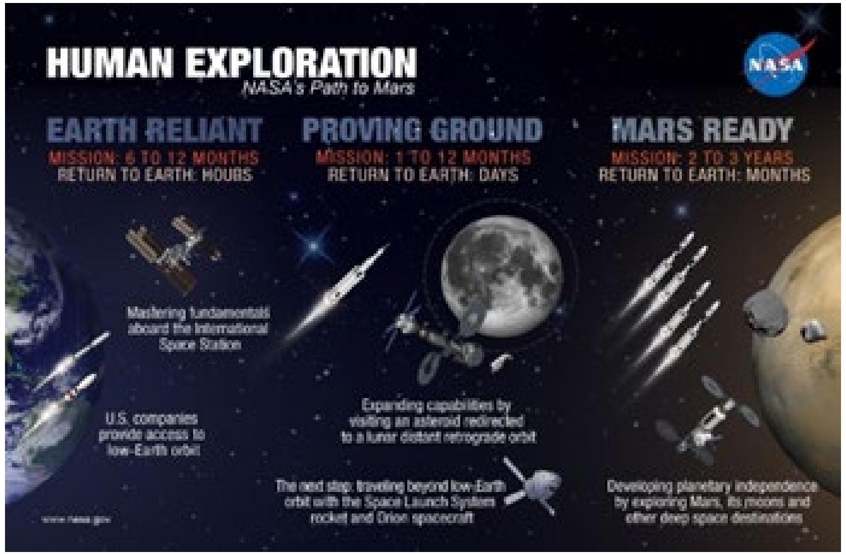
- Definition Phase:
  - Value becomes evident in the implementation phase
  - *"Time Consuming"*, *"What's the output"*, *"Why not use solution method___"*

- Abstraction Phase:
  - Identification and utilization of tools which facilitate effective development, management, and communication of abstracted artifacts

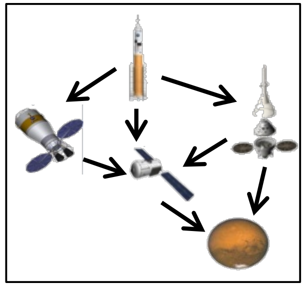
- Implementation Phase:
  - Lack of database of SoS tools and maps to appropriate abstraction artifacts
  - Revisions to definition and abstraction after initial implementation

Human Space Exploration: DAI Concept Application

- **SoS Traits:**
  - Operational and managerial independence of systems
  - Multi-national and multi-disciplinary stakeholders
  - Interdependencies between systems, integration of multiple independent systems

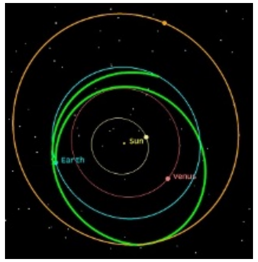


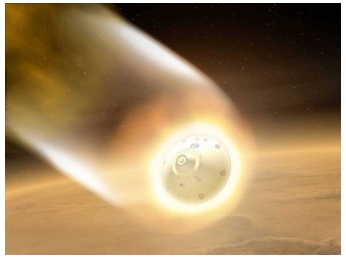
- **Problem Scope - Hybrid Evolution**
  - Some systems and interactions being fully described and modeled, and others still having higher multi-domain uncertainty



Explicitly assess impact of dependencies to evaluate holistic features

Evaluate technological choices upfront (cost, risk, objectives)





- **SoS Time Scale:**
  - Short to Medium Term Horizons

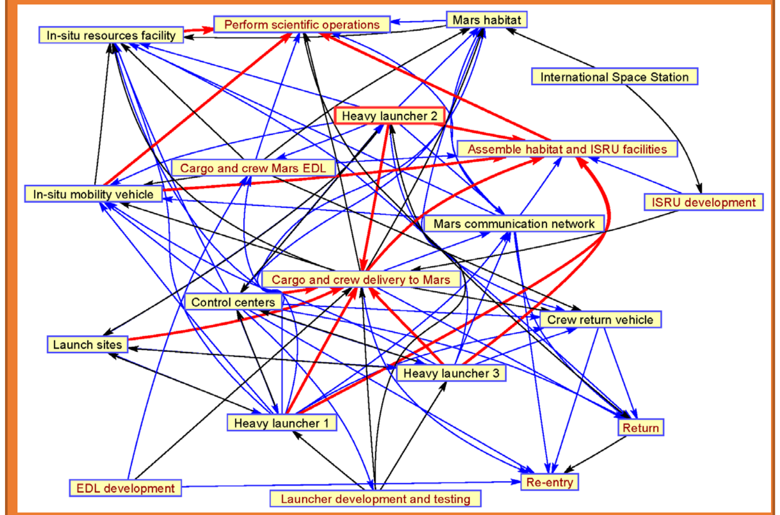
DAI - Human Space Exploration

Definition

Level	Resources	Operations	Policies	Economics
α	On-board systems and subsystems, low-level capabilities and functions	Subsystems goals and possible disruptions	Architectural and technological choices, subsystems interactions	Low-level cost and budget allocation
β	Control centers, ground support, communication networks, in-situ resource utilization, system-level capabilities	Systems disruptions, systems development, contractors, partners, orbit and trajectories	Location of facilities, architectural and technological choices, systems interactions	Budget allocation, cost of development and operation
γ	High-level functions, concept architectures	High-level disruptions, drivers, overarching goals	Launch windows, timelines, partnership with commercial entities	Overall budget allocation, driving mechanisms for partnership, cost of operations

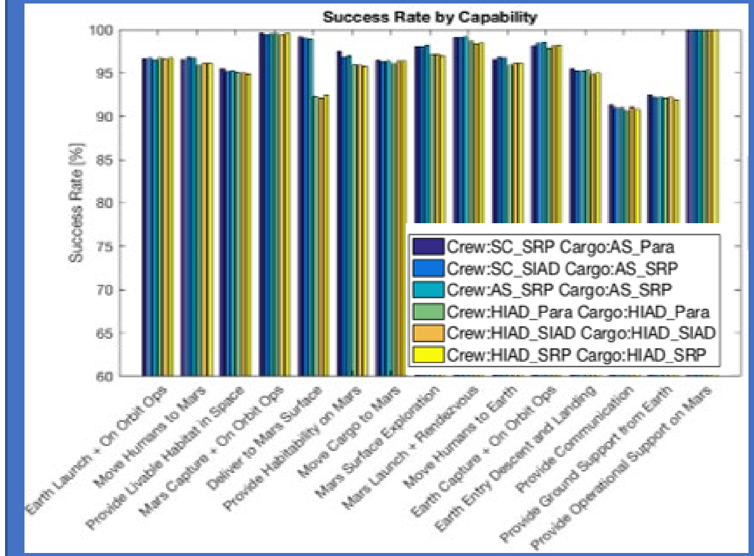
- Identified stakeholders at various levels
- ROPE table used to organize relevant pieces of the SoS design problem

Abstraction



- Use information from D. phase to model dependencies
- Define objectives of analysis and formulate problem
- Bridge D. and I. phase

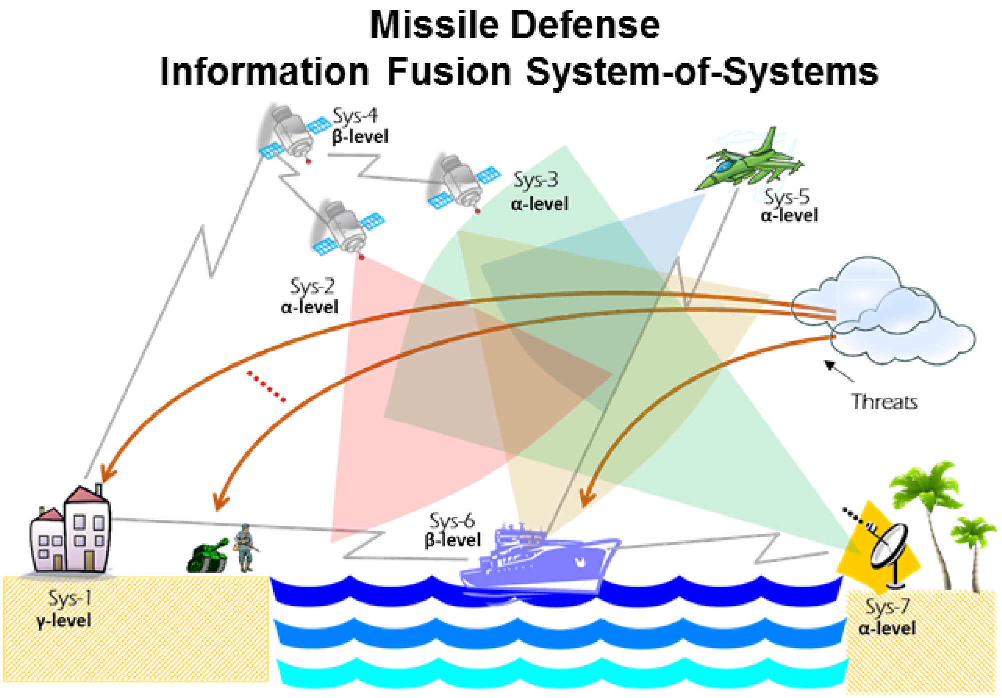
Implementation



- Use the models and requirements from A. phase to perform analytical studies: trade-off, risk analysis, robustness analysis
- Compare technological choices

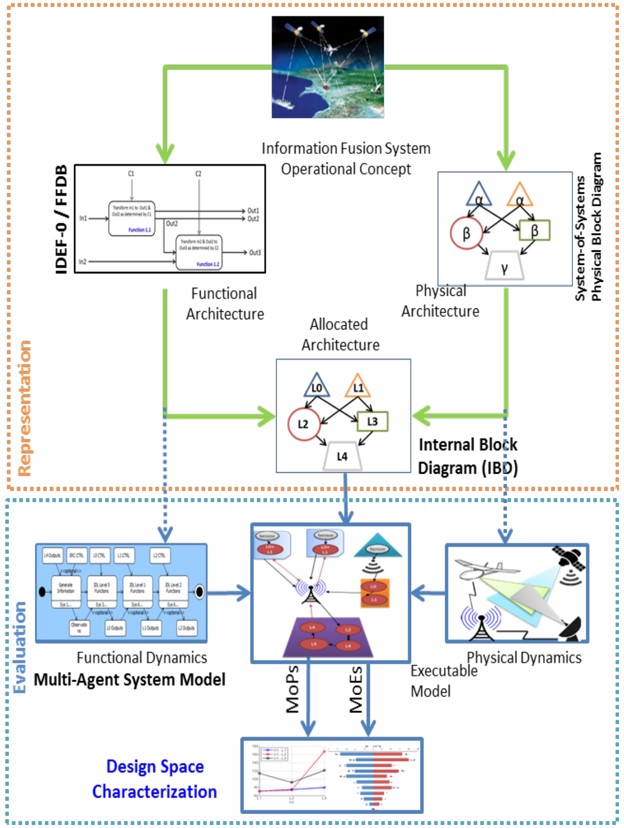
Information Fusion System-of-Systems: DAI Concept Application

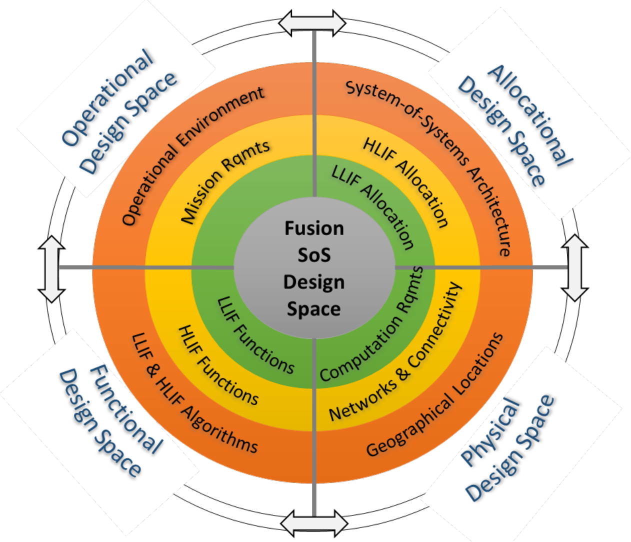
- **SoS Traits:**
  - Operational and managerial independence of information generating, processing, and fusing systems
  - Interdependencies between systems, multiple integration paths
- **Problem Scope - Fully Specified Evolution**
  - Clear objectives of SoS evolution
  - Clear understanding of current systems (relatively)
- **SoS Time Scale:**
  - Short to Medium Term Horizons



DAI – Information Fusion System-of-Systems

Definition	Abstraction	Implementation





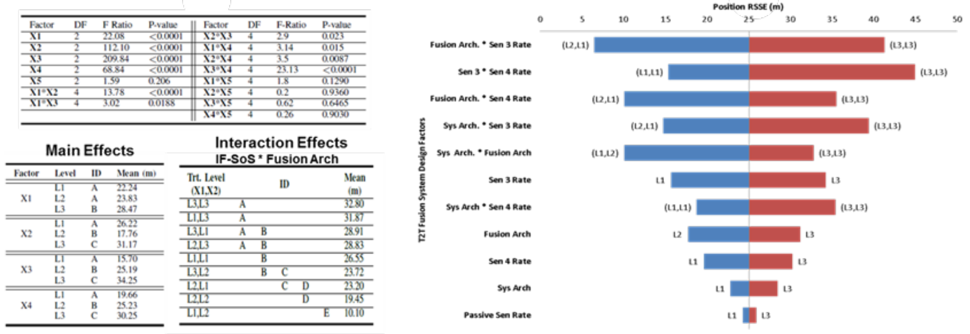
Factor	Design Var.	ID	L1	L2	L3
LLIF Allocation Stg.	DV_{LLIF}	X_1	$LL1$	$LL2$	$LL3$
HLIF Allocation Stg.	DV_{HLIF}	X_2	$HL1$	$HL2$	$HL3$
Pass. Sen Accuracy	$DV_{Sen+L0_{Pass1,2}}$	X_3	u^{hi}_{sen}	u^{med}_{sen}	u^{low}_{sen}
Act. Sen 1 Accuracy	$DV_{Sen+L0_{Act1}}$	X_4	u^{hi}_{sen}	u^{med}_{sen}	u^{low}_{sen}
Act. Sen 2 Accuracy	$DV_{Sen+L0_{Act2}}$	X_5	u^{hi}_{sen}	u^{med}_{sen}	u^{low}_{sen}
Act. Sen Rate	$DV_{Phys_{sys5,6}}$	X_6	Com_{high}	Com_{med}	Com_{low}
Fusion Method	DV_{L1-TF}	X_7	TF_{CI}	TF_{CIM}	TF_{ML}
Sen. Tsk. Sol. Avail.	DV_{L4-ST}	X_8	ST_{high}	ST_{med}	ST_{low}

Design of Experiments

$$Y_p = \beta_0 + \sum_{j=1}^{k} \beta_{jp} x_{jp} + \sum_{j=1}^{k-1} \sum_{l=j+1}^{k} \beta_{jp,lp} x_{jp} x_{lp} + \epsilon_p$$

ANOVA and Range Tests

Sensitivity Analysis



Most Important Design Considerations: Interactions between independent systems

SoS Architecting Process (MBSE)

Design Space Identification

Statistical Analysis and Quantification

Raz, et. al., System architecting and design space characterization, Systems Engineering, 2018 (Systems Engineering Best Journal Paper Award)

Conclusion and Future Work

- **A domain-agnostic System-of-Systems Engineering Framework:**
  - Create knowledge artifacts needed to support analysis of SoS design and evolution
  - Differentiate SoS evolution type and time-horizons
  - Qualitative reasoning and quantitative analytics

- **Continued development of DAI process**
  - Mapping lessons learned from prior research applications to process
  - Detailed generation and illustration of key ‘archetype’ SoS solutions via DAI process

Thank You & Questions

Today’s Presentation

Things to think about

- How can this be applied in your work environment?
- What did you hear that will influence your thinking?
- What is your take away from this presentation?

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Please

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- www.surveymonkey.com/r/2020_02_MeetingEval

Look in GlobalMeet chat box for cut & paste link

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