2018
Annual INCOSE
international workshop
Jacksonville, FL, USA
January 20 - 23, 2018

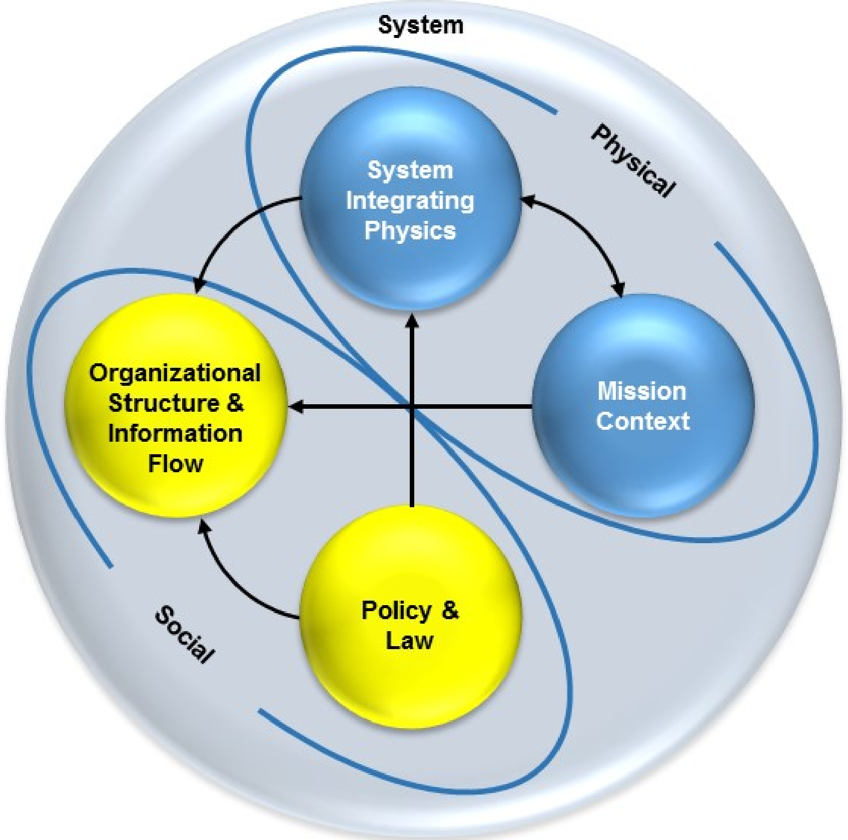
Engineering Elegant Systems: Postulates, Principles, and Hypotheses of Systems Engineering

Results of the NASA Systems Engineering Research Consortium

www.incose.org/IW2018

Understanding Systems Engineering

- Definition – System Engineering is the engineering discipline which integrates the system functions, system environment, and the engineering disciplines necessary to produce and/or operate an elegant system.
  - Elegant System - A system that is robust in application, fully meeting specified and adumbrated intent, is well structured, and is graceful in operation.



Primary Focus

- System Design and Integration
  - Identify system couplings and interactions
  - Identify system uncertainties and sensitivities
  - Identify emergent properties
  - Manage the effectiveness of the system
- Engineering Discipline Integration
  - Manage flow of information for system development and/or operations
  - Maintain system activities within budget and schedule

Supporting Activities

- Process application and execution

Systems Engineering Postulates

System Integration (physical/logical system)
Discipline Integration (social system)
Both System and Discipline Integration

- Postulate 1: Systems Engineering is product and environment specific, and context dependent.
- Postulate 2: The Systems Engineering domain consists of subsystems, their interactions among themselves, and their interactions with the system environment
- Postulate 3: The function of Systems Engineering is to integrate engineering disciplines in an elegant manner
- Postulate 4: Systems engineering influences and is influenced by organizational structure and culture
- Postulate 5: Systems engineering influences and is influenced by budget, schedule, policy, and law
- Postulate 6: Systems engineering spans the entire system life-cycle
- Postulate 7: Understanding of the system evolves as the system development or operation progresses
  - Postulate 7 Corollary: Understanding of the system degrades during operations if system understanding is not maintained.

MBSE Driver

Systems Engineering Principles

- Principle 1: Systems engineering integrates the system and the disciplines considering the budget and schedule constraints
- Principle 2: Complex Systems build Complex Systems

- Principle 3: The focus of systems engineering during the development phase is a progressively deeper understanding of the interactions, sensitivities, and behaviors of the system
  - Sub-Principle 3(a): Requirements are specific, agreed to preferences by the developing organization
  - Sub-Principle 3(b): Requirements and design are progressively defined as the development progresses
  - Sub-Principle 3(c): Hierarchical structures are not sufficient to fully model system interactions and couplings
  - Sub-Principle 3(d): A Product Breakdown Structure (PBS) provides a structure to integrate cost and schedule with system functions
- Principle 4: Systems engineering spans the entire system life-cycle
  - Sub-Principle 4(a): Systems engineering obtains an understanding of the system
  - Sub-Principle 4(b): Systems engineering models the system
  - Sub-Principle 4(c): Systems engineering designs and analyzes the system
  - Sub-Principle 4(d): Systems engineering tests the system
  - Sub-Principle 4(e): Systems engineering has an essential role in the assembly and manufacturing of the system
  - Sub-Principle 4(f): Systems engineering has an essential role during operations and decommissioning

- Principle 5: Systems engineering is based on a middle range set of theories
  - Sub-Principle 5(a): Systems engineering has a physical/logical basis
  - Sub-Principle 5(b): Systems engineering has a mathematical basis
  - Sub-Principle 5(c): Systems engineering has a sociological basis
- Principle 6: Systems engineering maps and manages the discipline interactions within the organization
- Principle 7: Decision quality depends on the system knowledge represented in the decision-making process
- Principle 8: Both Policy and Law must be properly understood to not overly constrain or under constrain the system implementation
- Principle 9: Systems engineering decisions are made under uncertainty accounting for risk
- Principle 10: Verification is a demonstrated understanding of all the system functions and interactions in the operational environment
- Principle 11: Validation is a demonstrated understanding of the system's value to the system stakeholders
- Principle 12: Systems engineering solutions are constrained based on the decision timeframe for the system need

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System Engineering Hypotheses

- Hypothesis 1: If a solution exists for a specific context, then there exists at least one ideal Systems Engineering solution for that specific context
  - Hamilton's Principle shows this for a physical system
    - $\int_{t_1}^{t_2} (\delta T - \delta V + \delta W) dt = 0$
- Hypothesis 2: System complexity is greater than or equal to the ideal system complexity necessary to fulfill all system outputs

- Hypothesis 3: Key Stakeholders preferences can be represented mathematically

- Hypothesis 4: The real physical system is the perfect model of the system
  - Kullback-Liebler Information shows this for ideal information representations of systems
    - $I(f, g) = \int f(x) \log(f(x))\, dx - \int f(x) \log(g(x|\theta))\, dx = 0$

System Models

System Model	Concept Definition	System Requirements	System Design	System Analysis	System Manufacturing	System Verification	System Validation	System Operation	System Disposal
System Integration									
Goal Function Tree (GFT)	√	√	√	√		√		√	√
System Value Model	√	√					√		
Relationship Model (SysML based)	√	√				√			
System Integrating Physics (e.g., System Exergy, Optical Transfer Function, Loads)		√	√	√	√	√		√	
State Analysis Model			√	√	√	√		√	
Multidisciplinary Design Optimization (MDO)			√	√	√	√		√	
Engineering Statistics	√		√	√	√	√		√	
Discipline Integration									
System Dynamics	√		√	√	√			√	√
Discrete Event Simulation (DES)					√	√		√	√
Agent Based Model (ABM)	√							√	√

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Consortium

- List of Consortium Members
  - Air Force Research Laboratory – Wright Patterson, Multidisciplinary Science and Technology Center: Jose A. Camberos, Ph.D., Kirk L. Yerkes, Ph.D.
  - George Washington University: Zoe Szajnfarber, Ph.D.
  - Iowa State University: Christina L. Bloebaum, Ph.D., Michael C. Dorneich, Ph.D.
  - Missouri University of Science & Technology: David Riggins, Ph.D.
  - NASA Langley Research Center: Peter A. Parker, Ph.D.
  - The University of Alabama in Huntsville: Phillip A. Farrington, Ph.D., Dawn R. Utley, Ph.D., Laird Burns, Ph.D., Paul Collopy, Ph.D., Bryan Mesmer, Ph.D., P. J. Benfield, Ph.D., Wes Colley, Ph.D.
  - The University of Michigan: Panos Y. Papalambros, Ph.D.
  - Marshall Space Flight Center: Peter Berg
  - Glenn Research Center: Karl Vaden
- Previous Consortium Members
  - Massachusetts Institute of Technology: Maria C. Yang, Ph.D.
  - The University of Texas, Arlington: Paul Componation, Ph.D.
  - Texas A&M University: Richard Malak, Ph.D.
  - Tri-Vector Corporation: Joey Shelton, Ph.D., Robert S. Ryan, Kenny Mitchell
  - Doty Consulting: John Doty, Ph.D.
  - The University of Colorado – Colorado Springs: Stephen B. Johnson, Ph.D.
  - The University of Dayton: John Doty, Ph.D.
  - Stevens Institute of Technology – Dinesh Verma
  - Spaceworks – John Olds (Cost Modeling Statistics)
  - Alabama A&M – Emeka Dunu (Supply Chain Management)
  - George Mason – John Gero (Agent Based Modeling)
  - Oregon State – Irem Tumer (Electrical Power Grid Robustness)
  - Arkansas – David Jensen (Failure Categorization)

~40 graduate students and 5 undergraduate students supported to date