PANEL: MISSION ENGINEERING
Research Challenges

Moderated by Dr. Judith Dahmann, MITRE Technical Fellow & Dr. Daniel DeLaurentis, SERC Chief Scientist, Purdue

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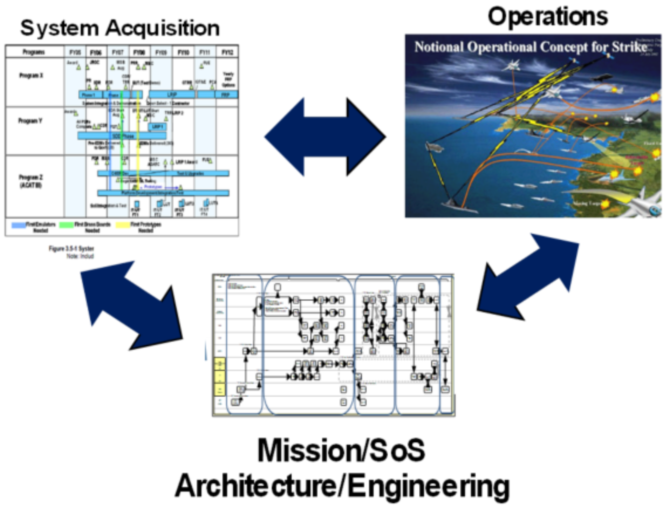
Increasingly systems engineering is being applied to larger sociotechnical systems of systems and enterprises. Recently, the US Department of Defense has shifted engineering focus from systems alone to addressing the larger mission context for systems and to treating the mission as the 'system of interest'.

This panel will address the research challenges posed by applying systems engineering to missions

- *What makes mission engineering different?*
- *What is new?*
- *What are the technical challenges?*
- *What are research areas which are called for to address these challenges?*



Mission Engineering is the deliberate planning, analyzing, organizing, and integrating of current and emerging operational and system **capabilities** to achieve desired operational mission effects

- Mission engineering treats the end-to-end mission as the "system"
- Individual systems, including organizations and other non-material elements, are components of the larger mission 'system' or system of systems
- Systems engineering is applied to the systems-of-systems supporting operational mission outcomes
- Mission engineering goes beyond data exchange among systems to address cross cutting functions, end to end control and trades across systems
- Technical trades exist at multiple levels; not just within individual systems or components
- Well-engineered composable mission architectures foster resilience, adaptability and rapid insertion of new technologies

PANELISTS

- **Elmer L. Roman**, OUSD, (R&E) AC / Engineering
- **Alejandro Salado**, Virginia Tech
- **Dorothy McKinney**, SE Consultant
- **Ryan Noguchi**, Aerospace Corporation
- **Donna Rhodes**, MIT

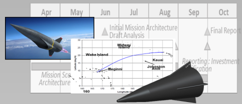
Elmer L. Roman, OUSD, (R&E) AC / Engineering

R&E Lines of Effort

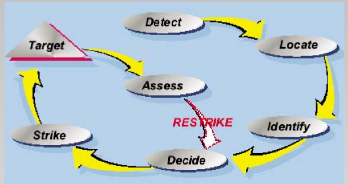
Examples of Current Mission Engineering Activities / Efforts

STUDIES

Rapid Precision Strike



Time Sensitive Targeting

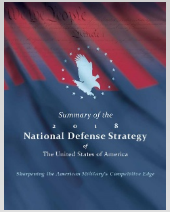


Directed Energy

ARCHITECTURE

JADC2

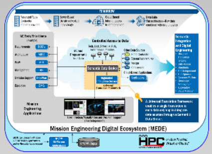
R&E AD Modernization



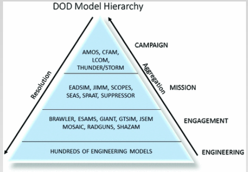
PROCESS / TOOLS

DoDI 5000.EN

Mission Engineering Guide



Digital Ecosystem



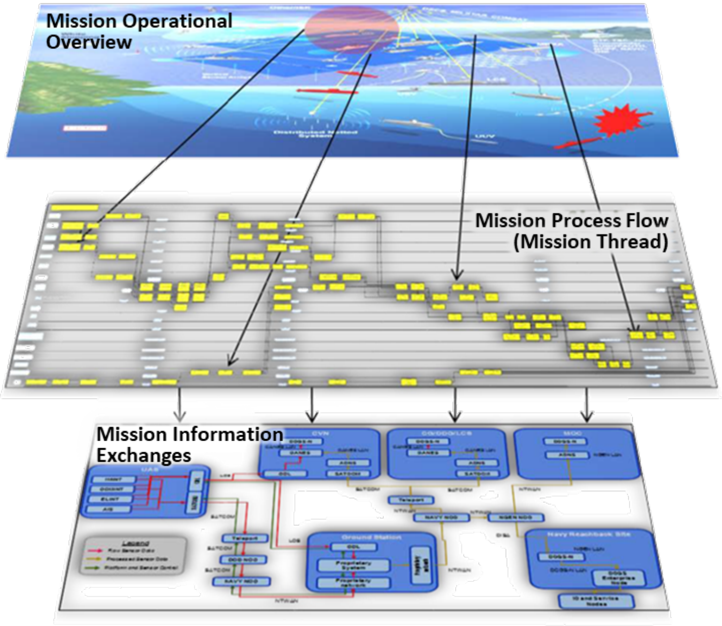
Simulation Tools

SYSTEMS ENGINEERING RESEARCH CENTER

SERC SPONSOR 12TH ANNUAL RESEARCH REVIEW

NOVEMBER 18, 2020

ME Obstacles and Challenges



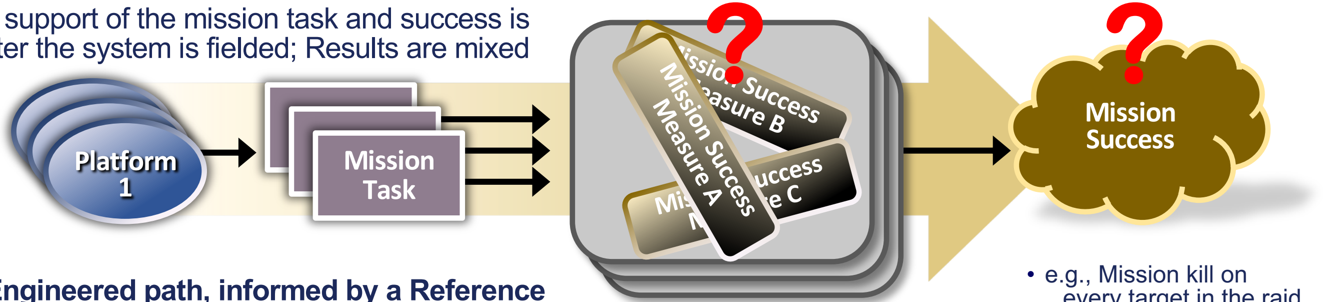
- How can we analyze System of Systems (SoS) across all domains using the tools that are available today?
- How do we evaluate complex operational and SoS architectures and perform trade space analysis?
- How can we ensure that ME is a repeatable process with reusable and trusted models and data?
- How does the department promote and utilize a Knowledge Management system across the engineering community?
- How can we drive the department to pursue and adopt a threat-informed, tops-down approach to improve mission outcomes and inform enterprise investment decisions?

Benefits of ME Architectures

Today's acquisition path with system / platform engineered focus

Platforms' support of the mission task and success is defined after the system is fielded; Results are mixed

Utility assessed after system is delivered and all trades have been made

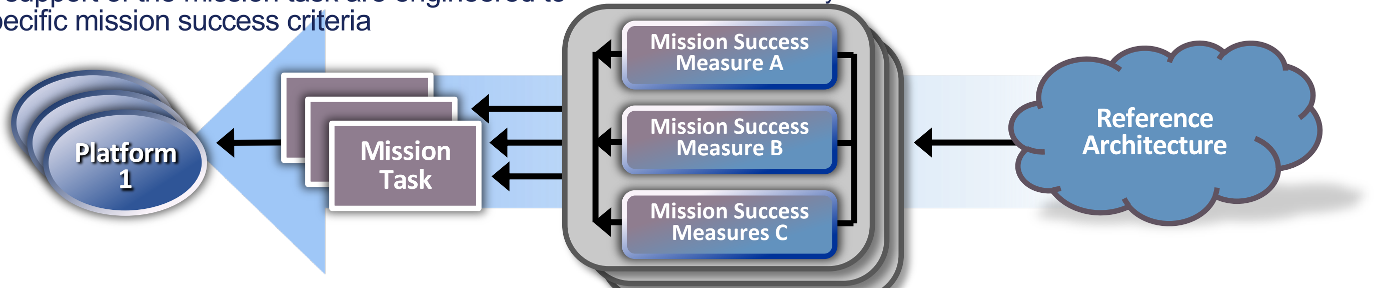


- e.g., Mission kill on every target in the raid
- e.g., No friends engaged

Mission Engineered path, informed by a Reference Architecture

Platforms' support of the mission task are engineered to support specific mission success criteria

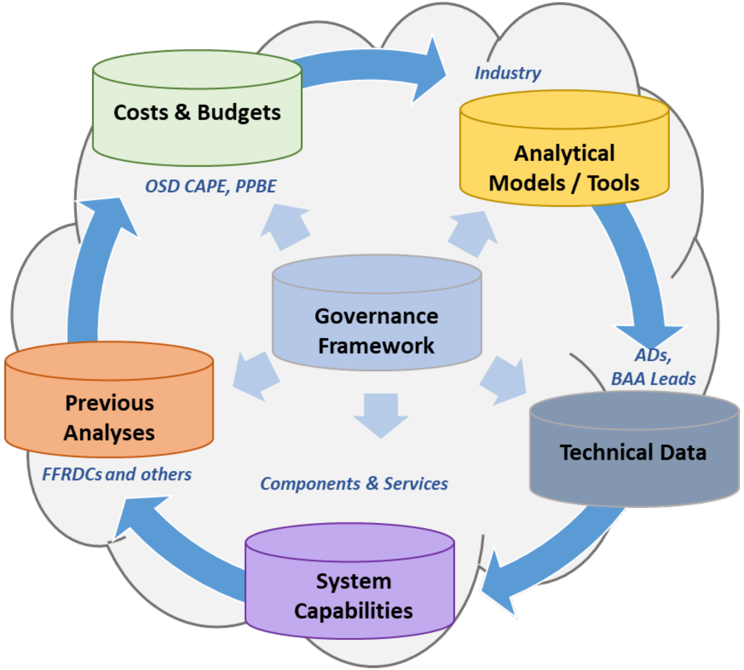
Mission measures align trades and utility



Evaluating mission contribution, scored against success measures, to inform prioritization, trades, and resource allocation prioritization

ME Knowledge Management

- Transparency of program performance data
- Industry-provided design models
- Increased oversight of program interdependencies
- Collaborative mission efficacy analysis
- Curation of data — accuracy of analyses depends on pedigree of data



Need collaborative environment, tailorable software tools, authoritative models, data

Alejandro Salado

Assistant Professor, Virginia Tech

Consultant, systems engineering & enterprise transformation

10+ as **systems engineer**, space systems

Chief Architect, **Space Weather Mission** Concept (for European Space Agency)

Co-Editor, **ISO/IEC/IEEE 21840:2019** Guidelines for the utilization of ISO/IEC/IEEE 15288 in the context of System of Systems (SoS) engineering

Research/consulting in problem formulation & architecture assessment, **CAS/MOSA** (US Army)

Director, **Graduate Certificate** in Mission Engineering (planned), Virginia Tech

MISSION ENGINEERING

FROM ISO…

Applying **15288** to SoS…

Total of **~180** outcomes

~50 as stated

The rest…

*Depending on **managerial** and **governance** independence…*

IN PROBLEM FORMULATION…

Focus on **outcome** vs action/output

Achieve a **state**

Lack of **control**

Self-balancing of competing objectives

WHEN "ARCHITECTING"…

Size & **heterogeneity**

Exogenous & **endo**genous blur

*How to **predict** effectiveness?*

SYSTEMS THEORY

+ Systems Engineering of **CLOSED** systems

Dorothy McKinney, SE Consultant

Dorothy McKinney, Director, Advanced Systems Thinking (consultancy)

- **Mission engineering** recognizes challenges we have faced in recent years as:
  - —Systems (and systems of systems) have become more complex
  - —The number and variety of stakeholders' perspectives has expanded
  - —Resources have become increasing limited, and constraints have multiplied
  - —Systems engineering has increasingly been held responsible for unintended consequences of the deployment and operation of systems
- Difficulties for engineers
  - —Skills needed far exceed traditional engineering skills
  - —The number and diversity of backgrounds and education (or the lack of it) in the different people we need to interact with poses many difficulties
  - —Although some customers are asking us to do mission engineering, it is not clear they are willing to provide the additional resources needed

Key Challenges

- Existing knowledge and conventional wisdom which are dysfunctional in mission engineering – teaching an old dog new tricks while doing paid contract work for the dog and his “pack” is tough!
- Interactive novel option generation (the convergence of psychological principles, systems thinking and decision science to enhance trade-offs)

Interesting Lessons Learned

- Quirky or non-traditional personalities seem to have an easier time of convincing stakeholders to cooperate
- Iteration as a learning/educational tool seems much more important than in traditional systems engineering

Key Approaches / Themes for Moving Ahead

- Use transdisciplinary approaches including:
  - —Disruptive collaboration and transdisciplinary fusion
  - —Immersive knowledge-sharing experiences (e.g. augmented reality)
  - —Co-creation of new knowledge (and unlearning in this process)
- Enabling technologies
  - —Convergence of engineering and entertainment/cinematic arts
  - —Combining model-based methods with interactive storytelling
  - —Convergence of traditional collaboration, crowdsourcing and social media
  - —Virtual reality & augmented reality use to enhance empathy
- New skill: Bouncing across disciplines plus non-discipline stakeholders, gathering and weaving threads of new meaning as you go

Ryan Noguchi, Aerospace Corporation

Background and Perspective

- Background
  - Director, Space Architecture Department, Aerospace Corporation
  - Previously Director and Senior Project Leader, System of Systems Engineering Office, Aerospace Corporation

- Perspectives
  - System architecting
  - Enterprise architecting
  - System of systems engineering
  - Enterprise systems engineering
  - Model based systems engineering and digital engineering
  - Mission engineering

Critical Needs for Mission Engineering

Technical Challenges…

- Need to integrate knowledge across a very diverse set of enterprises spanning the full mission thread
  - Managing and sharing authoritative sources of truth (ASOT)
  - Establishing standards for model and data interoperability
- Need to enable continuous assessment and synthesis
  - Triggered by evolving systems and evolving awareness
  - Providing mechanisms for discovery and notification
  - Identifying robust configurations to achieve the mission
- Need for decision-making in the face of high dimensionality
  - Managing numerous configurations—huge trade space!
  - Managing deep uncertainty with robust solutions
  - Maintaining balance across different notions of "value"
  - Probabilistic analysis and visualization
  - Managing tradeoffs among requirements and objectives; among missions, systems, and enterprises
  - Collapsing complexity carefully to inform decisions
- Need to facilitate mission agility
  - Designing more agile systems and more agile humans
  - Improving composability of systems of systems
  - Enabling new missions with existing assets
  - Enabling new configurations of assets to address mission needs

… and Non-Technical Challenges

- Need for incentives for establishing and sustaining collaboration between organizations and systems
  - Sharing of knowledge, information, and data
  - Sharing of systems, services, capabilities
  - Influencing system acquisition and evolution to accommodate partner or future needs
  - Incentivizing modularity, interoperability, flexibility, etc. when implementing systems
  - Culture of continuous assessment and improvement
- Need to establish governance mechanisms for ASOTs
  - Understanding the implications of potential decisions to current and future mission applications
- Need to expand horizons of the decision-space
  - Broader exploration of non-materiel solution space
  - Broader exploration of the threat space
  - Enterprise-level solutions vs. optimization within stovepipes
  - Value flexibility, interoperability, and adaptability over performance optimization
  - Acceptance of robust decision-making methods to address deep uncertainty
- Need to fund missions too, not just systems

Key Themes for Mission Engineering Enabling Research

- Addressing key technical challenges
  - *Integrating knowledge across a very diverse set of enterprises spanning the full mission thread*
  - *Enabling continuous assessment and synthesis*
  - *Enabling decision-making in the face of high dimensionality*
  - *Facilitating mission agility*
- Addressing key non-technical challenges
  - *Establishing incentives for establishing and sustaining collaboration between organizations and systems*
  - *Establishing governance mechanisms for ASOTs*
  - *Expanding horizons of the decision-space*
  - *Funding missions too, not just systems*
- Tools and techniques in related disciplines may be helpful to improve Mission Engineering
  - *Complexity theory*
  - *Systems science and systems thinking*
  - *Smart Cities design*
  - *Big Data analytics*
  - *Machine learning and artificial intelligence*
  - *High-dimensionality trade-off analysis*
    - And high-dimensionality visualization
  - *Transdisciplinary approaches*
  - *MBSE*
    - Enterprise modeling languages
    - Model and data integration
  - *Digital Twin*
    - Particularly at enterprise level

Donna Rhodes, MIT

Donna H. Rhodes

Massachusetts Institute of Technology

Academia

Anthropology + Systems Science

Systems engineering

Human systems + cognition

Industry

Aerospace & Defense + some commercial

Evolution of systems engineering

SE competency strategy

Enterprise transformation

Academia

Engineering Systems, Sociotechnical Systems

Systems of Systems

Systems Architecting Applied to Enterprises

Current Research

- Human-model interaction
- Model-centric decision making
- Leading indicators
- Model curation
- Digital transformation
- Digital twins –sociotechnical

Key Challenge/Learnings: "higher order" thinking for mission engineering – by individuals and teams - in our future workforce

THEORY

Collaborative Systems Thinking

"an emergent behavior of teams resulting from the interactions of the team members… utilizing a variety of thinking styles, design processes, tools, and languages to consider system attributes, interrelationships, context, and dynamics towards executing systems design."

(Lamb, 2009)

APPROACH

Capstone Projects

The Naval Postgraduate School's Department of Systems Engineering Approach to Mission Engineering Education through Capstone Projects

(Van Bossuyt, et al., 2019)

SERC: Research on "System Mindset" and ME Competencies

4. Systems Mindset
'Big Picture' Thinking
Adaptability
Paradoxical Mindset
Multi-Scale Abstraction
Critical Thinking

Atlas1.1: An Update to the Theory of Effective Systems Engineers

RT-171: Mission Engineering Competencies

MIT: Interactive Games to Improve Engineering Systems Thinking

Persona has a particular promoted playstyle, players are incentivized to playstyles (and the corresponding challenges and lessons) that they might normally avoid or never consider

(Ross, et al., 2014)

Moving Forward – deeper understanding of "intelligences"

"Systems Thinking" has been identified as a mission engineering competency - What do we really mean by this? How can we teach it? How can we augment it?

some preliminary thoughts

- **Ecosystem Thinking**
  - Creation of value, destruction of value
  - Value strategies, stakeholder saliency, externalities, grey zone
- **Adaptive Capacity**
  - Multi-faceted, individual and social, resilience to perturbations
  - Complex vulnerability/opportunity strategies – "platform" thinking
- **Anticipatory Thinking**
  - Exploration of relevant possible futures, internalized predictive models
  - Model-augmented, use of situational information
- **Harmonizing/Synchronizing**
  - Bringing into agreement, controlled movement in time
  - Analogy "musical intelligence" - *all composers begin as performers*

Theory of Multiple Intelligences

Only if we expand and reformulate our view of what counts as human intellect will we be able to devise more appropriate ways of assessing it and more effective ways of educating it.

Howard Gardner, 1983

Discussion