Michael DiMario, PhD
Ann Hodges
Agenda

• Why we’re here - Mike
• What we’ve done - Mike
• Mind map - Mike
• Priorities
  – Value proposition - Ann
  – Principles - Ann
  – Existing frameworks and literature search - Ann
  – Case studies - Mike
• Wrap up - Mike
Why we’re here: Charter overview

• **Purpose:** To provide an open forum for the development, application, and dissemination of systems engineering principles, best practices, and solutions to scaling systems engineering applications to Early Stage R&D (ESR&D) projects allowing the systems engineering effort to be tailored and commensurate with the anticipated risk to ensure the ESR&D outcomes are achieved.

• **Primary Goal:** To provide knowledge, guidelines, and frameworks for the application of systems engineering in ESR&D.
• **Scope:** Focus on activities at Technology Readiness Levels (TRLs) 1 – 5

• **Outcomes:**
  – An ESR&D SE framework that contains guidelines and processes for the “right” and “right-sized” tailored SE practices and products based on a TRL of 1-5 and other characteristics e.g., organizational culture and philosophies
  – Papers, articles, briefings, and tutorials
  – Support the development of additions to the INCOSE SE Handbook and standards related to ESR&D
Early Stage Research and Development (ESR&D) is one of the most crucial phases in the product development process. ESR&D is defined in terms of Technology Readiness Levels (TRLs) 1 – 5. It is a critical phase in the product development process. Many organizations/positions/key stakeholders are unwilling to apply SE in ESR&D due to perceptions of SE being process/cost heavy. Results in technical issues with solutions, difficulty in transitioning to higher TRLs, higher R&D costs, and extended development timelines. ESR&D differs from traditional SE in a number of important ways: ESR&D addresses higher risk technologies with multiple opportunities for failure. ESR&D accounts for the fact that there is much about the underlying technology and its associated concept of operations that is poorly understood. ESR&D is a way to practice SE for organizations without a strong SE culture. ESR&D of focused on areas of high “system development risk.” Lack of a commonly understood and accepted framework inhibits multi-disciplinary collaboration. A common framework that can be tailored and sustained for ESR&D, while enabling transition to TRL 5 and higher, is needed.
What we’ve done

• CORE Team officially formed February 2020
• Charter affirmed March 2020
• INCOSE recognized WG April 2020
• INCOSE Connect Site IT Logistics
• Publications
  – “Implementing Systems Engineering in Early Stage Research and Development (ESR&D) Engineering Projects” IS20 30\textsuperscript{th} Annual INCOSE International Symposium July 18-23, 2020
  – “Perceived Conflicts of Systems Engineering in Early Stage Research and Development” INCOSE InSight August 2021
• INCOSE LA Chapter presentation May 11, 2021
• IW21 working group meetings
• IS21 July 17-22, 2021 Panel
• September and November 2021 general working group meetings
• First Case Study planning underway 1\textsuperscript{st} QTR 2022
Focus areas

1. Value proposition
2. Principles
3. Existing frameworks and literature search
4. Case studies
1. Value Proposition Focus Area*
INCOSE’s Value Proposition for Applying SE Early

Lifecycle Costs and Cost to Extract Defects Through-out a Project (Walden et. al., 2015)
The Problem

• Value proposition is not compelling to researchers or funding organizations
  – Do not understand the value of SE and think of it as heavily process oriented, applicable only for mature technologies, and costly
The Result

• SE is often not applied to early stages of R&D
  – Resulting in the research, problem, or early prototype being solved or developed incorrectly or insufficiently incurring greater risk and not able to transition to higher TRLs
A Possible Solution

• Express the value proposition in terms of assuring quality of the research products throughout the project lifecycle
  – Result is a product that meets the stakeholder’s needs and requirements, increases the credibility of the research, and makes it more likely that the research will survive peer review, cross the Valley-of-Death while still achieving the goal of avoiding the time-consuming and costly rework implied in the INCOSE value proposition
Value Proposition

- Applying systems engineering to research activities early assures quality of the research products throughout the project lifecycle and provides a foundation for tech maturation
Focus Area Tasking

• Systematically test the value proposition with researchers
• Refine the value proposition based on researchers’ feedback
• Establish an assessment method for tracking quality throughout a project’s lifecycle
When is ESR&D needed?

- When system development risk is ignored or minimized
- For organizations without a strong SE capability/culture
- For organizations with a wide spectrum or project types, sponsors, and/or TRL levels
- When there is a high risk of technical failure
- When system requirements/ConOps are poorly defined
- Where there is a desire to institutionalize SE processes and procedures (e.g., CMMI level 3)
- ESR&D is a mechanism to transition engineering early out of research and prototype development and to iterate between research and engineering
SE in Early Stage R&D

2. Principles Focus Area

Ann Hodges
First things first - definition

What is a principle?

– Merriam-Webster: “a comprehensive and fundamental law, doctrine, or assumption; a rule or code of conduct”
  • A rule/belief that influences actions, explains the nature or workings of something
The Problem

• Identify principles that provide foundation for a framework
  – guidelines, processes and tools for the “right” and “right-sized”
    tailored systems engineering (SE) activities and deliverables to
    support early-stage research and development (R&D) projects

• Principles should be general enough to apply to a wide
  variety of research organizations, even if the missions differ
  – Industry
  – Academia
  – Government
Goals

Define a set of framework principles that
• is sensitive to the nature of R&D – the culture and goals
• reframes SE verbiage for the R&D culture
• enhances the integrity and repeatability of the R&D products
• is peer reviewed by R&D practitioners
  – Industry
  – Academia
  – National Laboratories
Focus Area Tasking

• Develop a draft set of principles – be sensitive to the “nature” of research
• Leverage the value proposition focus area
• Peer review the principles with researchers and SE for later in the life cycle
  – Industry
  – Academia
  – National Laboratories
  – Systems Engineers
• Refine the set of principles based on researchers’ feedback
The Nature and Nurture of R&D*
Understand the Nature, Seek to Nurture

Knowledge Evolution:
Surprise and Consolidation

Nature of Research

Science, Technology, and
their Coevolution

Intricate Dance of
Q&A Finding

Nurture People with
Care and Accountability

Embrace a culture of
Holistic Technoscientific Exploration

Nurture of Research

Align Organization, Funding
and Governance

*Adapted from [TSAO] Figure 0-1
**Principles – Nature of and Nurture R&D**

Nature of Research

- "Support informed contrariness"²
- Research is expansionist, SE is both reductionist + integrative”³
- Use a graded approach to applying SE processes⁴
- Support collaborative nature of research⁶
- Align organizational purpose, structure, resources⁸

Nurture of Research

- Insulate, not isolate, research from development⁷
- Select SE processes that preserve research quality, defensibility, future maturation⁵
- Reframe terms using researchers vocabulary⁴
- Fund people, not projects¹⁰
- Research is a “competitive sport”⁹

*Adapted from [TSAO] Figure 0-1
² Adapted from [COMP] pg 12, [TSAO] pg 178
³ Adapted from [TSAO] pg 182
⁴ [CONFL]
⁵ Ibid
⁶ [COMP], [TSAO]
⁷ [TSAO] pg 156
⁸ [TSAO] pg 162
⁹ [TSAO] pg 192
¹⁰ [TSAO] pg 159
Your thoughts – feedback?

• Thing 1
3. Existing Frameworks and Initial Concepts
ESR&D Framework for Research and Engineering Transition

• Innovation and research is noted with high failure
  – High risk and low return of investment
  – Projects fail at TRL 5-6 Valley of Death
  – Engineering transition is difficult and high risk
    • Research not appropriate for engineering transition
    • Basic research vs applied research
    • Solving the right problems for engineering transition

• Research and ESR&D is based in principles of expansionism vs reductionism
  – Continuous flow of ideas and experiment
  – Transition requires reductionism

• Framework must accommodate expansionism and reductionism
  – Example: Tailored process, tools and organization structure; Gated research artifacts transition to early engineered artifacts in a continual spiral of expansionism-reductionism-expansionism-reductionism using prescribed and tailored tools and processes; Research oriented engineer responsible for research whereby basic or applied research only performed to solve engineering problems
Initial Framework Concepts
Framework Based on Risk, Industry Standards and Project Type

- Risk-informed graded approach to the application of systems engineering (SE), project/program management (PM), and quality management (QM)
- Identified core set of practices that every project is required to follow – from the small best-effort research efforts to large pathfinder operational systems
- Implement differing level of rigor (timing, scope, formality) based on intrinsic project risk
  - Provide research-oriented projects an efficient and solid foundation for growth – either for future research efforts or further development of the research results – without stifling creativity and exploration
  - Start early in the project creation phase using a rigor-level determination template, followed by the tailoring of a project and product plan template for the determined level of rigor
- Developing project type category and subcategory templates for the risk-informed graded approach to increase efficiency and effectiveness.
Example from Los Alamos National Laboratory – Heidi Hahn (retired), PhD, ESEP, PMP

Initial Framework Concepts

LA-UR-19-25567
Another Framework Based on Risk, Standards and Project Type

• Risk-informed graded approach to the integrated application of systems engineering (SE), project management (PM), and quality management (QM)
  – Called this Mission Assurance
  – Quality standard for basic research is the ANSI standard, transitions to industry standard as TRL increases

• Identified core set of practices that every project is required to follow – from basic scientific research to advanced technology development
  – Provided the Mission Assurance Support Tool (MAST) as an implementation aid

• Implemented differing level of rigor (reviews, approvals, required documentation) based on project risk
  – Start early in the project initiation phase using a rigor-level determination template
  – Review risk-level determination throughout the project and adjust as needed
Initial Framework Concepts
Framework Based on Risk, Industry Standards and Project Type

• Extend risk-informed graded approaches for project/program management (PM) and quality management (QM) to SE
• Define SE “triggers” which drive implementation of SE (informal, semi-formal, formal)
• Define SE risks
  – Across project life cycle (e.g., concept, development, utilization phase)
  – Across project types (e.g., assessments, product development, test and evaluation)
  – By TRL (TRL 3: defines KPPs; TRL 4+: define specification)
4. Case Studies Focus Area

Michael DiMario, PhD
Objective

- Identify and Create Case Studies of Benefits and/or Problems of Systems Engineering in Early Stage R&D
  - Perform and examine empirical inquiry based on in-depth investigation of organizations and processes executing early systems engineering
The Result

• Analyze and Identify Frameworks for Early Stage R&D that are Enhanced via Systems Engineering
  – Document the qualitative and quantitative elements that provide successful R&D outcomes to a higher TRL and mitigate “Valleys of Death”
Focus Area Tasking

• Establish Case Study Strategic Approach
• Engage Associated INCOSE WGs and INCOSE Stakeholders
• Identify Existing or Create new Case Studies
• Solicit and Engage with R&D Organizations to Create or Test Case Studies
Future steps

• Flesh out the focus areas
  – Active participation – volunteer opportunities at various levels of engagement
  – Initiate case studies

• Additional publications
  – InSight editor offered the September 2023 issue for a *SE in ESR&D* theme
Wrap up

• Contact Michael DiMario mjdimario@outlook.com to volunteer or ask questions
  – Range of involvement = reviewer ↔ primary contributor
  – To volunteer, send email to Michael: provide name, email, organization, focus area(s) you’re interested in, level of involvement; optionally share any other background

• Focus area leads
  ➢ Value proposition: Ann Hodges
  ➢ Principles: Ann Hodges
  ➢ Frameworks, literature search: Ann Hodges
  ➢ Case studies: Michael DiMario
Bibliography

[COMP] A Complexity Primer for Systems Engineers, INCOSE-TP-2021-007-01.


