2024 Annual INCOSE international workshop
HYBRID EVENT
Torrance, CA, USA
January 27 - 30, 2024

SE in Early Stage R&D (ESRD) Working Group – Status and Collaboration Opportunity

Ann Hodges, Dr. Michael DiMario – co-chairs

Outline

- Why collaborate/participate with SE in ESRD
- Working group background
- Draft framework that bridges research and engineering
- Our ask, your opportunity
- Questions

Why collaborate with the SE in ESRD working group

SE in ESRD issues

- Projects have to reinvent previous research work
  - Experimental/research results not captured adequately
    - “write it down, strive for repeatability”
  - Lack research foundation for technical maturation and development
- Time-to-market is shrinking, competition growing
  - An enriched foundation for technical maturation provides speedup
- New technologies are drivers for new systems/products
- Lack of understanding the value of SE in ESRD – How does it apply to me? What are the crucial things to do, when to do them, and by whom?
  - Researchers: “Real Genius” movie – *“not my concern how research is applied”*
  - Systems engineers: *Wait for the handoff* from researchers to engage in development

Need to bridge research and engineering development

Working group background

Working group background

Why:

Promote SE value in ESRD resulting in decreased risk of transition to development and productization

Avoid "Valley of Death" and improve research and early development ROI

How:

Focus on Technology Readiness Levels 1-5

Provide ESRD framework with guidelines, processes ("right" + "right-sized") applicable to gov't, industry, academia

Papers, articles, briefings, tutorials

Case studies

What:

To provide an open forum for development, application, and usage of SE principles, best practices – provide guidelines and framework(s) to applying SE in ESRD

Who:

Co-chairs - Dr. M. DiMario, A. Hodges

188 members

Working group background – when

WG formation

2020

- IW20: Determine WG interest
- 4/20: Officially recognized
- IS20: (Hahn 2020)
- Core team formed

2021

- IW21: WG meetings
- INSIGHT: (DiMario 2021) article
- 5/21: LA Chapter presentation
- IS21: (Hodges 2021)
- General WG meetings

2022

- Evaluate WG input
- Model problems, solutions
- Identify focus areas
- 6/22: LA Chapter presentation

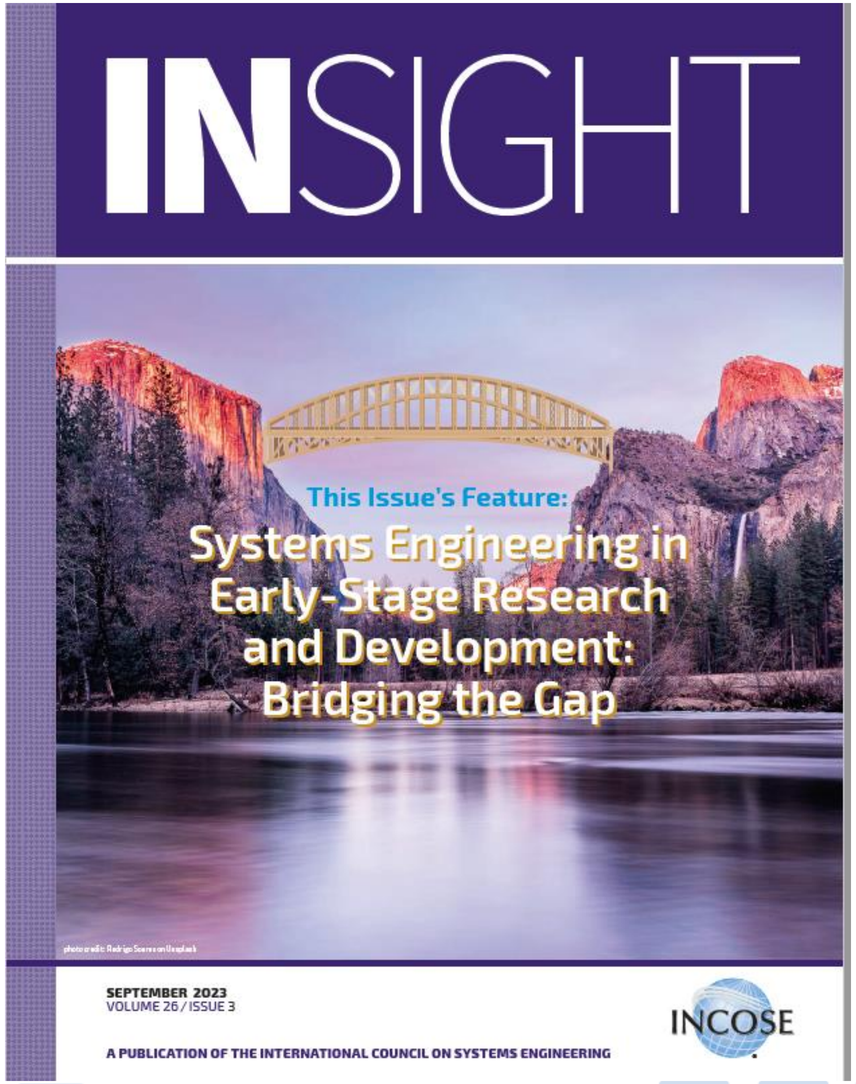
2023

- Draft framework developed
- INSIGHT 9/23 issue, co-chairs are theme editors
- INSIGHT 9/23 papers: (DiMario 2023), (Hodges 2023), (Sly 2023), (Ruth 2023), (Williams 2023),(Granados 2023), (Ritter 2023)
- WSRC 2023 briefing on (Hodges 2023)

2024

- IW24: Seeking collaborative partnerships with other WGs, FuSE integration, CAB case study possibilities
- Case study/studies
- Determine technical work products
- IS24: tutorial submission

Working group background



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INSIGHT

INCOSE

A PUBLICATION OF THE INTERNATIONAL COUNCIL ON SYSTEMS ENGINEERING
SEPTEMBER 2023 VOLUME 26 / ISSUE 3

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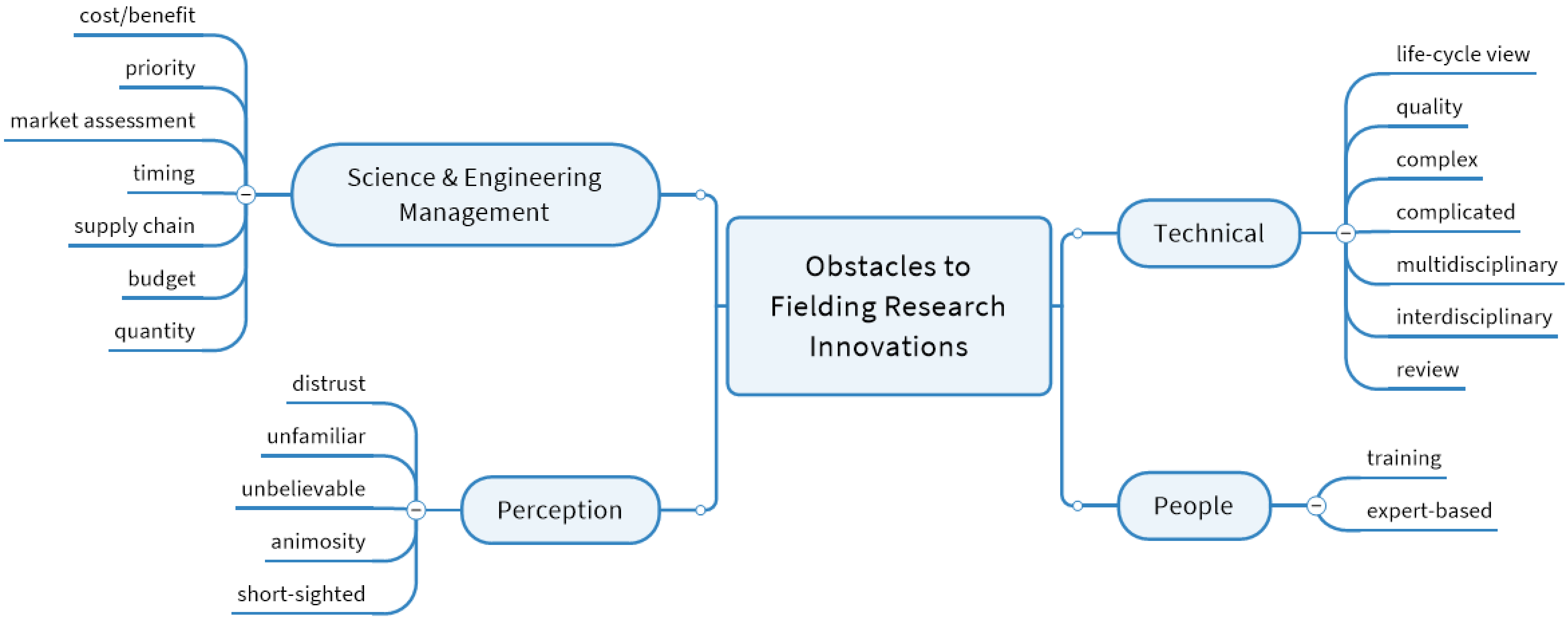
SEPTEMBER 2023
VOLUME 26 / ISSUE 3

Inside this issue

Draft framework that bridges research and engineering

Problem statement

Affinity diagram of barriers in (Anton 2022)



Framework elements

Value Proposition	**Principles**	**Standards Based**	**Risk-Informed Graded Approach**
MBSE	**TRL Context Sensitive**	**Research Domain Types**	**Training**
	Measures and Metrics	**Improvement**	

Framework elements – value proposition

- Right-sized SE provides credible research results that deliver a foundation for future technical maturation

- SE provides value when it delivers an R&D-focused SE strategy that serves as an organizational guide, involves stakeholders within and external to R&D

Express in terms meaningful to both researcher and business communities

Framework elements – risk-informed graded approach

- Application of rigor to practices and deliverables should be informed by the risk of the research
  - Rigor is a function of timing, scope and formality
- Graded approach adapted from (Hodges 2013) to determine relevant rigor includes consideration of intrinsic characteristics of both the research and the project, including:
  - Urgency of research deliverable(s)
  - Research objectives/requirements stability
  - Reliance on maturity level of underlying technology and/or manufacturing
  - Complexity of the technical, organizational, or procurements to support the research
  - Presence and availability of infrastructure (experimental, laboratory, test facilities)
  - Stakeholder expectations
- Generally, research projects' appropriate rigor is low based on risk (consequence of failure × likelihood of failure); higher consequence of failure (e.g., "grand challenge" or "moon shot" projects) will result in higher rigor recommendation

Framework elements – model-based SE (MBSE)

- Framework is tool agnostic
- Leverage content and formats amenable to later incorporation in MBSE tools – aids the transition to engineering
  - Use content/format researchers are familiar with
  - Don't require researchers to become MBSE tool mavens
- Start the digital thread early
  - Initiates the digital engineering ecosystem to enable go decision (MVP) fast-tracking of product to market with benefits for operating models & revenue stream

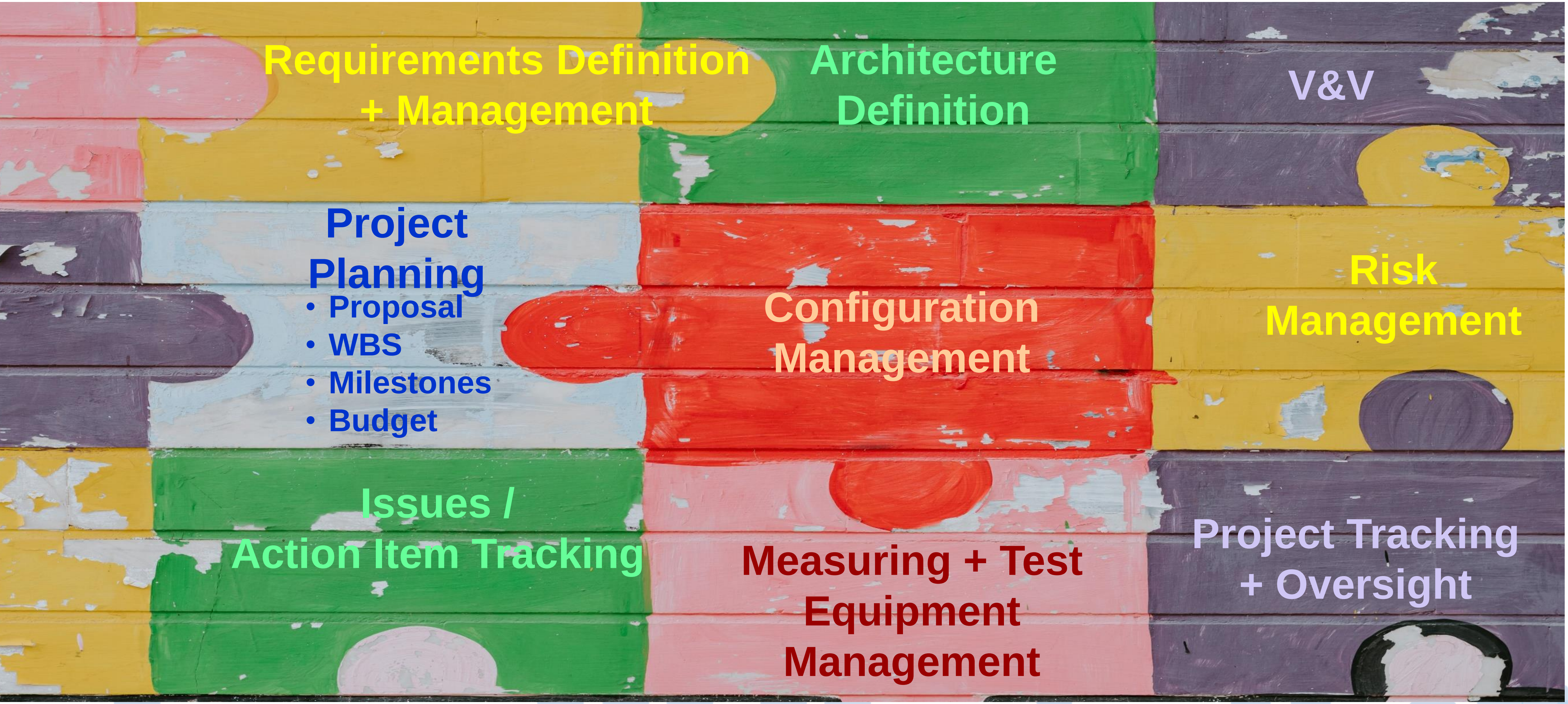
Framework elements – TRL context sensitive guidance/roadmap

- (DiMario 2023) describes 2 valleys of death in technology maturation
  - TRL 3-4 – failure to transition from research to a viable technology
  - TRL 5-6 – failure to transition to commercialization
- Framework guidance for SE activities and deliverables focuses on TRLs 1-6
  - Guidance for activities and artifacts
  - Artifacts comprise the initial set of items for the digital thread
  - 12 process areas/activities identified in the roadmap
  - Aligned with ISO/IEC 15288, INCOSE SEBoK, and other process/artifact guidance

Framework elements – TRL context sensitive guidance/roadmap

- Assumptions
  - Guidance is general enough to address all scientific research (e.g., materials science, device physics, quantum computing)
  - There may be TRL-specific requirements for each relevant domain
  - Trans-disciplinary team needed (Principal Investigator (PI), Systems Engineer, Project Manager, Science/Engineering Domain Lead, Sponsor)
  - Use increased rigor for higher-risk research (e.g., grand challenge, “moon shot”)
    - Formality: Examples = more formal plan, CM tool rather than shared drive + naming conventions
    - Increased scrutiny: Examples = more review + evaluation (e.g., external review panel of domain experts)
    - Increased monitoring: Examples = more frequent tracking and oversight (internally + externally)
  - Activities in the roadmap are based on previously mentioned standards, provide basis for bridging terminology into more general SE activities and deliverables
  - Roadmap focuses on planning and oversight of activities, assuming implementation occurs
  - RASIC + TRL 1-6 SE Roadmap is a job aid to provide process/artifact guidance for workshare between research and engineering domains – encourages a multi-disciplinary team

Framework elements – TRL context sensitive guidance/roadmap

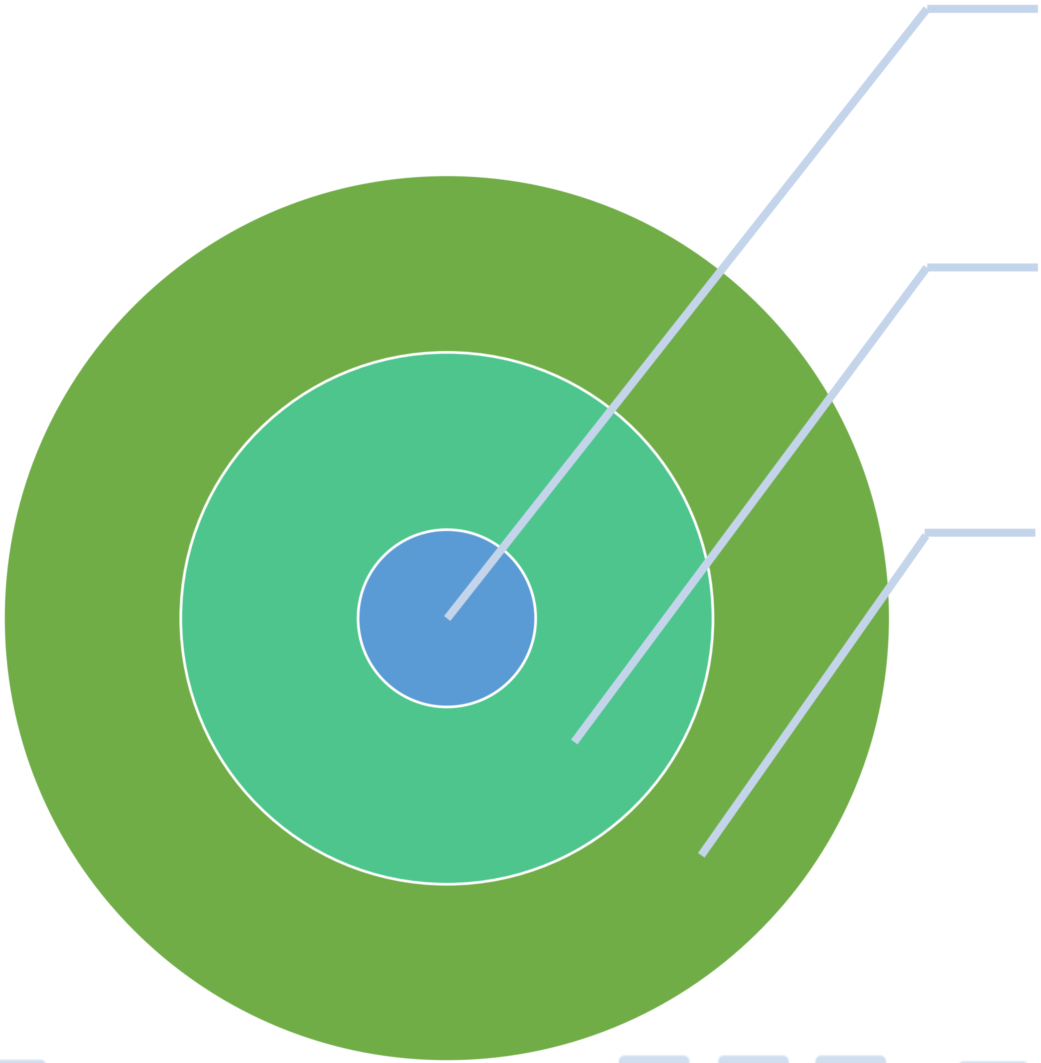


Framework elements – TRL context sensitive guidance/roadmap

Process Area	Principal Investigator	Project Manager	Systems Engineer	Science/ Engineering Domain Lead	Sponsor
Requirements Definition and Management	R,A	S	R	S	A
Architecture Definition	A, R	I	S	R, S	I
Verification and Validation (V&V)	A, R	I	S	R, S	S
Project Planning: Proposal/Charter	S	R	S	S	A
Project Planning: Milestone Definition	R	A	R	R	I
Project Planning: WBS Definition	S	R, A	S	C	I
Project Planning: Budget Definition	S	R	S	C	A
Configuration Management	A	C	R	S	I
Risk Management	A	R	R	S	I
Issues/Action Item Tracking	A	R	R	S	I
Measuring and Test Equipment Management	A, R	S	C	R	I
Project Tracking and Oversight	R	A	S	C	I

*RASIC = Responsible, Accountable, Supporting, Informed, Consulted

Framework elements – research domain types



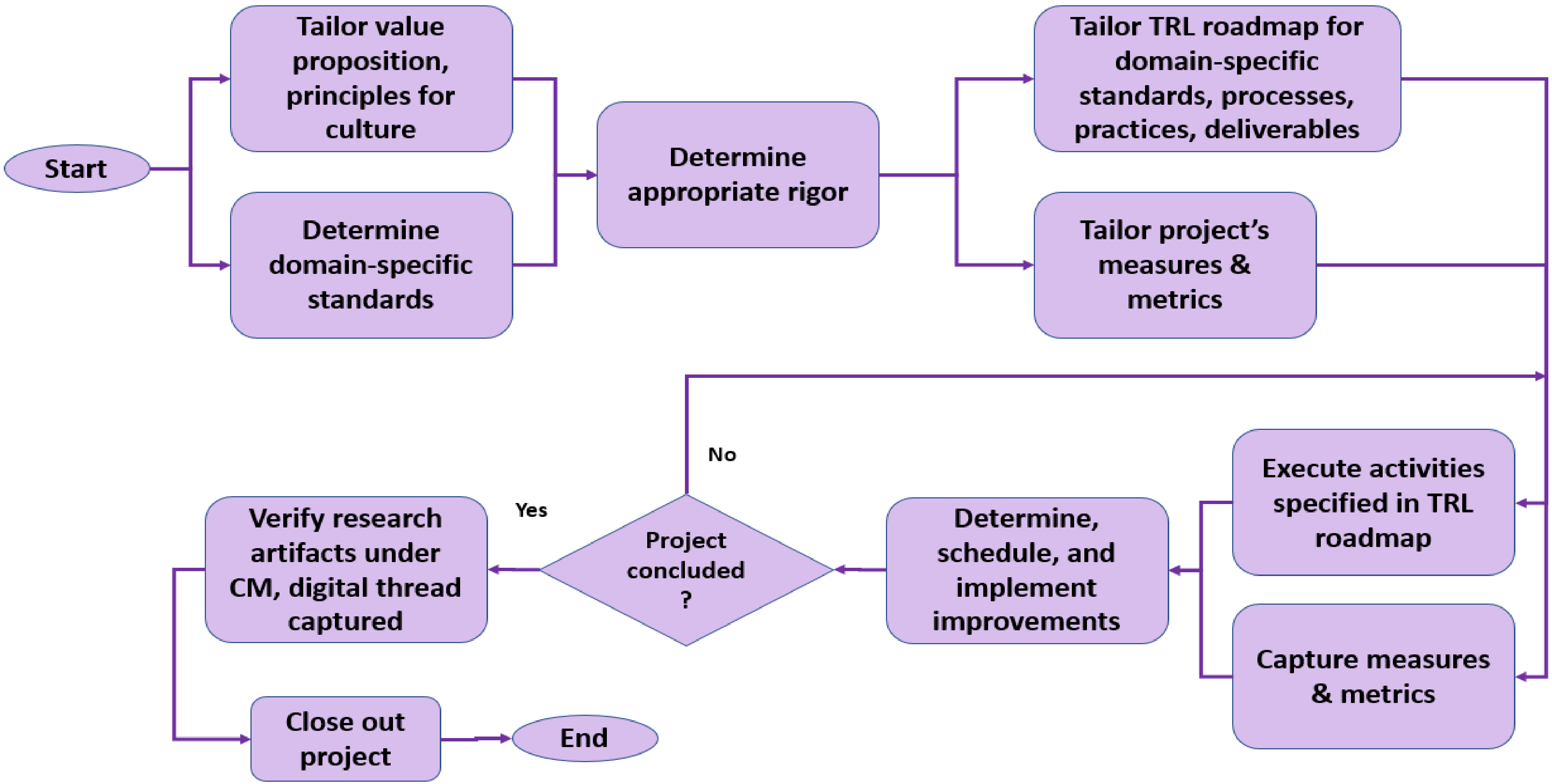
Common Core

Tailored Extensions (e.g., organizational, methodology)

Domain-specific (design- or analytical-specific requirements for each domain)

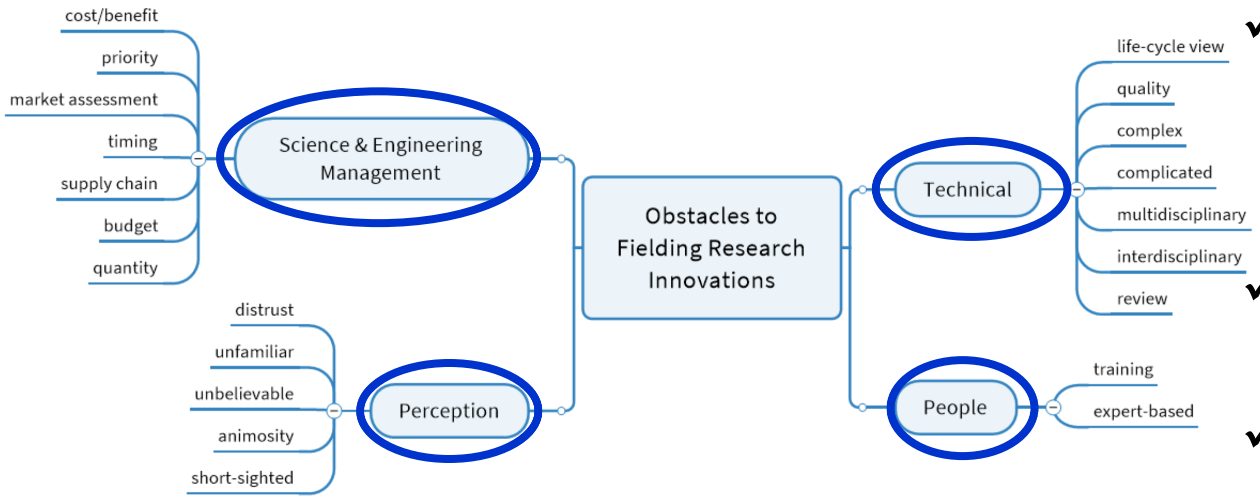
Adapted from (Long 2021), slide 23

Summary – using the SE in ESR&D framework elements



Summary – framework that bridges valley of death between research + engineering

Affinity diagram of barriers in (Anton 2022)



- ✓ Technical – increased awareness of life cycle perspective included in SE activities + deliverables
- ✓ Science & Engineering Management – Budget better informed by the life cycle view, earlier consideration of potential market and supply chain issues
- ✓ People – mutual training/coaching between PI/research team and Systems Engineer
- ✓ Perception – Increased potential for tackling some perception issues due to increased confidence/credibility in relevant standards, research approach, vetting and the ecosystem supporting the research activity

To bridge the valley of death between research and engineering, need to address barriers and questions

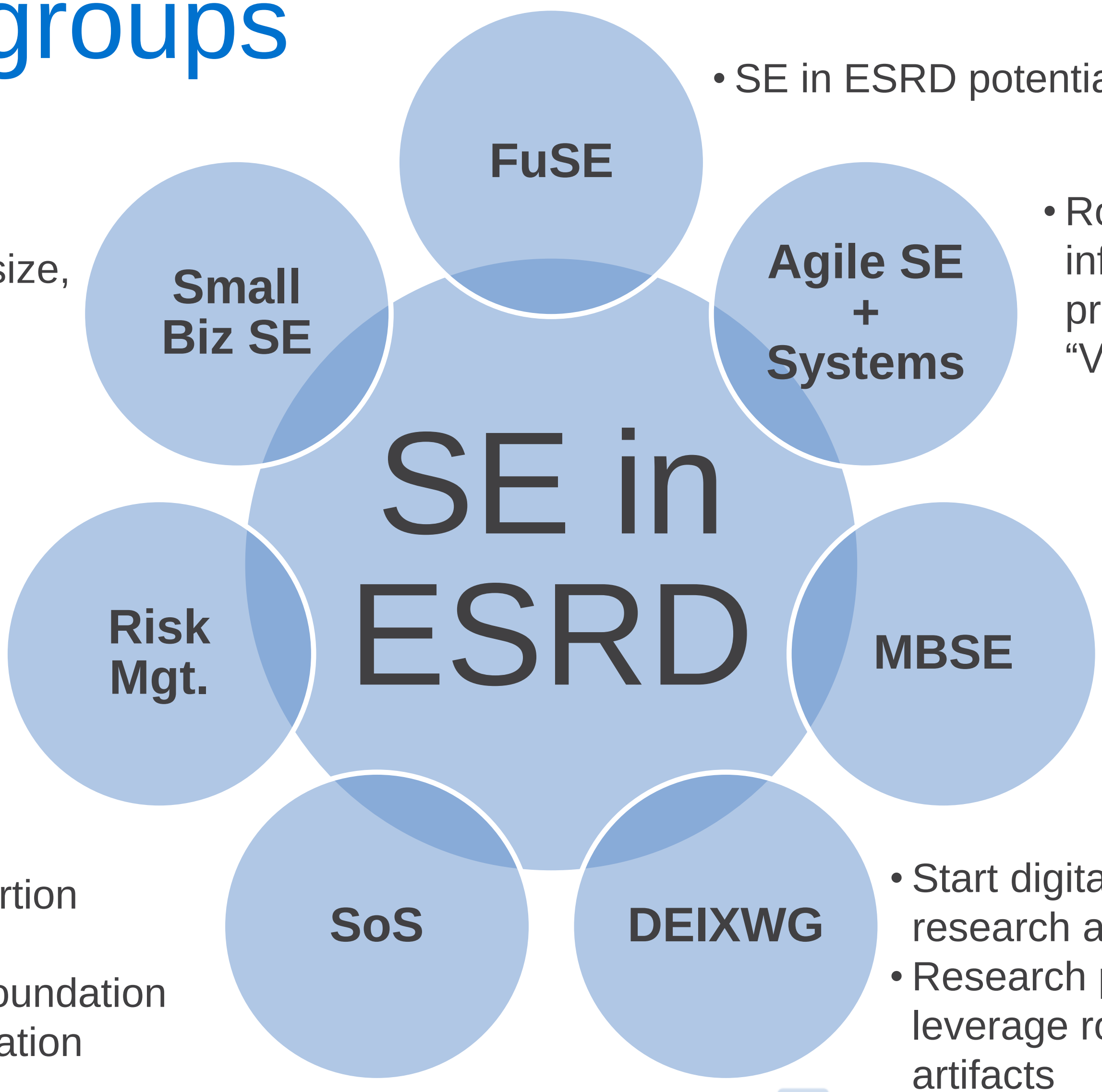
Summary – framework that bridges valley of death between research + engineering

- (DiMario 2021) posed questions for a framework that bridges the valley of death between research and engineering
  - ✓ Can the framework address the types of projects of interest? **Yes – domain-specific tailoring, risk-informed graded approach, research domain-type templates**
  - ✓ Does the framework address the cultural gap between SE and early-stage R&D (ESR&D)? **Yes – trans-disciplinary approach**
  - ✓ Does the framework support the range of internal and external stakeholders? **Yes**
  - ✓ Can the framework support different funding levels and funding allocation strategies? **Yes – risk-informed graded approach**
  - ✓ What is an acceptable level of process documentation, tools, and templates required by the framework? **Yes – risk-informed graded approach**
  - ✓ Will the framework support the transition to more formal SE should the effort move beyond the TRL level for ESR&D? **Yes – infrastructure for preserving research integrity and knowledge capture for future technical maturation**

To bridge the valley of death between research and engineering, need to address barriers and questions

Our ask,
your opportunity

On the hunt for collaborative opportunities with other working groups



- SE in ESRD potential new crosscutting theme

- Similarities in project/team size, needed rigor

- Roadmap activities/artifacts informs planning (e.g., epics, program increments) to avoid “Valleys of Death”

- Roadmap decreases risk in handoff between research and development
- Risk management is one of the key process areas, artifacts

- Roadmap suggests early models, tool agnostic
- Leverage format amenable to later incorporation into MBSE
- Use content/format researchers familiar with
- Don’t require researchers to be MBSE tool/language mavens

- New technology insertion challenge
- Roadmap provides foundation for technology maturation

- Start digital thread early, include research artifacts
- Research project patterns, may leverage roadmap processes, artifacts

Discussion

- Thing 1
- Thing 2

Our ask, your opportunity

- Support in expanding your working group's technical product(s) to include consideration of SE in ESRD
- SE in ESRD core team members attend other potential partner working group IW2024 meetings (future?)
- Case study opportunity
  - Use/review the framework, obtain feedback/address gaps from your working group's perspective
  - Search for research domain types
- For more information, contact
  - Ann Hodges (ann.hodges@incose.net)
  - Dr. Michael DiMario (mjdimario@outlook.com)

Questions

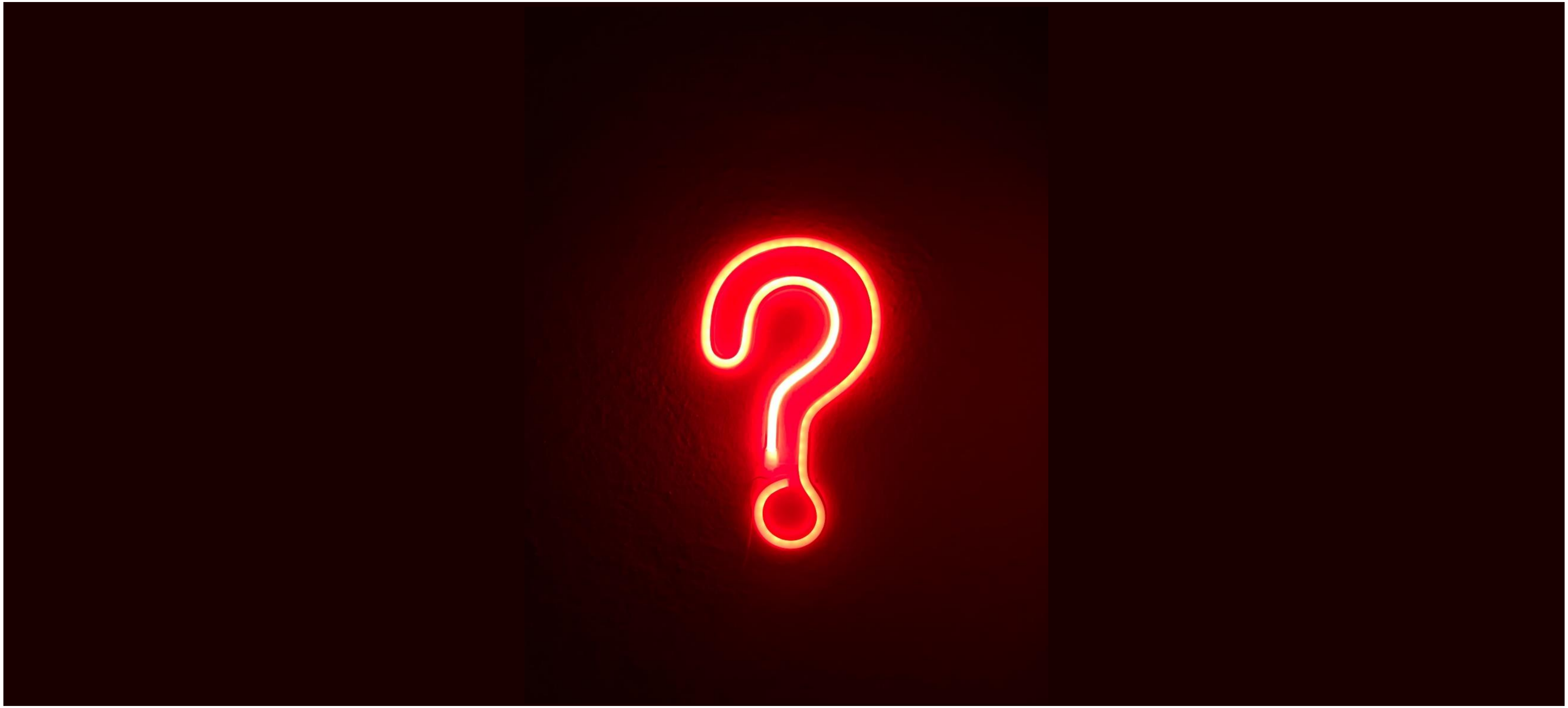


Photo by Simone Secci on Unsplash

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2024

Annual **INCOSE**

international workshop

HYBRID EVENT

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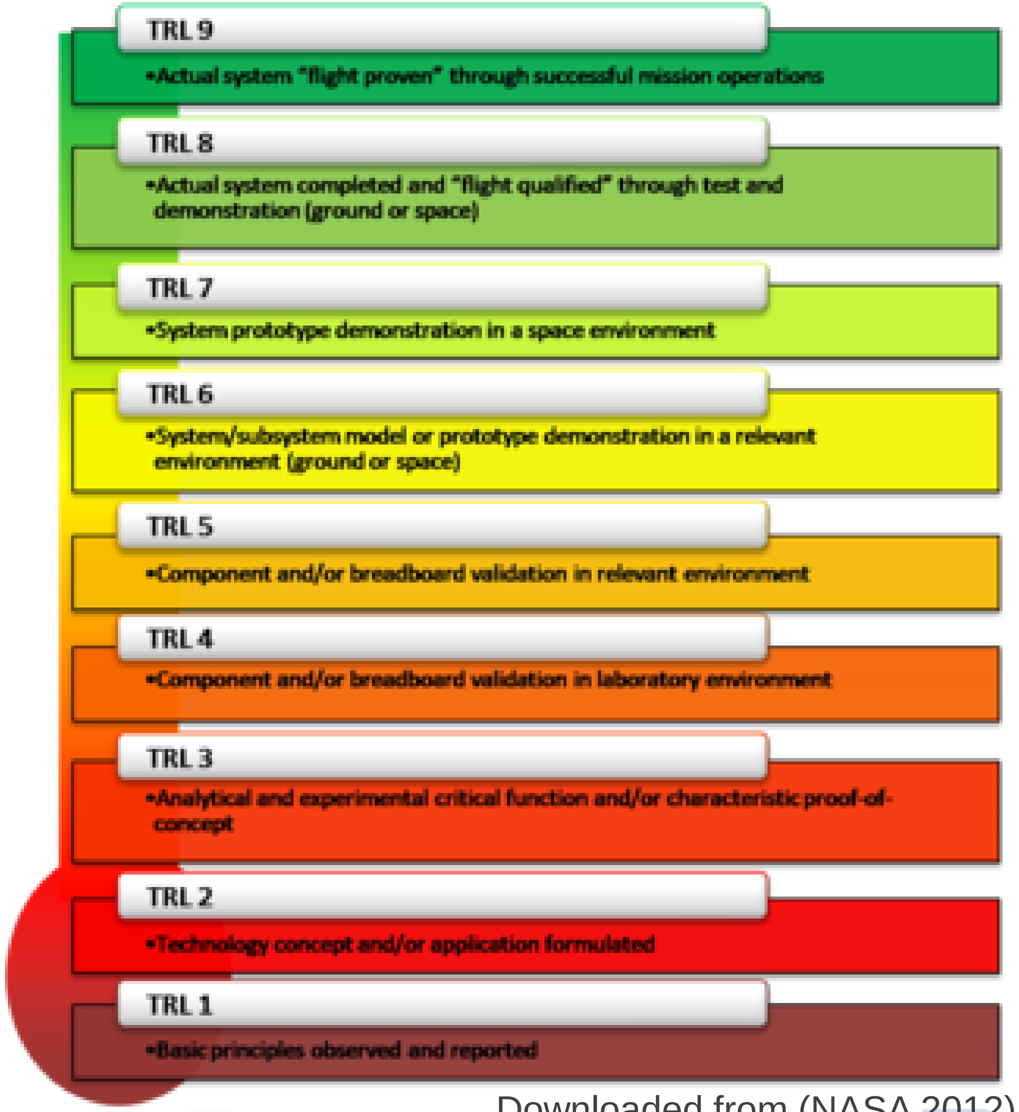
www.incose.org/IW2024

BACKUPS

Problem statement

- Researchers and funding organizations may not understand value of systems engineering (SE) in early-stage projects (TRLs 1-5)
  - SE is unnecessary cost
  - Process-heavy, applicable for mature technologies
- Results in
  - Lack of engineering rigor
  - Lack of understanding of innovation context
  - Increased risk of a “valley of death” between fundamental research and applied development



Downloaded from (NASA 2012)

Working group background

Charter

- ***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

Working group background

Charter

- ***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

Framework elements – principles

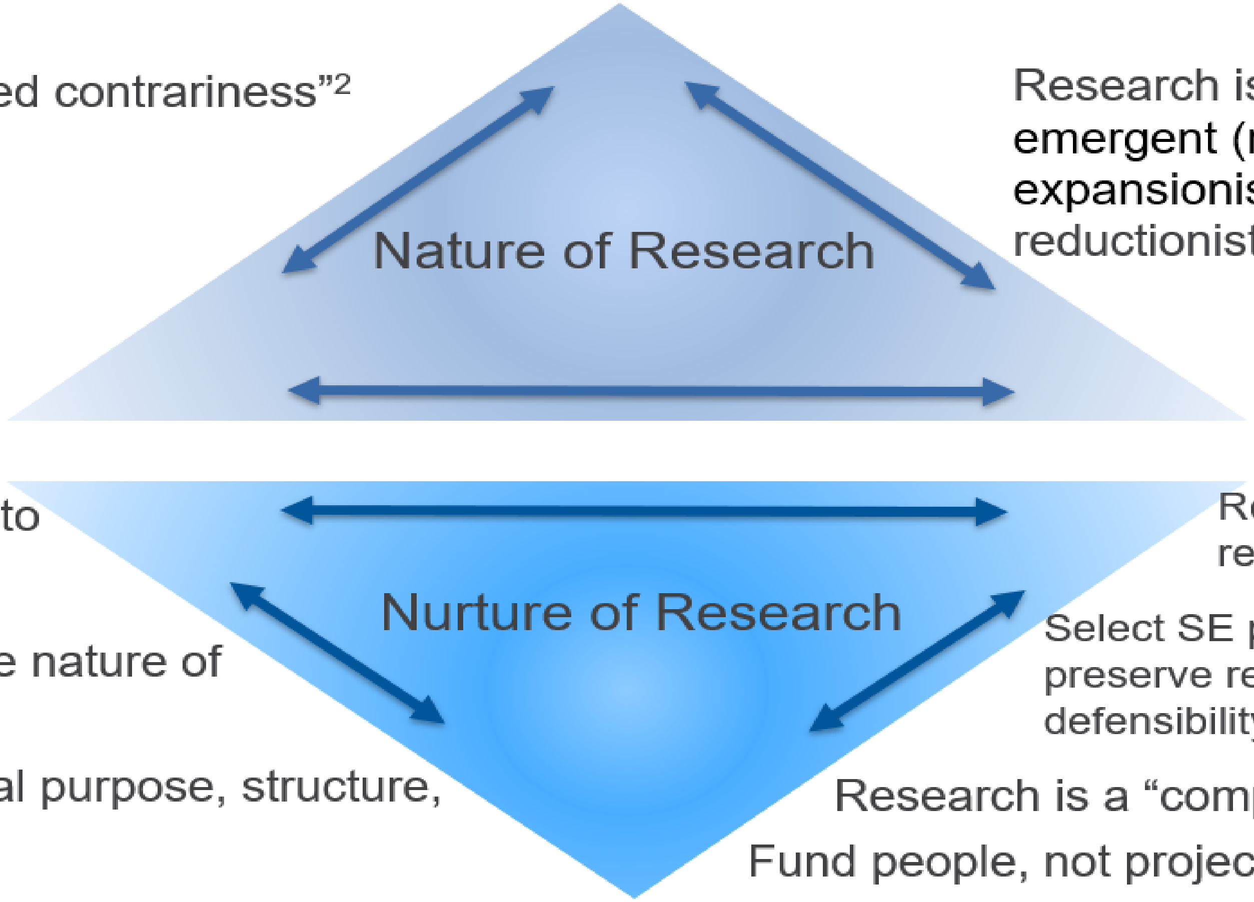
- Merriam-Webster definition: a principle “is a comprehensive and fundamental law, doctrine, or assumption; a rule or code of conduct”
- A belief that influences actions and/or explains the nature or workings of something
- Principles provide a foundation for an SE in ESR&D framework
  - Guidelines, processes, tools for the “right” and “right-sized” tailored SE activities and deliverables
  - Apply to a wide range of research organizations, regardless of mission – industry, academia, government
  - Sensitive to the nature of R&D – culture & goals
  - Reframe SE wording for R&D culture
  - Enhance integrity and repeatability of R&D “products”
  - Support the value proposition for applying SE in ESR&D

Framework elements – principles

Zoom in, zoom out: embrace both Q&A finding[1]

"Support informed contrariness"[2]

Research is expansionist and emergent (result of expansionist), SE is both reductionist + integrative"[3]



Use a graded approach to applying SE processes[4]

Reframe terms using researchers vocabulary[4]

Support collaborative nature of research[6]

Select SE processes that preserve research quality, defensibility, future maturation[5]

Align organizational purpose, structure, resources[8]

Research is a "competitive sport"[9]

Fund people, not projects[10]

Insulate, not isolate, research from development[7]

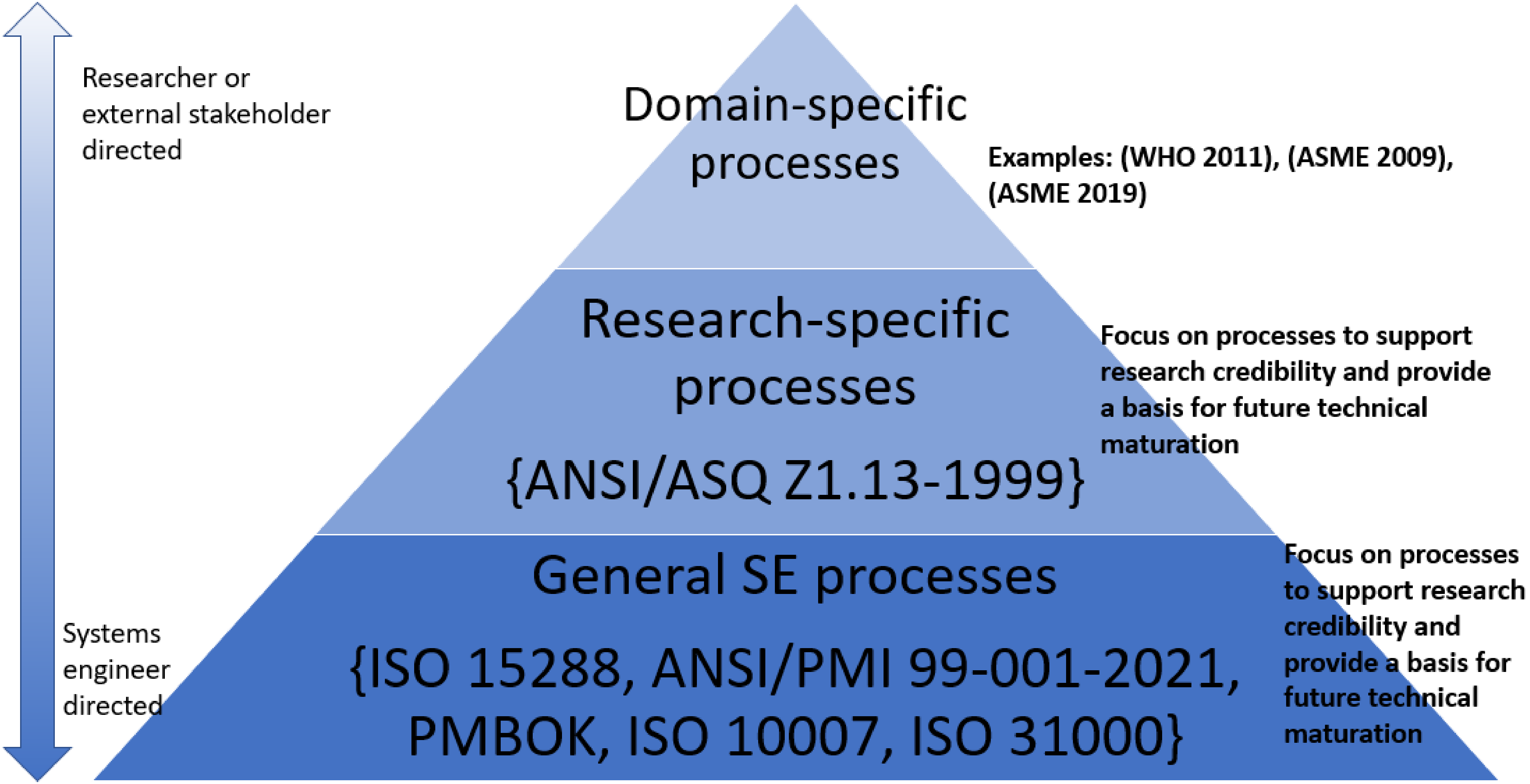
* Adapted from (Tsao 2021) Figure 0-1
[1] Adapted from (INCOSE 2021a) pg 12 (Tsao 2021) pg 178
[2] Adapted from (Tsao 2021) pg 182
[3] (DiMario 2021)

[4] (Hodges 2019)
[5] Ibid
[6] (INCOSE 2021a), (Tsao 2021)
[7] (Tsao 2021) pg 156
[8] (Tsao 2021) pg 162
[9] (Tsao 2021) pg 192
[10] (Tsao 2021) pg 159

Framework elements – standards based

- Industry standards reflect best practices, provide a foundation for recommended practices/deliverables
- Can provide increased credibility and confidence in the research process and results for stakeholders
- Consider broadly-accepted SE standards, more narrowly-focused domain standards, and standards important to external stakeholders
- Crucial to apply critical thinking regarding the appropriate standards
- Application of standards need to be rigor appropriate for ESR&D
- Reframe terminology to be understandable to researchers

Framework elements – standards based



Framework elements – TRL context sensitive guidance/roadmap
Example: Requirements Definition and Management

TRL Level Activities & Deliverables / Process Areas	BASIC RESEARCH 1 - Basic principles observed and reported	BASIC RESEARCH 2 - Technology concept and/or application formulated	TECHNOLOGY DEVELOPMENT 3 - Analytical and experimental critical function and/or characteristic proof-of-concept	TECHNOLOGY DEVELOPMENT 4 - Component and/or breadboard validation in laboratory environment	TECHNOLOGY DEVELOPMENT / DEMONSTRATION 5 - Component and/or breadboard validation in relevant environment	TECHNOLOGY DEMONSTRA-TION 6 - System/ subsystem model or prototype demonstration in relevant environment
Requirements Definition and Management	• Identify research objectives, sponsor key performance parameters • Specify TRL-specific domain requirements for the relevant domain(s) • Specify approach for capturing and managing research objectives, performance parameters, and derived requirements • Implement the management approach	• Refine research objectives, performance parameters, TRL-specific domain requirements based on experimental results • Research → engineering transition(s) defined and requirements considered • Identify figures of merit, trade studies, relevant simulations and needed fidelity, considering all life-cycle phases • Conduct trade studies, simulations, analyze results for refining research objectives and identifying derived requirements • Manage changes to research objectives, requirements	• Refine research objectives, performance parameters, TRL-specific domain requirements based on experimental results • Refine figures of merit, trade studies, relevant simulations and increased fidelity • Conduct updated trade studies, simulations, analyze results for updating research objectives, derived requirements and architecture alternatives • Manage changes to research objectives, requirements • Specify requirements management approach • Specify research objectives, performance parameters, TRL-specific domain requirements and other derived requirements in a format compatible for import into an MBSE tool	• Continue the first 4 activities from TRL 3 • Implement the requirements management approach • Import research objectives, performance parameters, TRL-specific domain requirements and other derived requirements in a format compatible for import into an MBSE tool	• Continue the first 4 activities from TRL 3 • Continue refining the requirements in an MBSE tool	• Continue the activities from the previous TRL

Framework elements – TRL context sensitive guidance/roadmap

SE activities +
deliv. by TRL

Framework elements – training

- Systems Engineer provides enough knowledge and skills to research team to understand + perform SE activities
  - Strategic: Facilitates determination of appropriate rigor level, establishes infrastructure (e.g., templates and processes) for the team
  - Tactical: Facilitates execution and monitoring of the SE activities in support of PI (mentor)
- PI and other research team leads provide the Systems Engineer with sufficient domain knowledge to tailor the SE practices for the team
  - PI coaches the Systems Engineer on the terminology the team will understand, tools to plan/conduct/capture/analyze results
- Domain Leads provide details on their domain to include in the SE roadmap to PI and Systems Engineer

Use a participative and coaching/mentoring approach for applying the SE framework

Framework elements – measures and metrics

- Definitions:
  - A “measure” is a value of something, such as temperature
  - A “metric” is comparing a value to some threshold, such as body temperature to “fever”
- Measures and metrics useful in assessing current performance, set goals for improvement, and forecast potential outcomes given the current context
- Assessment with respect to research objectives provides more effective and relevant information to support research progress
- Suggest Goal/Question/Measure-Metric approach
  - For a goal, pose questions to provide insight into the goal’s status
  - For a question, associated measures or metrics provide data (qualitative or quantitative) to address the question
- There are likely measures/metrics that are focused on the scientific exploration of the research project (e.g., key performance parameters or the project’s specific research objectives)

Framework elements – measures and metrics example for SE in ESR&D

Goals / Questions, Measures-Metrics	*Preserve research integrity, credibility*	*Provide foundation for future technical maturation*
Are requirements defined and managed? · % requirements in compatible format for more formal requirements mgt (goal 100% as approach TRL 4) · # requirements change over a time period (stability)	X	X
Is architecture defined and managed for each relevant research domain? · % architecture defined for relevant domains		X
Is a V&V approach defined and used? · % coverage of requirements, architecture for V&V planning items · % planned V&V conducted · % "pass" results · # of incomplete or incorrect items identified (implies technical debt)	X	X
Are technical and programmatic items to be configuration managed identified? Are those configuration items version controlled? · % items to be configuration managed version controlled	X	X
Is a change management approach specified and used? · # changes that fall under the criteria for change management over some specified time period are requested, implemented, verified	X	X
Is a risk management approach specified and used? · risk register exists, updated within some specified time period · # severe and high technical and programmatic risks over some specified time period · trend of severe and high technical and programmatic risks over some specified time period	X	X
Is an issues/action item tracking approach specified? · # of issues by severity level · trend of higher severity level issues over some specified time period	X	X

Framework elements – improvement

- Measures and metrics trends provide insight
  - Gaps in technical progress
  - Issues and risks
  - Identifying and addressing gaps is crucial to assure research project success
- Domain-specific TRL requirements/definitions may need to be adjusted as more knowledge is gained from research analysis