AH

Bridging the Transition Gap: A Framework for Systems Engineering in Early-Stage R&D

INCOSE Los Angeles Chapter
October 8, 2024

Ann Hodges, Dr. Michael DiMario, Ed Danis

Agenda

- Framework development
- Systems Engineering in Early-Stage R&D Working Group background
- Problem statement
- Framework elements overview
- Summary
- Future work

Framework development

Framework development

- Result of collaboration between the INCOSE Systems Engineering (SE) in Early-Stage R&D (ESRD) Working Group core team members
  - DOE National Laboratories
    - Sandia National Laboratories
    - Los Alamos National Laboratory
    - Idaho National Laboratory
    - Pacific Northwest National Laboratory
  - Industry
    - Lockheed Martin

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

493 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
- WSRC 2024: tutorial
- Trial monthly Intl collaboration mtgs

Working group background

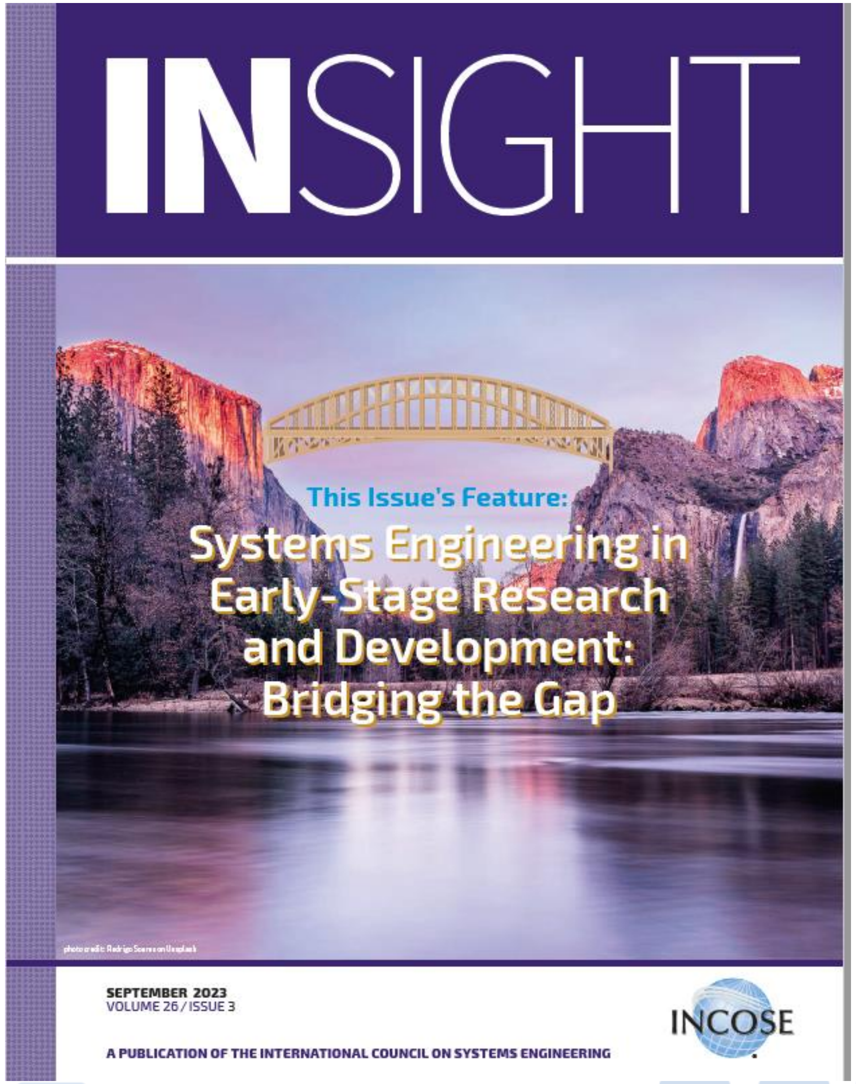


Table of Contents


Aerospace • Agriculture • Automotive • Biotech • Chemical • Communications
Defense • Electronics • Energy • Government • High-Tech • Life Sciences
Medical Devices & Diagnostics • Precision Manufacturing • Scientific Research

INSIGHT

INCOSE

A PUBLICATION OF THE INTERNATIONAL COUNCIL ON SYSTEMS ENGINEERING

SEPTEMBER 2023 VOLUME 26 / ISSUE 3

INSIDE THIS ISSUE

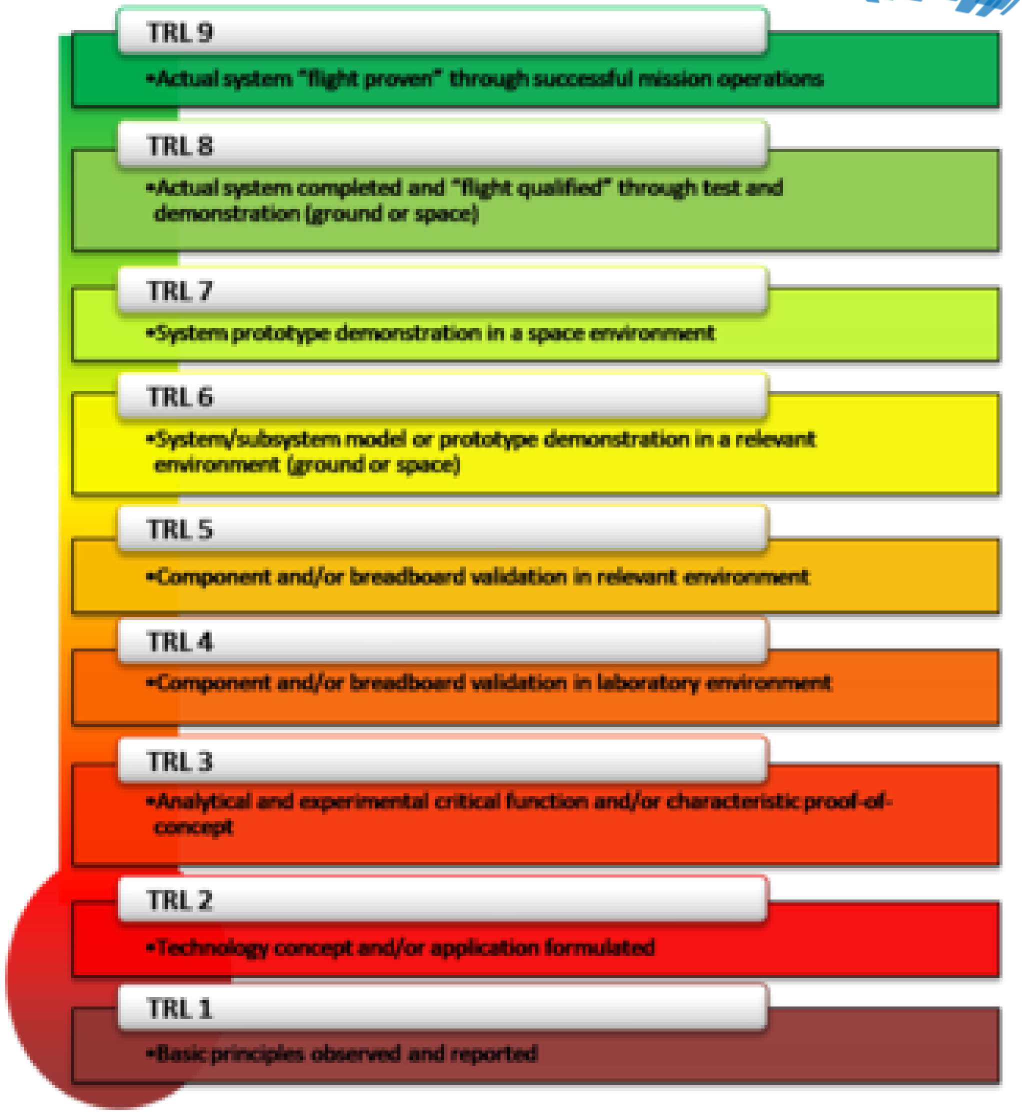
SEPTEMBER 2023 VOLUME 26 / ISSUE 3

Inside this issue

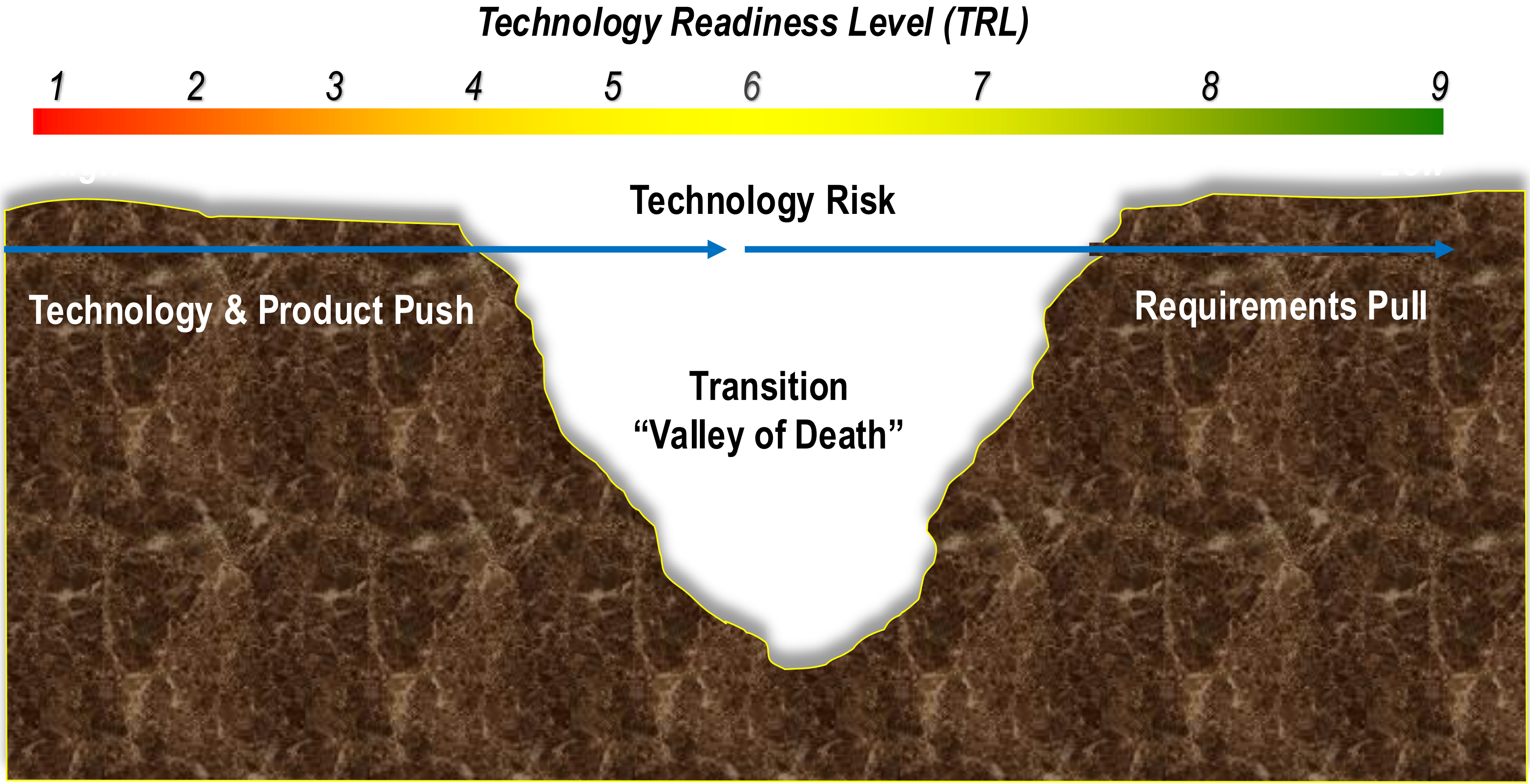
Problem statement

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
  - Risk of transition
- 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
  - No or low research ROI

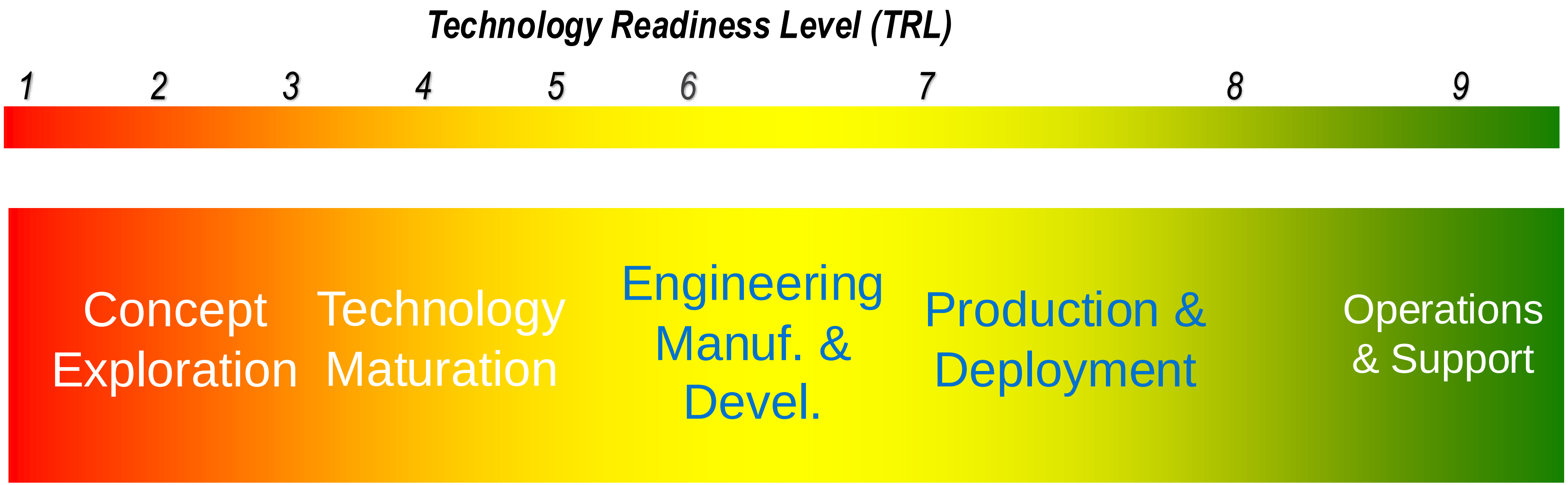


Problem Statement – Traditional Challenge for Transitioning Technology



Traditional Thinking States Requirements Very Early In the Technology Push Side of the Valley

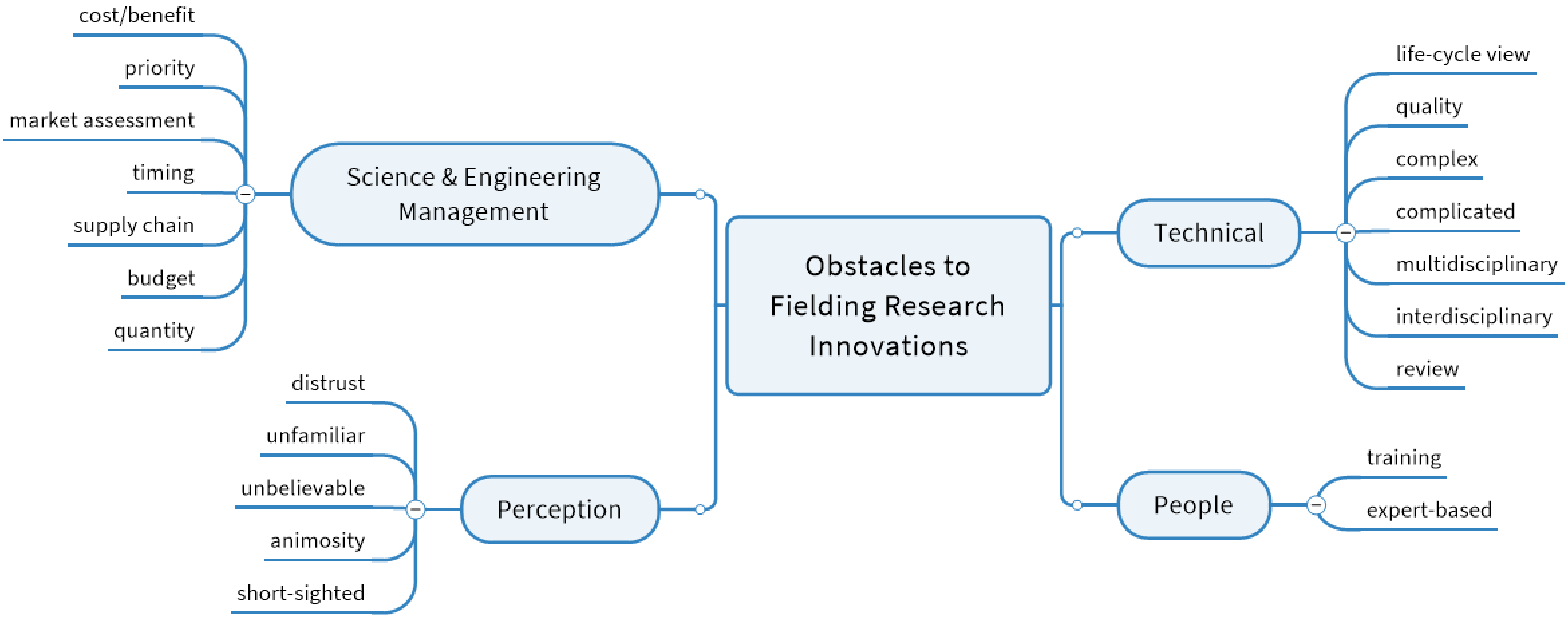
TRLs and Life Cycle Phases - notional mapping



Life Cycle adapted from (DoD 2024)

Problem Statement

Affinity diagram of barriers in (Anton 2022)



Framework elements overview

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

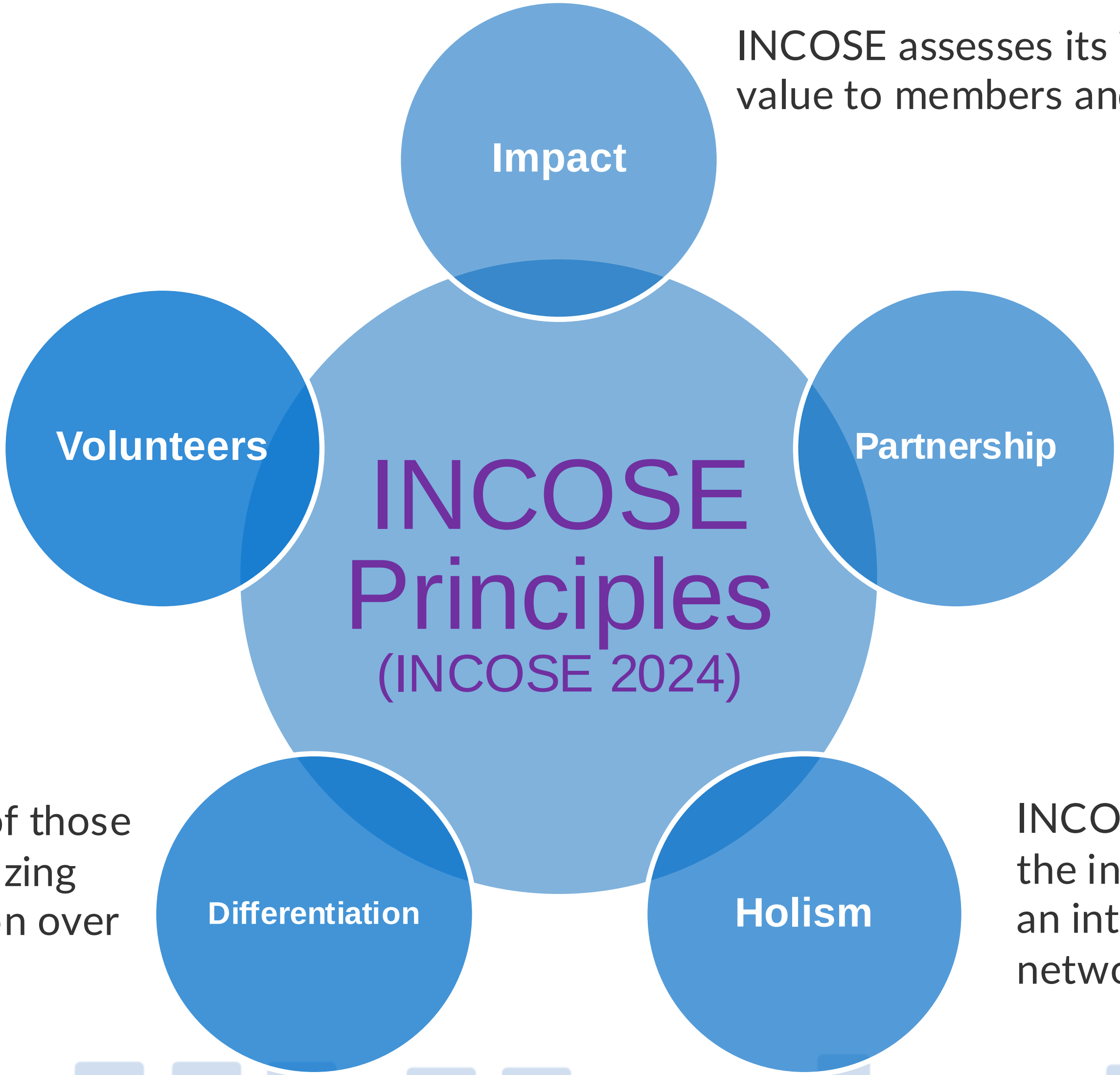
- SE provides value when it delivers an R&D-focused SE strategy that serves as an organizational guide, involves stakeholders within and external to R&D

Express in terms meaningful to both researcher and business communities

Framework Elements: 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



INCOSE assesses its impact based on the delivery of value to members and other stakeholders.

INCOSE is led by volunteers who set our fundamental direction.

INCOSE builds and disseminates products and services jointly with others to maximize our impact.

INCOSE recognizes the unique value of those who choose to affiliate with us, prioritizing direct affiliation and active participation over indirect or passive connection.

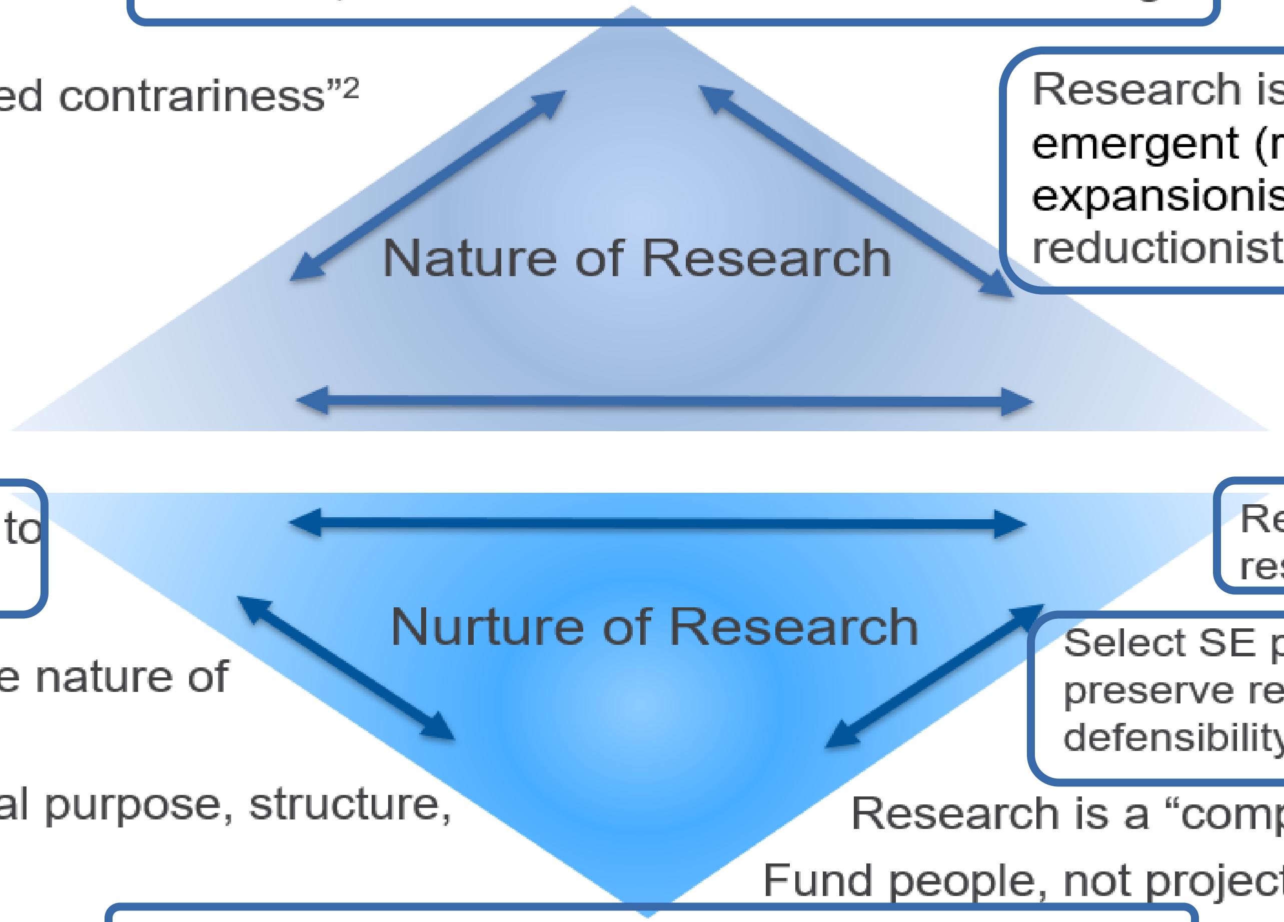
INCOSE emphasizes the whole over the individual parts in our creation of an integrated global technical network.

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]

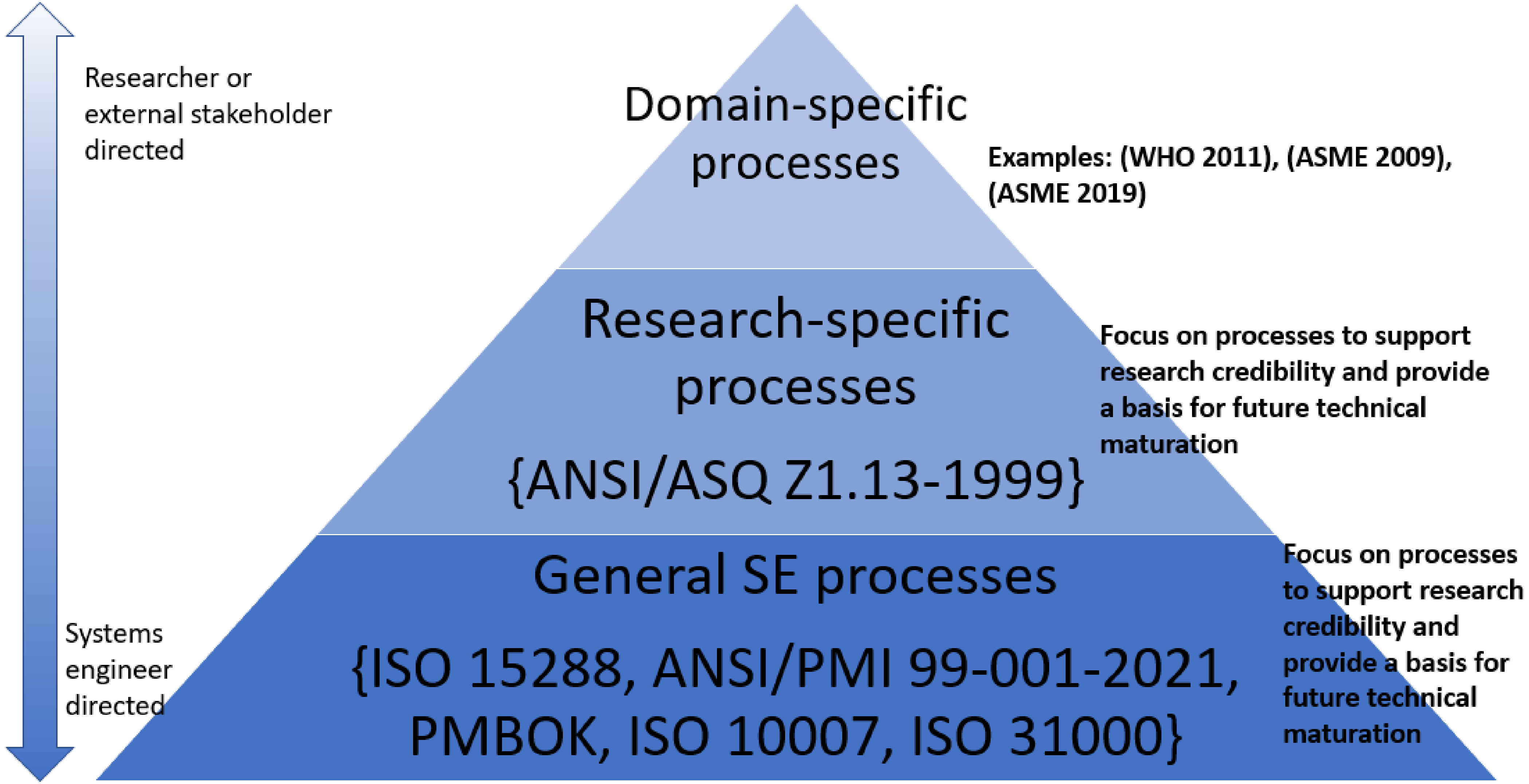
* Adapted from (Tsao 2021) Figure 0-1
[1] Adapted from (INCOSE 2021a) pg 12 (Tsao 2021) pg 178
[2] Adapted from (Tsao 2021) pg 182
[3] (DiMario 2021)

[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



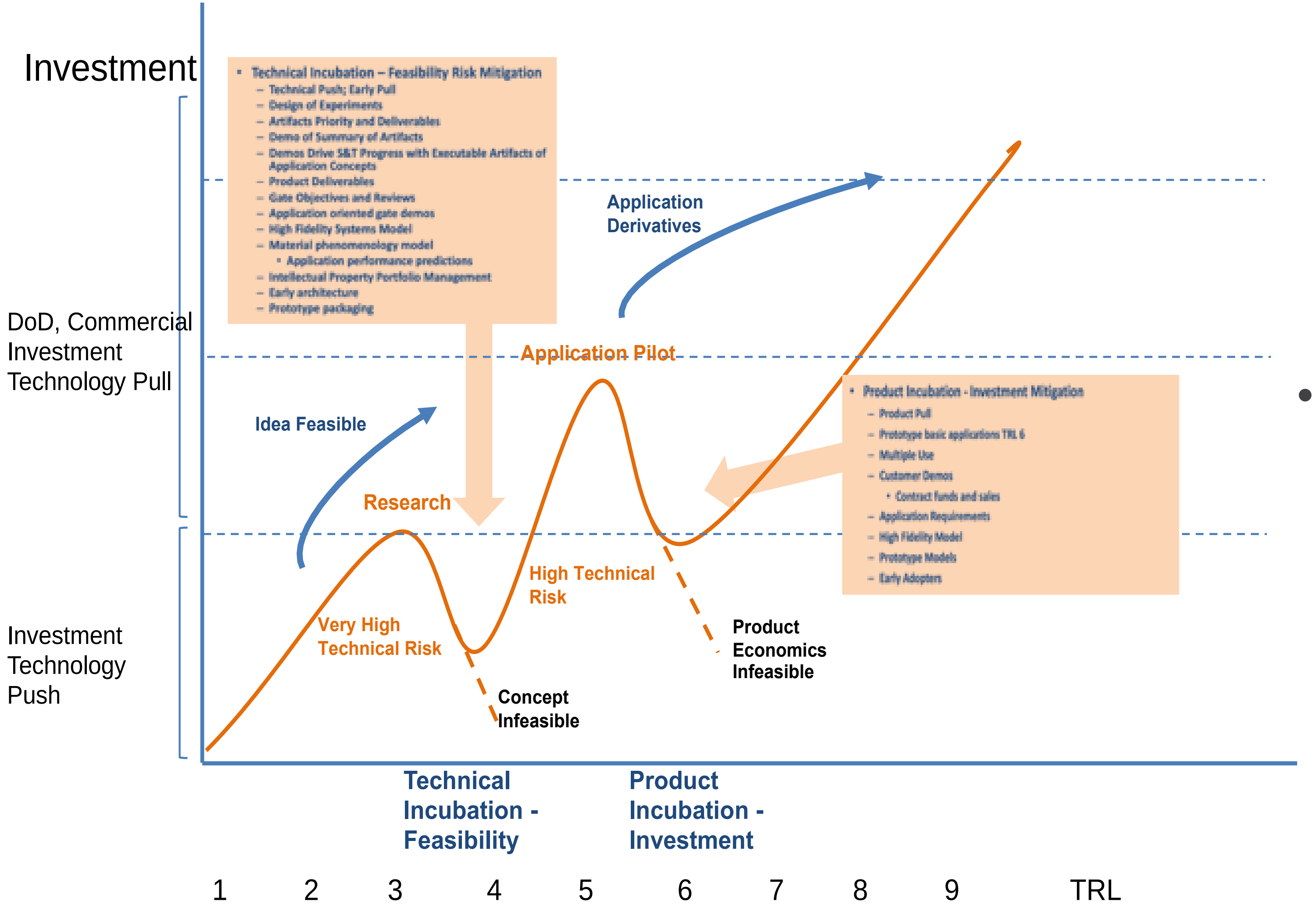
Framework Elements: Risk-Informed Graded Approach

- 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: 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
- 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

Framework Elements: TRL Context Sensitive Guidance/Roadmap



- Technical Incubation
  - Lacks requirements
  - Lacks models
  - Lacks interconnect definition
  - Parallel research and development
  - Technology Push
  - Early Valley of Death
    - Actions to Bridge Valley of Death
- Product Incubation
  - Application dependent
  - Pull or Push
  - Derivatives other than original intent
  - Later Valley of Death
    - Actions to Bridge Valley of Death

Specific Actions Targeting Valley of Death Reduce Transition Risk

Valleys of Death in Technology Maturation*

- Decisions are made with whatever information is available
- Premature commitments place increased risk
- Think from right to left
  - Projects want to jump straight to a solution; ask what are alternatives; why?
  - Failure is losing sight of the right
- Iterative planning such as prototyping
- Think slow, act fast – planning is cheap; delivery is expensive especially if you are wrong
- Opportunity is as important as risk
  - Risk is always present
  - Risk can kill a project
  - Go directly to risk mitigation and eliminate

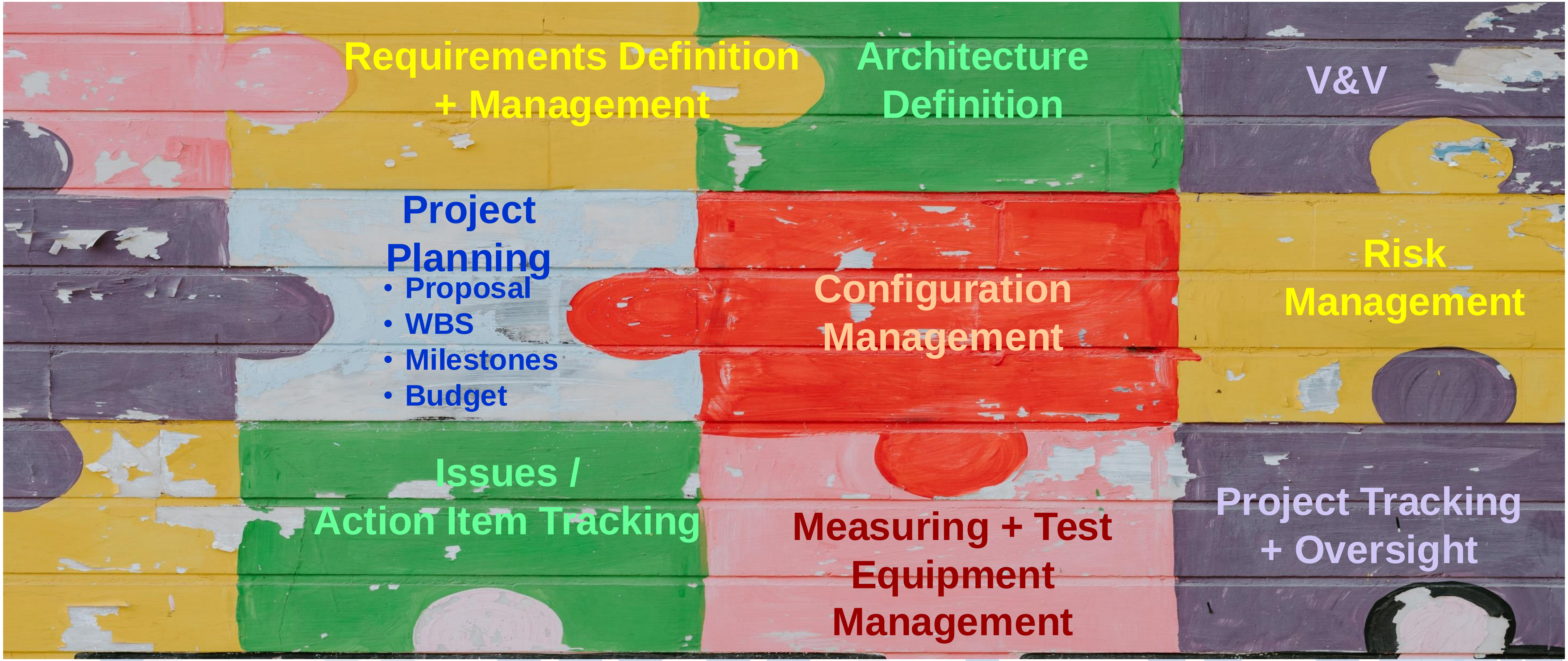
*(Flyvbjerg and Gardner 2023)

AH

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)
    - Details on "what" and "how" are specified by the project
  - 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

R=responsible; A=accountable; S=support; I=informed; C=consulted

Framework Elements: TRL Context Sensitive Guidance/Roadmap – Example

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 DEMONSTRATION 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 experiemental results * Model operational needs/requirements (e.g., use case) * 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 experiemental 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 * Refine operational needs/requirements model * Manage changes to research objectives, requirements * Specify requirements management approach * Specify research objectives, performance parameters, TRL-specific domain requirements and other derived	* 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

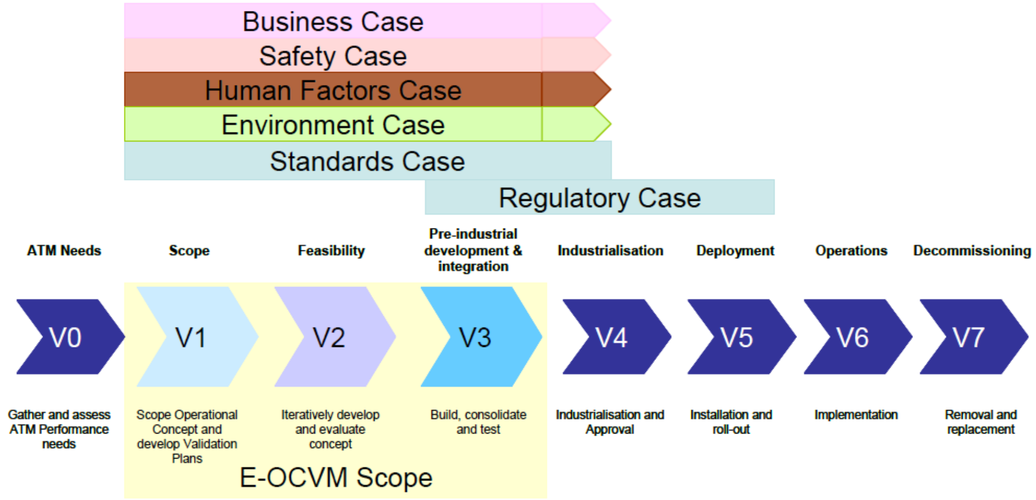
Framework Elements: TRL Context Sensitive Guidance/Roadmap – Example

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 DEMONSTRATION 6 - System/subsystem model or prototype demonstration in relevant environment
Configuration Management (CM)	* Specify programmatic (for example proposal, milestones, WBS, budget, tracking, risk management artifacts, issues management artifacts, records (e.g., experimental equipment calibration, schedule/cost actuals, briefings, reports)) and technical (for example experimental plans, experimental results, V&V results (including reviews), risks, issues, requirements) items to track - "configuration items" * Specify the approach for how changes will be managed for those configuration items (include impact analysis for performance, cost and schedule) * Specify how programmatic and technical items will be version controlled and tracked to support trend analysis and preserve integrity of results * Version control the identified configuration items * Implement the change management	* Refine configuration management approach as needed based on project experience * Perform change management * Perform version control	* Continue identified activities in previous TRL for this process area	* Continue identified activities in previous TRL for this process area	* Continue identified activities in previous TRL for this process area	* Continue identified activities in previous TRL for this process area

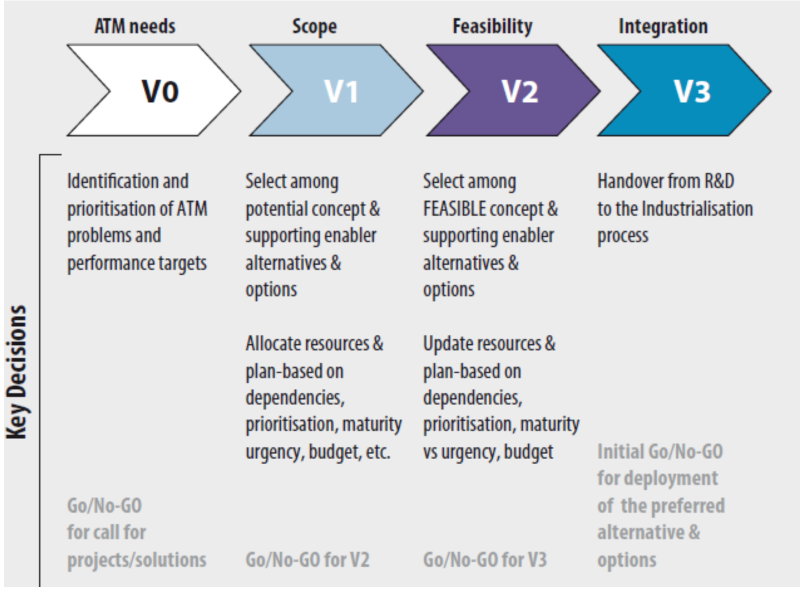
MD

Literature Case Story – European Operational Concept Validation Methodology (E-OCVM)

- Application to European Air Traffic Management (ATM) R&D
- Create framework versus rules - providing structure and transparency of R&D from early phases to implementation



(EUROCONTROL 2010a) Figure 4



(EUROCONTROL 2010a) Figure 6

Literature Case Story – European Operational Concept Validation Methodology (E-OCVM)

- Application to European Air Traffic Management (ATM) R&D
- Create framework versus rules - providing structure and transparency of R&D from early phases to implementation

Lifecycle Phase/Objectives	Typical activities	Typical Deliverables	Analysis Criteria for Lifecycle Transitions - Typical Generic Questions for each R&D Need Category[3]
V3: Pre-industrial Development and Integration The objective of this phase is threefold: - firstly, to further develop and refine operational concepts and supporting enablers to prepare their transition from research to an operational environment; - secondly, to validate that all concurrently developed concepts and supporting enablers (procedures, technology and human performance aspects) can work coherently together and are capable of delivering the required benefits; - thirdly, to establish that the concurrent packages can be integrated into the target ATM system.	**Integration and validation of the operational concept (with all other related concepts)** *The operational concept is integrated into the target system and validated using realistic scenarios. Its interaction with all related concepts is analysed.* **Technical specifications and feasibility assessments (pre-industrial prototype, technical specifications ready for possible standardisation)** *The technical specifications are developed to the level required for the industrialisation and for possible standardisation in the next phase. A pre-industrial prototype is developed on the basis of these specifications and validated.*	**Detailed Operational Concept** *The operational concept is fine tuned using a range of validation results.* *(e.g. OSED, DOD, etc).* **Operational procedures** *The operational procedures are fine tuned using validation results.* **Operational validation reports** *Allow understanding of the validation characteristics, the information captured during the validation, the analysis of the information and the consequent results –e.g. the acceptability/operability/suitability, the resulting changes to the Concept/Procedures.* **Logical system architecture** *The logical system architecture is fine-tuned reflecting possible impacts from validations and changes to the operational concept and supporting technical enabler(s).* **Technical system architecture** *Is developed to the level of detail required for industrialisation and for possible standardisation in the next phase .It will be used for the development of the pre-industrial prototype and for its integration into the representative system platform for validation.* **Technical specification (including interoperability, performance and CNS technologies requirements)** *To the level of detail required for industrialisation and for possible standardisation in the next phase (e.g. INTEROP, outline SARPs, MOPs etc).* **Pre-industrial prototype**	**Processes & procedures** *[V3.C3.1] Is the selected concept option confirmed to be operationally feasible when integrated into the end system, (showing that all interaction between people is viable based on prototyping of a realistic environment?* *[V3.C3.2] Following its integration into the end system, do we have a stable and validated definition of business processes, operational procedures, roles and responsibilities of actors, their tasks, and human performance elements required to implement (and if so intended to regulate) this concept option?* Note: In case of supporting technical enablers, we should consider the human–technology integration and the technical enabler elements below. **Human–technology integration** *[V3.C4.1] Have the relationships and interactions between human and machine been defined and validated in an operationally realistic environment using a pre-industrial prototype?* *[V3.C4.2] Have the relationships and interactions between people and technology been confirmed to be operationally feasible, and consistent with agreed human performance requirements?* **Technical enabler** *[V3.C5.1] Do we have a validated system architecture, HMI design, & technical specification ready to be used for industrialisation (and for standardisation if so intended)?* *[V3.C5.2] Are the interoperability requirements, the refined technical*

(EUROCONTROL 2010b) Annex 4, extracted portion of V3

E-OCVM continued*

- Strong linkages in “validation” and “verification”
  - Validation – Are we building the right system
  - Verification – Are we building the system right
- Provided mapping between TRLs and life cycle phases (Vn)
- Extends to early phases even though V1 – V3 are not fully developed
  - Use of Key Performance Indicators (KPIs) must be established early
- Evidence based – fitness for purpose judged by stakeholders
- Scalable framework
- Configuration management control of requirements

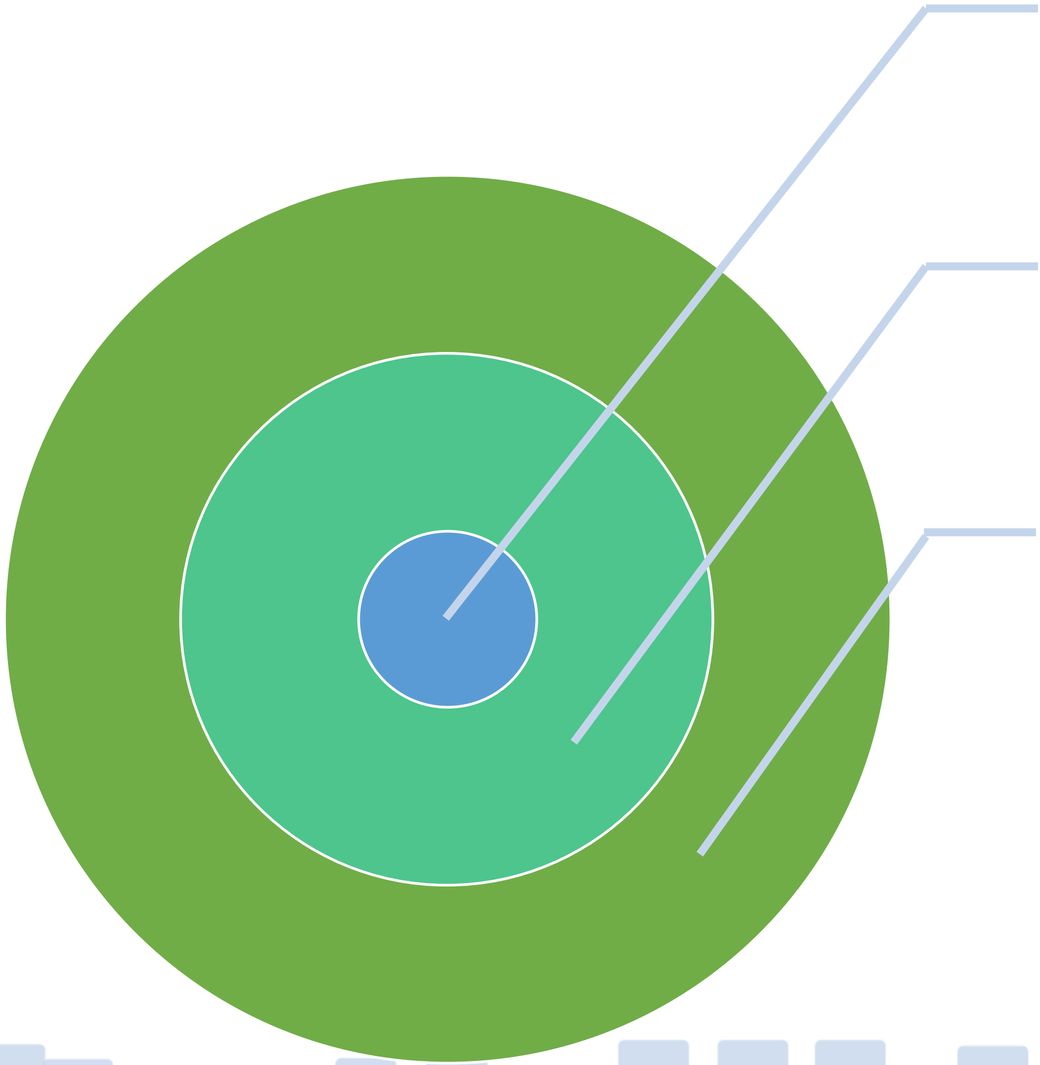
*(EUROCONTROL 2010a), (EUROCONTROL 2010b)

AH

Framework Elements: Model-based SE (MBSE) and Digital Engineering

- 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: 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

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 ESRD

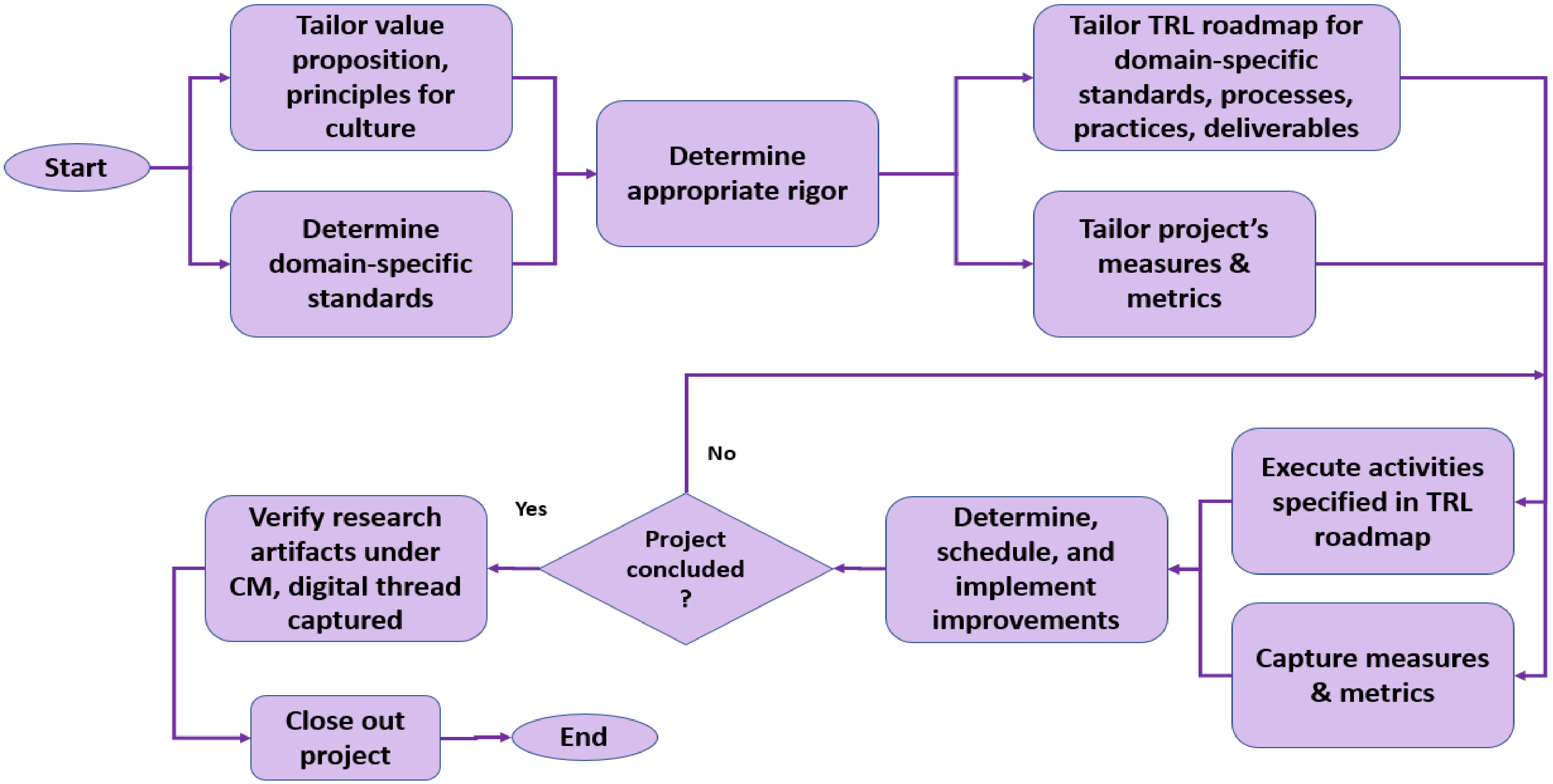
Goals / Questions, Measures-Metrics	*Preserve research integrity, credibility*	*Provide foundation for future technical maturation*
Are requirements defined and managed? · % requirements in compatible format for more formal requirements mgt (goal 100% as approach TRL 4) · # requirements change over a 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

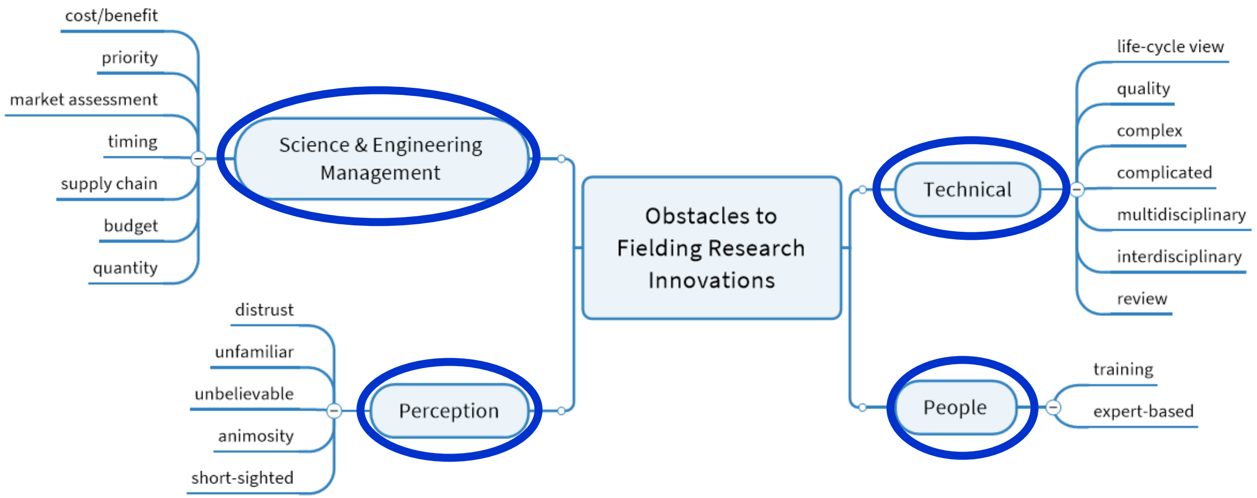
Summary

Framework Elements: Suggested Usage



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

Future work

Near-term plans

2025

- Case studies/stories using SE in ESRD framework
  - Leverage collaboration with other working groups, Chapters (e.g., Embedding SE in Organizations)
  - Research projects use of framework addressing pain points and identify leading improvement indicators, provide feedback (e.g., Leidos, Sandia National Laboratories)
  - “What-if usage” review of the framework
  - Use aspects of the framework (e.g., a process area), modifying existing process(es) using the framework
  - How quickly proposed S&T projects be assessed, when to pivot or kill
- Develop an INCOSE framework Technical Product (guidance for application of the SE in ESRD framework)
- SEBoK – SE in ESRD guidance (summary)
- Ongoing IW 2025 participation – focus on collaboration with other working groups
- Ongoing – periodic general working group meetings, elicit new ideas

2026

- Update framework based on usage, feedback
- Publish INCOSE framework Technical Product
- INCOSE SE Handbook and ISO 15288 – include guide for applying SE in ESRD
- Publish SE in ESRD paper for IS 2026
- Ongoing IW 2026 participation – focus on collaboration with other working groups
- Ongoing – periodic general working group meetings, elicit new ideas

Questions

Photo by Simone Secci on Unsplash

Bibliography

- Anton, P.S. 2022. “Challenges to Innovation Transition: The Valley of Death Results from More than a Lack of Flexible Funding”, Acquisition Innovation Research Center, March 2022.
- American Association of Mechanical Engineers (ASME) 2019. “VV-10 Standard for Verification and Validation in Computation Solid Dynamics”, 2019.
- ASME 2009. “VV-20 Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer”, 2009.
- American National Standard (ANS) 1999. Quality Guidelines for Research, ANSI/ASQ Z1.13-1999, 1999.
- American National Standards Institute/Project Management Institute (ANSI/PMI) 2021. The Standard for Project Management, ANSI/PMI 99-001-2021, 2021.
- Project Management Book of Knowledge (PMBOK) 2021. A Guide to the Project Management Body of Knowledge, seventh edition, Project Management Institute, 2021.
- Basili, V., Caldiera, G., Rombach, H. n.d. “The Goal Question Metric Approach”, viewed 7 April 2023, <https://www.cs.umd.edu/users/mvz/handouts/gqm.pdf>.
- Belcher, B., Rasmussen, K., Kemshaw, M., Zornes, D. 2016. “Defining and Assessing Research Quality in a Transdisciplinary Context”, Research Evaluation, vol. 25, issue 1, January 2016.
- Brennan, T., Ernst, P., Katz, J., Roth, E., “Building an R&D Strategy for Modern Times”, November 2020, McKinsey & Company, https://www.mckinsey.com/capabilities/strategy-and-corporate-finance/our-insights/building-an-r-and-d-strategy-for-modern-times
- Carson, R., Frenz, P., O’Donnell, E. 2015. Project Manager’s Guide to Systems Engineering Measurement for Project Success – A Basic Introduction to Systems Engineering Measures for Use by Project Managers, INCOSE-TP-2015-001-01, ver. 1.0, 2015.
- Delgatti, L. 2013. SysML Distilled: A Brief Guide to the Systems Modeling Language, Addison-Wesley, Boston, MA.
- DiMario, M., Hahn, H., Hodges, A., Mastin, G., Lombardo, N. 2021. Perceived Conflicts in Systems Engineering in Early-Stage Research and Development, INCOSE INSIGHT, vol. 24, issue 3, October 2021.

Bibliography, continued

- DiMario, M., Hodges A. 2023. “Systems Engineering Management in Research and Development Valley of Death”, INCOSE INSIGHT, vol. 26, issue 3, September 2023.
- Department of Defense 2024. “Acqnotes – The Defense Acquisition Encyclopedia, Acquisition Process – Defense Acquisition Phases”, Defense Acquisition Phases - Overview – AcqNotes updated 3//18/2024, accessed 5/7/2024.
- European Organisation for the Safety of Air Navigtion (EUROCONTROL) 2010a. “European Operational Concept Validation Methodology (E-OCVM)”, vol. 1, ver 3.0.
- European Organisation for the Safety of Air Navigtion (EUROCONTROL) 2010b. “European Operational Concept Validation Methodology (E-OCVM) Annexes”, vol. 2, ver 3.0.
- Flyvbjerg, B., Gardner, D. 2023. “How Big Things Get Done – The Surprising Factors”, Currency, New York.
- Granados, A., Tseng C. 2023. “Digital Engineering Enablers for Systems Engineering in Early Stage R&D”, INCOSE INSIGHT, vol. 26, issue 3, September 2023.
- Hahn, H., Hodges, A., Lombardo, N., Kerman, M. 2020. “Implementing Systems Engineering in Early Stage Research and Development (ESR&D) Engineering Projects”, 30th Annual INCOSE International Symposium, Cape Town, South Africa, July 18-23, 2020.
- Hodges, A. 2013. “Bricks for a Lean Systems Engineering Yellow Brick Road”, INCOSE International Symposium, INCOSE, Philadelphia, PA, June 24-27, 2013.
- Hodges, A. 2019. “Systems Engineering in Early Stage R&D Projects”, panel, A. Hodges, SAND2019 7310 C, INCOSE International Symposium, INCOSE, Orlando, FL, July 20-25, 2019.
- Hodges, A., Hahn, H. moderator, Lombardo, N., DiMario, M., Autran, F. 2021. “Systems Engineering at the Hello – Frameworks for Applying SE in Early Stage R&D”, panel, INCOSE International Symposium, INCOSE, virtual conference, July 17-21, 2021.
- Hodges, A., Granados A., 2023. “A Bridge Blueprint to Span the Chasm Between Research and Engineering – A Framework for SE in Early-Stage R&D”, INCOSE INSIGHT, vol. 26, issue 3, September 2023.
- Hodges, A., DiMario M., Granados A., 2024. “Use a Framework for SE in Early-Stage R&D to Build Your Bridge that Spans the Chasm Between Research and Engineering”, INCOSE International Symposium, INCOSE, Dublin, Ireland, July 2-6, 2024.
- INCOSE 2018. Systems Engineering Competency Framework, INCOSE-TP-2018-002-01.0.
- INCOSE 2021a. A Complexity Primer for Systems Engineers, INCOSE-TP-2021-007-01.
- INCOSE 2021b. Systems Engineering Practices for Small and Medium Enterprises, INCOSE-TP-2021-005-01.
- INCOSE 2024. INCOSE Principles, INCOSE Principles and Values, accessed 8/28/2024.
- ISO 10007 2017. Quality Management – Guidelines for Configuration Management, third edition, ISO 10007:2017(E), ISO 2017.
- ISO 15288 2015. Systems and Software Engineering – System Life Cycle Processes, ISO/IEC/IEEE 15288, first edition, 2015.
- ISO 31000 2018. Risk Management – Guidelines, second edition, ISO 31000:2018(E), ISO 2018.
- Merriam-Webster 2023. Viewed 28 March 2023, <Principle Definition & Meaning - Merriam-Webster>.
- Long, D. 2021. “Schema and Metamodels and Ontologies – Oh My”, INCOSE Enchantment Chapter presentation, January 13, 2021.

Bibliography, continued

- NASA 2012. “Technology Readiness Level”, last updated 1 April 2021, viewed 26 March 2023, <Technology Readiness Level | NASA>.
- NASA 2016. “Expanded Guidance for NASA Systems Engineering – Volume 1: Systems Engineering Practices”, NASA/SP-2016-6105-SUPPL.
- RAND 2022. “Standards for High-Quality and Objective Research and Analysis”, updated 24 January 2022. Viewed 6 April 2023. <https://www.rand.org/about/standards.html>.
- Ritter, C., Rhoades, M. 2023. “Incorporating Digital Twins in Early R&D of Megaprojects to Reduce Cost and Schedule Risk”, INCOSE INSIGHT, vol 26, issue 3, September 2023.
- Roedler, G., Jones, C. 2005. Technical Measurement – A Collaborative Project of PSM, INCOSE, and Industry, ver. 1.0, INCOSE Measurement Working Group, INCOSE-TP-2003-020-01.
- Ruth, S. 2023. “An Approach to Bridging the Gap Between the Attainment of Research Objectives and System Application”, INCOSE INSIGHT, vol 26, issue 3, September 2023.
- Sly, J., Crowne, D. 2023. “Systems Engineering in Technology Development”, INCOSE INSIGHT, vol 26, issue 3, September 2023.
- Solingen, R., Berghout, E., 1999. Goal/Question/Metric Method: A Practical Guide for Quality Improvement of Software Development, McGraw Hill Higher Education, 1999.
- Tsao J., Narayanaurti V. 2021. The Genesis of Technoscientific Revolutions - Rethinking the Nature and Nurture of Research, Harvard University Press, 2021.
- Walden, D., Roedler, G., Forsberg, K., Hamelin, R., Shortell, T. 2015. INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities, fourth edition, INCOSE-TP-2003-002-04, John Wiley & Sons, New York.
- Williams, A. 2023. “Enhancing Early Systems R&D Capabilities with Systems-Theoretic Process Analysis”, INCOSE INSIGHT, vol 26, issue 3, September 2023.
- World Health Organization (WHO) 2011. “Standards and Operational Guidance for Ethics Review of Health-Related Research with Human Participants”, section V Standards and Guidance for Researchers, WHO Press, 2011.
- Yuta Nakajima, Y., Fukatsu, T., “Applications of Model-Based Systems Engineering for JAXA’s Engineering Test Satellite-9 Project”, ESA MBSE2020, 28-29 September 2020, https://indico.esa.int/event/329/contributions/5515/attachments/3873/5600/0915_-_Presentation_-_Applications_of_Model-Based_Systems_Engineering_for_JAXAs_Engineering_Test_Satellite-9_Project.pdf