

Systems Engineering at the Hello – Frameworks for Applying Systems Engineering in Early Stage R&D

Nick Lombardo (Pacific Northwest National Laboratory)
Heidi Ann Hahn (New Mexico Tech)
Michael DiMario (Astrum Systems)
Ann Hodges (Sandia National Laboratories)
Frédéric Autran (Airbus Defence & Space)

Keywords. Early stage R&D; Early stage R&D frameworks; Systems Engineering in Early Stage R&D; System Engineering Management in Early Stage R&D

Topics. 1. Academia (curricula, course life cycle, etc.); 3.5. Technical Leadership; 3.7. Project Planning, Project Assessment, and/or Project Control; 5.10. Diversity (cultural boundaries, diverse engineering teams, training underserved groups, etc.); 6. Defense; 9. Enterprise SE (organization, policies, knowledge, etc.);

Abstract. Early stage R&D (ESR&D) is one of the most crucial phases in the design process. It blends and blurs the lines between science and engineering. Because of the differences in the social context and culture between research and engineering, many scientists, leaders, and program managers resist including systems engineering at this delicate phase, fearful of overburdensome activities that add little or no value for their R&D pursuits. Systems engineering applied in a risk-based, graded approach supports credibility of research results and provides a foundation for further technology maturation. This panel explores principles and frameworks that tailor systems engineering for ESR&D. Common frameworks adopted across technical disciplines reduce risk, increase return on investment, and enhance the opportunities for cross-discipline R&D collaboration which is becoming more critical in contemporary R&D. While all of the frameworks that will be discussed are risk-based, they view the problem space from different perspectives.

Biography

Nick Lombardo (Pacific Northwest National Laboratory)

Nick Lombardo is a Principle Project Engineer at the Pacific Northwest National Laboratory (PNNL) with over two decades of systems engineering experience. Over his 40-year career, Nick has served as a technical contributor, project and program manager, line manager, key account manager, and commercialization manager. He also served as the Director of Business development for Phytogenics, a biotechnology company he helped co-found targeting the production of therapeutic proteins from plants. Nick had a major leadership role in growing PNNL's systems engineering capability and currently serves as a systems engineering subject matter expert for the National Security Directorate. He led PNNL's effort to formally define a systems engineering framework and developed a risk-based systems engineering tailoring strategy compatible with a R&D-based organization such as PNNL. He helped create and implement an INCOSE certification training program and has developed a number of systems engineering training modules for PNNL staff. Nick is an International Council on Systems Engineering (INCOSE)-Certified Systems Engineering Professional (ESEP) and has served as PNNL's INCOSE Corporate Advisory Board representative and as Secretary for the INCOSE's Cascade Chapter. He has a B.S and M. Eng from Rensselaer Polytechnic Institute.

Position Paper

It is important for an organization to have a framework for executing ESR&D. A framework is a collection of institutional and codified processes, tools, and training that support the repeatable execution of a highly tailored SE process. Development of codified processes relies on having a system lifecycle from which processes can be defined. Life cycles expressed in broad categories (e.g., concept, development, utilization) are less effective for ESR&D given that much of what needs to be addressed falls into the "development" stage. Greater granularity is needed to describe the system lifecycle to successfully implement SE in ESR&D. The concept of maturity levels (technical, manufacturing, etc.) provides additional granularity that can be exploited by ESR&D. Another concept that could provide additional granularity is the concept of project types. SE activities and artifacts can be defined at each TRL level and for each project type. The question then becomes "What are the right activities?" that should be conducted for each TRL level or project type. Baseline activities can be assessed based on "system development risks" for that particular TRL level and/or project types (a hybrid of both concepts represents a third model and brings the advantage of each to the table). An example of a system development risk is the "strength of requirements," defined as the level of requirements definition, analysis, and stakeholder approval available to support system development, verification, and validation. Using the TRL model, a system at the proof of concept stage (e.g., TRL 3) should have at a minimum KPPs defined in order to mitigate the strength of requirements risk; for a system approaching a prototype (e.g., TRL 5), the system should have generated documents such as a SRD

developed in order to mitigate this risk. Using the project type framework, a project delivering a technology assessment would be expected to use system thinking to guide how the project might address requirements, whereas a technology development project would expect some level of requirements definition and analysis activities to take place. TRLs could be used to differentiate the activities for this type of project. The concept of technical debt is useful to apply to ESR&D. Technical debt is a concept that reflects the implied cost of additional rework (or delayed work) caused by choosing an easy solution now instead of using a better/more complete approach that would take longer. The premise of ESR&D is that some level of SE technical debt is acceptable given the project's fiscal, programmatic, technical, and/or technical risks as well as the organization's risk profile. The art is to get the balance of technical debt right--which is what ESR&D's mission is all about.

Heidi Ann Hahn (New Mexico Tech)

Dr. Heidi Hahn recently retired from Los Alamos National Laboratory as Senior Executive Advisor to the Associate Laboratory Director for Weapons Engineering Sciences. She had responsibility for engineering capability development including development of processes and tools to promote engineering capability; professional development of R&D engineers and engineering technicians; and engineering capability assessment. Currently, Heidi serves as an adjunct faculty member in Engineering Management Department at New Mexico Tech teaching courses in project management and systems engineering. She holds a Ph. D. in Industrial Engineering and Operations Research (Human Factors Option) from Virginia Tech and is a certified Expert Systems Engineering Professional (ESEP) and a certified Project Management Professional (PMP). Heidi is Past President of the Enchantment Chapter and has served on the chapter's Board of Directors since 2007. She also serves on INCOSE's Certification Advisory Group and the PMI/INCOSE/MIT Alliance Team.

Position Paper

Early-Stage Research and Development (ESR&D) is one of the most crucial phases in the product development process. It blends and blurs the lines between science and engineering. It is argued that it requires a risk-based, graded approach to effectively manage scope, cost, and complexity. ESR&D is defined in terms of Technology Readiness Levels (TRLs) between 1 and 5. TRLs 1-2 define basic research and TRLs 3-5 define research to prove application feasibility.

The value proposition for applying systems engineering (SE), including systems engineering management, to the early stages of R&D is that the cost to extract defects rises exponentially throughout a project, increasing three to six times between the concept and design phases but up to a thousand times in the production/test phases (Walden et al. 2015).

This value proposition is unclear to many leaders, program managers, and scientists, who are seemingly unwilling to use SE practices because of the perception that they are heavily process oriented, add unnecessary costs, and should be applied only to mature technologies. One can argue that misapplication of systems engineering principles has led to these negative perceptions of SE for R&D. However, the failure to apply SE in ESR&D results in R&D efforts that may have solved the wrong problem, selected the wrong architecture, required technical rework, has difficulty transitioning to later maturity levels, and results in higher R&D costs, low return on investment, and extended development timelines.

A fundamental difference between R&D and more traditional SE activities depends upon the ability to decompose complex systems into fundamental components having manageable complexity, bounded development costs, and highly predictable completion schedules. Traditional SE then, especially as it is represented in the left side of the V-Model, is a "reductionist" activity, in which the goal is to reduce a "perceived complexity" by establishing shared and valid models of the system (Sillitto et al. 2019).

ESR&D, however, is radically different. Innovation does not happen by reduction processes. Innovation depends upon the creativity and discovery that leads to "expansionism," which tends to increase complexity at the outset rather than reducing it.

Another key difference between SE and R&D involves "capabilities" versus "requirements." Addressing a capability need is, by design, the focus of most ESR&D. Creating a point solution, while contending with the multitude of new discoveries that redirect or derail a research or technical investigation, is a large challenge. It calls for special discipline. Moving away from simply meeting a capability need and moving prematurely toward satisfying requirements or demonstrating a performance envelope too early in development creates big issues.

Today the lack of a commonly understood and accepted framework inhibits multi-disciplinary collaboration. What is needed is a common process framework that can be tailored and sustained for ESR&D, while enabling transition to TRLs 6 and higher. Several such frameworks are under consideration by members of the SE in ESR&D Working Group. These frameworks are the subject of this panel.

Michael DiMario (Astrum Systems)

Dr. Michael DiMario is the Founder and CEO of Astrum Systems, a global consulting venture focused on advancing process of innovation using a comprehensive systems approach. His corporate career began at General Electric Medical and progressed to Lucent Bell Laboratories, and Lockheed Martin. With a background in engineering, quality management and computer engineering, DiMario's career has spanned the leadership and management of numerous critical research and development projects and organizations. Dr. DiMario has five granted patents, numerous corporate trade secrets, a published book on systems engineering, a book chapter on systems engineering, and numerous peer reviewed papers in regard to systems engineering, innovation, and quality management. He has been interviewed and quoted in Wired Magazine, GPS World, Sifted, Financial Times, and the Smithsonian Air and Space. He holds a PhD in Systems Engineering, MBA in Management of Technology, MS in Computer Engineering, and significant course work in Space Science. He co-chairs the INCOSE Early Systems Engineering and Research Working Group.

Position Paper

Early-stage low TRL R&D is a mixture of research and early engineering. In research and early development organizations, there are differing processes that constitute their particular framework that leads to success or failure. The organization's framework may be executed with first research followed by engineering, research only in support of engineering problems, or a cyclic iteration of research and engineering with varying degrees of success factors and exit strategies. Most, if not all, of these ventures result in low return on investment, high project failure rates, dead end research, research deliverables that cannot be engineered without starting over, and organizational social antagonism among researchers, engineers, and managers. In many cases, the research and subsequent engineering fails at TRL 5-6 whereby the project cannot cross the classic TRL Valley of Death. How could systems engineering be applied to reduce risk? A common framework of system engineering management can be developed to reduce risk, improve return on investment, and provide for greater collaboration among researchers, engineers and managers. To accomplish an organizational common framework, a process architecture and its requirements need to be established that initiates an executable framework and its associated processes. The early-stage engineering environment needs to establish a holistic research and engineering approach recognizing that the execution of research is expansionist and systems engineering is reductionist. Researchers and early R&D engineers have typically not embraced systems engineering because of perceptions of process centric and rigid rules following established standards. Heuristics are required versus rules, standards, and checklists creating a capability and outcome-based research and engineering versus a compliance-based environment. This panel member will be discussing a TRL based process architecture requirements that would lead to various frameworks to support the myriad of diverse R&D organizations.

Ann Hodges (Sandia National Laboratories)

Ann Hodges has worked over 45 years at Sandia National Laboratories and is a Distinguished Member of Technical Staff. She is the Mission Services Division's systems engineering lead for the systems engineering part of the Project and Product Delivery System (PPDS) framework at Sandia National Laboratories and is currently a project manager and systems engineer for a complex exploratory-phase project. She is a primary author of the PPDS framework, which is a risk-informed graded approach to the application of project management, systems engineering and quality management. She obtained a BBA and an MS in Computer Science from the University of NM, and holds CSEP, SAFe SPC4, and CMII certifications. Ann has held Leadership positions in the INCOSE Enchantment Chapter since 2011, as Director-at-Large, Past President and currently Secretary. She is the chair of the INCOSE Systems Engineering for Early Stage R&D working group. (SAND2020-12414C) Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Position Paper

Sandia National Laboratories has implemented a risk-informed graded approach to the application of systems engineering (SE), project/program management (PM), and quality management (QM). Risk is the key factor in this framework. A challenge in the framework development was determining the core set of practices that every project is required to follow – from the small best-effort research efforts to large pathfinder operational systems. The set of practices need to be at the right level of rigor to 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. Experienced systems engineers, program/project managers, and quality management subject matter experts with over 150 years of collective experience were involved in the definition of this framework.

The framework is applied 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. Rigor attributes consist of timing (how early, how often), scope (breadth and depth), and formality (form of artifacts, who has access). The technical project lead, supported by systems engineering, quality engineering, other specialty engineering, and project management subject matter experts, are involved in completing these templates for their project at the very beginning. The project and product plan templates are based on industry standards, lessons learned, and address the rigor attributes. The industry standards include PMBOK for PM, ISO 15288 for SE, and AS9100 for QM. Approximately 70% of Sandia projects are low-category projects (e.g., R&D and studies) which typically equates to lower rigor across all three rigor attributes, and therefore Sandia is keenly interested in ESR&D. The low-category project/product plan template contains the minimal set of practices and information for artifacts that facilitate capturing enough information for future growth, thus providing a roadmap for researchers. These are the practices and artifacts that provide the most value: a charter (why and what), milestone list, WBS, budget, change tracking, requirements management approach, risk management approach, configuration management approach, and quality control. The category determination, thereby the applied rigor, is reviewed when the project scope changes or minimally yearly for required changes in rigor.

A second organizing principle is project type. We are currently developing project type category and subcategory templates for the risk-informed graded approach to increase efficiency and effectiveness. We are utilizing a scalable, participative method to introduce this project type approach as well as identify best practices and work products common to each project type. This will better equip technical and leads with enough systems engineering/project management/quality management knowledge to perform defensible research that positions the project for potential future growth.

Frédéric Autran (Airbus Defence & Space)

Frédéric Autran is a Systems Engineering (SE) Senior Expert in Airbus Defense & Space. He has an engineering degree from Ecole Centrale de Paris (1984). He developed a Computer Aided Software Engineering environment

used for the A320 aircraft, and then consulted for the French Ministry of Defense, contributing to building a semantic interoperability framework for various French Army C3I systems. He joined Aérospatiale in 1997 to set up management of systems interoperability in the new French Air Force command and control system, introducing SE principles in this programme. Since 2000, he is deploying SE in Airbus Defence and Space. Corporately he chaired the "PLM4SE" group from 2011 to 2014 that defines the interface between SE activities and the Master Product Definition. He is a member of the Airbus group SE Steering Group. In INCOSE, he created and chaired the AFIS (French INCOSE chapter) SoS and Complex Systems working group from 2005 to 2009. He is the AFIS board associate director for certification. He chaired the Tool Vendor Challenge of the IS2012. He holds an Expert Systems Engineering Professional certification. He has participated in the INCOSE Certification Advisory Group 7/2014 to 7/2020, being the chair in 2017.

Position Paper

Unlike other panelists, I am not involved in research and technology development. But I deal with early stages of system development (aircrafts, satellite, command and control military systems etc.). And I wish there is a better coordination between system and technology development.

Early stage of system development is a challenge for systems engineers. I will define early stages as all what happens before development is actually planned and resources are allocated. It can be a bid phase, or a feasibility study, or even a proof of concept. We all know that the lack of proper systems engineering at that time is likely to provoke disaster during development. On the other hand, there is limited budget, because all what we do is at risk (risk of nogo decision). There is a tendency for discarding all SE activities that do not provide tangible marketing material. But we shall also remember that the goal of any commercial company is not only to get contract, but to have profitable contracts. This is what SE should support, by carefully analysing the problem and solution scope, identifying potential issues, and focusing the early engineering effort of the risky part of the development. This does not only addresses technical risks, but as well uncertainty on real operational needs, impact of the industrial organisation (e.g. multinational workshare - aka geographical or industrial return - decided by governments and not by engineers!). SE shall give inputs for an informed go-nogo decision.

Early stages of commercial products Systems Engineering often deals with two aspects of the system that seem to be completely disconnected, dealing with two extremes of the SE scope: defining a CONOPS and identifying the technologies. One may believe early stages should focus on CONOPS, technology will follow. The problem is that we need to setup innovative concepts, that are simply not feasible without the development of new technologies. Here is the link with laboratories (private or public). Early stage system development shall sketch a system/solution concept. The concepts may rely on low TRL technologies. Planning TRL increase shall be done in alignment with system development schedule. Thanks to appropriate SE techniques applied for technology development, it should be possible to evaluate the risks that the candidate technology is not mature enough when system realization begins. It should be a matter of classical risk management to decide to include or not this technology in the product to be developed. And maybe launch anyway the technology development so that it is available for the next generation system. To summarize my "commercial company" point of view, any technology development needs to be justified by a need regarding development of an end product, and systems engineering of this end product shall be used to set the targets of the technology R&D.