

Methods for Developing Successful Systems Engineers

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Abstract—Systems Engineering (SE) is a complex and challenging field that incorporates the knowledge of systems engineering processes, the ability to synthesize a wide-range of engineering disciplines, and the ability to lead a team of people to successfully accomplish the goals of a project. It requires hard technical skills and soft-skill leadership savvy. As a result, three main development needs are identified:

- 1) Knowledge of SE processes, the benefits of these processes to a project and their tailored application
- 2) Knowledge of a wide-range of engineering disciplines, how they interrelate in a system, and the development of sound technical judgement
- 3) Team leadership to direct and motivate a team of subsystem and discipline experts

This paper describes the establishment of a comprehensive training and development program for Systems Engineers at NASA Ames Research Center that addresses in part each of these three areas from the perspective of the implementing manager. A variety of methods have been utilized including the establishment of a SE Community of Practice, a unique and innovative web tool, on-line videos, classroom training in NASA's 17 Common Technical Processes, guidance on the tailored application of these processes, monthly technical talks, mentoring in both technical judgment and team leadership, and NASA's Leadership Development Programs.

While much of professional SE development must come through project experience, the approaches listed above can accelerate development. The diversity of skills required of Systems Engineering demands a multi-faceted approach to successfully train and develop this critical skill.

Keywords—development, training, leadership

I. INTRODUCTION

The role of the Lead Systems Engineer (LSE) is the most critical technical leadership position on projects. Systems Engineering is much more than a set of well-defined processes to which projects strictly adhered. At NASA, "systems engineering" is defined as a methodical, multi-disciplinary approach for the design, realization, technical management, operations, and retirement of a system that include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose[1].

Successful LSEs must possess a wide range of skills that generally fall within three main categories: 1) Knowledge of SE processes and the ability to tailor them to a give project, 2) Knowledge of a wide-range of engineering disciplines, how they interrelate in a system, and the development of technical judgement, and 3) Leadership skills to direct and motivate a team of subsystem leads and discipline experts.

The three skills listed above require training and development to meet the demands of this very challenging role. There are a number of methods that have been developed and instituted at NASA Ames Research Center. These methods are listed in the left-hand column of Table 1 below and reflect the relative effectiveness of each of method to the development needs. The relative level of effectiveness has been determined through feedback from staff members and observations made over time by the department manager.

TABLE I. EFFECTIVENESS OF DEVELOPMENT METHODS

Method	SE Processes	Discipline Engineering	Team Leadership
Classroom-based courses	High	High	Low
Mentoring and Coaching	Med	Med	High
Networking	High	High	Low
Technical Talks	Med	Med	Low
SE Development Program	Low	Low	High
Self-guided resources (SE Toolbox)	High	High	Low

The following sections discuss the more effective methods for each of the three developmental needs.

II. SYSTEMS ENGINEERING PROCESSES

A. Classroom-Based Learning

Becoming a skilled Systems Engineer requires an understanding of the SE processes that can be applied to a project. However, mere knowledge of the process is insufficient. Systems Engineers at all levels need to understand the *basis* for these processes and the *benefits* of judiciously applying them to a specific project. Understanding the basis of each process is an essential step to effectively tailor, or right-size, these processes based on the risk posture of the project. Both NASA Headquarters and the Systems

Engineering department NASA Ames have developed courses to help address this need.

NASA's Academy of Program/Project and Engineering Leadership (APPEL) provides a 3-day course on developing and implementing a Systems Engineering Management Plan (SEMP) which covers NASA's 17 Common Technical Processes[2]. APPEL also provides single and multi-day courses on the Fundamentals of Systems Engineering, Requirements Development and Management, and Space System Verification and Validation and several others.

Ames has developed a course that walks the learner through a much broader scope covering all agency-level and local Ames SE related documents. It covers the hierarchy from the top-level Engineering and Project Management policy at NASA to the Ames specific SE procedural document. It then introduces the Ames SE Best Practices associated with each of NASA's 17 Common Technical Processes and finally the 9 additional process documents invoked by the best practices. In this course Systems Engineers are taught by the Subject Matter Experts for each of these documents to help the learner grasp the material and provide a point of contact to reach out to when they encounter questions. Each of the instructors provide the basis and background for each document and discuss their benefits to a project.

B. Self-Guided Resources (SE Toolbox)

The most experienced SEs collect a vast array of reference material over many years. This material includes links to important technical references, a list of experts from various engineering disciplines, and documents from past projects. The SE Toolbox developed at Ames provides a single web-portal containing a superset of all resources gathered from the most senior SEs across Ames. No longer do individuals need to rely solely on their own set of resources and references over time. The SE Toolbox provides access to nearly all past spaceflight project documentation over a 15-year period, guidelines and templates for developing these SE related products, reference material for a variety of engineering disciplines, links to a large number of technical resources and training videos and materials, and a calendar that provides a single source for all upcoming training around the agency and beyond.

SEs can now view how projects similar to theirs tailored a given process or document. The SE Toolbox identifies the name of the individual who developed a specific document for a given project but also the name of the expert for a given document type such as a SEM. These resources have not just helped right-size a given process or document for a project but have enabled projects to do so in a much less time.

C. Networking

Conversations between SEs are a critical piece to developing Systems Engineers. SEs at Ames are taught the importance of the saying "it's not what you know, but who you know." While it is important that SEs gain technical expertise, gaining a network of experts from across the Center and the agency is crucial to their development. Knowing who to call to get an answer to a specific question can save significant time and money and help avoid the mistakes of the past. The SE Toolbox identifies experts for a variety of SE processes, product types, past project leadership across NASA Ames. Links from the SE Toolbox to the NASA Engineering Network, Systems Engineering Community of Practice also provide a large number of Systems Engineering related points of contact. Staff are highly encouraged by the SE Department Manager to reach out to these experts for answers and to develop relationships to be leveraged in the future.

III. KNOWLEDGE OF ENGINEERING DISCIPLINES

It is vital that Systems Engineers understand the role of the SE is not limited to implementing a set of processes. Lead Systems Engineers must have a working knowledge of all engineering disciplines required for a project to effectively lead the team in defining an architecture, assessing and addressing trades, and mitigating risks and problems along the path of implementation. Working knowledge must transform into sound technical judgement that can be applied to a myriad of decisions projects face along the path to product realization.

A. Self-Guided Resources (SE Toolbox)

Through the SE Toolbox Systems Engineers are provided a range of resources across 11 engineering disciplines common to spaceflight projects including training and guidance documents, technical videos, and a list of training courses offered within NASA and industry to grow their knowledge in a specific engineering discipline.

B. Technical Talks

The Ames SE Community of Practice (SE CoP) sponsors monthly technical talks targeted at common knowledge gaps at the Center. When a specific knowledge gap is identified the leader of the SE CoP reaches out to an expert in the field to develop a talk for an upcoming event. It is important that the supervisor over the Systems Engineers maintains a close understanding of the needs of their staff so that talks and training events are targeted to their needs. It requires a concerted and sustained effort to meet with the SE staff on a frequent basis to learn of their needs and proactively seek out experts capable of addressing their needs.

C. Networking

Developing a network of discipline experts to call upon is a critical element to the development of a Systems Engineer's understanding of the wide range of disciplines required. Understanding the tradeoffs at play across engineering disciplines is fundamental to being an effective SE. A key opportunity to growing the SE's network is to tap into the NASA Engineering Network (NEN) where Subject Matter

Experts (SME) are identified for more than 60 technical disciplines and sub-disciplines. Discussions are facilitated by the department manager and staff are encouraged to reach out on their own. NASA has developed a strong culture of supportiveness so cold-calls to experts around the country are expected and invited by the SMEs. In a similar way the SE department manager helps SEs make connections locally at Ames. When an SE has a need within a specific technical discipline, the SE department manager connects the SE to that expert at Ames.

IV. TEAM LEADERSHIP

A. Systems Engineering Leadership Development Program

The most elusive and perhaps the most important skill of an LSE is leadership. One of the top reasons projects fail at NASA, confirmed by experience at Ames Research Center, is poor team dynamics in large part attributed to poor leadership by the Project Manager or Lead Systems Engineer. Mastery of team leadership is not gained through a series of classes or reading leadership books. While courses and books are helpful, this skill is primarily formed through experience, both successes and failures. SEs need a safe place to make mistakes, ask questions, learn, and grow. It requires self-awareness, a level of humility, and a focus on the individual successes of their team members as well as the project.

NASA has developed a very effective training course for leadership development named the Systems Engineering Development Program (SELP). This program has been in practice for the past 15 years. The program's goals are to develop:

- Cross Agency Experience
- Advanced Leadership Skills
- Exposure to innovative government and industry-wide-systems engineering concepts

The 18-month program includes a temporary assignment for 1 year at another NASA center aimed at getting each learner out of the comfort zone and assigned a role on a project type for which they are less familiar.

The program accepts 24 highly qualified candidates from across the agency in a multi-step application process culminating with interviews conducted at NASA Headquarters. Once in the program there are quarterly meetings where the entire cohort of 24 is brought together to assess personal strengths and weaknesses and develop action plans to strengthen established skills and address areas of weakness. A mentor is assigned to each member by the host center to help them navigate challenges.

B. Mentoring and Coaching

While SELP is a prestigious program, it is of limited duration. Participants need support once returning to their home center. The supervisor plays a key role in furthering their development. It has been effective at Ames for the department manager to provide continued coaching and mentoring. This

relationship is most effective when trust has been established. LSEs in particular face a number of leadership and interpersonal challenges where fears arise. The SE needs to feel safe to share fears and challenges in order to receive insightful and honest feedback. It is essential their supervisor has their best interest in mind.

Within the Ames SE CoP a formal mentoring program was also established. Prospective mentees are required to complete a 1-page application describing their background, experience, current role, and mentoring goals. Their application is discussed with the SE department manager and then matched based on skills desired and personality with an individual from a pool of mentors. The SE department manager communicates to mentees the need to take responsibility for their growth and development and be the driving force behind the time with their mentors. Mentors and mentees are asked to commit to meeting 4 times and then reassess whether to continue. The 4-meeting commitment provides an easy "in" and graceful "out" of a relationship if it's not working. If this occurs the mentee is matched with another mentor who may be better suited to them. SEs typically know what they need to do but at times lack the necessary skills and confidence to lead their team. Having a coach or mentor who has their best interest in mind and is willing to speak truth is an important aspect of helping SEs develop into their full potential.

V. SUMMARY

The methods for developing Systems Engineers discussed here are certainly not the only methods to develop Systems Engineers. The various methods discussed help to illustrate the need and benefit of using a variety of methods to grow and develop individuals into Systems Engineering leaders.

The implementation of these methods have helped NASA Ames Systems Engineers be awarded three NASA Systems Engineering Technical Excellence Awards over a 6-year period, more than any other NASA Center during this timeframe.

Providing and sustaining a comprehensive development program for Systems Engineers almost certainly requires a supervisor with a passion and commitment for the growth of their staff. It is challenging to stand up a new training and development effort, but even more challenging to maintain a vibrant program over a sustained period of time. It requires supervisors with passion for people and the growth of their staff. This supervisory commitment propels successful development of Systems Engineering leaders toward achieving mission success.

REFERENCES

- [1] "NASA Systems Engineering Handbook, Expanded Guidance for NASA Systems Engineering" NASA, pp. 20, March 2016.
- [2] "NASA Procedural Requirements, NPR 7123.1" NASA, pp. 20, February 14, 2020