THE APPLICATION OF SYSTEMS ENGINEERING TO SCIENCE AND TECHNOLOGY PROJECT PLANNING

Bryan S. DeHoff, Thomas D. Archer, Carol Ventresca
SynGenics Corporation
5190 Olentangy River Road
Delaware, OH 43015

Robert L. Rapson
Materials and Manufacturing Directorate, Air Force Research Laboratory
2941 Hobson Way
Wright Patterson, OH 45433-7750

ABSTRACT

Within the Department of Defense (DOD) there has been an active effort to reinvigorate Systems Engineering disciplines and to attain their inherent benefits across the entire weapon systems acquisition process. While the typical application of Systems Engineering has been in the System Program Offices emphasizing design and production, the current initiative extends the Systems Engineering expectations earlier in the science and technology (S&T) realm of the Air Force Research Laboratory (AFRL). In response, AFRL has adopted a systems engineering process for planning and executing activities in the Exploratory Development and Advanced Development budget activities.

The Materials and Manufacturing Directorate within the Air Force Research Laboratory (AFRL/RX) has identified three phases in the S&T project life cycle—planning, execution, and closeout. Believing that if a project is planned well, it is more likely to execute well, the Systems Engineering team within AFRL/RX developed a streamlined systems engineering process for S&T planning. This paper describes the application of this process to various materials, processing, and manufacturing problems.

1. INTRODUCTION

The Department of Defense (DOD) and the Air Force (AF) are emphasizing the value of Systems Engineering (SE) at all levels of defense development programs. The Air Force Research Laboratory (AFRL) has directed that SE principles must be applied to programs in science and technology (S&T) as well. Within the Materials and Manufacturing Directorate (AFRL/RX), a small team has been formed and charged with implementation of SE. In the S&T world, there can be a tendency to view SE as acquisition-focused and inappropriate for the creativity and uncertainty inherent in many aspects of research. The successful approach has been to place the SE principles in a format and context compatible with the work and the culture. The RX SE team has provided a streamlined, flexible process and the education/training to tailor it for use in the unique situations encountered in RX. Immediate value has been realized in more focused S&T, in the SE framework that makes it much easier for all the stakeholders to communicate, and in a consistent, efficient approach.

2. THE CULTURE OF AN S&T ORGANIZATION

2.1 Culture of Scientific Development

The culture of AFRL/RX is one of highly educated and very busy people who need to understand and accept the value of any new “management requirement”, such as a new Systems Engineering process, before they will embrace it. In addition, the last thing to truly change in any organization is the culture. (Rapson, 2009)

This culture of AFRL/RX and the professional workforce values the scientific thought behind any process. Eight-five percent are civilians; fifteen percent are military. Two-thirds of this workforce holds advanced degrees primarily in the engineering and science disciplines. This workforce has spent years gaining the professional credentials needed to represent the Air Force as experts in their particular fields. In any established organization, there is a tendency for workers to resist change and to express frustration with any changes perceived as making it more difficult to perform their responsibilities. In addition, the S&T community across DOD is faced with an increasingly competitive budget environment. This is the culture that the RX SE team faced within AFRL/RX. The RX SE team agreed that people were already busy, that none of the current reporting and review requirements were being eliminated, and that, if the SE initiative were to be successful, it had to offer a better, more efficient and effective way of meeting existing expectations.

At first thought, the top-down and traditionally complex and expansive nature of SE is potentially at odds with the fundamental science of discovery, where understanding and characterization are typically bottom-up processes. This being the case, the materials scientist naturally challenges the imposition of a SE design process as duplicative and counterproductive. This cultural issue is expressed in comments that the application of SE to the design of exploratory development projects takes too long and costs too much. The challenge is convincing S&T leaders that the effective SE work in early S&T actually leads to a higher probability of transition sooner and at a lower cost, where technology transition is the stated objective of the S&T organization.

Historically, S&T efforts focus on specific scientific challenges; overcoming these challenges is the core technical effort in a program. That can lead to significant delays in transition when issues such as scaling, testing and verification, supportability, affordability, and maintainability are added as essential to qualifying for transition. In some cases, even the focus of the core technical effort changes as the S&T team, adopting a Systems Engineering approach in validating objectives, engages with a warfighter to better understand an end use. An added benefit of this dialogue is that the warfighter may envision potential applications of S&T that are unanticipated in the technical effort.

3. THE ESSENTIAL ELEMENTS OF SYSTEMS ENGINEERING

Across the S&T community, there is wide variation in what is considered Systems Engineering. This lack of consensus stems from the relative newness of the SE discipline, the lack of inclusion of its principles in traditional engineering curricula, and the prevalence of acquisition training, which appropriately concentrates on Systems Management rather than Systems Engineering as a technical discipline.

3.1 Academic Basis

The academic discipline of Systems Engineering is an outgrowth of the increasing complexity of developed products, including aircraft, launch vehicles, computers and communication systems. Buede points out that Systems Engineering is commonly viewed as a decomposition process, followed by the recomposition or integration process. (Buede, 2000, pp. 5-6) The decomposition process starts with the identified need or customer requirements, and decomposing that need into the relevant elements of a design. The recomposition process is the aspect of integrating all the elements of a design back into a functioning product which meets all the aspects of the identified need. The ubiquitous Systems Engineering "V" succinctly captures the basic steps of the Systems Engineering process (Figure 1).

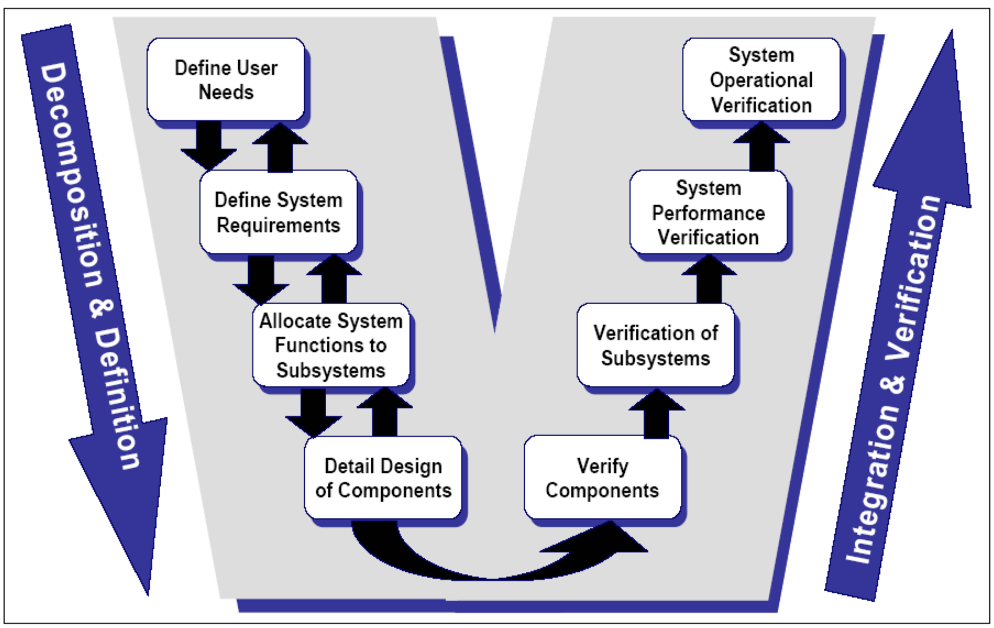

Figure 1. Systems Engineering "V" (Air Force Center for Systems Engineering at the Air Force Institute of Technology, 2005)

3.2 DOD Construct

Within the DOD, Systems Engineering has been the discipline of managing the increasingly complex aspects of modern systems, and Figure 2 places it in the context of a typical development program. These two diagrams illustrate the complexity that immediately comes to mind with any mention of Systems Engineering. To be useful in the S&T environment, the SE principles must be applied, but the SE process is tailored and greatly simplified.

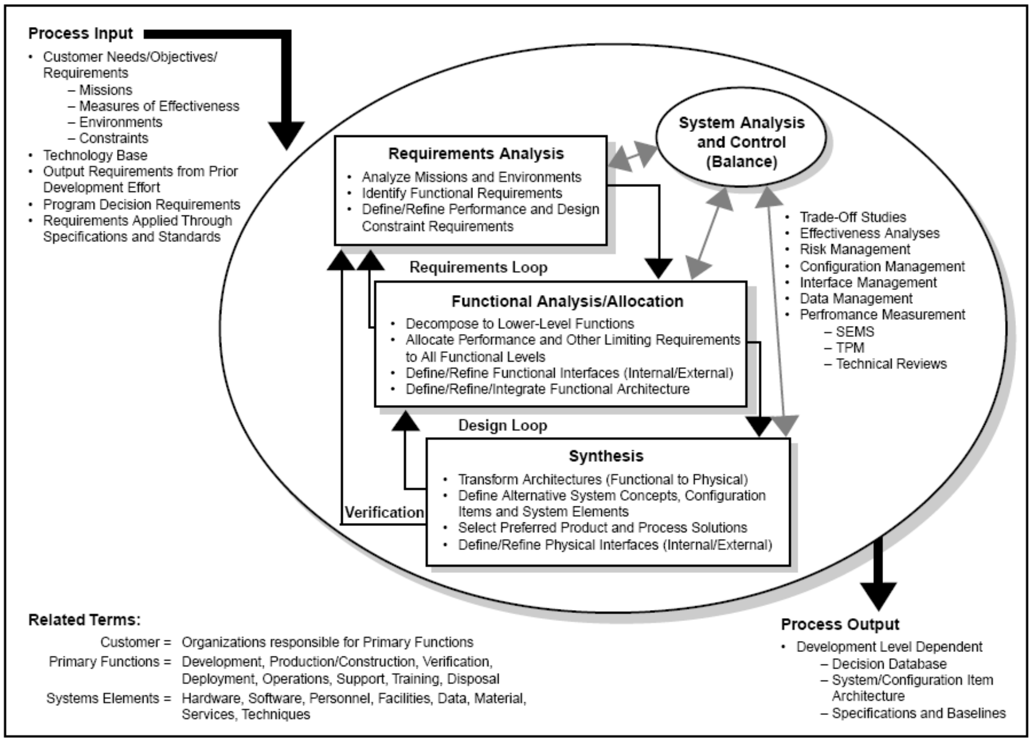

Figure 2. The DOD SE Process (DOD Systems Management College, 2001)

4. THE APPLICATION OF SYSTEMS ENGINEERING TO THE S&T ORGANIZATION

4.1 AFRL Elements of Systems Engineering

The Department of Defense (DOD) has set out to reinvigorate the application of Systems Engineering across all phases of the Defense Systems Life Cycle. Unlike the early application of SE in the acquisition of major complex systems, in the current application the SE tenets are being applied in the early design and development phases, to include the typical science and technology development phases. Compliance instructions are in place now which mandates the use of a SE process across the "entire" acquisition life cycle, including the AFRL-managed exploratory development and advanced development activities.

Through a process of dialogue and coordination, AFRL established an agreement regarding the essential elements of SE that both satisfy the intent of the compliance instructions and are appropriate to the nature of the S&T programs within the laboratory. These essential elements are expressed in the form of key questions, sometimes called "The Eight Questions," which each program manager is able to address during the planning, execution, and transition phases of his/her program. (Air Force Research Laboratory, 2008)

The key questions are the same across the entire AFRL S&T domain; however, the level of knowledge available to a program manager changes as a technology develops and matures. While every S&T program manager is expected to know the answers to these questions, the amount of information needed to document the answer to a particular question satisfactorily (e.g., during program or technical reviews) will change as a program progresses from a Basic Research effort through Exploratory Development to Advanced Development. Use of the key questions during reviews of basic research programs is optional to the director of each technical directorate and the Air Force Office of Scientific Research (AFOSR). The SE key questions are:

- Who is your customer and why?
- What are the customer's requirements and why?
- How will you demonstrate you have met the requirements and why?
- What are the technology options and why?
- Which is the best approach and why?
- What are the risks to developing the selected technology and why?
- How will you structure your program to meet requirements and mitigate risk and why?
- What is your business-based transition plan that meets customer approval and why?

These questions do not eliminate the ability of the S&T Program Manager to focus on a far-term, high-payoff technology challenge, but they do keep the focus on the needs of the Air Force, both near and far term.

4.2 The Science and Technology Project Life Cycle

The Science and Technology projects conducted within AFRL are the point of intersection between the existing culture and the new Systems Engineering mindset. Conducting a Science and Technology project involves activities in the planning, execution and transition or delivery phases, (Figure 3). Looking at these phases in reverse, the end result of the technology development project should be either a delivery of a mature technology to an acquisition program for use by a warfighter, or a transfer of a technology with an improved maturity level to another technology project, which has the goal of advancing that technology along the road to eventual delivery. In order to reach this handoff, the middle phase of the project life cycle is the execution phase, where the work of the project is actually accomplished. The beginning of the life cycle is the project planning phase, where the strategic goals of the organization are refined, and distilled into the specific technical objectives of a technology effort.

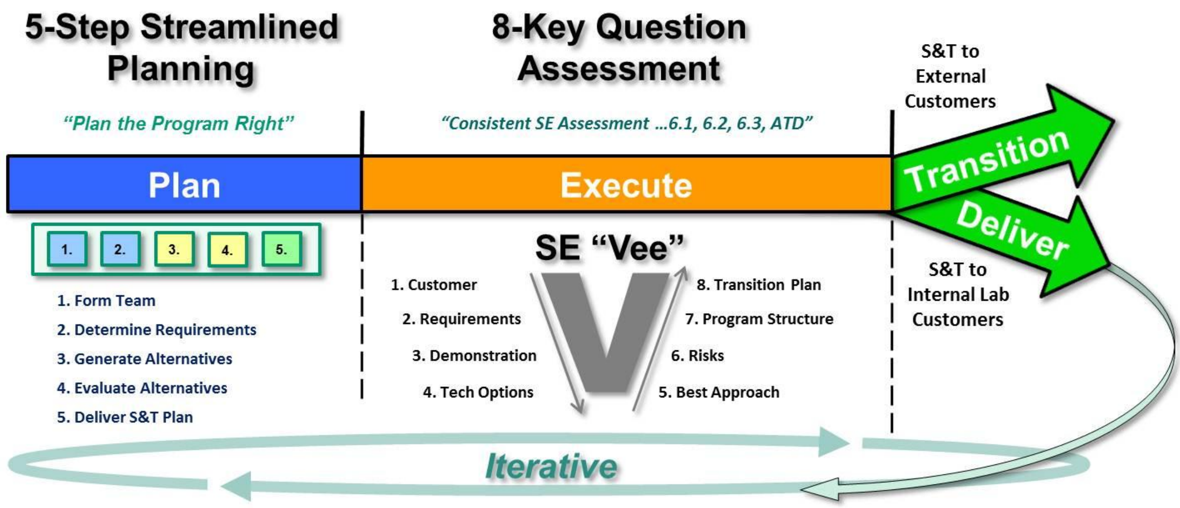

Figure 3. Life Cycle of a Science and Technology Project

4.3 Toolbox of Techniques

In recognition that the projects within AFRL/RX are highly varied, a strategy of variable response was established. Figure 4 suggests that the degree of rigor of the SE approach should start out at a low level and increase in response to the complexity of the project or issue at hand. Thus, a basic research task or an early exploratory development program would warrant a low level of system engineering activity, such as a conversation between the SE team and the program manager. An advanced development program might entail customer involvement in establishing requirements and inter-directorate cooperation or industry participation in the analysis of alternatives.

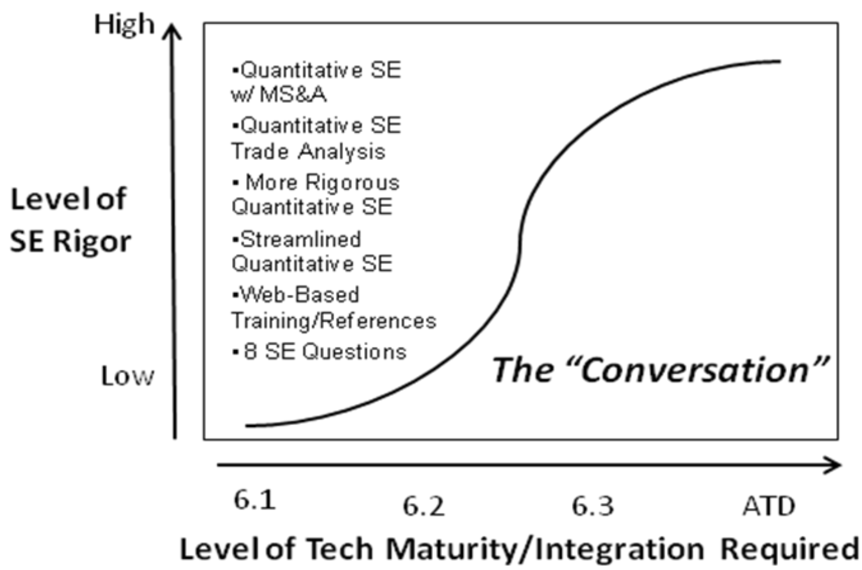

Figure 4. Tailored SE Toolbox for S&T Program Planning

The key questions of the essential elements of SE are appropriate for both the planning and execution phases of the project life cycle. The compliance documents issued in response to the mandate to employ SE in the AFRL domain suggest applying the questions to the planning and execution phase; however, there is no guidance on how to apply these questions to the programs comprising the S&T portfolio.

Addressing each phase of the project lifecycle as a separate problem, the AFRL/RX Systems Engineering team first developed an implementing instruction to guide the use of the key questions during the execution phase, and then developed a descriptive guide and workbook to assist the S&T managers in the Project Planning phase. The backbone of the planning phase guidance is the Streamlined Systems Engineering Process for S&T Planning (Figure 5). This streamlined process allows the flexible rigor described in Figure 4, while establishing clear milestones for each step.

The RX SE team, recognizing the nature of the S&T function, has incorporated the intent of the key questions into a more recognizable, structured, yet flexible process called Streamlined Systems Engineering Process for S&T Planning:

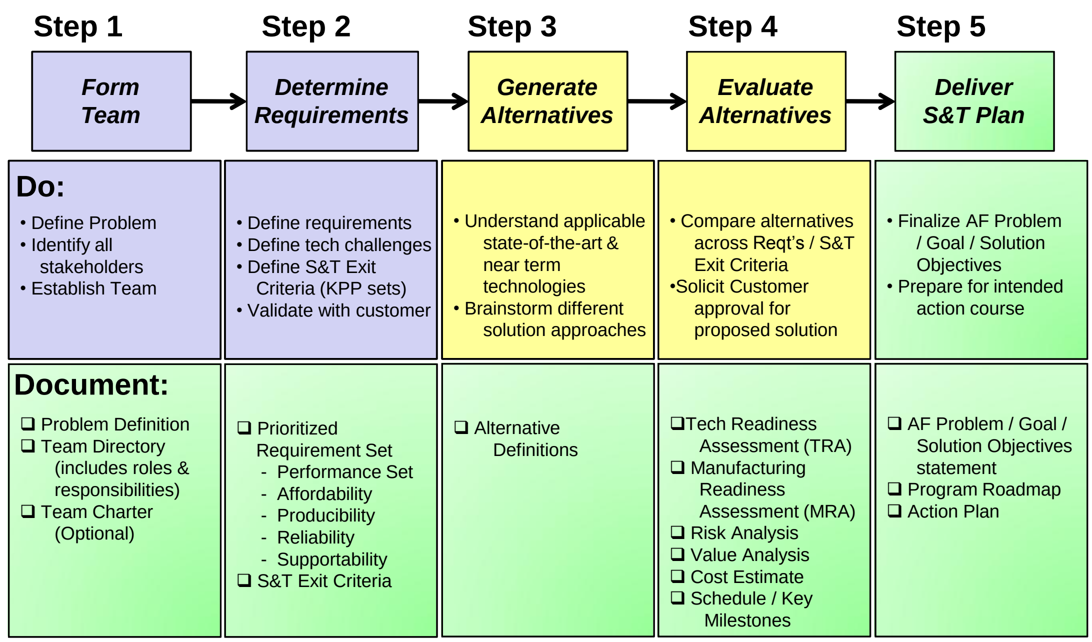

Figure 5.The Streamlined SE Process for S&T Planning

The classic elements of Systems Engineering—requirements, alternatives, and analysis of alternatives—are visible. It is recognized that the S&T environment is inherently one of learning through the process. The steps of the process, and the implementation details, provide a useful and powerful framework. Nevertheless, in practice they evolve starting with "the conversation", moving eventually to an analytical state. The degree of analytical rigor varies significantly, starting with qualitative and notional parameters for technically immature S&T to more rigor, with measurable objectives as the technology matures.

4.4 Customer Focused Approach

During the development of the guide and workbook, the RX Systems Engineering team sought to implement this Systems Engineering perspective, represented by the Key Questions, with an Internal Customer approach. When a project or planning issue came to the attention of the Systems Engineering Team, the S&T Program Manager was treated as an internal customer. This meant that the results of the Systems Engineering effort were privileged products for the use of the Program Manager. Further distribution was the prerogative of the Program Manager and occurred only upon his/her explicit release. This approach helped establish an attitude of trust that the team could explore this new way of planning without risk. Because no two problems were ever identical, the specific approach within the five steps was tailored for each program.

The SE Team also encouraged the project teams to use a manual approach—hands on with facilitated guidance. This gave the Program Manager first-hand experience with the terms and methods, and the payoff was familiarity and ownership of the process by the Program Manager. The Privileged Customer relationship has been a key to success in that the teams have always learned something about the way they were viewing the problem. By stressing a manual scoring approach instead of a computer model, we found the dialogue among the team members centered on the process rather than the data entry.

5. THE APPLICATION OF THE STREAMLINED PLANNING PROCESS TO MATERIALS AND PROCESSING CHALLENGES

5.1 Range of Experience

Recalling the three phases of the Project Life Cycle, Planning, Execution and Transition / Delivery, the AFRL/RX SE team has used the privileged customer relationship to assist 5 teams in planning the projects necessary to respond to specific technical challenges. The key questions have become a standard part of the program reviews during the execution phase, and the SE Team just completed an application of the Streamlined SE Process for S&T Planning to identify projects with a high potential to transition.

Within the Planning phase, the projects have crossed the development spectrum from Basic Research to Advanced Technology Development as well as multiple small rapid response projects.

5.2 Lessons Learned

In applying the Streamlined SE Process, the most significant lesson learned is the importance of team commitment to at least start the process, then keep it moving. People who are otherwise reluctant to participate will agree, if only to protect their interests, to attend a kick-off meeting. When they have that chance to see how the process works, there is a strong tendency to become engaged then committed. The success of the planning activities has been directly proportional to the commitment of the team to stay on task and complete the steps in quick succession. If the team membership is distracted by other priorities, and allows weeks to pass between meetings, the effort loses relevance.

However, where the Program Manager is an active customer, and able to keep the team of subject matter experts on task, the process is completed in reasonable time. In one case, this positioned the program team to receive $40 Million in additional technology funds.

5.3 Progress toward a Culture Change

The cultural change is being driven by two factors, one external one internal. The external factor is the resource reduction which means programs are now in competition for funding and a rational justification for programs is essential. The Streamlined Systems Engineering process is an effective approach to support the rational justification.

While measuring culture change is usually the realm of sociologist studying events in the distant past, the process of infusing the concepts of Systems Engineering into the planning, execution and transition phases of the S&T projects within the AFRL is moving forward, and progress can be seen. Recommendations for teams to “Take a look at that plan from the SE perspective” are becoming more frequent, and the number of project teams adopting the process on their own is increasing as well.

The internal factor driving the adoption of the Streamlined Systems Engineering is its fundamental utility. Program managers who use the process once tend to come back to it again, especially when there are several stakeholders or a variety of subject matter experts involved. Their reasons are:

- Standard process that is recursive, flexible and scalable
- A consistent framework for subject-matter experts, warfighters and managers to
    - Capture, discuss, negotiate, and evolve alternatives
    - Ultimately achieve consensus and
    - Realize the highest probability of “system” success.
- Set of analysis tools for comparing alternatives across multiple requirements.
- Worksheets and scorecards: a framework for presentation of results, for doing “what-if’s” and for easily evaluating changes as new information becomes available.
- Documented results with their underlying rationale.

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