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**TECHNICAL OPERATIONS SUPPORT III (TOPS III)
Delivery Order 0006: An Air Force Research Laboratory (AFRL)/RX
Streamlined Science and Technology (S&T) Planning Guide for
Applying Tailored Systems Engineering (SE) Guide and Companion
Workbook**

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Final Report**

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Foreword

The “Spirit” of Systems Engineering

The Spirit of this Guide is to incorporate Systems Engineering principles into any planning activity and to cultivate an atmosphere of open “Conversation” with your team of technical experts and potential Customers/Stakeholders.

“The Power of System Engineering is in the Discovery.”

The Streamlined Process introduced in this Guide has been crafted to cultivate discovery, and is by design, iterative in that as you conduct and complete each sequential activity, you and your team may learn new insights and understandings that impact and build upon previous findings.

Incremental SE Rigor – from back of the envelope to detailed tool assisted analysis

From the start of a project, document “What you know and don’t know,” for as soon as an idea is written, understanding takes place, and discussions can begin. Conversation is Key! With understanding comes comprehension, and the better ability to determine the amount of effort (rigor) needed to invest and analyze the problem-solution space. From a small team or Integrated Product Team (IPT), to full up modeling and simulation, this Guide and its companion Workbook should be usable on any 6.1, 6.2, or 6.3 research effort using an incremental “rigor” approach.

“Takes Too Long and Costs Too Much!”

Many may feel any kind of Systems Engineering Process takes too long and costs too much; however, if the right discussions and decisions are made upfront thus avoiding significant errors, then the investment of time is usually worth the effort.

The Pirates’ Code – “...more what you’d call “Guidelines” than actual rules?”

(Pirates of the Caribbean: The Curse of the Black Pearl (2003))

In the spirit of the code, the Process Steps in this Guide are but “Guidelines and not actual rules”meaning, nothing in this Guide is to be viewed as required, in fact, everything can be tailored, and customization is highly encouraged to fit your situation. The goal is to create an environment to generate and document the best discussions (...The SE Conversation).

Robert Rapson
Chief Engineer
Materials and Manufacturing Directorate

Purpose

The AFRL Materials and Manufacturing Directorate (AFRL/RX) Streamlined S&T Planning Guide and Workbook have been created to help RX apply the tenets of Systems Engineering (SE). The Guide explains how to conduct a SE-based S&T planning process using tailorable worksheets to help facilitate the process, open communications, and capture the information necessary for good planning. SE Facilitator support is available from the AFRL/RX Systems Engineering Working Group (SEWG) for any RX Program Manager wanting to use this Guide on their project.

Although focused on experience in Materials and Manufacturing, the process should be applicable to any S&T planning process.

Using the Guide and Workbook should enable an S&T Team to create and document a SE-based program plan using a “customer focused” tailored SE approach.

AFRL/RX is pursuing this tailored approach to SE in order to:

- Comply with Department of Defense, Air Force, and Air Force Research Laboratory guidance.
- Develop an SE Culture appropriate for an S&T environment
- Improve Program Management effectiveness and efficiency
- Improve the quality and success of technology transitions and deliveries.

Why is strategic program/project planning with a tailored SE process important?

- Help understand where technology / concept ideas fit customer requirements
- Provide a solid basis for approval / maintenance of funding (marketing/advocacy)
- Build a firm foundation for the increased likelihood of program success
- Link AF S&T Vision to AFRL products

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Dr. Kenneth Barker, AFRL Chief Engineer, SEC Chair

Mr. William Nolte, SEC Secretariat

*Take time and think well upon your subject.
Nothing valuable can be lost by taking time.*

- Abe Lincoln

*A Systems Engineering approach allows a methodical process
to explore and select the optimized actions
to plan and execute better S&T programs.*

Executive Summary

RX is implementing Systems Engineering (SE) in accordance with guidance from the Department of Defense and Air Force policies.

RX SE, as adapted for Science & Technology (S&T), has its roots in the AFRL Affordability Initiative, the essence of which has been vetted in the Integrated Product & Process Development (IPPD) SE management approach.

SE tailored for S&T consists of three major phases, 1). Plan, 2). Execute, and 3). Deliver / Transition technology capability (Figure ES – 1). This Guide provides an outline for Phase #1 Plan (Figure ES-2). For phase #2 Execute, the SE principles are applied when reporting the answers to the 8-Key Questions (SE “Vee”) at AFRL/RX Lab Management Reviews (LMRs) and Program Baseline Reviews (PBRs).

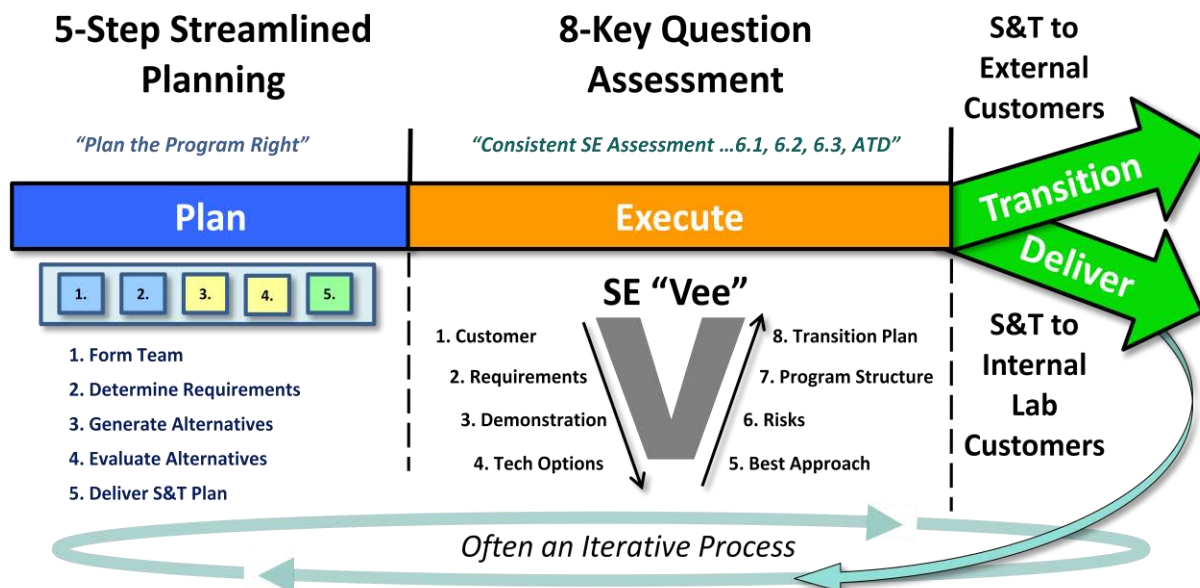


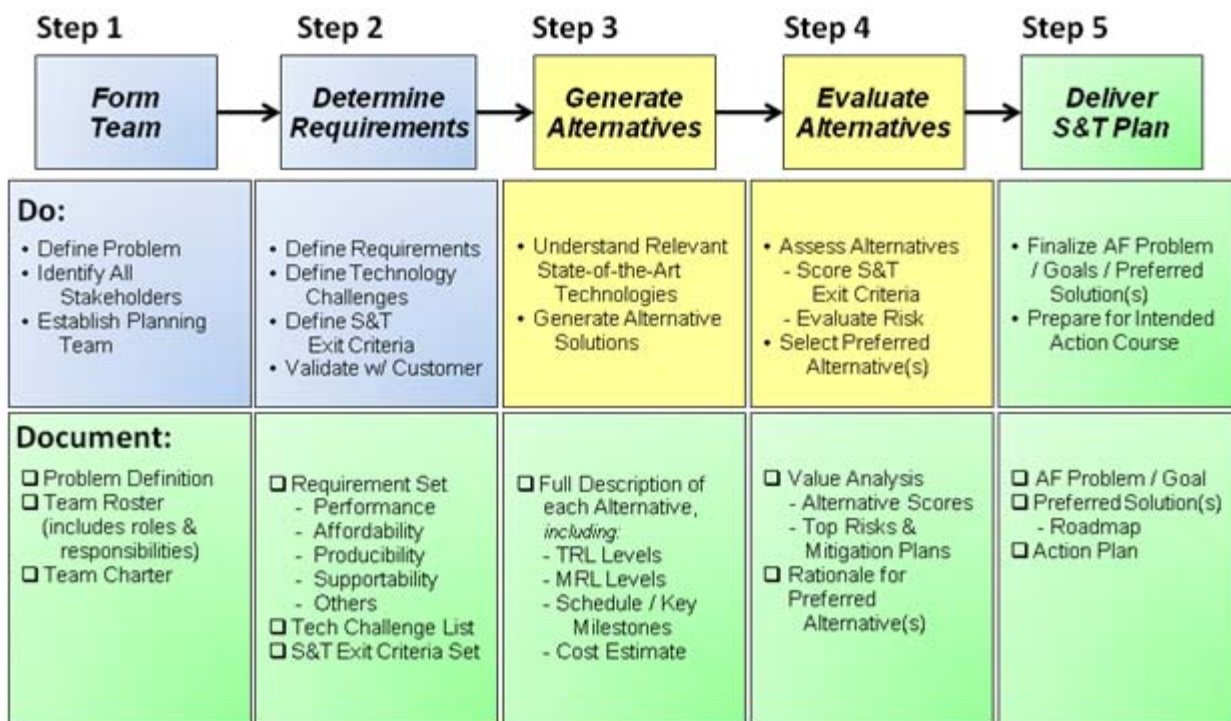
Figure ES - 1. SE Tailored for S&T Programs

The RX SE team developed a *five-step* Streamlined S&T Planning Process to address the *two challenges* perceived in S&T – “it costs too much and it takes too long.” This planning process adapts the *basic SE principles* in IPPD and other techniques for an SE-based approach for programs at any level of S&T maturity.

Figure ES - 2 lays out the basic Streamlined S&T Planning Process to conducting the initial and any subsequent project planning, at minimal time and expense. References throughout the Guide point to other SE tools if a more in-depth analysis is required.

The colors in the AFRL/RX Streamlined S&T Planning Process have a specific meaning:

- Blue – denotes “Problem” Space – identifying the key program characteristics, which includes performance parameters, etc.
- Yellow – denotes “Solutions” or Trade Space – Alternative Analysis
- Green – shows desired documentation of the planning process



Based on S&T IPPD Process (Version 3 – 2002)

Figure ES - 2. Five-Step Streamlined S&T Planning Process activities and outputs

The RX planning method forms the foundation of the SE Conversation and include:

- The Planning Process must include a **team** of knowledgeable stakeholders
- The S&T Planning Process is highly **collaborative** and **iterative** in nature
- The level of rigor required is **tailorable** to the specific S&T problem
- **Documentation** is required at each step of the process

Introduction to Systems Engineering Tailored for S&T Planning

RX SE, as tailored for S&T, has its roots in the AFRL Affordability Initiative, the essence of which has been vetted in the Integrated Product & Process Development (IPPD) SE management approach. Recent positive experience with tailored SE in AFRL S&T has demonstrated the relevance and benefit for AFRL programs.

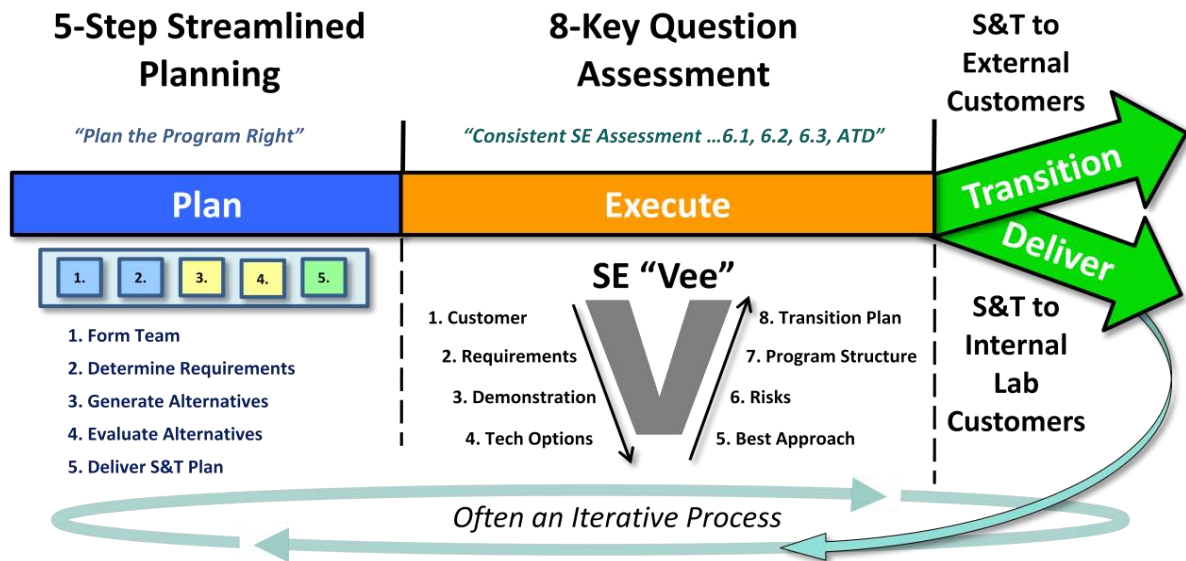


Figure 1: SE Tailored for S&T Programs

For any existing or proposed S&T program, tailored SE consists of three phases, as shown in Figure 1:

- In the *five-step* streamlined **planning** phase, tailored SE principles are used to carefully craft an S&T program that is executable and meets customer expectations. Steps in this planning phase, along with tools available for use in this phase, will be discussed in detail in this Guide.
- In the program **execution** phase, the eight SE questions shown in Appendix C are regularly used to ensure each S&T program continues to progress in a satisfactory manner. AFRL/RX Instruction 61-104 addresses this phase.
- In the last phase, the **delivery/transition or close out** phase, the technology products matured by an S&T program and meeting the customer expectations called out in the planning phase, are either delivered to another internal S&T customer (6.1 technologies delivered to a corresponding 6.2 Applied Research program, or 6.3 technology products delivered to another Technology Directorate's 6.3 integration program); or transitioned to an external AF or DoD customer for insertion into a military system.

This three-phase process is often an inherently iterative activity in an S&T environment, as plans are adjusted with maturing technology and evolving customer requirements and expectations. Additionally, many S&T programs will deliver technologies in a spiral manner, with each spiral providing greater depth in the form of more improved, capable and affordable product.

Although the word “*transition*” is sometimes used to depict the internal AFRL delivery of S&T products, the DoD/DAU *Manager’s Guide to Technology Transition in an Evolutionary Acquisition Environment* definition of transition, tailored for Air Force applications, is defined as follows:

- Technology transition is the use of technology in military systems to create effective weapons & support systems
- Technology transitions can occur during the development of new systems, or after a system has been fielded for a number of years
- Technology transitions can occur between government organizations, such as when AFRL transitions a technology to an AFMC Product Center for use in a specific AF system; or between government and industry, such as when AFRL transitions technology to a System prime or sub-contractor; and vice versa, such as when industry transitions technology to an AFMC Product Center.

A broad spectrum of SE-based methods and toolsets are available commercially. Decisions regarding which method, from relatively quick and simple, to complex and more time-consuming, might prove cost effective in any given case depends primarily on the level of technology maturity and particular end-application involved. It is incumbent on the S&T program manager to determine the level of SE analysis most appropriate to support decisions required for a particular S&T program. The RX SEWG (The SE Team) can assist in determining the tools most appropriate for the problem at hand.

In tailoring SE for application to S&T, it is useful to think of the range of available SE-based methods as a continuum, as illustrated in Figure 2. In this figure, the vertical axis depicts the rigor, also highly related to the complexity, of SE planning and analysis methods ranging from simply asking the eight SE questions to pursuing a full-blown modeling and simulation analysis at the top of the scale. For many basic and applied research S&T efforts, the eight-question level of conversation will suffice, whereas for 6.2/6.3 programs delivering technology products to a customer, much greater qualitative and quantitative levels of analysis may be required to ensure customer acceptance of the technology deliverables.

Tailored SE Toolbox for S&T Program Planning

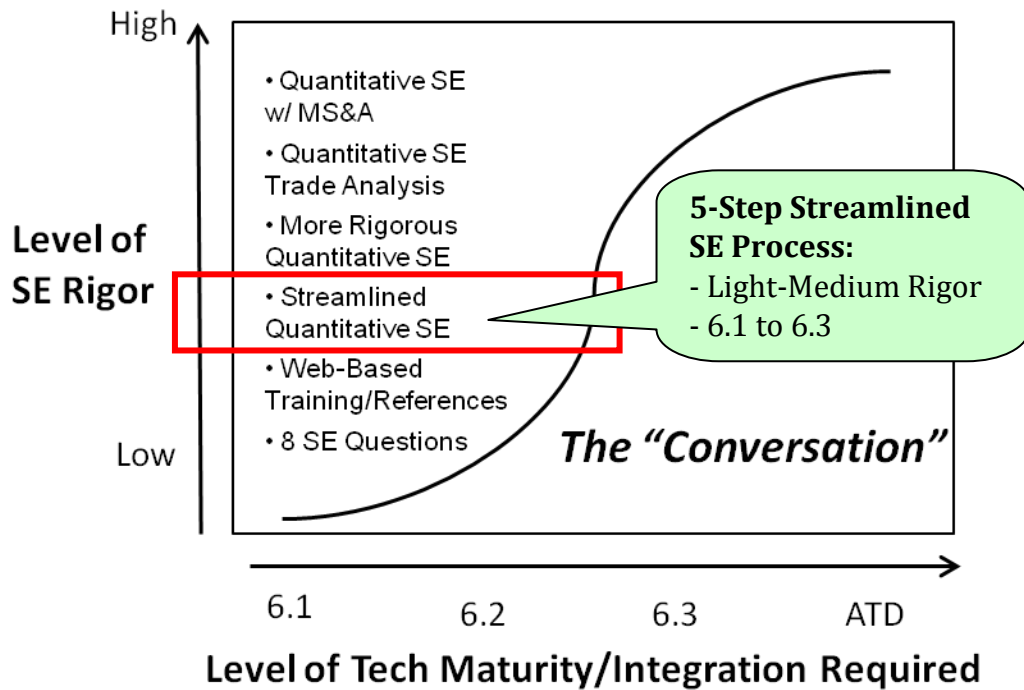


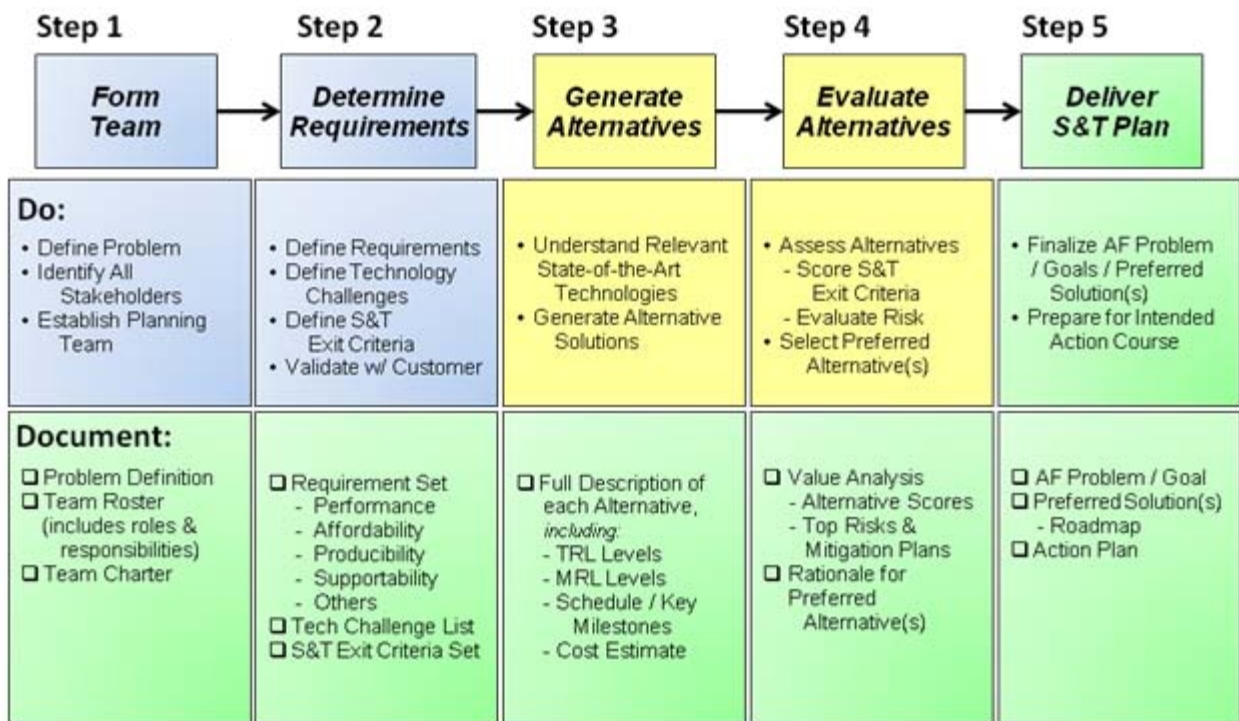
Figure 2: Tailored Systems Engineering for S&T

Tailored SE can be accomplished effectively in RX by applying the approach that best fits each case; owned by the team, appropriate to the requirement, and using analytical tools as appropriate

AFRL/RX Streamlined S&T Planning Process

The RX Streamlined S&T Planning Process, as shown in Figure 3, is not a new concept, but is founded on the Integrated Product and Process Development (IPPD) process that emerged in AFRL from the Affordability Initiative of the 1990s.

The value of the streamlined process is two-fold. First, a quick and focused application of this planning process can reveal the right technology direction for the S&T team to pursue. Second, following the process can foster the right choices regarding what level of SE analysis would ultimately be appropriate for the case at hand.



Based on S&T IPPD Process (Version 3 - 2002)

Figure 3: The RX 5-Step Streamlined S&T Planning Process and Products

The five-Step process is not serial. Iteration happens when understanding, requirements, and customers change, or when new technology solutions become viable.

Based on experience of applying this process, there are **two secrets** to success:

First, total commitment – The first step at the beginning of this process is getting ***commitment*** between the requestor of the effort and the members of the organization using the process. Without a formal commitment including accountability, the process drags out and becomes frustrating to all involved.

Second, complete documentation of each step is critical for success.

By the end of this SE process, the anticipated ***products*** include:

- Problem Definition
- Team Listing
- Prioritized Requirements
- S&T Exit Criteria
- Alternative Solutions
- Evaluation of Alternatives, including selection of proposed program approach
- A documented S&T Plan built from the above activities.

The worksheets provided in the Guide and Workbook are not intended to be the “end-all” list of questions. They are simply a starting point to assist the team to ensure all appropriate topics are considered and to guide the team through the planning process.

The Worksheets available in this Guide and in the companion Workbook are provided to foster a TEAM approach, to decompose the problem and to stimulate creativity and discussions by using the principles of SE to analyze the solutions.

The following diagram provides an overview of the Streamlined SE Process along with the activity Worksheets created to generate discussion and provide a starting point for documenting each step. Detailed instructions for each Worksheet are available in this Streamlined S&T Planning Guide.

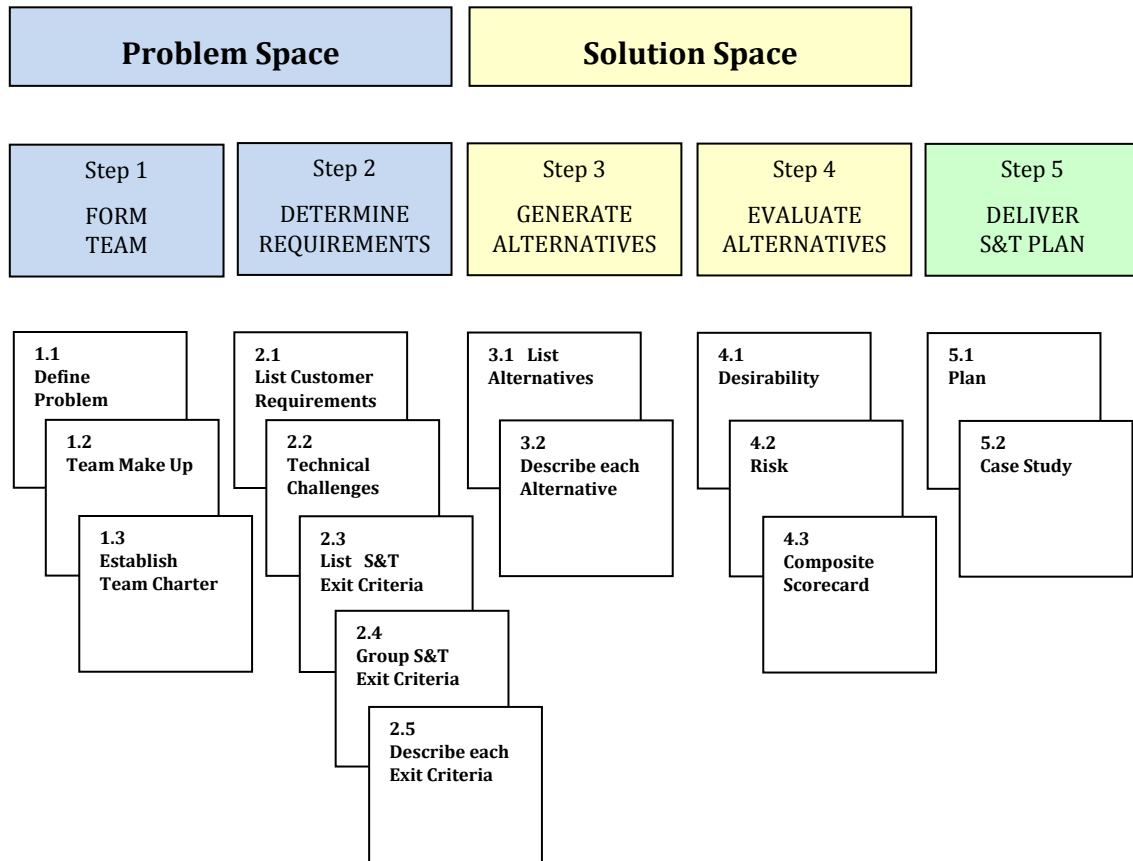


Figure 4. The Streamlined SE Process and accompanying activity Worksheets

The Worksheets for the above activities can be tailored, expanded upon, customized or ignored to suit the needs of your planning.

So, Let's Get Started!

STEP 1 – FORM TEAM

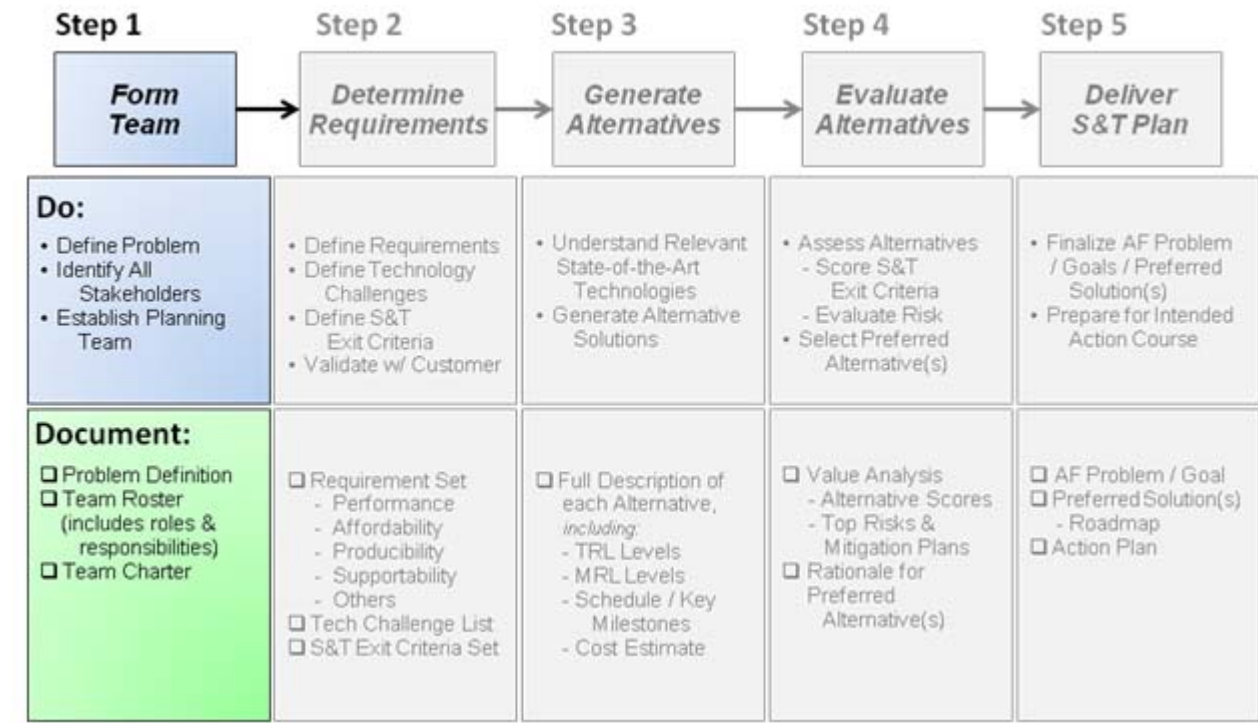


Figure 5: STEP 1 – FORM TEAM

Step 1 of the Planning Process involves understanding (defining) the real problem and the formation of the right **team of stakeholders**. Whether a small, two or three member team, or a larger Integrated Product Team (IPT), working the steps of the process in this Guide results in improved *communication*.

Note: the Problem Space addressed in S&T planning can vary greatly.

- In **Basic** and **Applied Research**, the Problem Space may be very general, advancing the science in a given technical area with a range of possible engineering applications.
- For an **Advanced Technology Development** program, there is usually a much more specific technology pull, where a Warfighter customer needs a material solution to a specific capability gap.

This SE Guide can be applied with equal success across the entire S&T spectrum, from low TRL S&T programs to those involving transition to specific problem owners and end customers. In this regard, the team has to be flexible in how it approaches each planning task. It may be equally productive to focus on a specific transition directly to a customer or on a low TRL challenge, which may transition through another research group, even another Technology Directorate (TD), for necessary technology maturation and subsequent integration into a specific system.

The key point is the team can use the logic flow in this streamlined SE method to plan at whatever level of technology maturity inherent in the S&T challenge at hand. Flexibility and commitment are required for the team to develop a tailored program plan that they own.

To be effective, the S&T planning team needs the right people:

- **Team Leader:** Typically, the Program or Project Manager (PM) is required to lead the team and interface with customers.
- **Team members:** carefully selected to fit the project challenge, committed to the process by participating in team meetings, accomplishing the tasks required by the process, including homework between meetings and drawing on subject matter expertise when required.
- **Scribe:** a dedicated member recording the meeting discussions. The role played by the scribe needs to be both reflective as well as forward looking. The scribe cannot effectively serve as a meeting participant as well. The RX SE Office can assist with this role if necessary.
- **SE Facilitator:** can be made available in RX to coach the S&T team members with regard to the process, facilitate meetings, and ensure that documentation critical to success is effectively captured and maintained by the team. A Facilitator is not required and teams can use this process autonomously; a Facilitator is recommended if the team has no prior experience in SE.

For Step 1, the Team Leader could conduct a Team Orientation Meeting to review the expected roles and responsibilities of the team members and ensure each member understands expectations. The PM or an SE Facilitator can present the RX Streamlined S&T Planning Process and a Project Overview by reviewing what is known of the AF Problem Statement and the results of any preliminary problem exploration by the PM.

A beneficial team exercise at this early stage of problem definition is to construct a **“Systems” functional work breakdown structure** of the problem and the environment in which the problem exists, identifying the inputs and outputs, the complexity and relationships between functional systems. More information concerning diagramming a work or functional breakdown structure can be found at **Appendix E**.

Step 1

Form Team

- Define Problem
- Identify All Stakeholders
- Establish Planning Team

- ☐ Problem Definition
- ☐ Team Roster
(includes roles & responsibilities)
- ☐ Team Charter

Step 1 – FORM TEAM

(See Streamlined SE Process Workbook for suggested Worksheets)

- ☐ Worksheet 1.1 – Define Problem
- ☐ Worksheet 1.2 – Team Make-up / Roles
- ☐ Worksheet 1.3 – Establish Team Charter

Pre – Meeting Homework:

The S&T PM and or a small team of close Tech Advisors should accomplish the three Step 1 worksheets individually as a first cut, before requesting the support of a larger team.

Three worksheets are part of Step 1 to help identify and understand the problem space and build an effective team. All worksheets are also available in the companion Workbook to this Guide. The Worksheets are designed to spur creative thoughts and discussion and should take no more than 10-20 minutes each to complete.

“If you can’t explain it simply, you don’t understand it well enough.” Albert. Einstein

*“We can’t solve problems by using the same kind of thinking we used when we created them.”
- Albert. Einstein*

❑ Worksheet 1.1 – Define Problem

Who is the Customer? (*Who brought the problem?*)

In technology programs there may be multiple organizations who will use the technology (particularly for lower TRL programs). The first test in identifying a customer is the financial test. Customer organizations usually have a direct financial investment in continuing the technology development/maturation at the conclusion of the program under consideration. Externally funded programs usually have external customers.

Time frame of Problem (*When/Urgency of Need?*):

The first data point to identify is the time frame associated with a customer's need. Is it a near-, mid-, or far-term problem? This can be an important constraint to the proposed problem response.

Describe the Problem (*Scope/Major Issues/Constraints*):

A good problem description captures the primary issue and any supporting facts in terms that relate to the Air Force or the DoD need. For example, the root cause might be scoped as a performance, affordability, or reliability issue, or other as determined.

Who Owns the Problem? (*Who has the task to solve the problem?*)

In this process, the Problem Owner is the organization responsible for implementing the identified material solution to the problem. Air Force problems are usually owned by either acquisition or sustainment organizations, or even the Warfighters themselves (including field maintainers). Members of the AFRL community working through this process are typically not the Problem Owner, but rather the solution owner.

Who is the End User? (*Who turns the wrench/pushes the button?*)

Most of the time the end user is not the problem owner. In most cases, the end user is the operational user of the Air Force system incorporating the technology solution.

Why Should AFRL/RX be Working This Issue?

How does this problem fit within AFRL/RX? Is there a clear alignment with a Core Technical Competency, or established product line? Are there other AFRL Directorates or outside organizations working this issue as well?

Who Needs to be Included as Partners in this Issue?

The Team needs to consider if other RX Divisions, AFRL Directorates, or external organizations should be included in this effort.

What Do We NOT Know?

As part of defining the problem space, capturing aspects of the problem that are unknown or unspecified will help guide subsequent discussions by the team.

*Step 1: Form Team. Start to think of the team in specific terms of the problem at hand.
Different problems require different member experiences and skills.*

Worksheet 1.1

Define Problem

Project Name: _____
Member Name: _____
Role: _____
Worksheet Date: _____

The team works with the Customer(s)/Stakeholder(s) to scope the problem space.

Who is the Customer? *(Who brought the problem?)* _____

Time frame of Problem *(When Needed/Urgency?)* _____

Describe the Problem *(Scope/Major Issues/Constraints)* _____

Who Owns the Problem? *(Who has the task to solve the problem?)*

Who is the End User? *(Who turns the wrench/pushes the button?)* _____

Why should AFRL/RX be working this issue? _____

Who Needs to be included as Partners in this issue? _____

What Do We NOT Know? _____

... the "SE Conversation" begins with understanding of the problem...What is the "Discontent?" ...and Why?

❑ Worksheet 1.2 – Team Make-up / Roles

Worksheet 1.2 will assist the Program Manager/Team Leader in assembling the most appropriate team in this planning effort. Three steps suggested to build the roster:

1. For both **Core Team** and **Augmentee** roles, identify all **stakeholder** organizations necessary to build a program plan, then;
2. List Candidate **Core Team Members** and their roles/responsibilities.
3. List anticipated **Augmentees**, understanding that this role will probably change as the planning becomes more definitive.

A “**Stakeholder**” can be defined as a person representing an organization who is actively involved in the program or whose interests may be positively or negatively affected by the performance or completion of the program; or an organization or individual with direct or indirect influence on the requirements of the end-use application or system. Typical stakeholder organizations are the technology **developer**, **industry partner**, **acquirer**, and **end-user**.

When identifying the team needed to address the problem at hand, the focus needs to be kept on the development of the Program Plan, as the list of people needed to build the S&T Plan are likely to be different than the team needed to execute the program.

Once the Stakeholder organizations are identified, specific core team members and potential augmentees representing the stakeholders need to be recruited with a commitment to participate in the planning effort.

Three keys to a successful team;

1. Have the right members on the team
2. Keep the team small as possible, and
3. Keep the team moving. ...*“You can’t steer a car that’s not moving”*

Table 1 suggests some typical members for both teams. All team members should understand the roles they are expected to play. Core Team members are critical to the program planning phase and should commit to attending meetings, while others (i.e., augmentees) may play a supporting role needing to attend meetings if and when required.

<u>CORE MEMBERS:</u>	<u>Augmentees:</u>
• Team Leader / Program Manager • Researcher / Scientists • Engineers • Customers • Industry Partners	• Financial • Procurement • Logisticians • “Gray Beards” • Select Subject Matter Experts

Table 1. Possible Typical Team Members

Worksheet 1.2

Team Make-up / Roles

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

With the Problem understood, a team approach (Core plus Augmentees) must be defined, i.e., identify the skills needed to discuss and refine the Problem

Team Directory, Roles & Responsibilities

Role/Responsibility

ORG/Symbol

Name / Contact Info

CORE TEAM MEMBERS

- _____
- _____
- _____
- _____
- _____
- _____
- _____

Augmentees (includes SMEs, Finance, Contracting, etc.)

- _____
- _____
- _____
- _____

...the "SE Conversation" continues... include the right expertise and Stakeholders

❑ Worksheet 1.3 – Establish Team Charter

A “Planning” Team Charter should capture the problem statement, document roles and responsibilities of the team members, and set the planning process duration. When all team members agree to the details, you have a Planning Team Charter with a better chance of success in program planning and execution.

Formality of this charter varies with the program at hand. For basic research or in-house development projects, an informal charter might suffice. Advanced Technology Demonstration (ATD) and approved High Visibility Programs (HVPs) have formal charter requirements as defined in AFRL instructions. Experience has shown the time spent in addressing member responsibilities will help define the specific expectations for all the members on the team.

Goal / Objectives

The Team Charter Agreement establishes the “goal” of the parties to plan an executable program. Execution of the resulting program is a totally separate effort although most of the planning team members may continue on as execution IPT members.

Schedule

It’s important to get a “team” agreed-upon schedule to establish the duration of the S&T Planning Process along with the number or frequency of the meetings.

Resources

Document any resources available to the team and effort.

Authority / Accountability

Official recognition of the direction to conduct the work.

Signatures

Signatures solidify the agreement and commitment of all parties, which, if not attained, can spell non-support in regards to time, resources, and quality of information collected and the conclusions arrived at.

❑ DOCUMENT: Planning Team Charter

Highly recommended, particularly for large IPTs, to clearly state the roles, responsibilities, expectations, and contributions of the members of the team, to get buy-in and establish ownership of the team process.

Worksheet 1.3

Establish Team Charter

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Core Team stays with the entire process. Other persons (Augmentees) are brought in with needed expertise where appropriate.

Use Worksheets 1.1 and 1.2 as backup to this activity

“Planning” Team Charter

- **Goal/Objectives:** _____

- **Schedule**
 - **Meeting frequency** (Weekly, monthly, etc.) _____
 - **Duration: Start:** (mm/dd/yyyy) _____ **End:** (mm/dd/yyyy) _____
- **Resources** (Available to the Team): _____
- **Authority / Accountability** of Team Membership: _____

As a Core Team Member for this planning effort, I understand the following is expected of all Core Team Members:

- **Commit to participate in all team meetings**
- **Complete any pre-meeting “homework” on schedule**
- **Participate in the documentation of each step before proceeding to the next step**

Signatures of all core planning team members commitment

1.	4.
2.	5.
3.	6.

(The above is just a suggested outline. Expand with extra pages if needed)

...a Team Charter formalizes expectations, removes doubt, and improves the SE “Conversation”

STEP 2 – DETERMINE REQUIREMENTS

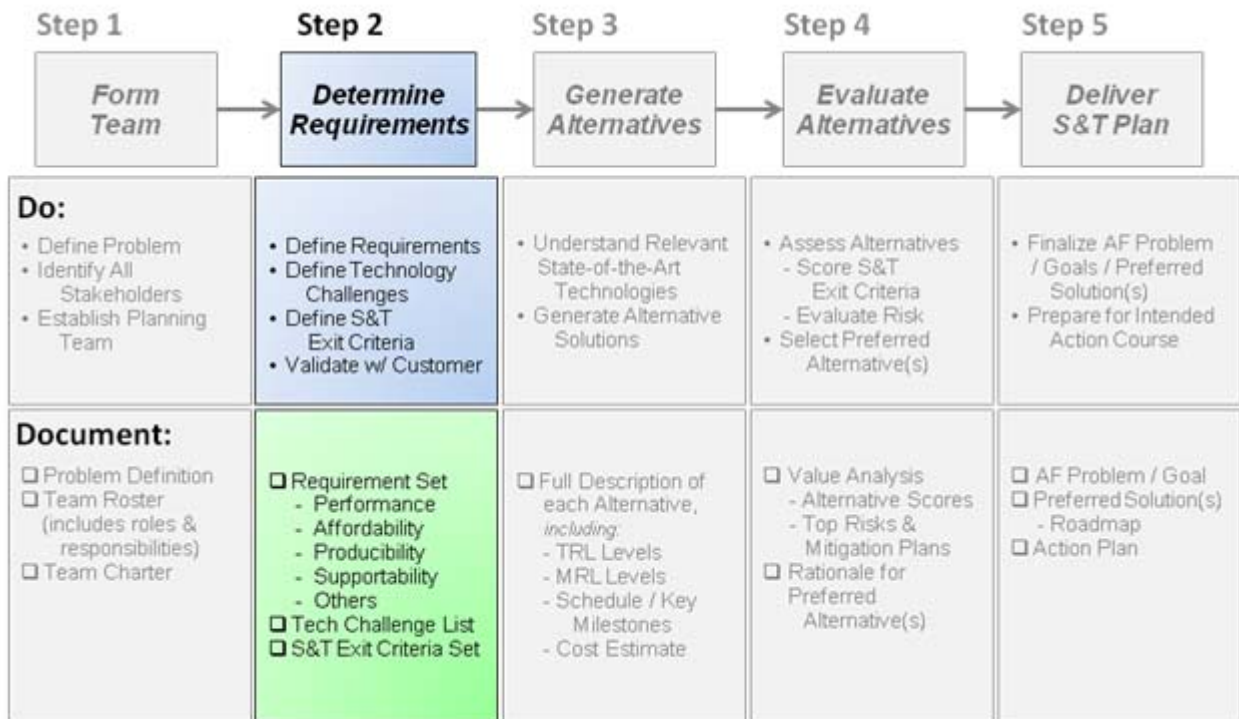


Figure 6. STEP 2 – DETERMINE REQUIREMENTS

In Step 2 the team completes the definition of the problem space. Leveraging on the expertise in the team, the PM/Team Lead should direct a discussion that starts with identifying the customer **requirements**, distilling those requirements into **technical challenges** and finally assembling a set of **S&T exit criteria**. This discussion is frequently an iterative process, as each step reveals more information that affects the knowledge previously gained.

It is always better to have the customer involved when identifying requirements. Throughout the requirements identification process, assumptions may be made that will need to be verified with your customer representative.

For relatively low TRL S&T programs with several potential customers and a more generic problem space, problem owners/customers/end users may be hypothesized by the S&T planning team. Communication with potential customers is always a plus, even at the basic research level of planning. For these programs, the S&T planning team may have to formulate a set of “stretch” requirements applicable to the future Air Force using their best judgment.

Definitions of each of the steps will help the team focus their discussion.

Requirement – a parameter, condition, necessity that can be measured and verified in a test demonstration.

Technical Challenge – the reason why the customer’s requirement isn’t available today. What is the technical “hurdle” being addressed?

S&T Exit Criteria – technical accomplishments achieved by a laboratory S&T program that are specific, measurable, and which, when achieved, signify successful completion of the S&T program (i.e., technology ready for next development phase, whether internal or external to AFRL).

Validate (Validation) – a confirmation or endorsement, preferable from a User/Customer, of the logic, arguments, and specifications drawn in the team’s postulation.

Requirements are usually stated in terms of a threshold (i.e., acceptable) level and an objective (desired) level. However, with some S&T efforts, customer requirements may not have formal thresholds and objectives, but there are still limits at which the customer peak and lose interest.

For example, a customer requirement might be to increase the range of a missile by 20%. In pure acquisition terminology, that range increase isn’t a formal requirement at this time, but merely what the customer desires. Through the use of Subject Matter Experts (SMEs) or Modeling and Simulation (M&S) tools, the customer, together with the team, could learn that improvements less than 15% have no benefit. Therefore, a threshold would be a 15% improvement, and the objective remains 20%. At the same time, they might learn that increases between 20% and 30% have diminishing payoff, so after 30%, the customer has no interest.

Continuing this example to the next step of identifying the **technical challenges**, the team applies the principles of missile design to distill the range requirement into the technical constituents of missile range, asking “What is preventing that requirement from being achievable today?” A technical challenge to increased range might be to increase the pressure capability of a composite case without increasing the weight.

Each **technical challenge** needs to be translated into specific **S&T exit criteria**. For this example, the S&T exit criteria might be associated with the fiber strength, resin properties, winding method, or other aspects of the component design. The scientist and engineer cannot assume the customer will understand this translation of the problem and should keep the communication open by providing the translation between the user’s language and the technical language.

At this point in the team process, it is recommended that the proposed requirement set be **validated** by the customer representative, if they are not already active on the team.

While engaging the customer in the development of the requirements during the iterative discussions is very beneficial, that involvement can lead to another negative phenomenon: **Requirements Creep!** This occurs as the team or the customer become excited with the possibilities of the new capability, and seeks to push the requirements beyond what was originally established. Once a requirement has been developed and the measurable parameters are identified, the team needs to exercise a requirements management process to guard against requirements creep.

Note: in many cases, requirement definition requires more than one iteration of the streamlined process. In a hypothetical example portrayed in Table 2, one can see a comparison after a first and second application of the Streamlined Planning Process. In this example, the first quick pass was not accomplished at a sufficient level of detail, resulting in a lack of definition of desired Warfighter capabilities and quantitative metrics. A second, more in-depth, application of the process results in a much clearer quantitative definition of customer expectations.

<u>First Application</u>	<u>After Second Application</u>
• Attribute-level metrics based on expected characteristics (i.e., output power, efficiency, etc.) • Product-level metrics based on supporting expected characteristics • Examples: ○ Efficiency: 10% (what we can do currently today) ○ No effective range metric ○ No magazine depth metric ○ No weight or volume metric ○ No probability of effect metric	• Attribute-level metrics based on Warfighter desired capabilities (i.e., range, time-on-station, etc.) • Product-level metrics based on providing the attribute-level capabilities • Examples: ○ Efficiency: 20% ○ 20 nm typical target slant range ○ 100 target/sortie magazine depth ○ Less than 15,000 lbs total weight ○ Less than 5% probability of second shot required to achieve effect

Table 2: Hypothetical S&T Program Requirements after first and second application of Tailored Systems Engineering (improved metrics depicted in **blue** text).

Each requirement should be carefully reviewed to determine it can eventually be satisfied by a technical solution. Depending on the complexity of the requirement, this may or may not be accomplished during the S&T program. When RX technology developments are integrated into components, such as a turbine engine component, testing of the component is frequently part of a follow-on S&T Program by another AFRL directorate or a follow-on acquirer/developer before delivery to the end user.

There is a possibility that once the team begins developing this requirement set, they realize the team is missing a needed skill set or role. That is the *iterative* nature inherent in this problem-solving process, and should not be rejected.

A **SE facilitator** can help lead a requirements generation review of the problem statement, exploring what's known, not known, and identify the technical challenges resulting from the requirements. During Step 2, the SE facilitator can help the team members update and prioritize (high, medium, low) requirements and check the list for completeness. As the requirements are translated into technical challenges and S&T exit criteria, the SE facilitator can assist the team members with appropriate tools to sufficiently describe the S&T exit criteria for measurability and testability.

The worksheet activities of Step 2 are designed to help the team get the requirements, technical challenges, and the derived S&T exit criteria down on paper. The better these are identified and validated, the greater the chance of program success.

The final documents produced during Step 2 are the refined customer requirements, technical challenges, and prioritized/weighted S&T Exit Criteria, which completes the definition of the problem space.

“Warfighters are known to have Alligator Eyes and Chicken Wallets.”

....Attributed to a Command Staffer

Step 2

Determine Requirements

- Define Requirements
- Define Technology Challenges
- Define S&T Exit Criteria
- Validate w/ Customer

- ☐ Requirement Set
 - Performance
 - Affordability
 - Producibility
 - Supportability
 - Others
- ☐ Tech Challenge List
- ☐ S&T Exit Criteria Set

Step 2 – Determine Requirements

(See Streamlined SE Process Workbook for suggested Worksheets)

- ☐ Worksheet 2.1 – List of Customer Requirements
- ☐ Worksheet 2.2 – Technical Challenges
- ☐ Worksheet 2.3 – List of S&T Exit Criteria
- ☐ Worksheet 2.4 – Group S&T Exit Criteria by Category
- ☐ Worksheet 2.5 – S&T Exit Criteria Complete Description

Homework –

In advance of a team requirements meeting, take a moment and fill out the first three Step 2 Worksheets with what you think you know about the customer's requirements, the technical challenges to overcome, and the threshold and objective values to measure success.

"Gentlemen, we have run out of money. Now we have to think" (Winston Churchill)

❑ Worksheet 2.1 – List of Customer Requirements

Worksheet 2.1 is available to guide the PM or team through a deductive, iterative process of developing and qualifying customer requirements. As the understanding of the problem space and customers' desires evolve, the ability to best identify and quantify the requirements for the project improves. During the process, the team may need to periodically return and modify the requirements list.

Requirement: The set of all (customer) expectations for procured products and/or services where each expectation is expressible in terms of a formalized desirement.

Good customer requirements are well-crafted characteristics that describe a desired capability and generally fall into common areas such as performance, cost, scheduled availability, affordability, producibility, reliability, and supportability.

Requirement Name

Use Worksheet 2.1 to enter a descriptive name for each Requirement.

Requirement Description

Provide as much quantified information to describe the requirement as available.

Threshold

After listing the requirement(s), determine the incremental acceptable Threshold value(s) that must be achieved for the technology to advance to the next stage of development or transition (usually stated as a minimum or maximum value).

Objective

Determine the ultimate, end-state capability as the Objective value. This is where a customer representative(s) is so important to validate the needs, conditions, and desires. The stretch-goal value that is desirable, but not essential (often viewed as the requirements trade space if parameters such as cost or schedule are more important to the customer).

❑ DOCUMENT: Requirements Set

Activity generates a set of desired capability requirements.

"Everything looks like a nail if you're a hammer" - Anonymous

Step 2: Requirements. A solid understanding of the requirements, technical challenges, and how they're stated as S&T Exit Criteria are critical steps in Problem Space documentation.

Worksheet 2.1

List of Customer Requirements

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Core Team refines the understanding of the Customer's Problem into stated requirements and validates them with the Customer

Requirement Name	Requirement Description (Be as specific as possible)	Threshold*	Objective*

**Desirable – vary with maturity of task*

Threshold: *The measurable value that must be achieved for the technology to advance to the next stage of development or transition (usually given as a minimum or maximum value).*

Objective: *The stretch-goal value that is desirable, but not essential (often viewed as the requirements trade space if parameters such as cost or schedule are more important to the customer).*

☐ **DOCUMENT:** *Validate this worksheet with your customer representatives / stakeholders to ensure agreement with the goals.*

...the "Conversation" continues... What capability does my Customer (Want) Need? ...and Why?

❑ Worksheet 2.2 – Technical Challenge(s)

With the customer requirements defined, the PM or team needs to identify the technical challenges that are appropriate for the level of S&T effort being planned.

Technical Challenges are the technical hurdles that must be overcome to provide a new and/or improved capability.

The amount of rigor or effort involved in this step varies depending on the complexity of the problem and the expectations of the Stakeholders. The effort can range from a guided discussion by the core team members, to a formal Goals, Objectives, Technical Challenges, and Approach (GOTChA) analysis or other formal technical planning methodology.

What might be Technical Challenge(s)?

A well worded Technical Challenge answers the question, “What is preventing us from achieving the stated objective today?” *For example, but not inclusive:*

- Physical constraints: Min/Max size, Min/Max weight, Min/Max transportability
- Power constraints – Min/Max power required, Min/Max conversion efficiency
- Properties: Min/Max strength, Min/Max thickness, Min/Max flexibility
- Coatings – Min/Max thickness, Min/Max wear, Min/Max conduction, corrosion

Requirement Name

Carry forward the Requirement Name from Worksheet 2.1 into Worksheet 2.2.

Technical Challenge Issues

Use worksheet 2.2 to describe the Technical Challenge Issues in as much detail as possible. The issues stated here will help derive accurate S&T Exit Criteria in the next worksheet activity.

❑ DOCUMENT: Technical Challenge(s)

In any S&T effort, there should be some technological hurdle to overcome; otherwise, the technology would be developed in the commercial world. The discussions and documentation of the technical challenges should help steer the team to better understand the requirement and to better state the S&T Exit Criteria.

For additional references on identifying Technical Challenges, see: [RX Systems Engineering COP](https://livelink.ebs.af.mil/livelink/lisapi.dll?func=ll&objId=17081764&objAction=browse&sort=name&viewType=1) <https://livelink.ebs.af.mil/livelink/lisapi.dll?func=ll&objId=17081764&objAction=browse&sort=name&viewType=1>

Worksheet 2.2

Technical Challenges

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Team now has to turn the Customer Requirements into actionable S&T descriptions (S&T Exit Criteria). This step helps the team decompose the Customer Requirements into Technical Issues (Challenges).

Requirement Name	Technical Challenge Issues

...the SE Conversation continues by identifying "Where's the S&T in this challenge?"...and Why?

❑ Worksheet 2.3 – List S&T Exit Criteria

Worksheet 2.3 is designed to define the S&T Exit Criteria associated with each stated requirement and the derived technical challenges in terms of physical, measurable attributes; and stated as a threshold (acceptable) and objective (goal) level. As part of the **S&T Exit Criteria**, the desired means of demonstrating/validating appropriate TRL and MRL levels (See Appendix H) have been achieved should be described.

As with Technical Challenges, there is not necessarily a one-to-one relationship between the requirements defined in Step 2.1 and the S&T exit criteria defined here. Some requirements may need several S&T exit criteria defined, whereas other S&T exit criteria may meet several user requirements for a given problem. However, it is valuable to verify that all requirements containing technical challenges map to at least one S&T exit criterion, and all S&T exit criteria map to at least one requirement.

S&T Exit Criteria, which include S&T Key Performance Parameters (KPPs), are levels of measurable performance (thresholds) that must be achieved for program success.

- **Research program**, where successful completion allows entry into the next program development phase.
- **Development product** has achieved an expected level of functionality, where successful achievement allows entry into the next development phase.

Criteria Name

Name may very well be the same as the requirement or it may be more specific.

Description

What are the key performance criteria for to determine success?

Threshold / Objective

Threshold / Objective should match the same values as previously documented on Worksheet 2.1, Customer Requirements List.

RQT Name

Correlate the requirement name to the criterion. In some cases, there may be multiple criteria for a single requirement.

❑ DOCUMENT: S&T Exit Criteria

S&T Exit Criteria should be validated against all requirements and tech challenges. Validation can range from simple confirmation on an early program, to ATDs where requirements and criteria are fully documented and signed by all participants.

Worksheet 2.3

List of S&T Exit Criteria

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

Customer Requirements are usually at a fairly high level. The team now has to define and document what a final product, technology, or system must do, including the parameters that define successful completion. Worksheets 2.1 and 2.2 should lead into this step.

Criteria Name	Description	Threshold*	Objective*	RQT Name

**Desirable – vary with maturity of task*

Threshold: *The measurable value that must be achieved for the technology to advance to the next stage of development or transition (usually given as a minimum or maximum value).*

Objective: *The stretch-goal value that is desirable, but not essential (often viewed as the requirements trade space if parameters such as cost or schedule are more important to the customer).*

*...the “Conversation” continues... What S&T Exit Criteria demonstrates the Requirement(s) have been met?” -
....and Why?*

❑ Worksheet 2.4 – Group S&T Exit Criteria by Category

With the requirements captured, the technical challenges understood, and the S&T Exit Criteria stated, the S&T Exit Criteria should be grouped by like type (categories), such as cost, schedule, and performance. Grouping of the Exit Criteria may be difficult but the results are usually worth the effort.

Here is a suggested list of groupings to add to or delete:

- **Cost:** Acquisition, Deployment, Operating Cost at Point of Use, Development Cost
- **Schedule:** FY (Fiscal Year) required for transition; FY required for delivery to another TD for subsequent development
- **Performance:** Power, Reliability, Weight, Footprint, Set-up Time, Diagnostics, Repair, Surge Capacity-Spike/-Continuous, Improved System Efficiency
- **Logistics:** Air/Ship/Truck/Rail Transportability, Service Life, Storage Costs, Preventative Maintenance Inspections, Scalability, Disposal
- **Human Factors:** Skill Level Required for Set-Up/Use, Man-Hours
- **Environmental:** Emissions, certifications, disposal
- **Strategic:** Significant or Unique Operational Need or Unique Technical Competency
- **Political:** Outside influences. (For example, a host country wanting deployed base structures to appear temporary, or not permanent, i.e., a Valley Forge “Tent-City” appearance, so as not to cause local populations to feel the occupation is long-term)

Worksheet 2.4

Group S&T

Exit Criteria

by Category

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

S&T Exit Criteria negotiated by the team can usually be grouped into common topics, identified such as P-1, P-2, etc. for Performance; C-1, C-2, etc. for Cost.

There is no limit to the number of S&T Exit Criterion, but this is the logical place to consider consolidation, combining the criteria, if appropriate.

ID	S&T Exit Criteria	Description
Group:		
Group:		

Possible Category Groupings (add more type categories depending on your technology)

C = Cost (development, acquisition, deploy, point of use operation)

HF = Human Factors (Skill Level)

S = Schedule

E = Environment (EPA, certifications, etc.)

P = Performance (reliability, weight, footprint, set-up time)

ST = Strategic (outside influences, be they political or otherwise)

L = Logistics (transport, service life, storage, scalability, disposal)

POL = Political (constrictions)

...the "Conversation" continues... What groups form the S&T Exit Criterion?" -....and Why?

❑ Worksheet 2.5 – Group S&T Exit Criteria Complete Description

The last Step 2 activity is to compile the information into a Scorecard or complete description of the S&T Exit Criteria.

ID	Name	Priority /Wt*	Units	Threshold Value	Threshold Rationale	Objective Value	Objective Rationale	How Measured
----	------	---------------	-------	-----------------	---------------------	-----------------	---------------------	--------------

ID	Method to track identification, i.e., C-1, C-2, C-3, P-1, P-2, etc. as defined in Worksheet 2.4							
Name	Recognizable title identifying the thrust of the concept							
Priority / Wt	Either/Or, Priority, sorts the list from the most important to the least important, possibly in a High-Med-Low ranking; Weight is a relative value to the importance of the contribution, for example, score a weight value of 1.0 if the criteria is critical to the capability, 0.7 if the criteria is important, and 0.5 if not as important.							
Units	The component or scale of measurement being used, for example, miles per gallon, distance, weight, time, decibels, etc.							
Threshold Value	An incremental value that demonstrates a targeted difference never attained before, usually a stepped improvement.							
Threshold Rationale	The reason the Threshold Value was chosen as an incremental step given the maturity of the technology.							
Objective Value	The ultimate/target value providing real capability once attained.							
Objective Rationale	The reason the Objective value was chosen as an incremental step given the maturity of the technology.							
How Measured	How will the alternatives selected be measured demonstrating the requirements have been met?							

Worksheet 2.5

S&T Exit Criteria

Complete Description

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Team defines the detailed quantitative attributes of the S&T Exit Criteria.

ID	Name	Priority /Wt*	Units	Threshold Value	Threshold Rationale	Objective Value	Objective Rationale	How Measured
Group --								
Group --								

*Can be used to compare relative importance of S&T Exit Criteria. These are suggestive, use whatever scale you determine relevant/needed"

Priority qualitative ranking: High, Medium, Low,Or

Weight scores contribution importance: -1= critical contribution to capability, 0.7 important contribution, and 0.5 if not too important

Threshold: The measurable value that must be achieved for the technology to advance to the next stage of development or transition (usually given as a minimum or maximum value).

Objective: The stretch-goal value that is desirable, but not essential (often viewed as the requirements trade space if parameters such as cost or schedule are more important to the customer).

...the "Conversation" continues... When is 'more or less' better and how do you measure it?" -....and Why?

STEP 3 – GENERATE ALTERNATIVES

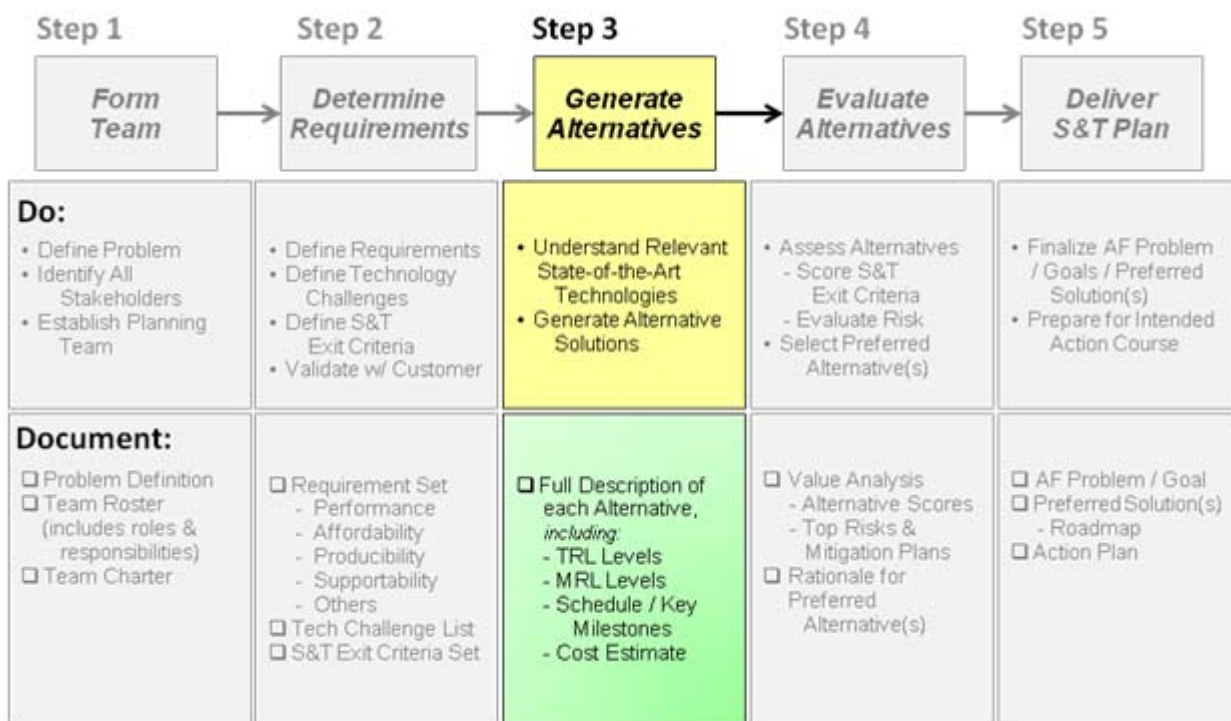


Figure 7. STEP 3 – GENERATE ALTERNATIVES

In Step 3, the planning team, possibly assisted by a SE Facilitator, will generate a list of alternatives (documented on Worksheet 3.1) that might solve the problem as defined in Steps 1 and 2. The Step 3 activity might be accomplished in a single meeting for a simple problem; or the team might require several meetings depending on the complexity. NOTE, a pitfall of conducting this activity: the results of alternative generation frequently reflect the area of expertise of the people on the team; for example, an all-RX team is likely to generate an all-material solution. A multi-directorate approach is very desirable to solve critical Warfighter problems. Alternatives need to fit within the problem space defined by the S&T exit criteria, but remain unconstrained in creativity and approach.

Allow creativity. Avoid the ‘quick leap’ to familiar technology solutions

The previous steps provided the team some insight into why the current process or way of operating was no longer acceptable to the customer. In order to offer an improvement to the customer, the team needs to be familiar with the current process or state of the art. Different problems will be dealing with different periods of appropriate responses; ranging between near-, mid-, and far-term.

First, let's define the term "**performance baseline.**" The baseline is viewed as the way the user is currently addressing the problem, or the current technology, doctrine, operations or training approach used to meet the user's need.

The planning team must be aware of recent developments in relevant technology areas across the scientific community, including AFRL, DOD, other government agencies such as NASA and DOE, academia, and industry. For late 6.2 or 6.3 technology efforts, knowledge of the "State-of-the-Art" (SOTA) will help the planning team identify near-term technologies that have the potential of transitioning into an Air Force system within a reasonable timeframe. Current state, or SOTA knowledge, is constantly gained via continued education, literature searches, guest speakers, technology briefings, conferences, symposiums, and experimentation.

Next, the team must determine if AFRL/RX is in a **leadership position** in the particular technical area under consideration. From both an in-house research and program management viewpoint, leadership in the technology area with knowledge of the specific customer requirements and S&T exit criteria (generated in Step 2), is crucial to the success of the team in solving the problem.

If it is determined RX possesses the technical competency to invest in the technical area(s) under consideration, then the planning team should be ready to continue to conduct the "Generate Alternative Solutions" activity by listing on them Worksheet 3.1.

Discussing the SOTA and Near-Term Technologies with the team at the beginning of the Generate Alternatives step can be a good way to bring the team up to a same level of knowledge about the Problem-Solution space and will help the team to generate better solutions to the problem(s) at hand.



Generate Alternatives in the S&T Environment

Brainstorming is traditionally viewed as part of a Teambuilding process that challenges the group participants to "step outside of their comfort zones" and strengthen team problem solving skills. The idea is to suspend critical thinking and generate a number of ideas that represent potential solutions that might provide breakthrough program product or process results.

The importance of the alternatives generation activity is to ensure awareness of all relevant research and not make the 'quick leap' decision to a given technology solution without at least considering viable alternative approaches.

Often, the alternative solution set consists of several technologies with different levels of maturity (i.e., technical risk), but offer different levels of payoff to the customer, as suggested in the Figure 7. Alternative A might offer great potential payoff, but is early in technology maturity and has potentially greater risk, while Alternative C is mature, ready to transition, but has limited payoff potential.

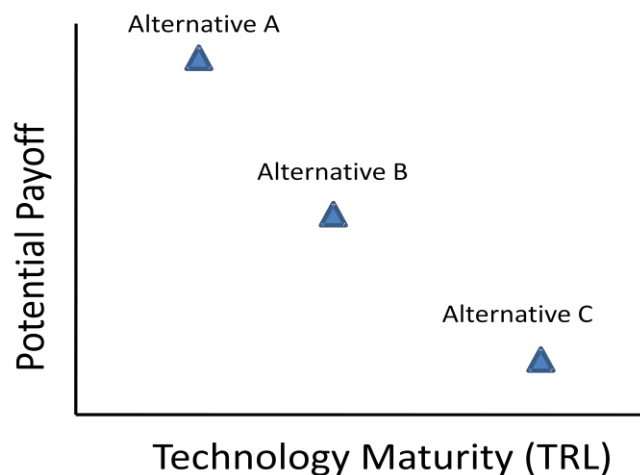


Figure 8. Comparison of Alternative Solutions

Although all three solutions might meet the S&T Exit Criteria, considerations such as S&T development cost and timeframe, along with transition cost and timeframe may drive the planning team to a particular solution in the evaluation step of this process.

It is common for AFRL Scientists and Engineers to concentrate on the materiel solutions to solve a problem. However, sometimes customers come to AFRL looking for answers to solve their problems, when a change to their current operations, training or logistics; a non-materiel solution is still a viable option. The team should be comfortable in going back to the customer and evaluating non-materiel solutions before proceeding with a technology development.

Step 3

Generate Alternatives

- Understand Relevant State-of-the-Art Technologies
- Generate Alternative Solutions

- ☐ Full Description of each Alternative, including:
 - TRL Levels
 - MRL Levels
 - Schedule / Key Milestones
 - Cost Estimate

Step 3 – GENERATE ALTERNATIVES

(See Streamlined SE Process Workbook for suggested Worksheets)

- ☐ Worksheet 3.1 – List Alternatives
- ☐ Worksheet 3.2 – Alternatives Complete Description

Homework:

Before the Step 3 “Alternatives Generation” Team Meeting, each team member should attempt to complete worksheets 3.1 and 3.2 from their own expertise.

“Logic will get you from A to B. Imagination will take you everywhere” - Albert Einstein

❑ Worksheet 3.1 – List Alternatives

At this point in the process, the team of Scientists and Engineers can be released to unleash their creative genius and propose ideas to solve the technical problem. As previously mentioned, filling out Worksheet 3.1 is likely to be an iterative process, as a detailed description of the potential solutions is likely to require some elements of discovery. A process facilitator may be a good resource to invite.

Worksheet 3.1, Team Members should suggest technology concepts/alternatives which could apply to the problem as defined by the conclusion of Step 2. AFRL Scientists and Engineers have always been good at creative technical solutions; this step in the process is to help focus that creativity to the problem at hand.

Alternative Name

Starting with the S&T Exit Criteria, each Team Member should identify technology solutions which have the potential to solve the technical challenges represented by the Exit Criteria. While evaluating Alternatives is not to occur at this point in the process, the essential elements of each alternative should include an understanding of how each alternative addresses the S&T Exit Criteria, the anticipated performance of the alternative relative to the Exit Criteria, and the sense of confidence or uncertainty around that anticipated prediction.

Questions to spur the team's thinking:

- What option/alternatives might solve the stated problem?
- Explore “What If?” and “Why Not?” (Modeling, Experimentation, Leverage)
- Consider Near-Term/Low Payoff solutions as well as Far-Term/High Payoff ideas.
- Do not evaluate or discount any idea at this point
- Is a material solution the only option? Material solutions, the physical materials and tools necessary to execute any work, enterprise, etc.; specif., weapons, equipment, supplies, etc. of the armed forces. Non-Material solutions include changes to current Tactics, Training, and Mission Operations to address deficiencies have been considered by the customer (MAJCOMs).

❑ Document: List Alternative Solutions

List of Alternatives owned by the team (Worksheet 3.1)

Step 3: Generate Alternatives. List all the possible ways to solve a problem.

Worksheet 3.1

List Alternatives

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Team identifies possible solutions (called Alternatives) to satisfy each of the S&T Exit Criteria. The Alternatives may be existing technologies, but the team should also explore novel approaches that may offer enhanced payoff... even if it seems a higher risk.

Alternative Name	Description

...the "Conversation" continues...What Alternatives might satisfy the S&T Exit Criteria?and Why?

❑ Worksheet 3.2 – Alternatives Complete Descriptions

With the collection of alternatives gathered, it now falls to the team's responsibility to best define and describe each alternative in as much detail as possible for informed decision making in Step 4. Worksheet 3.2 is designed to provide that definition, one per each alternative. Sketches of each alternative can also help the team visualize the nature of the proposed technical solution.

Alternative Name: Enter the alternative name here

Description: Describe the alternative, concept, opportunity in as much detail as possible

Any Considerations: Highlight any crucial fact of knowledge or limiting conditions

Estimate Cost and Schedule: Any ballpark cost figures and estimate of schedule

Estimate Initial TRL: Where is this technology currently?

Estimate Final TRL: Where could it be if developed further?

Estimate Initial MRL: What is the current manufacturing ability for this technology?

Estimate Final MRL: What could the final manufacturing ability be for this technology?

Estimate Payoff to Maturity score: Based on Maturity, what's the impact of this technology?

Picture or graphic representation: helpful if available

NOTE: As with any of the offered worksheets, the worksheets can be customized, expanded or deleted as needed depending on the nature of the information required. A Quad Chart like presentation may be desirable.

*"If we knew what is was we were doing, it would not be called research, would it?"
-Albert Einstein*

Worksheet 3.2

Alternatives

Complete

Descriptions

(One Worksheet per Alternative)

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

Describe the “attributes” of each Alternative in as great a detail as possible as they pertain to each S&T Exit Criterion. Some form of Description/Quad Chart presentation (attached to Worksheet 3.2), could make value assessment and decision briefing easier as you go.

Alternative Name: _____

Description: _____

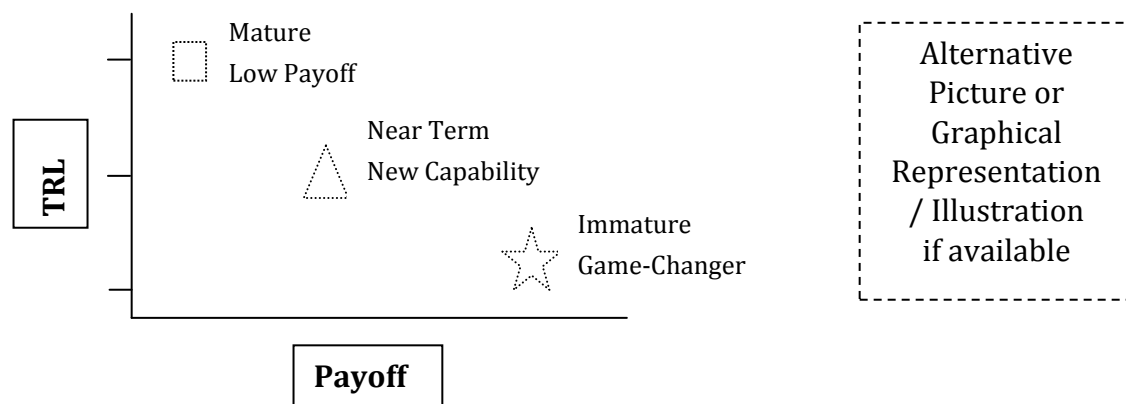
Any Considerations: _____

Estimate Cost and Schedule: _____

Estimate Initial TRL: _____ **Final TRL:** _____

Estimate Initial MRL: _____ **Final MRL:** _____

Estimate Payoff to Maturity score: *(Score the Alternative on the table below)*



STEP 4 – EVALUATE ALTERNATIVES

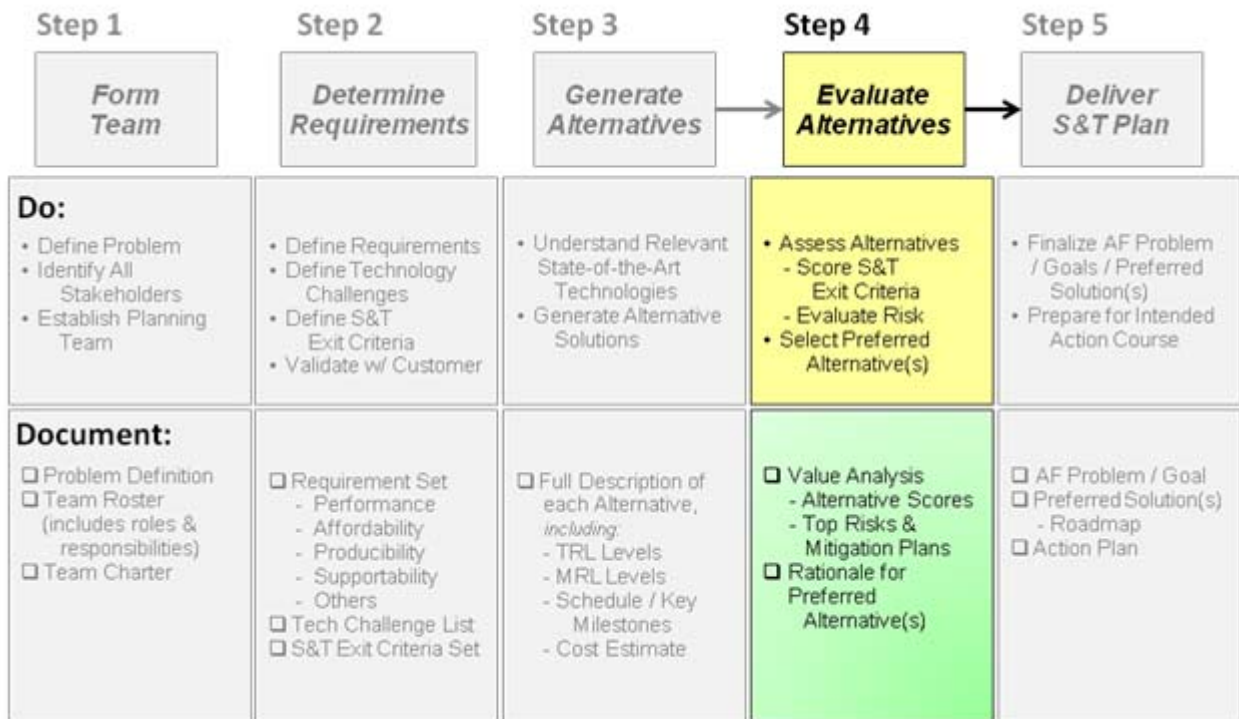


Figure 9: STEP 4 – EVALUATE ALTERNATIVES

In Step 4, the team compares and evaluates the potential of each alternative solution against the stated S&T Exit Criteria from the Problem Space. This comparison of alternatives against the S&T Exit Criteria assumes the team knows early in the process whether the solutions will or will not solve the problem to the satisfaction of the customer. After that, the various solutions can be scored in terms of which one offers the best value to the customer, with “value” being determined by the team.

In order to evaluate the alternative, the team needs to go through a process of discovery for each alternative. In advance of the team meeting, the Team Leader should assign each proposed alternative solution to one or more of the team members, based on their level of knowledge of the topic. The Team Member(s), as the focal point for that topic, needs to be able to evaluate the idea against the Problem specific S&T Exit Criteria as defined in Step 2. This requires more than just a knowledge of the technology; it also requires an understanding of the unique interactions between the technology and the intended application.

Recent experience with this process demonstrates this is frequently the point where the team realizes they are missing sufficient expertise necessary to fully analyze the different alternatives proposed. If this is the case, the SE Facilitator may assist in helping to obtain the necessary information or expertise, or the team can be augmented with appropriate SME(s).

Step 4 is envisioned to be completed in one or two team meetings with necessary homework completed by the focal points for each potential alternative prior to and in between the meetings. At the first meeting, the team reviews the data collected for each alternative (Worksheet 3.2) and comes to agreement as to the validity and completeness of the information provided. As part of this same meeting, the SE Facilitator can conduct an Alternatives Evaluation using a variety of Value Analysis methods. Examples of the Worksheets to assess Technology and Manufacturing Readiness Assessments (Levels), Risk Analysis and Value Analysis are available in a later section of this SE Guide.

Once the Alternative Value Analysis is complete, the Team Leader then leads the team in select a preferred alternative, or alternatives. Note, for many S&T programs, multiple alternatives may be chosen for further technology development, with the highest payoff approach eventually down-selected at higher levels of technical maturity. Once a preferred alternative is selected, greater detailed S&T Program Planning information can be obtained and documented. Caution is urged to review the results of the value analysis carefully; does the team agree with the scoring for each alternative, and are there errors in assumptions which the scoring brings to light which need to be corrected?

Step 4, Evaluation of Alternatives, has the following general tasks:

- Agree upon an alternative scoring system and ranking methodology.
- Evaluate (i.e., score) how each alternative is expected to perform with respect to each S&T exit criteria (threshold and objective) using Worksheet 4.1.
- Identify and qualitatively estimate the risks and potential risk mitigation approaches associated with each alternative actually achieving the expected performance with respect to the S&T exit criteria using Worksheet 4.2;
- Calculate a relative risk factor for each alternative.
- Using Worksheet 4.3, assess and iterate the alternative evaluation results; this is known as Value Analysis.
- Develop the team consensus on preferred alternative(s), including selection rationale; document on Worksheet 4.3.

In the S&T environment, by its very nature, so much is unknown that these tasks can often appear to be both difficult and frustrating. The first time a team works the process is typically the most difficult, but it does get easier as the process proceeds. The process itself is not difficult, but it does force a Systems Engineering discipline on a team that will help it to arrive at a rational preferred solution.

During this evaluation process, S&T exit criteria may end up being re-thought and rephrased. Some may be dropped, while others may be added. There may be missing information that is important, but not so difficult to discover and include. Usually, at this point in a streamlined SE process, high precision is neither possible nor necessary. Critical issues will become apparent and further analysis often will reveal whether they justify additional work. The proposed alternatives were developed by the team with an expectation that they will solve the problem to the satisfaction of the customer. Evaluation of Alternatives is the step where those expectations are initially rationalized, quantified and ranked to produce a preferred solution(s).

Scoring System and Ranking Calculation

The team is free to select a scoring and ranking system of its own design. The simple weighted additive system described in **Step 4 Worksheets** is suitable for a first cut, streamlined SE process. Higher level systems such as those based on weighted geometric means could subsequently be implemented if desired.

This simple methodology has the following characteristics:

- Relatively intuitive for people with a technical background.
- Easily implemented in the attached worksheets.
- Failing to meet any one or more of the S&T exit criteria thresholds should result in a zero composite score so that excelling in meeting one S&T exit criteria does not mask the failure to meet other criteria.

An example criteria scoring table is shown below:

Score Value	Description
5	Expected to meet or exceed the objective S&T exit criteria
4	Expected to fall between the threshold and objective S&T exit criteria
3	Expected to meet the threshold S&T Exit Criteria
1	Expected to fall short of the threshold S&T Exit Criteria, but there's some hope from additional development
0	Cannot foreseeably meet the S&T Exit Criteria

- Note: This method does not incorporate *desireability* concepts which have the advantage of dealing more powerfully and flexibly with non-linear S&T exit criteria and risk. Desireability concepts require special software and a leader or facilitator experienced with the methodology.

Evaluate each Alternative with Respect to each S&T Exit Criteria

From experience, this process can be completed most efficiently in three general tasks:

1. As a group, evaluate one example alternative with respect to each S&T exit criteria and risk, preferably led by someone with prior process experience.
2. Assign qualified S&T Team members or recruited SME's selected alternatives to evaluate with respect to each S&T exit criteria and risk.
3. Again, assemble as a group to evaluate and edit the results from step 2.

Task 1 can sometimes lead to refining the weighted S&T exit criteria generated during step two of the Streamlined SE Planning process. These useful changes are best discovered and made collectively before the team members struggle with them individually. It is helpful to consider this first task as a learning experience, but once completed, the additional tasks often require only a fraction of the time of the first effort.

Often at this point of the process, the team realizes they are missing sufficient expertise or information necessary to fully analyze the different alternatives proposed. If this is the case, an SE Facilitator may be able to step in and help to obtain the necessary information or expertise, or the team can be augmented with appropriate SME(s).

Hopefully, Step 4 can be completed in one to four team meetings, with necessary homework completed by the focal points for each potential alternative prior to and after the meetings. It is rare to complete this step in one meeting, but if the number of criteria are less than 10, the number of alternatives are fewer than five, and the team is well acquainted with each alternative, it can be accomplished.

Team Meeting 1:

- Team agrees upon the alternative scoring and ranking system.
- Team reviews the data collected for each alternative (Worksheets 3.2) and comes to agreement as to the validity and completeness of the information provided.
- Team scores one alternative against each S&T exit criteria as a working exercise; need to refine the S&T exit criteria is determined.
 - Evaluate how this alternative is expected to perform with respect to each S&T exit criteria (threshold and objective) using Worksheet 4.1.
 - Identify and qualitatively estimate the risk associated with this alternative actually achieving the expected performance with respect to the S&T exit criteria using Worksheet 4.2.

- Assign homework, one (or occasionally more to a qualified person) alternative to score against the S&T exit criteria and risk analysis.

Team Leader's work between meetings

- Create the Value Assessment spreadsheet (Worksheet 4.3).
- Collect the data from the homework assignments and enter it in the spreadsheet.
 - Based on the S&T Exit Criteria, calculate a relative ranking for each alternative.
 - Document relative risk scores for each alternative.

Team Meetings 2+:

- Assemble and review the results of the individual homework.
- Execute the Alternatives Evaluation using the agreed upon Value Analysis methods (the team leader may have done this prior to the meeting). This is essentially populating a spreadsheet with the agreed upon value analysis method.

At this point people usually discover specific additional information is useful or necessary for a valid assessment.

Value Analysis Evaluation

The results of the value analysis will be a relative ranking of the alternatives based upon:

- Their expected ability to meet the S&T exit criteria. and
- The relative risks associated with each alternative.

The team leader may then want to perform at least a rough sensitivity analysis on the results (a "what if" assessment). The question to ask is whether small changes in any alternative-to-exit criteria value will significantly change the alternative rankings? The other issue to explore is whether the relative importance of the S&T exit criteria (weights) are still valid?

Once the Alternative Value Analyses are complete, the Team Leader guides the team to select a preferred alternative, or set of alternatives. In many S&T programs, several alternatives are often selected for further technology development, with the highest payoff approach eventually down-selected at higher levels of technical maturity. Once a preferred

alternative (or alternatives) is (are) chosen, a decision can be made as to pursuing more detailed S&T Program Planning information for their proposed solution based on the results of the Value Analysis.

Caution is urged to review the results of the value analysis carefully; does the team agree with the scoring for each alternative, and are there errors in assumptions, which the scoring brings to light, which need to be corrected?

NOTE: It can happen that a given planning team scores the alternatives based on their level of knowledge and discussions, only to have alternatives scores modified once new SMEs participate and contribute their knowledge, often in the areas of affordability and manufacturability. It is very likely the planning team will evaluate the scoring more than once, conducting further research into the alternative technology, and adjusting the scores accordingly. This involves an iterative process of discovery and does not mean that one person or the team as a whole can unfairly or intentionally lead the planning activity to a foregone conclusion.

At the conclusion of Step4, the team should have a strong understanding of the rationale for the preferred alternative(s), and be able to complete the elements of a typical S&T Plan, in the format specified by a Technology Review or other format as required.

Step 4

Evaluate Alternatives

- Assess Alternatives
 - Score S&T Exit Criteria
 - Evaluate Risk
- Select Preferred Alternative(s)

- ☐ Value Analysis
 - Alternative Scores
 - Top Risks & Mitigation Plans
- ☐ Rationale for Preferred Alternative(s)

Step 4 – EVALUATE ALTERNATIVES

(See Streamlined SE Process Workbook for suggested Worksheets)

- ☐ Worksheet 4.1 – Desirability for each S&T Exit Criteria Vs. each Alternative
- ☐ Worksheet 4.2 – Risk of Achieving each S&T Exit Criteria Vs. each Alternative
- ☐ Worksheet 4.3 – Composite Scorecard

Homework:

The Homework is to complete an individual perspective of each alternative on Worksheet 4.1. .

❑ Worksheet 4.1 – Desirability for each S&T Exit Criteria Vs. each Alternative

To conduct a complete evaluation of alternatives against the defined Problem Space, the information about each alternative needs to be collected in an organized format. Use one Worksheet 4.1 per alternative to record the evaluation against each of the agreed to S&T Exit Criteria, with the realization that additional information is likely to be generated as the team expands their understanding of the alternatives, criteria, and the problem.

Alternative Name:					
EC ID	Exit Criteria	EC Weight	Alt Score	EC Score ($Wt \times Sc$)	Rationale
Alternative Score ($EC1 \text{ Score} + EC2 \text{ Score} + EC3...$)					

Alternative Name: Insert the name of the alternative solution.

EC ID: Enter S&T Exit Criteria Identification (tracking) nomenclature or leave blank

Exit Criteria: Enter S&T Exit Criteria (EC) name/title from Worksheet 2.5

EC Weight: the relative importance of the Exit Criteria compared to the other Exit Criteria. Indicates which S&T Exit Criteria are more important than others to solving the problem.

Alt Score: Score as to how well the alternative satisfies the S&T Exit Criteria. Team should agree upon a scoring system and use it consistently throughout the process.

Examples of Scoring Systems:

Numerical Scale: 0 to 5; 0 = fails to 5 = meets/exceeds objective criteria
+/-/0: "+" meets threshold criteria, "-" fails, "0" meets current capability

EC Score ($Wt \times Sc$): multiply the EC **Weight** value times the Alt **Score**.

Alternative Score – Add each EC score to produce the overall Alternative Desirability Score. If three S&T Exit Criteria are being measured, the Alternative Score would be $EC1 \text{ Score} + EC2 \text{ Score} + EC3 \text{ Score}$.

If any Alternative fails to meet one or more S&T Exit Criteria threshold values, the alternative is generally accepted as undesirable and receives a total composite score of zero (0). However, it is still recommended the Alternative be retained for the final discussion as there may be methods to overcome the failing area(s).

Rationale: Use this area to document the logic, both Pro and Con, used in the decisions to score the Weight, Score, and EC Score values.

Step 4. Evaluate Alternatives (Value Analysis) The Measures of Merit
are Desirability (Worksheet 4.1) and Risk (Worksheet 4.2)

Worksheet 4.1

Desirability for each S&T Exit Criteria Vs. each Alternative

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

(One Worksheet per Alternative)

Certain Exit Criteria (EC) are more important than other Exit Criteria. Enter an EC Weight value from Step 2 to score the relative importance of each exit criteria compared to the other exit criteria.

Certain Alternatives are more credible to attain the Exit Criteria. Enter an Alternative (Alt) Score as to how well the Alternative satisfies each S&T Exit Criterion based on a team establish scoring method. If any Alternative fails to meet one or more S&T Exit Criteria, a zero score is entered. A zero score essentially fails that alternative ($EC\ Wt\ Score \times 0 = 0$), however, it is still recommended the Alternative be retained for the final discussion.

Multiply EC Weight times the Alt Score ($Wt \times Sc$) for an "EC" Score. Add all the EC scores together for an overall Alternative Score ($EC1\ Score + EC2\ Score + EC3...$)

Alternate Name:					
EC ID	Exit Criteria	EC Wt	Alt Score	EC Score ($Wt \times Sc$)	Rationale
Alternative Score ($EC1\ Score + EC2\ Score + EC3...$)					

DOCUMENT: The Team should negotiate one overall Alternative score for each Alternative that is then transferred and compiled on the Composite Worksheet 4.3

The SE "Conversation" continues "Desirability is a S&T Exit Criteria value with room for flexibility"

❑ **Worksheet 4.2 – Risk of Achieving each S&T Exit Criterion Vs. each Alternative**

In the S&T planning context, **Risk Assessment** is the determination of risk related to the alternative's ability to achieve the threshold values of the S&T Exit Criteria. In Step 4.2, risks are determined and assessed for probability of occurrence and consequence.

Steps in the Risk Assessment process include:

- ❑ Identify, characterize, and assess the major threats to achieving the S&T Exit Criteria threshold values
- ❑ Identify ways to reduce and/or eliminate each risk, known as risk mitigation
- ❑ Prioritize risk reduction measures based on the technology development strategy

Each risk should be assessed for probability of occurrence and potential impact. High Risk simply means the team should consider Risk vs. Payoff plus Mitigation! The score should also consider difficulty of risk mitigation.

On worksheet 4.2, the Team should begin by identifying the top risks, along with potential risk mitigation approaches for each Alternative to meet the threshold values for the S&T Exit Criteria; typically, risks can be associated with one or more of the S&T Exit Criteria. The Team then scores the Alternative against each S&T Exit Criteria from a risk standpoint to establish a Risk Value Score. Each potential risk should be scored, based both on its potential impact to the S&T Exit criteria, as well as to the ease of implementation of risk mitigation approaches. Following the evaluation of each of the individual risks, the Team should negotiate one overall Risk score for each Alternative that is then transferred to Composite Scorecard, Worksheet 4.3.

Alternative Name: Insert the name of the alternative solution.

EC ID: Identification code, numerical or otherwise, to label and track Exit Criteria (EC)

Exit Criteria: Enter S&T Exit Criteria name/title from Worksheet 2.5

Risk Description: Describe the Risk(s) associated with each alternative actually achieving the expected performance with respect to the S&T Exit Criteria

Risk Score: Calculate a score based on a team agreed upon scoring scale.

Potential / Mitigation: Describe the Potential for Risk and the Mitigation Plans including any difficulties of risk mitigation.

Worksheet 4.2

Risk of Achieving each S&T Exit Criterion Vs. each Alternative

(One Worksheet per Alternative)

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Team identifies the top Risks for each Alternative to meet the threshold values for all of the S&T Exit Criteria.

The Team evaluates the Risk of each Alternative against each S&T Exit Criteria and generates a Risk Score (Risk in this context is the probability of failure (Pf) to exceed the Exit Criterion minimum limits (Worksheet 2.5)).

High Risk does not mean the team should not explore all possible Alternatives (see Payoff to Maturity space on Worksheet 3.2). High Risk simply means the team should consider Risk vs. Payoff plus Mitigation difficulty. The score should also include consideration of mitigation difficulty.

Alternate Name:				
EC ID	Exit Criteria	Risk Description	Risk Score	Potential / Mitigation

Overall Risk Score: _____

DOCUMENT: The Team should negotiate one overall Risk score for each Alternative. Each Alternative's overall Risk Score is then transferred to the Composite Scorecard -- Worksheet 4.3

...the "Conversation" continues...What's the Probability of Failure (Risk) to achieve each S&T Exit Criterion?

❑ Worksheet 4.3 – Composite Scorecard

Worksheet 4.3 may be the last worksheet of Step 4, but it is certainly not the end of the *SE Conversation*. Once all the Alternative Desirability and Risk scores have been entered onto the Composite Scorecard, the team's next task is to step back, analyze the results, and select a preferred alternative, or alternatives.

EC ID: Enter any S&T Exit Criteria tracking nomenclature or leave blank

Exit Criteria: Enter S&T Exit Criteria name/title from Worksheet 2.5

Alternative Name: Insert the name of the alternative solution or other identifier

Composite Score: *Transfer Alternative Score from Worksheet 4.1*

Risk Score: *Transfer Alternative Risk Score from Worksheet 4.2*

Preferred Alternative(s) / Rationale: Indicate the Team's selection

Preferred Alternative(s) Decision Documentation: Include any documentation arguments justifying the selection of the preferred alternative

The Composite Scorecard is used to help guide the planning team to a Preferred Alternative(s). The scores on this worksheet should be analyzed by asking the following questions:

- 1 - "Does the ranking of the composite scores pass the sanity test, i.e., do the values make sense?" If the scores of more than one alternative are very close in total value, how do the distinguishing strengths and weaknesses of the competing alternatives impact solving the problem at hand?
- 2 - "Is risk level, taking into account potential risk mitigation approaches, acceptable for the higher scoring Alternatives?"

Based on this analysis, the team normally selects its Preferred Alternative(s) and moves on to the Step 5 Action Plan to fully develop the Preferred Alternative(s).

Worksheet 4.3

Composite Scorecard

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

Transfer all Alternative and Risk scores from each Alternatives Worksheet (4.1 and 4.2) to this Composite Scorecard

		ALTERNATIVES			
EC ID	Exit Criteria	Alternative	Alternative	Alternative	Alternative
Alternative Score (Worksheet 4.1)					
Risk Score (Worksheet 4.2)					
Preferred Alternative(s) / Rationale					
Preferred Alternative(s) Decision Documentation					

The Composite Scorecard is not the final answer, but presents the team with values for them to agree on the Preferred Alternative(s).

Analyze the scores by asking the questions:

- 1 - Does the ranking of the composite scores pass the sanity test, i.e., do the values make sense?
- 2 - Do Risks outweigh the scores for the high scoring Alternatives?

Based on this review, the team moves on to the Action Plan for the Preferred Alternative(s). Often in S&T it is common to have multiple alternatives selected for initial development.

...the "Conversation" continues...If a score doesn't make sense ...discuss why it scored as it did?

STEP 5 – DELIVER S&T PLAN

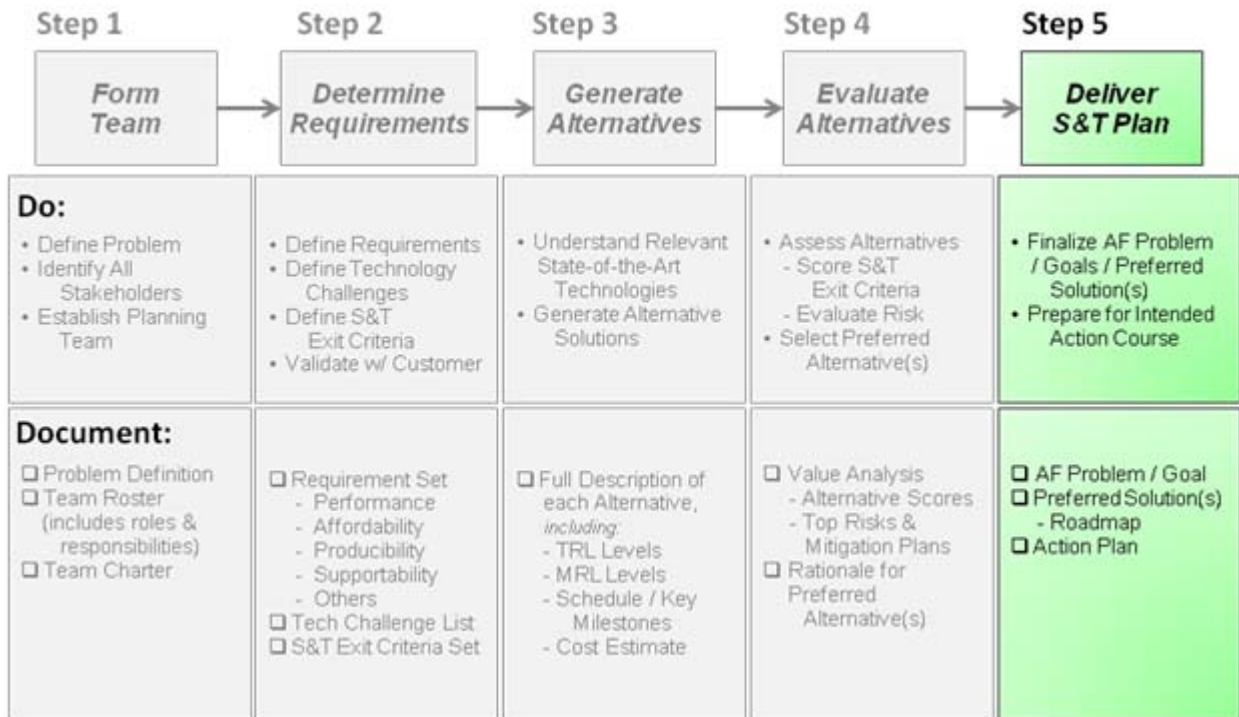


Figure 10: STEP 5 – DELIVER S&T PLAN

Step 5, the culmination of the SE-based planning process, delivers a Plan for the proposed S&T program using the Preferred Alternative(s) selected in Step 4. Often, once a preferred alternative is selected on a first run through this planning process, it is necessary to continue to add a higher level of detail to the proposed program plan. Additional details on topics such as specific program technical and schedule milestones and resources (funding, manpower, and in-house laboratory/test facilities) required will need to be obtained; this information can then be provided to the appropriate S&T management chain in a format suitable for the particular program advocacy forum (examples include Technology Investment Reviews, Technical Review Boards, etc). A S&T program roadmap showing these milestones (including TRL and MRL values) and required funding as a function of fiscal year is also highly beneficial. For relatively high TRL programs, additional detail on the benefits of the proposed program to the customer using the Preferred Alternative are often also necessary.

Assuming the team does arrive at a Preferred Alternative (i.e., Technology Solution) that adequately meets the S&T Exit Criteria (and the foundational customer requirements), their main job now is to prepare the actual program plan and advocate for program approval/initiation.

Step 5

Deliver S&T Plan

- Finalize AF Problem / Goals / Preferred Solution(s)
- Prepare for Intended Action Course

- ☐ AF Problem / Goal
- ☐ Preferred Solution(s)
- Roadmap
- ☐ Action Plan

Step 5 – DELIVER S&T PLAN

(See Streamlined SE Process Workbook for suggested Worksheets)

- ☐ Worksheet 5.1 – Program Action Plan
- ☐ Worksheet 5.2 – SE Case Study

Homework:

Before the team meets for what may well be the final time during the planning process, thought should be given as to the best approach for advocating the proposed program up the S&T management chain. This may well include obtaining additional information on the proposed program and creating draft documents (roadmaps, investment strategy sheets, etc) that will be required for program advocacy.

❑ Worksheet 5.1 – Program Action Plan

The Team should agree upon the plan to advocate for approval/implementation of the proposed S&T program incorporating the Preferred Alternative(s). Depending on the nature of the proposed program, the Action Plan could range from a fairly simple White Paper or Roadmap to a fully detailed advocacy briefing/package. Worksheet 5.1 provides a possible outline based on principles of good program management.

Details necessary to complete this Action Plan include programmatic technology performance, cost and schedule estimates, a basic program execution strategy of external contracts and in-house activities, as well as the type of funding (6.1, 6.2, 6.3) required.

Step 5. Build the Plan: With the Problem Space understood and the Solution Space fully explored, Advocacy Briefs and Action Plans can be generated for the Preferred Alternative(s).

Worksheet 5.1

Program Action Plan

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Team should agree upon the plan to advocate for approval/implementation of the proposed S&T program incorporating the Preferred Alternative(s). Depending on the nature of the proposed program, the Action Plan could range from a simple White Paper or Roadmap to a fully detailed advocacy briefing/package. Worksheet 5.1 provides a possible outline based on principles of good program management.

Details necessary to complete this Action Plan include programmatic technology performance, cost and schedule estimates, a basic program execution strategy of external contracts and in-house activities, as well as the type of funding (6.1, 6.2, 6.3) required.

Program Action Plan *Checklist* (possible outline)

- ☐ Document details of the planning process:
 - ☐ AF problem
 - ☐ Customer(s)/owners/end users
 - ☐ Requirements
 - ☐ S&T Exit Criteria
 - ☐ Details of each alternative solution considered
 - ☐ Preferred alternative(s) selected (include rationale)
- ☐ Document proposed program execution/management plan
 - ☐ Proposed S&T program schedule (*with milestones and decision points*) – *may be in the form of a technology roadmap*
 - ☐ Required resources
 - ☐ Proposed execution approach (inhouse, external contracts)
 - ☐ Risk management approach

- **Describe the recommended next steps in advocacy process:**

...the SE "Conversation" never stops...A well thought out plan is easier to defend and execute.

❑ Worksheet 5.2 – SE Case Study

The Case Study summarizes how the” use of the Streamlined S&T Process helped or didn’t without finger pointing...Another words, the lessons learned of the process: Was the right problem identified correctly? Were the right requirements derived from the problem? Were the stakeholders who needed to be on the team invited and participated? Etc.

It is with hope the process of identifying the problem, defining the requirements, and generating alternatives, and the manner by which the team came to select the Preferred Alternative, was a positive experience. Other projects who have used this process, commented, the learning journey was very rewarding as the knowledge and preconceived notions changed as the SE Conversation continued.

The Case Study is a high-level account of the team’s work to arrive at a decision recommending a preferred solution and action plan. Did you have appropriate Customer involvement? Was the Problem Statement captured accurately? What lessons did the team learn in the process of determining a solution? The Case Study is a place to summarize the positive and the negative without” finger pointing” anyone specific, but a constructive report that can be filed on the SE CoP website for others to learn from.

The outline provided in Worksheet 5.2 is only notional and can be whatever the team/author decides to report.

Worksheet 5.2

SE Case Study

While the actions, activities, and experiences of applying the Systems Engineering Streamlined Planning Process are still fresh in the mind of the Core Team and other participants, a Case Study is a useful document to capture the team's discoveries.

Case Study

Description of Problem Space

Background

Study Objectives

Study Process

Description of Technical Effort

The Integrated Product Team

Kickoff Meeting, *date*

Technical and Systems Engineering Process Conclusions

Systems Engineering

Additional Observations

Lessons Learned and Recommendations

Appendix A. List of Acronyms and Terms

Appendix B. References

...the SE "Conversation" never stops...don't be surprised to find this process wasn't worth the time invested.

EXAMPLE PROGRAM: Aerospace Ground Equipment Lifetime Coating Evaluation for System Sustainment (AGELESS)

Problem Background:

The Air Force annually spends over \$69M annually on corrosion mitigation associated with non-powered support equipment, primarily portable aircraft work-stands. Labor and material costs are increasing, while workforce shaping is reducing available maintenance resources.

Study Objectives:

This FY07-08 AFRL/RX Director-sponsored Company Grade Officer Initiative Program, a “quick-look” mini-program with direct field application, used streamlined SE methods to select an optimum method for corrosion mitigation of non-powered AGE. A number of technology alternatives were considered, including:

- Coatings conforming to MIL-PRF-26925
- Metallization (aka metal wire arc spray)
- Hot-dip galvanization
- Electro galvanization

These four potential solutions will be used in the example worksheets that follow; it should be noted that although each of these solutions is much more mature than technologies usually considered for an S&T program plan, they still serve a useful purpose in illustrating the Streamlined SE Planning method for S&T.

In this study, the **hot-dip galvanization** process was determined to be the best solution because it possesses superior capabilities for three high priority requirements and no inferior capabilities with respect to the remaining requirements. Hot-dip galvanization is applicable to only low strength steels, which are the materials used in aerospace ground equipment structures. The hot-dip galvanization process was assessed to have superior capabilities to treat hard-to-reach surfaces and was the preferred alternative by USAF maintainers.

The **electro galvanization** process was determined to possess superior capabilities for two high priority requirements, but had issues with widespread availability and limitations for treating hard-to-reach surfaces. However, this process is not limited to low strength steels and could be the preferred choice for coating other applications. The **metallization** process has superior capabilities for reducing environmental impact and for producing damage tolerant protection, but it has major issues in hard-to-reach surfaces and is also too expensive, thus failing to meet threshold requirements. Additionally, there were some concerns the metallization process would change metallurgical properties of the structure, which is undesirable. The **coatings conforming to MIL-PRF-26915** provided essentially the same capabilities as the current painting practices, with some advantages of producing more damage tolerant protection and but with some disadvantages of requiring extra processing steps.

Results of this study were presented to the Aircraft Ground Support Equipment Working Group (AGSEWG), with final recommendations made to the Combat Sustainment Group for analysis.

Worksheet Examples

The following Example Worksheets are based on an actual Aerospace Ground Equipment Longevity Coating Evaluation for System Sustainment (AGELESS) Study performed by an RX CGO SE Team. The general results of this study can be used to demonstrate the possible results of a team using the Streamlined S&T Planning Process to develop a recommended program plan.

Step 1: Form Team. Start to think of the team in specific terms of the problem at hand.
Different problems require different members with their experiences and skills.

Worksheet 1.1

Define Problem

EXAMPLE

Project Name: AGE Corrosion Mitigation

Member Name: Jack Sparrow

Role: Team Lead/Program Manager

Worksheet Date: Today

The team works with the customer(s) to scope the problem space.

Who is the Customer? *(Who brought the problem?)* AGE Program Office at WR-ALC/LEEV

Time frame of Problem *(When Needed/Urgency?):* Near-Term

Describe the Problem *(Scope/Major Issues/Constraints):* Corrosion mitigation costs too high for non-powered Aerospace Ground Equipment (AGE)! Annual \$69M+ corrosion mitigation costs, with increasing labor & material costs; workforce shaping has reduced maintenance man hours (MMH) available. Desire: extended coating life, not total AGE life.

Who is the Problem Owner? AGE Program Office at WR-ALC/LEEV

Who is the End User? *(Who turns the wrench/pushes the button?)* All AF Flight-Line Ops

Why Should AFRL/RX be Working This Issue? RX, through RXS Coating Tech Integration Office and Corrosion Prevention & Control Office, has core tech competency in this area.

Who Needs to be Included as Partners In This Issue? _____

What Do We NOT Know? What are the specific "bad actors," which drive AGE coating problem(s); how often & how are current coating repairs made?

... the "SE Conversation" begins with understanding of the problem...What is the "Discontent?" ...and Why?

Worksheet 1.2

Team Make-up / Roles

EXAMPLE

Project Name: AGE Corrosion Mitigation
 Member Name: Jack Sparrow
 Role: Team Lead/Program Manager
 Worksheet Date: Today

With the Problem understood, a team approach (Core plus Augmentees) must be defined, i.e., identify the skills needed to discuss and refine the Problem

Team Directory, Roles & Responsibilities

<u>Role/Responsibility</u>	<u>ORG/Symbol</u>	<u>Name / Contact Info</u>
CORE TEAM MEMBERS		
• <u>Team Lead / PM</u>	<u>AFRL/RXS</u>	<u>Jack Sparrow</u>
• <u>Principal Investigator</u>	<u>CTIO RA</u>	<u>Mike Spicer (RXSS) Chief Eng</u>
• <u>In-House Researcher</u>	<u>RXSA UDRI</u>	<u>Al Topcoat</u>
• <u>Corrosion Engineer</u>	<u>AFCPCO/WR-ALC</u>	<u>Rusty Standish</u>
• <u>SE Facilitator</u>	<u>AFRL/RXOB</u>	<u>Dr. Jim Malas</u>
• <u>Customer(s) (Acquirer)</u>	<u>WR-ALC/LEEV</u>	<u>Mr. David Robert</u>
• <u>Customer(s) (User)</u>	<u>445 AW/A4 (C-5)</u>	<u>MSgt Albert</u>
Augmentees (includes SMEs, Finance, Contracting, etc.)		
• <u>Finance</u>	<u>AFRL/RXF</u>	<u>Ms. Paula Money Penny</u>
• <u>Contracting</u>	<u>AFRL/RXK</u>	<u>Mr. Ty Downe</u>
• _____	_____	_____
• _____	_____	_____

...the "SE Conversation" continues... including all the right expertise and Stakeholders

Worksheet 1.3

Establish Team Charter

EXAMPLE

Project Name: AGE Corrosion Mitigation

Member Name: Jack Sparrow

Role: Team Lead/Program Manager

Worksheet Date: Today

Core Team stays with the entire process. Other persons with needed expertise are brought in only where appropriate.

Use Worksheets 1.1 and 1.2 as backup to this activity

“Planning” Team Charter

Goal/Objectives: Plan S&T program to address increasing non-powered AGE coating corrosion mitigation costs

- **Schedule**

- **Meeting frequency** (Weekly, monthly, etc.) Meet once per week
- **Duration: Start:** (mm/dd/yyyy) 03/19/2007 **End:** (mm/dd/yyyy) 09/30/2008

- **Resources** (Available to the Team): normal office support & TDY funding for two face-to-face meetings

- **Authority / Accountability** of Team Membership: Dr. H. Honcho, RXS Div Chief

As a Core Team Member for this planning effort, I understand the following is expected of all Core Team Members:

- **Commit to participate in all team meetings**
- **Commit to complete all “homework” on schedule**
- **Participate in the documentation of each step before proceeding to the next step**

Signatures of all core planning team members commitment

1.	4.
2.	5.
3.	6.

(The above is just a suggested outline. Expand with extra pages if needed)

... the SE Conversation is solidified when a Team Charter formalizes expectations

Step 2: Requirements. A firm understanding of the requirements, technical challenges, and how they're stated as S&T Exit Criteria are critical steps in Problem Space documentation.

Worksheet 2.1

List of Customer Requirements

EXAMPLE

Project Name: AGE Corrosion Mitigation

Member Name: Jack Sparrow

Role: Team Lead/Program Manager

Worksheet Date: Today

The Core Team refines the understanding of the Customer's Problem into stated requirements and validates them with the Customer

Requirement Name	Requirement Description (as specific as possible)	Threshold*	Objective*
Coating Durability	New coating solution with at least 2X lifetime over current; Desire 4X current (Between PDM)	2X	4X
EPA / ESH Compliant	Reduce environmental waste stream	30% Less	50% Less
Coating Coverage	Ability to coat / treat "Hard to Reach" surfaces (inside 4ft long, 1 inch ID pipe)	95%	100%
Affordability	Reduction in corrosion mitigation materials costs and labor (funding & manpower)	40% reduction	60% reduction
Ease of Repair	Reparability at least as good as current	Same	better
Looks / Appearance	Clean appearance		

**Desirable – vary with maturity of task*

Threshold: The measurable value that must be achieved for the technology to advance to the next stage of development or transition (usually given as a minimum or maximum value).

Objective: The stretch-goal value that is desirable, but not essential (often viewed as the requirements trade space if parameters such as cost or schedule are more important to the customer).

☐ **DOCUMENT:** Validate this worksheet with your customer representatives / stakeholders to ensure agreement with the goals.

...the "Conversation" continues... What capability does my Customer (Want) Need?....and Why?

Worksheet 2.2

Technical Challenges

EXAMPLE

Project Name: AGE Corrosion Mitigation

Member Name: Jack Sparrow

Role: Team Lead/Program Manager

Worksheet Date: Today

The Team now has to turn the Customer Requirements into actionable S&T descriptions S&T Exit Criteria). This step helps the team decompose the Customer Requirements into Technical Issues (Challenges).

Requirement Name	Technical Challenge Issues
Coating Durability	Coating adhesion to base metal structure with no change to metallurgical structure, while exhibiting desired durability characteristics
EPA / ESH Compliant	Coating applied in a non-toxic, low hazardous waste process; Green/earth friendly
Coating Coverage	Ability to coat total surface including recessed and tight access areas, and inside diameters of open tubing/pipe
Affordability	Coating process and materials affordable
Ease of Repair	Durable Repairs within currently accepted repair times

...the SE Conversation continues by identifying "Where's the S&T in this challenge?"...and Why?

Worksheet 2.3

List of S&T

Exit Criteria

EXAMPLE

Project Name: AGE Corrosion Mitigation

Member Name: Jack Sparrow

Role: Team Lead/Program Manager

Worksheet Date: Today

Customer Requirements are usually at fairly high level. The team now has to define and document what a final product, technology, or system must do, including the parameters that define successful completion. Worksheets 2.1 and 2.2 should lead into this step.

<i>Criteria Name</i>	<i>Description</i>	<i>Threshold*</i>	<i>Objective*</i>	<i>RQT Name</i>
Coating Durability	Resistance to impact & weather (rust/corrosion)	2X current	4X current	Coating Durability
EPA / ESH Compliance	Reduce environmental waste stream	30% Reduction	40% Reduction	EPA / ESH Compliant
Surface Coverage	Amount of surface covered	95%	100%	Coating Coverage
Affordability	Reduction in corrosion mitigation materials costs and labor	40% Reduction	60% Reduction	Affordability
Repairability	Ease of repair	Same as current	Better than current	Repairability

**Desirable – vary with maturity of task*

Threshold: *The measurable value that must be achieved for the technology to advance to the next stage of development or transition (usually given as a minimum or maximum value).*

Objective: *The stretch-goal value that is desirable, but not essential (often viewed as the requirements trade space if parameters such as cost or schedule are more important to the customer).*

*...the "Conversation" continues... What S&T Exit Criteria demonstrate the Requirement(s) have been met?" -
....and Why?*

Worksheet 2.4

Group S&T

Exit Criteria

by Category

EXAMPLE

Project Name: AGE Corrosion Mitigation

Member Name: Jack Sparrow

Role: Team Lead/Program Manager

Worksheet Date: Today

S&T Exit Criteria negotiated by the team can usually be grouped into common topics, identified such as P-1, P-2, etc. for Performance, C-1, C-2, etc. for Cost.

There is no limit to the number of S&T Exit Criterion but this is the logical place to consider consolidation, combining the criteria, if appropriate.

ID	S&T Exit Criteria	Description
Group: PERFORMANCE		
P-1	Durability	Resistance to impact & weather
P-2	EPA / ESH Compliance	Reduce environmental waste stream
P-3	Surface Coverage	% of total surface area covered
P-4	Repairability	Ease of repair
Group: COST		
C-1	Affordability	Reduction in corrosion mitigation materials costs and labor

Possible Category Groupings (add categories depending on technology)

C= Cost (development, acquisition, deploy, point of use operation)

HF = Human Factors

S = Schedule

E = Environment (EPA, certifications, etc.)

P = Performance (reliability, weight, footprint, set-up time)

ST = Strategic (outside influences, be they political or otherwise)

L = Logistics (transport, service life, storage, scalability, disposal)

POL = Political (constrictions)

...the "Conversation" continues... What groups form the S&T Exit Criterion?" -....and Why?

Worksheet 2.5

S&T Exit Criteria

Complete Description

EXAMPLE

Project Name: AGE Corrosion Mitigation
 Member Name: Jack Sparrow
 Role: Team Lead/Program Manager

Worksheet Date: Today

The Team defines the detailed quantitative attributes of the S&T Exit Criteria.

ID	Name	Priority /Wt*	Units	Threshold Value	Threshold Rationale	Objective Value	Objective Rationale	How Measured
Group PERFORMANCE								
P 1	Durability	1.0	months	2x Current	Customer req't	4X Current	Customer goal	Env chamber tests
P 2	EPA / ESH Compliance	0.7	Gallons waste	30% Reduction	Customer req't	40% Reduction	Customer goal	Pilot process tests
P-3	Surface Coverage	1.0	% surface covered	95%	Hand touch-up other 5%	100%	Customer goal	Pilot process tests
P-4	Repairability	0.7	Minutes per repair	Same as current	Customer req't	Better than Current	Customer goal	Pilot process tests
Group COST								
C-1	Affordability	1.0	dollars	40% reduction	Customer req't	60% Reduction	Customer goal	Detailed cost estimates

*Can be used to compare relative importance of S&T Exit Criteria. These are suggestive, use whatever scale you determine relevant/needed."

Priority qualitative ranking: High, Medium, Low....Or,

Weight scores contribution importance: 1 = critical contribution to capability, 0.7 important contribution, and 0.5 if not too important

Threshold: The measurable value that must be achieved for the technology to advance to the next stage of development or transition (usually given as a minimum or maximum value).

Objective: The stretch-goal value that is desirable, but not essential (often viewed as the requirements trade space if parameters such as cost or schedule are more important to the customer).

...the "Conversation" continues... When is 'more or less' better and how do you measure it?" -....and Why?

Step 3: Generate Alternatives. Explore and list all the possible ways to solve a problem
are important steps in documenting the Solution Space.

Worksheet 3.1

List Alternatives

EXAMPLE

Project Name: AGE Corrosion Mitigation

Member Name: Jack Sparrow

Role: Team Lead/Program Manager

Worksheet Date: Today

The Team identifies possible solutions (Alternatives) to satisfy each of the S&T Exit Criteria. The Alternatives may be existing technologies, but the team should also explore novel approaches that may offer enhanced payoff... even if it seems a higher risk.

Alternative Name	Description
Coatings conforming to MIL-PRF-26915	New paint that conforms to MIL-PRF-26915, similar to current paint methods. However, it is believed there are additional application process steps required.
Metallization (aka Metal Wire Arc Spray)	Process applies a thermally sprayed coating of metal much like spraying paint. Two metal wires, zinc or aluminum, are fed to a spray gun device. A positively charged wire meets a second negatively charged wire at the gun head, creating a high temperature arc. Dry compressed air atomizes the molten material and propels it to the surface being coated.
Electro Galvanization	Electro-plating deposition of zinc over steel or iron to prevent galvanic corrosion of the underlying surface. Galvanizing provides the relative corrosion resistance of zinc, which, under most service conditions, is considerably less than those of iron and steel. The zinc is consumed first as a sacrificial anode, so it cathodically protects exposed steel. In any scratches through the zinc coating, the exposed steel will be cathodically protected by the surrounding zinc coating, unlike an item which is painted with no prior galvanizing.
Hot-Dip Galvanization	Process of coating iron, steel, or aluminum surfaces with a thin zinc layer by dipping the metal in a molten bath of zinc at 860°F (460°C). A dull, gray, fairly strong sacrificial zinc coating inhibits corrosion, protecting the underlying surface from the elements. 50 microns thick (10 times the protection of zinc plating - 3 microns)

...the "Conversation" continues...What Alternatives might satisfy the S&T Exit Criteria?and Why?

Worksheet 3.2

Alternatives

Complete Descriptions

(One Worksheet per Alternative)

EXAMPLE

Project Name: AGE Corrosion Mitigation
Member Name: Jack Sparrow
Role: Team Lead/Program Manager
Worksheet Date: Today

Describe the "attributes" of each Alternative in as great a detail as possible as they pertain to each S&T Exit Criterion. Some form of Description/Quad Chart presentation (attached to Worksheet 3.2), could make value assessment and decision briefing easier as you go.

Alternative Name: Hot-Dip Galvanization (HDG)

Description: Process whereby fabricated steel, structural steel, castings, or small parts, including fasteners, are immersed in a kettle or vat of molten zinc, resulting in a metallurgically bonded alloy coating that protects the steel from corrosion.

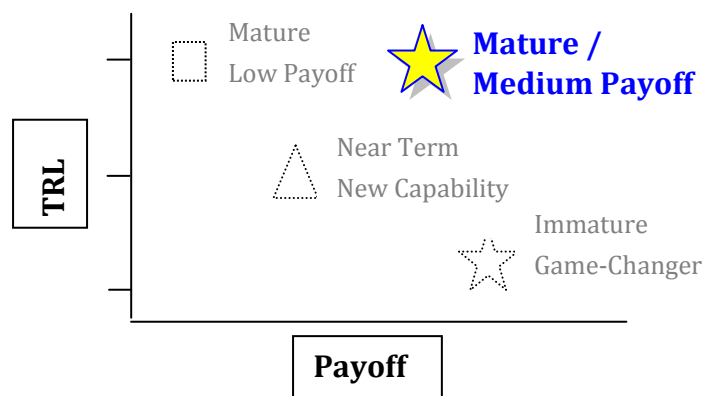
Any Considerations: Can AGE be dis-assembled into smaller components, or will vat tank need to be large enough to accommodate large assembled units?

Estimate Cost and Schedule: _____

Estimate Initial TRL: 6 Final TRL: 9

Estimate Initial MRL: 8 Final MRL: 8

Estimate Payoff to Maturity score: (Score the Alternative on the table below)



Dipping AGE into molten zinc

Step 4. Evaluate Alternatives (Value Analysis) The Measures of Merit
are Desirability (Worksheet 4.1) and Risk (Worksheet 4.2)

Worksheet 4.1

Desirability for each S&T Exit Criteria Vs. each Alternative

(One Worksheet per Alternative)

Project Name: AGE Corrosion Mitigation

Member Name: Jack Sparrow

Role: Team Lead/Program Manager

Worksheet Date: Today

EXAMPLE

Certain Exit Criteria (EC) are more important than other Exit Criteria. Enter an EC Weight value from Step 2 to score the relative importance of each exit criteria compared to the other exit criteria.

Certain Alternatives are more credible to attain the Exit Criteria. Enter an Alternative (Alt) Score as to how well the Alternative satisfies each S&T Exit Criterion based on a team establish scoring method. If any Alternative fails to meet one or more S&T Exit Criteria, a zero score is entered. A zero score essentially fails that alternative ($EC \text{ Wt Score} \times 0 = 0$), however, it is still recommended the Alternative be retained for the final discussion.

Multiply EC Weight times the Alt Score ($Wt \times Sc$) for an "EC" Score. Add all the EC scores together for an overall Alternative Score ($EC1 \text{ Score} + EC2 \text{ Score} + EC3 \text{ Score} \dots$)

Alternate Name: Hot Dip Galvanization (HDG)					
EC ID	Exit Criteria	EC Wt	Alt Score	EC Score ($Wt \times Sc$)	Rationale
P-1	Durability	1.0	8	8	Thick Zinc Coating
P-2	EPA / ESH Compliance	0.7	7	5	No spray, but Zn vapor
P-3	Surface Coverage	1.0	9	9	Liquid immersion
P-4	Repairability	0.7	8	6	Can electroplate repairs
C-1	Affordability	1.0	7	7	Equiv to current method
Alternative Score ($EC1 \text{ Score} + EC2 \text{ Score} + EC3 \dots$)			39	35	

Note: "3" denotes alternative equivalent to the capability as the current method,
"7" denotes superior capability (meets threshold value), and
"10" denotes superior capability (meets objective value)

DOCUMENT: The Team should negotiate one overall Alternative Desirability score for each Alternative that is then transferred and compiled on the Composite Worksheet 4.3

The SE "Conversation" continues "...Desirability is a S&T Exit Criteria value with room for flexibility"

Worksheet 4.2

Risk of Achieving each S&T Exit Criterion Vs. each Alternative

(One Worksheet per Alternative)

EXAMPLE

Project Name: AGE Corrosion Mitigation

Member Name: Jack Sparrow

Role: Team Lead/Program Manager

Worksheet Date: Today

The Team identifies the top 3-5 Risks for each Alternative to meet the threshold values for all of the S&T Exit Criteria.

The Team evaluates the Risk of each Alternative against each S&T Exit Criteria and generates a Risk Score (Risk in this context is the probability of failure (Pf) to exceed the Exit Criterion minimum limits (Worksheet 2.5)).

Risk does not mean the team should not explore all possible Alternatives (see Payoff to Maturity space on Worksheet 3.2). High Risk simply means the team should consider Risk vs. Payoff plus Mitigation! The score should also include consideration of mitigation difficulty.

Alternate Name: <u>Hot Dip Galvanization (HDG)</u>				
EC ID	Exit Criteria	Risk Description	Risk Score	Potential / Mitigation
P-1	Durability	None	10	Highly durable
P-2	EPA / ESH Compliance	Molten metal	7	Use remote handling to prevent burns; vapor recovery system needs to be installed
P-3	Surface Coverage	None	10	100% coverage (open pipes)
P-4	Repairability	Field-level repairability	9	Apply portable electroplating brushes to repair small areas
C-1	Affordability	Size of hot-dip tanks	8	Assume AGE stands can be disassembled into smaller components

Overall Risk Score: 9 - Low

DOCUMENT: The Team should negotiate one overall Risk score for the Alternative. Each Alternative's overall Risk Score is then transferred to the Composite Scorecard -- Worksheet 4.3

...the "Conversation" continues...What's the Probability of Failure (Risk) to achieve each S&T Exit Criterion?

Worksheet 4.3

Composite Scorecard

EXAMPLE -

Project Name: AGE Corrosion Mitigation

Member Name: Jack Sparrow

Role: Team Lead/Program Manager

Worksheet Date: Today

Transfer all Alternative and Risk scores from each Alternative Worksheets (4.1 and 4.2) to this Composite Scorecard

		ALTERNATIVES			
EC ID	Exit Criteria	Coatings to MIL-PRF-26915	Metallization	Electro Galvanization	Hot-Dip Galvanization
P-1	Durability	3	7	5	8
P-2	EPA / ESH Compliance	2	2	5	5
P-3	Surface Coverage	2	0	6	9
P-4	Repairability	2	4	6	6
C-1	Affordability	3	2	8	7
Alternative Score Single Entry per (Worksheet 4.1)		12	0	29	35
Risk Single Entry per (Worksheet 4.2)		10- Low	5 - Medium	10 - Low	9 - Low
Preferred Alternative(s) / Rationale		Hot-Dip Galvanization is the best solution. Superior capabilities in durability & surface coverage offset slightly higher cost relative to Electro-Galvanization; risk acceptable.			
Preferred Alternative(s) Decision Documentation					

The Composite Scorecard is not the final answer, but presents the team with values to discuss and agree on for the Preferred Alternative(s).

Analyze the scores by asking the questions:

- 1 - Does the ranking of the composite scores pass the sanity test, i.e., do the values make sense?
- 2 - Do Risks outweigh the scores for the high scoring Alternatives?

Based on this review, the team moves on to the Action Plan for the Preferred Alternative(s). Often in S&T it is common to have multiple alternatives selected for initial development.

...the "Conversation" continues...If a score doesn't make sense, ...discuss why it scored as it did?

Step 5. Build the Plan: With the Problem Space understood and the Solution Space fully explored, Advocacy Briefs and Action Plans can be generation on the Preferred Alternative(s).

Worksheet 5.1

Program Action Plan

Project Name: AGE Corrosion Mitigation

Member Name: Jack Sparrow

Role: Team Lead/Program Manager

Worksheet Date: Today

The Team should agree upon the plan to advocate for approval/implementation of the proposed S&T program incorporating the Preferred Alternative(s). Depending on the nature of the proposed program, the Action Plan could range from a simple White Paper or Roadmap to a fully detailed advocacy briefing/package. Worksheet 5.1 provides a possible outline based on principles of good program management.

Details necessary to complete this Action Plan include programmatic technology performance, cost and schedule estimates, a basic program execution strategy of external contracts and in-house activities, as well as the type of funding (6.1, 6.2, 6.3) required.

Program Action Plan Checklist

- ☐ Document details of the planning process:
 - ☐ AF problem: Corrosion mitigation costs too much – strains sustainment dollars
 - ☐ Customer(s)/owners/end users: ALCs and ALL Flight Line Users
 - ☐ Requirements: Costs, Environment, Performance
 - ☐ S&T exit criteria: Less cost than current, green, highly durable
 - ☐ Details of each alternative solution considered: Four options
 - ☐ Preferred alternative(s) selected (include rationale): Hot Dip Galvanization
- ☐ Document proposed program execution/management plan
 - ☐ Proposed S&T program schedule (*with milestones and decision points*) – *may be in the form of a technology roadmap*
 - ☐ Required resources
 - ☐ Proposed execution approach (inhouse, external contracts)
 - ☐ Risk management approach

- **Describe the recommended next steps in advocacy process:**

...the SE "Conversation" never stops...A well thought out plan is easier to defend and execute.

APPENDIX SECTION

AFRL/RX STREAMLINED S&T PLANNING PROCESS

Tailored Systems Engineering (SE) Principles
which can be applied to plan
Science & Technology (S&T) programs

(Additional reading on the SE Streamlined Process)

APPENDIX A – Acronyms

AF	Air Force
AFI	Air Force Instruction
AFMC	Air Force Material Command
AFRL	Air Force Research Laboratory
ATD	Advanced Technology Demonstration
CONOPS	Concept of Operations
COP	Community of Practice
COTS	Commercial-Off-the-Shelf
DAPA	Defense Acquisition Performance Assessment
DAU	Defense Acquisition University
DoD	Department of Defense
EC	Exit Criteria
EMD	Engineering Manufacturing Development
FOS	Family of Systems
GOTChA	Goals, Objectives, Technical Challenges, and Approach
HVP	High Visibility Program
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
KPP	Key Performance Parameter
LMR	Laboratory Management Review
LRIP	Low Rate Initial Production
MAJCOM	Major Command
MRA	Manufacturing Readiness Assessment
MRL	Manufacturing Readiness Level
MS	Milestone
M&S	Modeling and Simulation
MS&A	Modeling, Simulation and Analysis
PMR/PBR	Program Management/Program Baseline Review
PM	Program Manager
SE	Systems Engineering
SEADS	Systems Engineering Analysis Decision Support
SEC	Systems Engineering Council
SETFST	Systems Engineering Tailored for Science and Technology
SEWG	Systems Engineering Working Group
S&T	Science and technology
SME	Subject Matter Experts
SOS	System of Systems
SOTA	State-of-the-Art
TD	Technology Directorate
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
V&V	Verification and Validation
WBS	Work Breakdown Structure
WS	Worksheet

APPENDIX B – References

References

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Early Systems Engineering Guidebook, SAF/AQR, 31 March 2009

APPENDIX C – Background – Systems Engineering (SE)

What is Systems Engineering?

Systems Engineering (SE) is a methodology and a process that can enhance the likelihood of customer and stakeholder needs being satisfied in a high quality, trustworthy, cost efficient, and schedule compliant manner throughout a system's entire life cycle, including development.

AFI 63-1201, *Life Cycle Systems Engineering*, states “Air Force SE involves comprehensive planning, management, and execution of rigorous technical efforts to develop, field, & sustain robust products and systems.”

SE collects, coordinates, & ensures traceability of all stakeholder needs into a set of system requirements through a balanced process that takes into account effectiveness, performance, cost, schedule, and risk.

From a DoD viewpoint, SE activities are based around the following eight technical management processes: Technical Planning, Requirements Management, Interface Management, Technical Planning, Configuration Management, Technical Data Management, Technical Assessment, and Decision Analysis.

AFMCI63-1201, 14 October 2009

Systems Engineering (SE): SE encompasses the entire set of scientific, technical, and managerial efforts needed to conceive, evolve requirements, develop, verify capabilities, deploy, support, sustain, and dispose of a robust product, platform, system, or integrated System-of-Systems/Family-of-Systems (SoS/FoS) capability to meet user needs. SE may be referred to as a discipline, a methodology, an approach, a practice, a process, a set of processes and sub-processes, or various other terms; however, its fundamental elements – systematic technical and managerial processes and measurements – remain the same regardless of the collective nomenclature. SE provides the integrating technical and managerial process to define and balance performance, cost, schedule, risk, supportability, and security for an item, system, and SoS/FoS throughout their life cycle. SE requires an interdisciplinary execution approach.

The Air Force Mandate for Systems Engineering

The 2006 Defense Acquisition Performance Assessment (DAPA) Project Report survey found that 96% of respondents cited at least one of the following three areas as critical to maintaining program cost, schedule, and performance (shown in ranked order):

- Requirements instability
- Funding instability
- Technology maturity

As a validated method to improve acquisition program management, the Air Force has formally mandated SE in the form of two instructions:

- **AFI 63-1201, *Life Cycle Systems Engineering***, which clarifies and emphasizes the use of disciplined, seamless SE practices throughout the concept/product/system life cycle
- **AFI 63-101: Acquisition & Sustainment Life Cycle Management**, which designates life cycle SE as one of the six tenets of Integrated Life Cycle Management (ILCM) and emphasizes SE as the integrating mechanism for balanced solutions

AFI 63-1201 states that application of SE fundamentals must begin with concept inception, and must cover all efforts across all life cycle phases, to include sustainment & disposal, for all Air Force products and systems. This instruction introduces the terminology, **Early SE**, which provides an audit trail from the users' capability gaps & needs, through concept selection, high-level system requirements refinement, & documentation of development plans. AFI 63-101 specifically mentions the role of AFRL in the SE process, stating "AFRL/CC will ensure incorporation of SE methodologies **tailored for AFRL technology development** done in support of evolutionary acquisition programs."

The Role of AFRL in Early Systems Engineering

The Air Force has emphasized the benefits of Early SE to the extent that in March 2009 an *Air Force Early Systems Engineering Guidebook* was published. This document clearly lays out the role of AFRL in Early SE, stating the following:

A technology organization, typically AFRL, works with acquisition organizations to ensure:

- Relevant technologies are considered, and that they are compatible with the desired time frame and expressed acceptable risk levels
- New approaches made possible by emerging technologies, as well as technologies that will improve a system's effectiveness and/or reduce its cost
- Risks and uncertainties associated with new technologies are estimated and impacts are assessed
- Insight as to user/operator needs is gained, allowing technologists to better focus their technology roadmaps

These AFRL roles apply to both evolutionary acquisitions for fielded Air Force systems as well as to newly emerging systems such as the long range strike bomber. Application of tailored SE principles will greatly assist AFRL scientists and engineers as they engage in all levels of science and technology.

Advantages of Applying Early SE in Science & Technology (S&T)

What is the benefit of applying early or tailored SE in S&T programs? The *2006 Defense Acquisition Performance Assessment (DAPA) Project Report* states that the greatest trade space, and thus the largest risk reduction opportunity in the DoD Acquisition Life Cycle, exists between Milestones (MS) A and B (Figure 1). A second major finding was that for many major DoD acquisition programs, balancing and integration of technology maturity, system capability, cost and program risk is not being achieved and agreed to prior to Milestone B, thereby engendering excessive cost, schedule and performance risk.

It is sometimes difficult to justify Early SE in terms that AFRL program managers and their supervisory chain can relate to. The costs of Early SE are immediately evident in terms of resources (people & funding) and schedule time. The benefits, although sometimes less obvious in the near term, have been shown in several studies to significantly improve the quality of S&T deliverables over the long haul. These benefits include:

- Cost avoidance (reduction of rework from requirements shift or interface mismatches)
- Risk management (early risk identification and mitigation)
- Improved efficiency (clearer organizational boundaries and interfaces)
- Better technology products (resulting from a better understanding and satisfaction of customer needs)

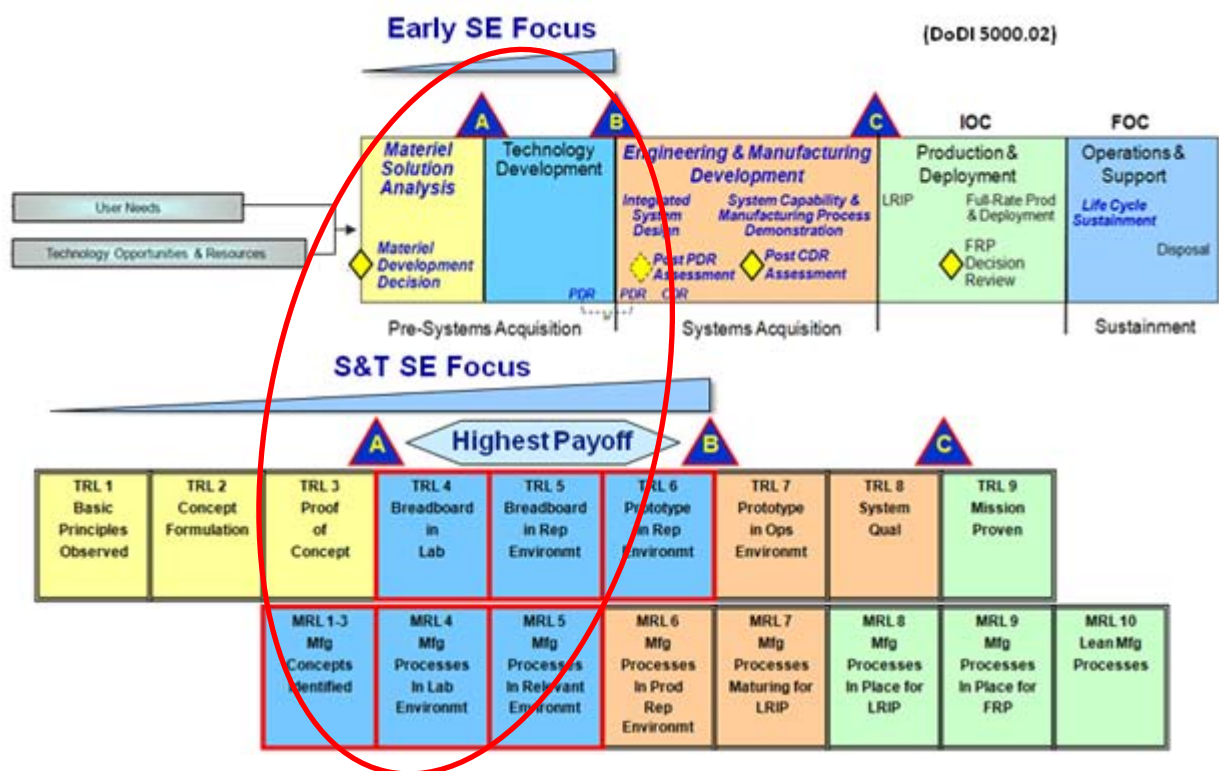


Figure 11. Greatest Trade Space/Largest Risk Reduction Opportunity – Exists Between Milestones (MS) A & B

AFRL lies at the heart of this maximum payoff trade space; and researchers, engineers, and designers who have employed tailored SE consistently report that:

- Teams gain clarity on customer requirements, making it much easier to define technology and program goals early on
- Previously overlooked technical and programmatic issues are now routinely considered up front
- Applied research (6.2) and advanced development (6.3) programs focus more on customers, and consciously think through potential transition issues
- Program advocacy is much stronger and more effective
- Programs gain continuity and stay the course in spite of personnel turnover
- The process enhances funding continuity and opens new avenues for external funding
- The process provides an enhanced ability to revisit established courses of action

When tailored SE is applied by S&T teams, a number of difficulties that persist in attempts to successfully execute S&T programs are reduced or alleviated, including:

- Requirements creep
- Ineffective customer engagement or buy-in
- Insufficient technology maturity planning
- Unproductive technology transition planning
- Weak sponsor or user commitment
- Poor basis for decisions driven by resource constraints

**New AFRL Environment: competition for resources,
emphasis on integration, teamwork is essential.**

History of SE in AFRL

For more than a decade, AFRL has sustained a commitment to enhance their core business processes through the *tailored* application of SE in both the planning and the execution of the S&T portfolio.

Leading the other military services in compliance with direction from an OSD Affordability Task Force, AFRL tasked its Technology Directorates (TDs) in February 2000 to implement an *Affordability Policy* during the execution of advanced technology development programs. This initiative was based on a strategy of *tailoring* SE methods that were proven successful in industry for use in the Air Force S&T environment.

In July 2002, AFRL established an Acquisition Center of Excellence (AFRL/AE) to lead a transformation in the way the latest technologies were planned, developed, and delivered to the AFRL customer base. A memorandum signed in February 2003 by AFRL/CC and SAF/AQR detailing a new Technology Transition Initiative was followed by a memorandum signed in July 2003 directing implementation of a series of actions. Among these actions were imperatives to ensure implementation of SE principles among the AFRL TDs and to craft a comprehensive SE strategy for AFRL that would complement SE initiatives then under development by other acquisition organizations in the Air Force.

In 2005, the AFRL Systems Engineering Working Group (SEWG) achieved Command Section signature and release of a new AFRL Instruction, AFRLI 61-104 "Science and Technology SE Initiative." The AFRLI 61-104 Attachment 2, "Eight (8)-Key SE Questions" provides a foundation for AFRL/RX SE Assessment Standards in the conduct of Program Baseline Reviews (PBR), Laboratory Management Reviews (LMR), and Technical Management Reviews.

The same 8-Key SE Questions are asked across the entire AFRL S&T portfolio. While every S&T program manager is expected to know the answers to these questions, the amount of knowledge needed to answer a particular question satisfactorily (i.e. at LMRs) will change as a program matures from 6.1 to 6.2, and eventually to 6.3.

How do we do it? AFRL "8-Key Questions" per AFRLI 61-104, Attachment 2

1. **Who** is your customer? ...and Why?
2. **What** are the Customer's **requirements**? ...and Why?
3. **How** will you **demonstrate** you have met the requirements? ...and Why?
4. **What** are the **technology options**? ...and Why?
5. **Which** is the **best approach**? ...and Why?
6. **What** are the **risks** to developing the selected technology? ...and Why?
7. **How** will you **structure** your **program** to meet requirements and mitigate risk? ...and Why?
8. **What** is your **business-based transition plan** that meets customer approval? ...and Why?

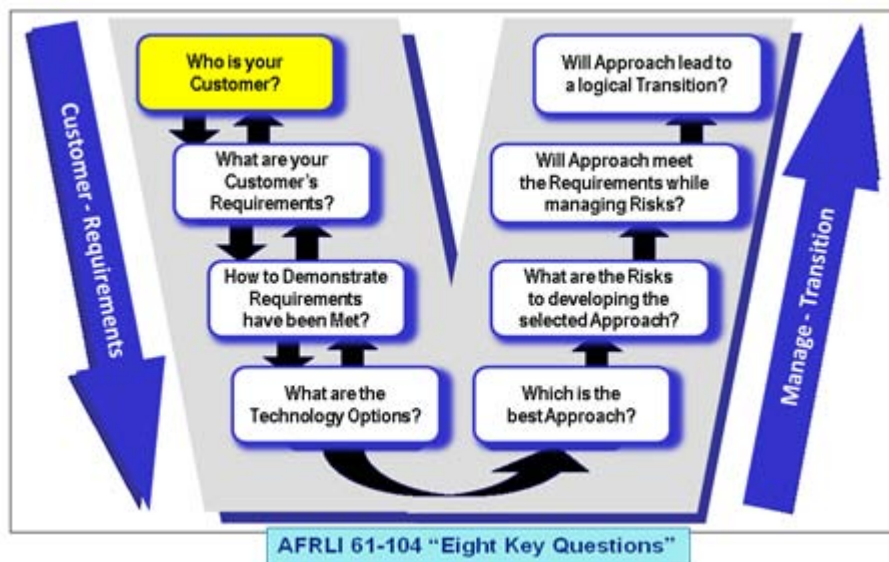


Figure 12. 8- Key Questions presented as Systems Engineering 'Vee'

By 2007, a senior-level Systems Engineering Council (SEC) had been established in AFRL, chaired by the AFRL/XP Deputy for SE and Program Management, and including a Chief Engineer or senior engineer from each AFRL TD. The primary objectives of the SEC are to institutionalize the adoption of SE across AFRL and to leverage SE best practices. A principal focus of this council is, as it has been from the outset, to appropriately *tailor* SE methods for use across the S&T community.

As mentioned earlier, a variety of SE-related formal guidance has been provided from the DOD and the Air Force itself. Appendix G gives a more detailed sampling of this guidance.

APPENDIX D – Conducting Brainstorming Sessions

Brainstorming: a group creativity technique designed to generate a large number of ideas to solve a problem. Brainstorming is a special form of problem solving, where the mind seeks to see solutions never before thought.

Individual Brainstorming before and after Group Sessions: Creativity comes from a blend of both the individual and the collective "ideation." This means providing time for people to think and learn about the topic before the group brainstorm, as well as time to reflect about what happened after the meetings.

Encourage the right mindset and have fun. Consider using an ice-breaker or creativity exercise to get group members into the right frame of mind. Keep the exercise fun.

Ground Rules:

Stated in the memo and at the beginning of the session, there are *four basic rules* in brainstorming intended to reduce social inhibitions among group members, stimulate idea generation, and increase overall creativity of the group.

1. **Quantity:** Facilitate problem solving through the maxim *quantity breeds quality*. Generate as many ideas as possible in a certain amount of time. The assumption is the greater the number of ideas generated, the greater the chance of producing a radical and effective solution
2. **Withhold judgment and criticism:** Focus on extending or adding to ideas, reserving criticism for a later 'critical stage' of the process. By suspending judgment, participants will feel free to generate unusual ideas
3. **No Idea too Stupid -- Encourage unusual ideas:** To get a long list of good ideas, the 'stormers' must look from new perspectives and be creative
4. **Combine and improve ideas:** Good ideas can be combined to form a single better good idea.

Set the problem

Before a brainstorming session, it is important to define the problem for which the alternative/solutions will be generated. The problem must be clear, not too big, and captured in a specific question. If the problem is too big, the facilitator should break it down into smaller components, each with its own question.

Create a list of lead questions

During the brainstorm session the creativity may decrease. At this moment, the facilitator should stimulate creativity by suggesting a lead question to answer, such as *Can we combine these ideas or look at from another perspective?*

Conduct Session

The facilitator leads the brainstorming session and ensures the ground rules are followed. Possible steps in a typical session are:

1. A warm-up session, to expose novice participants to the criticism-free environment. A simple problem is brainstormed, for example *What should be the CEO's retirement present?* or *What can be improved in Microsoft Windows?*.
2. The facilitator presents the problem and gives a further explanation if needed.
3. The facilitator asks the group for their ideas.
4. If no ideas are forthcoming, the facilitator suggests a lead to encourage creativity.
5. All participants present their ideas, and the idea collector records them.
6. To ensure clarity, participants may elaborate on their ideas.
7. When time is up, the facilitator organizes the ideas based on the topic goal and encourages discussion.
8. Ideas are categorized.
9. The whole list is reviewed to ensure everyone understands the ideas.
10. Duplicate ideas and obviously infeasible solutions are removed.
11. The facilitator thanks all for participating.

The Process

- Participants who have ideas but were unable to present them are encouraged to write their ideas down and present them later.
- The idea collector should repeat the idea in the words he or she has written verbatim, to confirm that it expresses the meaning intended by the originator.
- When many participants are having ideas, the one with the most associated idea should have priority. This is to encourage elaboration on previous ideas.
- During a brainstorming session, managers and other superiors may be discouraged from attending, since it may inhibit and reduce the effect of the four basic rules, especially the generation of unusual ideas.

Evaluation

Usually the group itself will evaluate the ideas and select one or possibly two approaches as potential solution(s) to the problem.

- The solution should not require resources or skills the members of the group do not have or cannot acquire.
- If acquiring additional resources or skills is necessary, that needs to be the first part of the solution.
- There must be a way to measure progress and success.
- The steps to carry out the solution must be clear to all, and amenable to being assigned to the members so that each will have an important role.
- There must be a common decision making process to enable a coordinated effort to proceed, and to reassign tasks as the project unfolds.
- There should be evaluations at milestones to decide whether the group is on track toward a final solution.
- There should be incentives to participation so that participants maintain their efforts.

APPENDIX E – Work Breakdown Structure (WBS)

A WBS is one approach to help structure the problem and to establish the relationships of systems necessary to address all functional considerations.

WBS: Define the work (elements) of the project... a “Progressive Elaboration” deliverables-oriented hierarchy.

Level 1: Major System (*per MILSTD 881A: Aircraft, Missile, Ordnance, Space, Sea, Surface Vehicle, etc.*)

Level 2: Major elements of Level 1 (*Air Vehicle, Cost, Test & Evaluation, Training, Systems Engineering, etc.*)

Level 3: Subdivided Level 2 elements (*Frame, Power, Displays & Control, Com/Identification, etc.*)

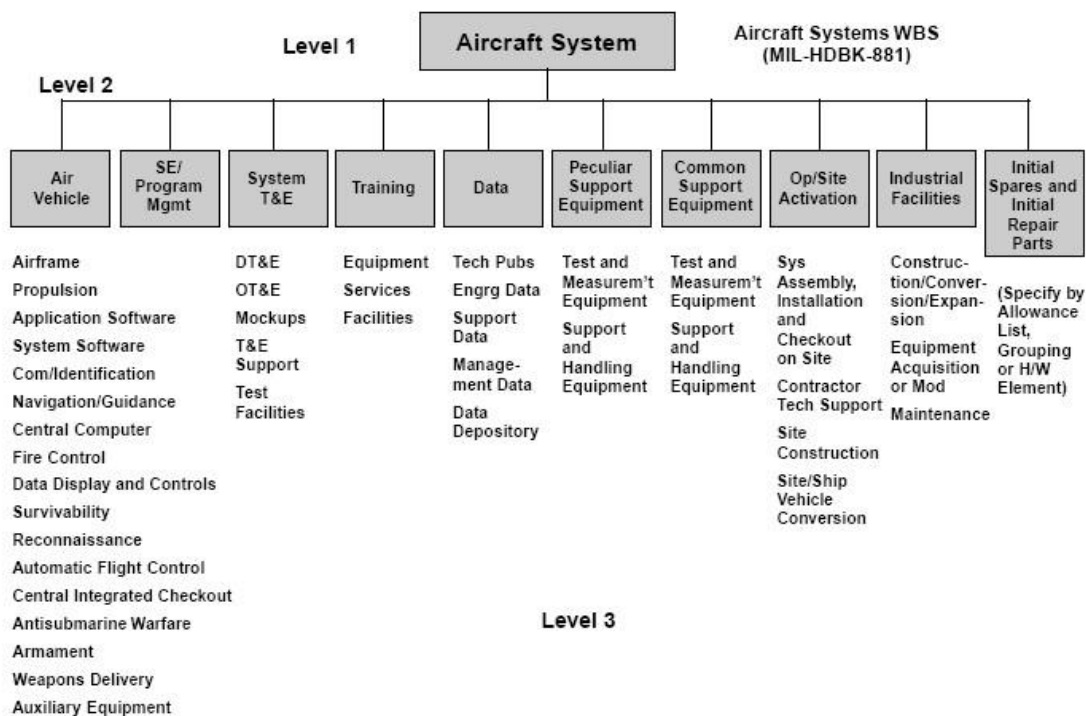


Figure 13. WBS Example to functionally/systematically breakdown elements of the problem/environment

APPENDIX F – Lessons Learned Regarding SE in S&T

The following aspects are often essential to successful planning of an S&T program or project:

- Developing documentation
- Maintaining the team throughout the project
- Sticking to the plan
- Coordinating with the full team as things change
- Non-participating Scribe role
- Building plans and briefings from RX Streamlined SE Core Process products
- The “Team” owns each step in the process and its products

A fixed number of focused team meetings should be defined in the team charter to scope the extent of the program or project planning, understanding that significant changes can lead to iterative planning cycles.

Lessons Learned from AFRL/RX Case Studies:

- Process provided a disciplined analysis of options.
- Process identified need to interface with strong customers outside AFRL (even to DOD and industry)
- Process established a consistent framework for information exchange and synthesis among managers and Subject Matter Experts (SMEs).
- Challenges to process effectiveness include dependence on team participation and SME support.
- Customer/User involvement in the process is extremely valuable; enabling the team to gain insights that otherwise would not have been captured.
- Process is effective as an analysis and a decision-supporting tool in that it reveals sensitivities and quantifies risks.
- Process is easily updated as knowledge evolves.
- Execution of even a part of the process accelerates discovery and causes redirection of thought and effort into more fruitful avenues.
- Team members learned from application of the process about other tools, and surfaced unspoken issues.
- Structured dialogue driven by the process codified thinking.
- Streamlining the process and motivating participants are important.
- Need to establish a timeline and follow it.

APPENDIX G – Systems Engineering Guidance

National Research Council

Pre-Milestone A and Early-Phase Systems Engineering, 2008 Study Report

- Most critical SE activities during Pre-Milestone A/B are
 - Consistent and coordinated user requirements
 - Clear definition of Key Performance Parameters
 - Analysis of Alternatives
 - Structured user, acquirer, industry, sponsors, and S&T collaboration
 - CONOPS
 - Assessment of system performance with Modeling, Simulation and Analysis (MS&A)
 - Architecture
 - Risk assessment
 - Consensus on how requirements will be tested
 - Technology Maturation Plan
 - Establishing cost credibility

Under Secretary of Defense (Acquisition Technology & Logistics)

Policy for Systems Engineering in DoD, 20 February 2004 memo

- SE must be embedded in planning and performed across acquisition life cycle

Systems Engineering Plan (SEP) Preparation Guide, 24 September 2004

- Documentation will include
 - Requirements
 - *Tailored* SE processes
 - Entry and exit criteria

Policy Addendum for Systems Engineering, 22 October 2004

- Program reviews should be event driven
- Peer reviews should be accomplished
- SE best practices in the Defense Acquisition Guide should be *tailored* to meet program needs

Defense Acquisition Guidebook, <https://akss.dau.mil/dag/>

- SE processes are applied early in concept definition, and then continuously throughout the total life cycle
- Balanced solutions are best achieved by applying SE to planning, development, and implementation of a system
- Relevant technologies are considered that they are compatible with the desired time frame and express acceptable risk levels
- New approaches made possible by emerging technologies, as well as by technologies that will improve a system's effectiveness and/or reduce its cost
- Risks and uncertainties associated with new technologies are estimated, and impacts are assessed
- Insight as to user/operator needs is gained, allowing technologists to better focus their technology roadmaps

SAF/AQ Policy on Life Cycle Systems Engineering—Concept Phase

Air Force Instruction 63-1201, Life Cycle Systems Engineering, 23 July 2007

- Fundamental elements of SE are technical processes and measurements
- SE stakeholders include researchers, acquirers, developers, users, operators, testers, trainers, maintainers, and sustainers
- Application of SE must begin with concept inception
- SE involves comprehensive planning and addresses architecting, requirements development and management, design, technical management, test and evaluation, and verification and validation
- Early SE provides an audit trail from the users' capability gaps & needs, through concept selection, high-level system requirements refinement, & documentation of development plans

Technology Transition Initiative, signed 4 February 2003 by AFRL and SAF/AQ

- AFRL's portfolio will...incorporate systems engineering methods *tailored* to the nature of specific technology programs
- SE will be used to achieve *best value* results, accounting for the critical considerations of customer requirements, exit criteria, technology assessment, risk and schedule

Air Force Research Laboratory

AFRLI 61-104, 17 March 2008

- The objectives of the application of SE to AFRL S&T programs are:
 - Stronger AFRL program management and decision-making processes and competencies
 - Alignment and integration of the AFRL technology transition process with those used by customer organizations
 - Consistent delivery of technology products that represent *best value* solutions to needed warfighting capabilities. Best value is defined as the optimum balance of technology solutions that meet (both) customer requirements and the transition risk associated with successful acquisition of those technology solutions
 - Improved rate of successful technology transition to the customers

APPENDIX H – TRL vs. MRL

S&T Exit Criteria, which include S&T Key Performance Parameters (KPPs), are levels of measurable performance (thresholds and objectives) that must be achieved for program success. The demonstrated performance within an S&T environment is used to establish a given technology maturity level, known as a Technology Readiness Level (TRL) (Figure 14).

S&T Exit Criteria are particularly important for S&T programs with transitionable technology products, where these metrics will need to be achieved and validated in a way that follow-on acquisition programs have acceptable risk in meeting the requirement set defined in Step 1.

An AFRL 6.3 ATD program, for example, will typically mature a given technology deliverable only to a TRL value of 5 or 6 before transitioning to an acquirer or other customer. In the case of basic or applied research programs delivering more immature technologies to internal AFRL customers, the TRL deliverable level may be at a much lower value.

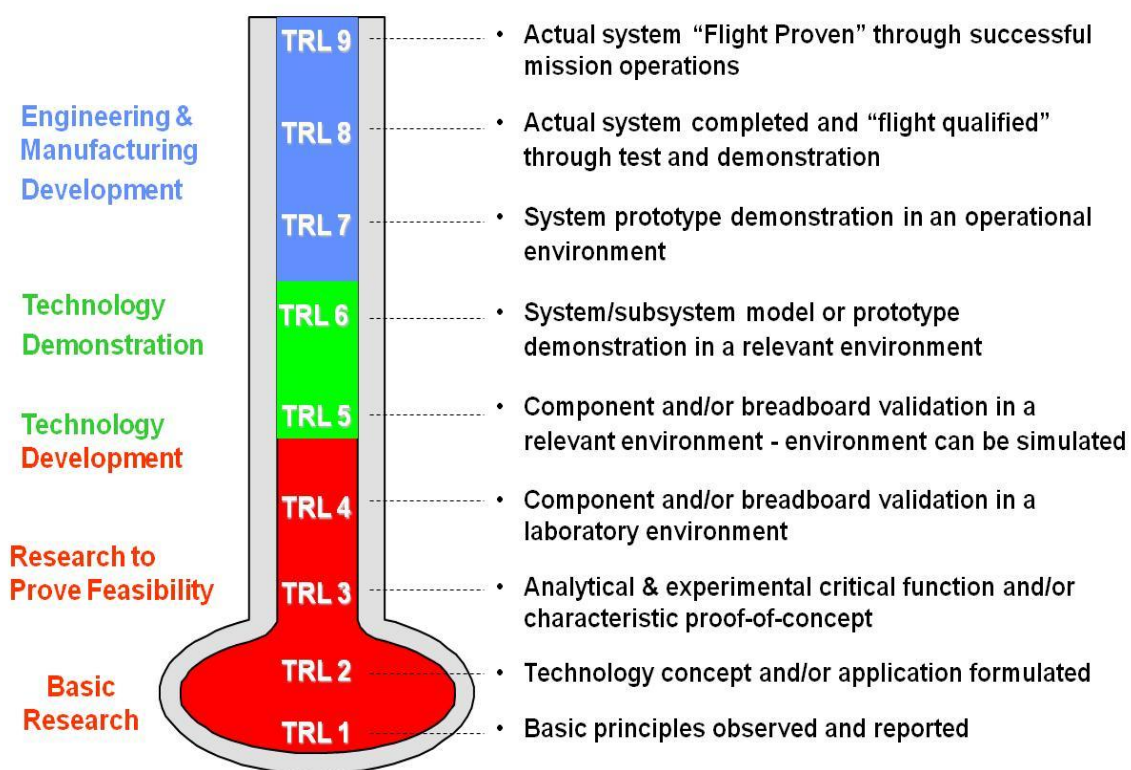


Figure 14. Technology Readiness Levels (TRL) (Definitions taken from DoD 5002)

TRLs are not the only measure of the maturity of technology. It is very possible for a technology to meet all the definitions of a TRL 6 yet be unacceptable for transition to the customer. For this reason, additional dimension of maturity should be evaluated or considered for a given technology solution. Software Readiness Levels (SRL) and Manufacturing Readiness Levels (MRL) are two common areas of consideration. Figure 15 shows the MRL definitions.

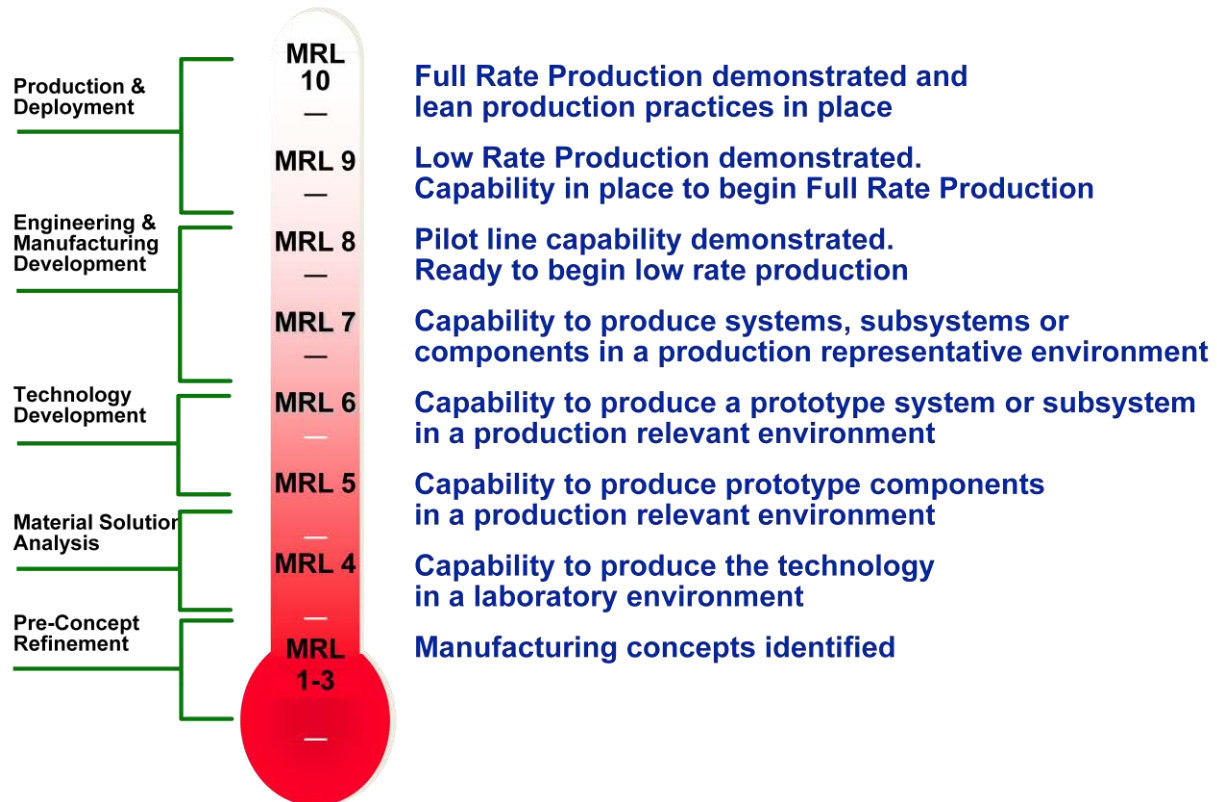


Figure 15. Manufacturing Readiness Levels (MRL) Definitions



Workbook

NAME _____

ACTIVITY _____

DATE _____

***A Companion Workbook to the
AFRL/RX Streamlined S&T Planning Guide
for Applying Tailored Systems Engineering (SE)***

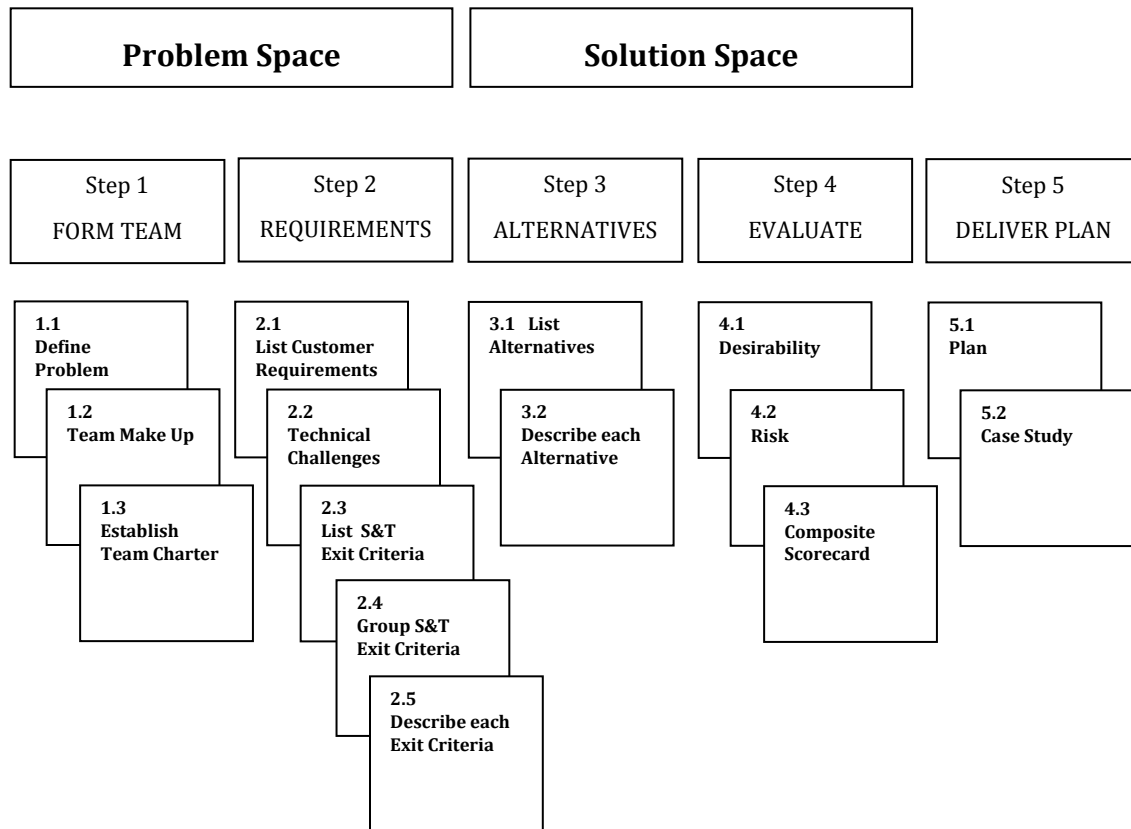
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Workbook Intro

The Worksheets in this Workbook are to foster a TEAM approach to decomposing a problem and to using the principles of Systems Engineering to stimulate creativity and discussion.

Detailed instructions for each Worksheet are available in the Streamlined S&T Planning Guide.



The above Worksheet activities can be used to guide your Team's process and are meant to be customized, expanded, or changed to suit your purpose.

*Step 1: Form Team. Start to think of the team in specific terms of the problem at hand.
Different problems require different member experiences and skills.*

Worksheet 1.1

Define Problem

Project Name: _____
Member Name: _____
Role: _____
Worksheet Date: _____

The team works with the Customer(s)/Stakeholder(s) to scope the problem space.

Who is the Customer? *(Who brought the problem?)* _____

Time frame of Problem *(When Needed/Urgency?):* _____

Describe the Problem *(Scope/Major Issues/Constraints):* _____

Who is the Problem Owner? *(Who has the task to solve the problem?)*

Who is the End User? *(Who turns the wrench/pushes the button?)* _____

Why should AFRL/RX be working this issue? _____

Who Needs to be included as Partners in this issue? _____

What Do We NOT Know? _____

... the "SE Conversation" begins with understanding of the problem...What is the "Discontent?" ...and Why?

Worksheet 1.2

Team Make-up / Roles

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

*With the Problem understood, a team approach (Core plus Augmentees)
must be defined, i.e., identify the skills needed to discuss and refine the Problem*

Team Directory, Roles & Responsibilities

Role/Responsibility

ORG/Symbol

Name / Contact Info

CORE TEAM MEMBERS

- _____
- _____
- _____
- _____
- _____
- _____
- _____

Augmentees *(includes SMEs, Finance, Contracting, etc.)*

- _____
- _____
- _____
- _____

...the "SE Conversation" continues... including all the right expertise and Stakeholders

Worksheet 1.3

Establish Team Charter

Project Name: _____
Member Name: _____
Role: _____
Worksheet Date: _____

The Core Team stays with the entire process. Other persons (Augmentees) are brought in with needed expertise where appropriate.

Use Worksheets 1.1 and 1.2 as backup to this activity

“Planning” Team Charter

- **Goal/Objectives:** _____

- **Schedule**
 - **Meeting frequency** (Weekly, monthly, etc.) _____
 - **Duration: Start:** (mm/dd/yyyy) _____ **End:** (mm/dd/yyyy) _____
- **Resources** (Available to the Team): _____
- **Authority / Accountability** of Team Membership: _____

As a Core Team Member for this planning effort, I understand the following is expected of all Core Team Members:

- **Commit to participate in all team meetings**
- **Commit to complete all “homework” on schedule**
- **Participate in the documentation of each step before proceeding to the next step**

Signatures of all core planning team members commitment

4.	4.
5.	5.
6.	6.

(The above is just a suggested outline. Expand with extra pages if needed)

.. a Team Charter formalizes expectations, removes doubt, and improves the SE “Conversation”

Step 2: Requirements. A solid understanding of the requirements, technical challenges, and how they're stated as S&T Exit Criteria are critical steps in Problem Space documentation.

Worksheet 2.1

List of Customer Requirements

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Core Team refines the understanding of the Customer's Problem into stated requirements and validates them with the Customer

Requirement Name	Requirement Description (Be as specific as possible)	Threshold*	Objective*

**Desirable – vary with maturity of task*

Threshold: *The measurable value that must be achieved for the technology to advance to the next stage of development or transition (usually given as a minimum or maximum value).*

Objective: *The stretch-goal value that is desirable, but not essential (often viewed as the requirements trade space if parameters such as cost or schedule are more important to the customer).*

☐ **DOCUMENT:** *Validate this worksheet with your customer representatives / stakeholders to ensure agreement with the goals.*

...the "Conversation" continues... What capability does my Customer (Want) Need? ...and Why?

Worksheet 2.2

Technical Challenges

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Team now has to turn the Customer Requirements into actionable S&T descriptions (S&T Exit Criteria). This step helps the team decompose the Customer Requirements into Technical Issues (Challenges).

Requirement Name	Technical Challenge Issues

....the SE Conversation continues by identifying "Where's the S&T in this challenge?"...and Why?

Worksheet 2.3

List of S&T Exit Criteria

Project Name: _____
 Member Name: _____
 Role: _____
 Worksheet Date: _____

Customer Requirements are usually at a fairly high level. The team now has to define and document what a final product, technology, or system must do, including the parameters that define successful completion. (Worksheets 2.1 and 2.2) should lead into this step.

Criteria Name	Description	Threshold*	Objective*	RQT Name

**Desirable – vary with maturity of task*

Threshold: *The measurable value that must be achieved for the technology to advance to the next stage of development or transition (usually given as a minimum or maximum value).*

Objective: *The stretch-goal value that is desirable, but not essential (often viewed as the requirements trade space if parameters such as cost or schedule are more important to the customer).*

*...the “Conversation” continues... What S&T Exit Criteria demonstrates the Requirement(s) have been met?” -
and Why?*

Worksheet 2.4

Group S&T

Exit Criteria

by Category

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

S&T Exit Criteria negotiated by the team can usually be grouped into common topics, identified such as P-1, P-2, etc. for Performance, C-1, C-2, etc. for Cost.

There is no limit to the number of S&T Exit Criterion but this is the logical place to consider consolidation, combining the criteria, if appropriate.

ID	S&T Exit Criteria	Description
Group:		
Group:		

Possible Category Groupings (add categories depending on technology)

C= Cost (development, acquisition, deploy, point of use operation)

HF = Human Factors

S = Schedule

E = Environment (EPA, certifications, etc.)

P = Performance (reliability, weight, footprint, set-up time)

ST = Strategic (outside influences, be they political or otherwise)

L = Logistics (transport, service life, storage, scalability, disposal)

POL – Political (constrictions)

...the "Conversation" continues... What groups form the S&T Exit Criterion?" -....and Why?

Worksheet 2.5

S&T Exit Criteria

Complete Description

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Team defines the detailed quantitative attributes of the S&T Exit Criteria.

ID	Name	Priority /Wt*	Units	Threshold Value	Threshold Rationale	Objective Value	Objective Rationale	How Measured
Group --								
Group --								

*Can be used to compare relative importance of S&T Exit Criteria. These are suggestive, use whatever scale you determine relevant/needed."

Priority qualitative ranking: High, Medium, Low....Or,

Weight scores contribution importance: 1 = critical contribution to capability, 0.7 important contribution, and 0.5 if not too important

Threshold: The measurable value that must be achieved for the technology to advance to the next stage of development or transition (usually given as a minimum or maximum value).

Objective: The stretch-goal value that is desirable, but not essential (often viewed as the requirements trade space if parameters such as cost or schedule are more important to the customer).

...the "Conversation" continues... When is 'more or less' better and how do you measure it?" -....and Why?

Step 3: Generate Alternatives. List all the possible ways to solve a problem.

Worksheet 3.1

List Alternatives

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Team identifies possible solutions (called Alternatives) to satisfy each of the S&T Exit Criteria. The Alternatives may be existing technologies, but the team should also explore novel approaches that may offer enhanced payoff... even if it seems a higher risk.

Alternative Name	Description

...the "Conversation" continues...What Alternatives might satisfy the S&T Exit Criteria?and Why?

Worksheet 3.2

Alternatives

Complete Descriptions

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

(One Worksheet per Alternative)

Describe the "attributes" of each Alternative in as great a detail as possible as they pertain to each S&T Exit Criterion. Some form of Description/Quad Chart presentation (attached to Worksheet 3.2) could make value assessment and decision briefing easier as you go.

Alternative Name: _____

Description: _____

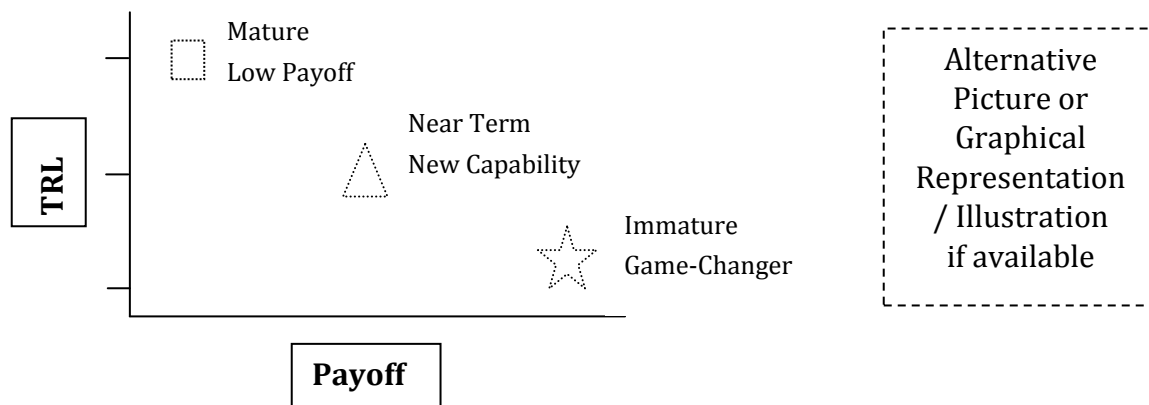
Any Considerations: _____

Estimate Cost and Schedule: _____

Estimate Initial TRL: _____ **Final TRL:** _____

Estimate Initial MRL: _____ **Final MRL:** _____

Estimate Payoff to Maturity score: *(Score the Alternative on the table below)*



Step 4. Evaluate Alternatives (Value Analysis) The Measures of Merit
are Desirability (Worksheet 4.1) and Risk (Worksheet 4.2)

Worksheet 4.1

Desirability for each S&T Exit Criteria Vs. each Alternative

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

(One Worksheet per Alternative)

Certain Exit Criteria (EC) are more important than other Exit Criteria. Enter an EC Weight value from Step 2 to score the relative importance of each exit criteria compared to the other exit criteria.

Certain Alternatives are more credible to attain the Exit Criteria. Enter an Alternative (Alt) Score as to how well the Alternative satisfies each S&T Exit Criterion based on a team establish scoring method. If any Alternative fails to meet one or more S&T Exit Criteria, a zero score is entered. A zero score essentially fails that alternative ($EC\ Wt\ Score \times 0 = 0$), however, it is still recommended the Alternative be retained for the final discussion.

Multiply EC Weight times the Alt Score ($Wt \times Sc$) for an "EC" Score. Add all the EC scores together for an overall Alternative Score ($EC1\ Score + EC2\ Score + EC3\ Score...$)

Alternate Name:					
EC ID	Exit Criteria	EC Wt	Alt Score	EC Score ($Wt \times Sc$)	Rationale
Alternative Score ($EC1\ Score + EC2\ Score + EC3...$)					

DOCUMENT: The Team should negotiate one overall Alternative score for each Alternative that is then transferred and compiled on the Composite Worksheet 4.3

The SE "Conversation" continues "Desirability is a S&T Exit Criteria value with room for flexibility"

Worksheet 4.2

Risk of Achieving each S&T Exit Criterion Vs. each Alternative

(One Worksheet per Alternative)

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Team identifies the top Risks for each Alternative to meet the threshold values for all of the S&T Exit Criteria.

The Team evaluates the Risk of each Alternative against each S&T Exit Criteria and generates a Risk Score (Risk in this context is the probability of failure (Pf) to exceed the Exit Criterion minimum limits (Worksheet 2.5)).

High Risk does not mean the team should not explore all possible Alternatives (see Payoff to Maturity space on Worksheet 3.2). High Risk simply means the team should consider Risk vs. Payoff plus Mitigation difficulty. The score should also include consideration of mitigation difficulty.

Alternate Name:				
EC ID	Exit Criteria	Risk Description	Risk Score	Potential / Mitigation

Overall Risk Score: _____

DOCUMENT: The Team should negotiate one overall Risk score for each Alternative. Each Alternative's overall Risk Score is then transferred to the Composite Scorecard -- Worksheet 4.3

...the "Conversation" continues...What's the Probability of Failure (Risk) to achieve each S&T Exit Criterion?

Worksheet 4.3

Composite Scorecard

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

Transfer all Alternative and Risk scores from each Alternative Worksheets (4.1 and 4.2) to this Composite Scorecard

		ALTERNATIVES			
EC ID	Exit Criteria	Alternative	Alternative	Alternative	Alternative
Alternative Score (Worksheet 4.1)					
Risk Score (Worksheet 4.2)					
Preferred Alternative(s) / Rationale					
Preferred Alternative(s) Decision Documentation					

The Composite Scorecard is not the final answer, but presents the team with values for them to agree on the Preferred Alternative(s).

Analyze the scores by asking the questions:

- 1 - Does the ranking of the composite scores pass the sanity test, i.e., do the values make sense?
- 2 - Do Risks outweigh the scores for the high scoring Alternatives?

Based on this review, the team moves on to the Action Plan for the Preferred Alternative(s). Often in S&T it is common to have multiple alternatives selected for initial development.

...the "Conversation" continues...If a score doesn't make sense, ...discuss why it scored as it did?

Step 5. Build the Plan: With the Problem Space understood and the Solution Space fully explored, Advocacy Briefs and Action Plans can be generated for the Preferred Alternative(s).

Worksheet 5.1

Program Action Plan

Project Name: _____

Member Name: _____

Role: _____

Worksheet Date: _____

The Team should agree upon the plan to advocate for approval/implementation of the proposed S&T program incorporating the Preferred Alternative(s). Depending on the nature of the proposed program, the Action Plan could range from a simple White Paper or Roadmap to a fully detailed advocacy briefing/package. Worksheet 5.1 provides a possible outline based on principles of good program management.

Details necessary to complete this Action Plan include programmatic technology performance, cost and schedule estimates, a basic program execution strategy of external contracts and in-house activities, as well as the type of funding (6.1, 6.2, 6.3) required.

Program Action Plan Checklist (possible outline)

- ☐ Document details of the planning process:
 - ☐ AF problem
 - ☐ Customer(s)/owners/end users
 - ☐ Requirements
 - ☐ S&T Exit Criteria
 - ☐ Details of each alternative solution considered
 - ☐ Preferred alternative(s) selected (include rationale)
- ☐ Document proposed program execution/management plan
 - ☐ Proposed S&T program schedule (with milestones and decision points) – may be in the form of a technology roadmap
 - ☐ Required resources
 - ☐ Proposed execution approach (inhouse, external contracts)
 - ☐ Risk management approach

- **Describe the recommended next steps in advocacy process:**

...the SE "Conversation" never stops...A well thought out plan is easier to defend and execute.

Worksheet 5.2

SE Case Study

While the actions, activities, and experiences of applying the Systems Engineering Streamlined Planning Process are still fresh in the mind of the Core Team and other participants, a Case Study is a useful document to capture the team's discoveries.

Case Study

Description of Problem Space

Background

Study Objectives

Study Process

Description of Technical Effort

The Integrated Product Team

Kickoff Meeting, *date*

Technical and Systems Engineering Process Conclusions

Systems Engineering

Additional Observations

Lessons Learned and Recommendations

Appendix A. List of Acronyms and Terms

Appendix B. References

...the SE "Conversation" never stops...don't be surprised to find this process wasn't worth the time invested.