

Systems Engineering

August 1997

A Way of Thinking

A Way of Doing Business

Enabling Organized Transition
from Need to Product

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American Institute of Aeronautics and Astronautics
Systems Engineering Technical Committee



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In today's increasingly competitive marketplace, many organizations are turning to systems engineering practices to improve their responsiveness to the needs and expectations of various stakeholders (customer, user, buyer, media, public).

This brochure is intended to provide a basic understanding of systems engineering and why its application is essential in today's business environment.

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Why Systems Engineering?

In the first days of a new project, reality is often subservient to enthusiasm and optimism . . . and obscured by the inherent desire to succeed in spite of the fact that technologies, time, and funding constraints may preclude obtaining the desired goals

The need to balance these natural inclinations is a prime driver for implementing an integrated and structured approach to guide the team and to validate that promises are achievable

❑ The Systems Engineering Mission –

- Assure the fully integrated development and realization of products which meet stakeholders' expectations within cost, schedule, and risk constraints

❑ The Bottom Line

When properly implemented, systems engineering will –

- Provide a structured process for integrating and linking requirements, schedule, decision milestones, and verification – it works best when the project team is committed to the systems engineering process
- Enable the project team to work to a single, integrated set of requirements and processes
- Enable integration of the system at the requirements and design stages (before sunk costs) rather than waiting until hardware and software is available
- Reduce unplanned and costly reengineering necessary to resolve omissions and integration difficulties

Effective Systems Engineering enables the project team to sense, anticipate, and prepare for continuing change in an orderly manner

Each Project Implements Systems Engineering To A Different Degree And Depth

In the past, some projects applied systems engineering as an absolute set of tasks, forgetting the real mission of systems engineering . . . The result was often the generation of unneeded data - and a diversion of funds from more productive efforts

However, today it is recognized that different projects need to implement systems engineering in different ways while maintaining the integrity of the process

- ❑ Match Systems Engineering Methods To Project Needs –
 - Some projects (such as research and technology or in-house studies) often only need to have the stakeholder requirements defined and validated - with limited follow-up activities to ensure the integrity of requirements implementation
 - Established projects (with little, if any, discretionary budget) are best supported by occasional monitoring of project results to determine impact on related organizational efforts
 - Projects using the Integrated Product and Process Team (IPPT) approach use systems engineering to ensure the process is defined and adhered to by the project, to identify and resolve conflicts, and to verify that requirements developed by the team meet stakeholder expectations - with the IPPTs accomplishing many of the detailed functions usually associated with systems engineering organizations
 - New and complex projects typically need robust systems engineering to succeed
 - In all cases, the methods for applying the systems engineering process must be adapted to project and team needs

Application of Systems Engineering should provide solutions to stakeholders' problems – not exacerbate them

What Is Systems Engineering?

Systems Engineering brings two vital elements to a project that are not usually present:

- ❑ A disciplined focus on the end product, its enabling products, and its internal and external operational environment (i.e., a system view)
- ❑ A disciplined vision of stakeholders' expectations independent of daily project demands

❑ The Systems Engineering Process –

- Plan and organize the technical aspects of the project
- Analyze the problem posed by the stakeholders
 - Define the stakeholders' problem by converting needs and expectations into validated and integrated technical requirements
 - Develop detailed technical requirements to the extent necessary to enable feasible and economical design solutions
- Assess and evaluate alternatives which may satisfy these needs and expectations and select a balanced solution for each system element as well as a balanced solution for the system as a whole
- Ensure implementation of the balanced solution (design the end product)
- Verify the solution satisfies the stakeholder's requirements

❑ Enabling Resources –

- Requirements Management
- Risk Management
- Technical Reviews (Progress Measurement)

Systems Engineering approach must help the project team to tenaciously pursue stakeholder expectations - or there may not be a customer for the next product

Plan And Organize The Technical Aspects

In a major effort –

- ❑ Experience, skill, dedication, understanding, “doing the right things,” “doing things right,” and
- ❑ Collocation, concurrent engineering, integrated product and process teams, and
- ❑ The most sophisticated tools,

May not be sufficient to overcome the absence of planning and organizing the effort

❑ Answering Key Questions Ensures Effective Planning –

- What is the general problem we are trying to solve?
- What are the influencing factors and constraints?
- How will we know when we have adequately defined the problem?
- What is our organization and schedule for solving the problem?
- What is our methodology for implementing the systems engineering process?
- How will we know when we have adequately solved the problem?

❑ A Few Tools Are Sufficient –

- Engineering Plan – a continuously updated repository for most of the answers to the foregoing questions
- Technical Event Plan – a set of key project events and the corresponding activities (and associated criteria) required to achieve satisfactory completion
- Engineering Schedule – a task oriented calendar schedule for implementing the engineering plan and for scheduling the technical events

A good plan forces the project team to think, to define its vision, to determine its resources, and to know where the team is going - it is not a doorstep

Analyze And Understand The Problem Before Attempting To Solve It

The marketplace has changed – development processes used in the past do not enable an enterprise to meet today's complex challenges and today's competitive markets

It is no longer sufficient to advise a "customer" that the project team knows what is needed and then proceed with a preconceived goal (or one that meets an enterprise's singular view of the marketplace)

- ❑ Defining The Stakeholder Problem Is An Outward Looking Activity – From The System To Its Environment
 - How does the product affect its environment?
 - How is the product affected by its environment and constraints?
 - How will the politics of the environment affect the requirements?
 - Can the technical elements be performed within the acquisition imposed constraints?

- ❑ Defining The Detailed Technical Problem Is A Downward Looking Activity – From The System To Its Many Layers Of Subsystems
 - Conduct appropriate detailed analyses
 - Choose appropriate analytical methods (e.g., structured analysis, object oriented analysis, simulation and modeling, information modeling, rapid prototyping)

- ❑ These Efforts Enable The Project Team To –
 - Identify and quantify operational requirements
 - Identify how well and under what conditions the end product must accomplish its purpose
 - Identify what the end product must be able to do (in terms of both hardware and software) to produce the required operational behaviors
 - Identify enabling elements (such as test and production equipment)
 - Define the system hierarchy and its hardware and software elements

There are no easy short-cuts – just lots of detailed detective work accomplished in a disciplined, cost-driven environment

Assess And Select Alternatives

Most projects begin with preconceived notions of stakeholder expectations, or what is “best” for the user, or how an existing product can be adapted at least cost and effort. . .

Stakeholders, however, expect project teams to assess their needs and determine the most balanced alternative which meets their expectations

- Why Conduct Assessments Of Alternatives?
 - To respond to customer direction and need
 - To challenge requirements, especially with respect to performance expectations
 - To explore viable and cost-effective alternatives
 - To select the best (balanced) technical solution from several alternatives
 - To identify and reduce technical risks through evaluation of competing alternatives
 - To resolve technical problems discovered during design
 - To answer lower-level “what if ” questions

- Elements of Success Include –
 - Identify unbiased selection criteria
 - Document evaluation methods
 - Convert results into derived requirements

Simply meeting requirements may not ensure that Stakeholder needs and expectations are met

Define and Verify The Solution

The engineering of a product occurs in several distinct stages –

- ❑ Transformation of needs and expectations into requirements
- ❑ Implementation of requirements (Design)
- ❑ Implementation of design (Manufacturing)

- ❑ Assure Suitability and Effectiveness Of The Solution –
 - Develop models and prototypes to reduce implementation risks
 - Identify key product attributes and enabling product requirements
 - Perform sensitivity analyses to establish design margins
 - Provide quantitative assessments of potential off-the-shelf products based on demonstrated performance
 - Assist in selecting the preferred system solution
- ❑ Assure Conduct of Design Trade Studies –
 - Evaluate design approach options
 - Evaluate each design solution alternative
- ❑ Assure Avoidance Of Predetermined Designs –
 - Design follows requirements
 - Requirements do not document design on an after-the-fact basis
- ❑ Verify The Solution
 - Verify the end product meets its specified requirements
 - Verify the end product appropriately integrates with other end products and with enabling products
 - Resolve implementation anomalies

If requirements are properly defined, design and verification should offer fewer surprises

Requirements Management - Focusing on Stakeholder Needs and Expectations

No matter how effectively an enterprise transitions from a given solution (design) to an end product, if the enterprise does not properly define and manage the evolving requirements set, the ultimate end product will not provide stakeholders with the expected solution

□ What Is A Requirement?

- If it prescribes that something must be accomplished, transformed, produced, provided, or constrained . . . it's a requirement!
- Requirements state WHAT is needed – the product team determines HOW the requirement will be accomplished

□ Requirements Management -

- Integration of requirements from multiple and separate sources (statement of work, specifications, standards, customer discussions, management directives) at program start - minimizes post-design integration of hardware and software
- Analysis of these integrated requirements for ambiguities, conflicts, and omissions so the project team operates to a single, validated set of requirements (i.e., team members begin from the same starting point)
- Identification and resolution of issues - identification of those requirements needing further analysis, simulations, or trade studies to establish quantitative and measurable objectives
- Conversion of analytical results into balanced, derived requirements
- Controlled evolution of requirements throughout a product's life cycle

A product's life cycle costs are determined early in requirements development – timely analysis and integration of requirements at this point can achieve substantial long-term savings

Risk Management - Identifying And Controlling "Surprises" Before Harm Is Done To The Project

Most risk management programs fail because risks are viewed as team failures; i.e., are based on the premise that good project managers and team members are omnipotent and omniscient

Effective risk management programs succeed because they are premised on the basis that things can and will go wrong, but early identification can simplify resolution and prevent severe harm to the project

□ What Is Risk?

Any concern that might adversely affect the project (specifically, a potential inability to meet a given requirement)

□ Risk Management –

- Integrate risk evaluations into all technical decision processes (risk management as an adjunct wastes a project's time and funds)
- Establish positive feedback to encourage early warning of impending danger (don't reward those who sit on developing risks)
- Designate domain specialists to assess cumulative impact of all concerns on the project's ability to achieve its objectives in their respective areas
- Implement a no-risk / no-test policy - project tests should be conducted to reduce risks to the Stakeholders, not to expand research
- For each significant risk, establish a mitigation plan, assess the mitigation plan as though it were a new high risk program, fund it, and make sure its manager meets the designated milestones - or adopt the predetermined fallback position
- Establish technical performance boundaries on critical and known problem areas and track progress with a vengeance

Risk Management works best if the management team believes it must know the real story - and is willing to do something about it no matter how painful in the near term

Technical Reviews - How Are We Doing?

Technical reviews should not be inquisitions . . . or expensive vu-graph productions . . . or a necessary evil to get out of the way

They should be concise, to the point checks to ensure that one stage of development has been satisfactorily completed before allowing progression to the next stage

- Why Conduct Technical Reviews ?
 - They enable project management to determine on a periodic basis how effectively the team is transitioning from stakeholder needs and expectations, to requirements, to design, and finally to delivered product
 - Whether they are internal (conducted among team members) or contractual (with stakeholder participation), they provide a means to observe technical progress and to obtain approval to proceed to the next level of activity

- Criteria For Effective Technical Reviews –
 - Initiate technical reviews in the early days of a program - but keep them simple to avoid diverting the team from their real purpose
 - Establish clear objectives for each technical review
 - Technical reviews should reflect progress against established requirements
 - Plan technical reviews around key events to the extent practicable
 - Record action items and follow-up through closure

Technical reviews should benefit the project team – not impede it

Systems Engineering Is A Process . . . And More

The systems engineering process is a roadmap, a pathway to help the project team achieve its goals - As with systems engineering tools, the process assists but is not a substitute for getting the job done . . .

Unlike many processes, systems engineering must have a proper environment to flourish – in fact, such an environment is a crucial factor in its application

□ Elements Of Success –

- Organizations need to understand that systems engineering is as much a way of thinking and doing business as it is a process
- It requires a firm commitment of all participants – from the most senior member of management to the new hire at his or her work station
- Systems engineering doesn't call for an isolated team “doing systems engineering” – but rather, it instills an infrastructure in which the organization, the project management team, and team members operate on a daily basis
- Systems engineering defines how the organization discerns a problem, how it approaches the development of a solution to that problem, and how it implements the plan which enables the problem to be solved

The development environment is fragile – if all do not share a common vision and the commitment, failure to meet project objectives is likely

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- American Institute of Aeronautics and Astronautics (AIAA) Systems Engineering Technical Committee

and

- International Council on Systems Engineering (INCOSE) Systems Engineering Management Methods Working Group

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