The Fundamentals of Systems Engineering

An Integrated Product/Process Team (IPPT) Approach to Concurrent and Systems Engineering for New/Upgrade Product Development Projects

<u>Introductory Seminar</u> (For Student Practitioners)

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- # About This Tutorial:
  - ## Assumed Audience Knowledge:
    - Everyone in typical audience knows some of the presented material and alternate good methods. (Although the individual may not realize that some of the common sense approaches work together until they are described.)
  - ## Tutorial Objectives:
    - To build understanding of System Engineering as a profession via general descriptions of what major methods are common, along with when, where, and why they are employed.

- History:
  - Many individual military systems already were somewhat complicated by the end of WWII. However, the first major success in describing the means to organize weapons development at the project and engineering level was after the Vietnam Conflict with publication of Army Field Manual 770-78, Systems Engineering.
  - Subsequently, military/aerospace systems have increased in scope, scale, & complexity.

- Why does that matter to you?
  - Commercial products are becoming large in scope and scale, with complexity such that an approach useful for their development is like that needed for military/aerospace systems.
  - So, because much of today's employment is related to complex products development, entry level software and hardware engineers and project management assistants can have more perceived value by showing knowledge of methods described in this seminar.

- Integrated Product/Process Teaming
  - It isn’t well known that the parallel product design and process development concepts known as Concurrent Engineering (also called Simultaneous Engineering) essentially are identical to defense industry approach called integrated product/process development.
  - So, few know that only minor adapting and tailoring for downscaling provides the useful IPPT framework and approach for solving many current and upcoming problems.

- IPPT Project Planning:
  - As a discipline, ***Concurrent Engineering is to Systems Engineering as chemistry is to physics.*** Critically important and sufficiently complex to involve specialists, the CE field nevertheless is contained within the SE field for the majority of its application.
    - (Even those who would argue for differences between Concurrent and System Engineering should agree that goals of both named approaches are similar and generally overlapping.)

- IPPT Project Planning (Continued):
  - Because product design is inseparable from manufacturing and support processes, IPPT or Concurrent Engineering ensures that its impact on their ultimate costs at all decision points is considered during development.
  - A key goal of Systems Engineering related project planning is to quickly define stable specifications via gaining both consensus of the affected parties and their commitment to develop a conforming product.

- IPPT Project Planning (Continued):
  - Integrated information sharing necessary for concurrence of tasks results in an integrated approach that facilitates application of Quality Function Deployment (QFD).
  - This results in a shorter project development duration to obtain the same end result, which helps producers to meet time-to-market needs with something more substantial than another announcement of a later introduction date.

- IPPT Project Planning (Continued):
  - A key to success is experienced production engineers on the development team. Final output can be built with minimum variability and tested with common equipment. Robust designs reuse as much as possible and start from scratch only if necessary.
  - Successful projects come from designs with customer and other users requirements held paramount while engineering and project management staff have a life-cycle perspective for the product.

- Systems Engineering Defined ("Old"):
  - SysEng is defined In AFM 770-78 as selective application of scientific/engineering efforts to:
    - **Transform** an operational need into a description of a system configuration which best satisfies [it] according to the measures of effectiveness;
    - **Integrate** related technical parameters and ensure compatibility of physical, functional, and technical program interfaces in a manner which optimizes the total system definition and design.
    - **Integrate** the efforts of all engineering disciplines and specialties into the total engineering effort.

- Systems Engineering Defined ("New"):
  - SysEng is defined by INCOSE as:
    - an interdisciplinary approach & means to enable realization of successful systems. It defines the customer required functionality early in the development cycle, documents those requirements, then proceeds with design synthesis & system validation while considering the complete problem:
    - e.g., Operations, Performance, Test, Manufacturing, Cost and Schedule, Training and Support, Disposal
    - Systems Engineering integrates the disciplines and specialty groups into a team effort forming a structured development process that moves from concept to production to operation. Systems Engineering considers both business and technical needs of the customers with goal to provide a quality product that meets user needs.

- Systems Engineering:
  - System Engineering includes management and execution of the abstract process of problem identification and definition, system hardware and software conception, planning and design, system integration & verification, system fielding for use, and safe disposal at the end of system life.
  - The usual approach is top-down, with requirements allocation to system elements that balance life-cycle cost and effectiveness to result in a producible system.

- Systems Engineering (Continued):
  - System engineers synthesize system design concepts, perform tradeoff analyses, and provide hardware and software requirements to specialty designers.
  - During detailed design, System Engineers check for requirements fulfillment, resolve hardware and software interface issues, and verify product is ready for a seamless transfer to production.
  - System Engineering involves time, in terms of project phases, and logical problem solving for decision making in the large (compared to the usual level for application of trade-off analyses).

- Systems Engineering (Continued):
  - The process can be a profession, although its knowledge base is not as detailed as some specialty design engineering. Also, because it involves design of systems that combine hardware and software to achieve objectives, approach and mental perspective often are more important than the specific knowledge base.
  - To show its criticality and value added, common symptoms of not using an IPPT approach are excess costs, schedule slips, and deficient performance.

- Systems Engineering (Continued):
  - Dissatisfaction with Systems Engineering can arise from inadequate funding because then nearly all the outputs from the process have matching inadequacy. Managers without full understanding in this area tend to blame the individual engineers for producing too little output while assigned to meet impossible schedules.
  - Because front end System Engineering work is to avoid project surprises, it becomes a "pay now or pay far more later" situation.

- Systems Engineering (Continued):
  - A basic tenet of System Engineering is goal-directed tailoring of processes and tools to scope and scale of projects.
  - Too little process adds risk but too much adds cost.
  - Tailoring uses judgment based on experience that may resemble the current project only in a superficial way, so inconsistency in results is likely.

- Systems Engineering (Continued):
  - Product Life Cycle Concept Names:
    - Program Planning -- Determining what ***management*** for what projects will be required to implement system and subsystems development, considering need for Research and Development (R&D) and availability of inventory items.
    - Project Planning -- Determining what tasks will be required to develop a major system or individual subsystem(s) for operational use.

- Systems Engineering (Continued):
  - Product Life Cycle Concept Names (Cont.):
    - System Development -- Implementing project plan by specifying requirements, establishing concept architecture, simulation modeling, prototyping, designing products, manufacturing subassemblies, integrating hardware/software into (sub)system(s), and testing for fulfillment of specified requirements. SysEng outputs are system specifications (stating customer needs as functional & performance requirements), derived hardware/software specs and general interface specs, then procedures for verifying fulfillment of the derived requirements.

- Systems Engineering (Continued):
  - Product Life Cycle Concept Names (Cont.):
    - System Development (Continued) -- The specialty designers produce mechanical drawings, electrical schematics, parts lists, procurement specifications, and change orders to the foregoing.
    - Production -- Manufacturing or purchasing the subassemblies and building systems, installing software, environmental stress screening (ESS), and acceptance tests for selloff to customer. This may include developing the necessary production facilities.

- Systems Engineering (Continued):
  - Product Life Cycle Concept Names (Cont.):
    - Distribution -- Delivery and installation of system for users. This includes handling, packaging, transportation, unpacking, installation, setup, and user testing.
    - Operations -- Application of system. This includes field changes in hardware/software, or operating procedures as maintenance or enhancement.
    - Retirement – Removal/disposal of the system on secondary market (if still usable) or as either inert or recyclable scrap when no operational value left.

- Systems Engineering (Continued):
  - SysEng Process Concept Names:
    - Problem Definition -- Identifying and sufficiently understanding the problems causing the set of symptoms to communicate the situation clearly to all interested parties.
    - Criteria Definition -- Develop objectives of solution system and criteria to measure level of objectives satisfaction.
    - System Synthesis – Propose/identify alternatives and deduce consequences of implementing each.

- Systems Engineering (Continued):
  - SysEng Process Concept Names (Cont.):
    - Alternatives Optimization -- Determine the best use of each alternative by modeling or analysis.
    - Decision Making -- Evaluate and rank proposed options with respect to developed criteria.
    - Implementation Planning -- Prepare for execution of next phase in project.

- Military Systems Engineering:
  - SysEng Process Concept Names:
    - Functional Analysis
      - Basic Input Analysis
      - Operational Requirements Analysis
      - Preparation of Specifications
    - Synthesis of Conceptual System
      - architectural concept designs
    - Evaluation and Decision
      - trade-off analysis
    - Description of System Elements
      - system level specifications

- Military Systems Engineering (Continued):
  - SysEng Process Concept Names (Cont.):
    - System Design (Support)
      - subsystem level specifications
      - development of requirements verification procedures and maintenance testing requirements
    - System Integration and Verification
      - engineering (development) testing (support)
      - system integration testing
      - system acceptance testing
    - Systems Engineering Management
      - Includes Project Risk Management

- Medical Systems Engineering:
  - SysEng Process Concept Names are similar to the general and military, except for:
    - Medical Risk Analysis (how used)
      - Hazard Analysis
      - Fault Tree Analysis (descend to crosscheck or identify high reliability need for single point failure item)
    - System Validation
      - mostly subsystem requirements verification (with one or more of test, demonstration, inspection, or analysis)
      - system interoperability testing
      - customer commissioning for patient treatment

- Systems Engineering Perspective:
  - Primary approach is applying a "holistic view," to comprehend and to maintain perspective of customers and users despite usual employer pressures to put schedule and budget ahead of complete requirements fulfillment (quality).
  - Skillfully applied Systems Engineering keeps the programs technically honest, because system functions and interfaces are recognized as the means to accomplish the operational missions rather than as the purpose for the design.

- Systems Engineering Perspective (Cont.):
  - System Engineers are the top level problem solvers without parochial bias. (Broad general knowledge of non-technical as well as technical disciplines within business, management, and government can help with this.)
  - Partitioning of systems into manageable subsystems is a typical high level System Engineering task.
  - Often, System Analysis activities are part of the necessary system design tasks.

- What is Product Quality?
  - The objective measurement of manufactured product quality is its degree of conformance to requirements.
  - Quality Assurance earns its keep by reducing the cost of non-conformance to well below the cost of quality, by working to have the quality built in (because it cannot be tested in).
  - Providing product quality is the fundamental reason to establish requirements for product functions and their levels of performance.

- Requirements Development:
  - ***Knowing that necessity to fulfill system objectives determines when to convert an informational string of text into a requirement is a key to success.***
  - That is, each proposed requirement must be evaluated for its contribution to customer(s) desired system missions accomplishment (via quantification and allocation of goals) before its inclusion in a system specification.

- Requirements Development (Cont.):
  - Initial functional requirements should be technology independent and free of any implementation concept, to maximum possible extent. (One major exception is interface with another existing or planned system.)
  - A standard format helps to gather associated requirements for finding redundancies or conflicts.
  - Requirements should be unambiguous and explicit, of course.

- Requirements Development (Cont.):
  - Many such requirements “rules” exist, with main intent to assist completeness of their information transfer to design specialists who are to develop the resulting system.
  - Ability to compose and to design traceable verification of requirements allows trained system engineers to be quite "generic" in application; to be quickly adaptive from one project to another unrelated project.

- Educational Requirements:
  - Some academics express the belief (surprise, surprise) that a graduate degree is necessary for advanced knowledge and experience that supports System Engineering effectiveness.
  - Contrarily, one’s approach and attitude are of greatest importance. Ability to understand the results expected from the specialty designers and probable methods for accomplishing their allocated requirements verification usually is adequate.

- IPPT Compliance Tools:
  - Document Templates:
    - The PMP Tailoring Plan (or the cited separate document) provides the instructions for tailoring project work by describing deletions of or within each standard project document.
      - Entire documents may be deleted if the safety standards are met and the regulatory requirements are fulfilled.
      - Usually, sections or specific portions of the project documents are deleted by the tailoring.
      - In each document, the deleted part is replaced by, “This [section/subsection/paragraph] is deleted in accordance with [document ID], the [Project Name] Tailoring Plan.”

- IPPT Compliance Tools (Continued):
  - Document Templates (Continued):
    - Multi-use Requirements Specification templates contain detailed instructions in early subsections, to guide providing project information for system, hardware, and software specifications (& possible inclusion of subsidiary implementation/design “requirements”).
    - Templates for the ancillary documents also instruct providing records necessary for fulfilling design qualification objectives, such as complying with international, domestic standards for safety, or with company standards for availability.

- IPPT Compliance Tools (Continued):
  - Document Templates (Continued):
    - Template content descriptions enable authors to quickly learn where information should be placed.
    - Thus, QA and other reviewers can evaluate likely adequacy of provided content – even when it is well outside their domains of expertise.
    - Such standardization is especially helpful when upgrading poorly documented legacy systems that require extensive reverse engineering and capture of widely scattered and untraced requirements information.

- IPPT Compliance Tools (Continued):
  - Requirements Management Tools:
    - Commercial requirements management tools are database programs that:
      - Import requirements from specifications and assign a project unique identifier (PUI) to each requirement.
      - Maintain attachment to the specifications, such that revision may be made in the tool or the specification.
      - Provide Attributes to hold the assigned values for each requirement's associated information.
      - Enable assigning PUI to PUI linkages to one or more requirements in other documents to establish source driver and responder relationships.

- IPPT Compliance Tools (Continued):
  - Requirements Management Tools:
    - Commercial requirements management tools (Continued):
      - With pre-importation setup steps, all of the information necessary for a Requirements Verification Trace Matrix (RVTM) can be imported or installed in the requirements management tool.
      - Support for custom reports is provided by most tools, because it is defining rules for selecting items from the database to order for meaningful display or to generate a useful report.

- IPPT Compliance Tools (Continued):
  - Requirements Management Tools:
    - Commercial requirements mgt tools (Continued):
      - Provided support ranges from fairly intuitive format layout and selection of sorting and inclusion/exclusion rules for populating the report to only the next level up from pure programming of another utility to access the database.
      - A major feature of requirements management tools is automatic notification of which other requirement(s) possibly are affected (based on their PUIs linking) by revision to a requirement.
      - (This is accomplished within the spreadsheet RVTM by examining the adjacent traced items.)

- Implementation Issues:
  - Introducing Changes to Projects:
    - Even when supported by management, changes should be introduced gradually into the projects already begun. (<u>You</u> know why and how processes are improved, but those with less training may not.)
      - Overzealous mandates can set back use of new methods. Instead, begin with development of selected examples for upcoming project work.

- Implementation Issues (Continued):
  - Introducing Changes to Projects (Continued):
    - Smooth Change Introduction:
      - Most engineers are pleased when a Systems Engineer offers to derive “their” draft HRS or SRS requirements from the PRD, so systems work is reduced to review and corrections and they can quickly return to the “real work”.
      - When something is published, critics (that previously didn’t have time to answer your questions) will do more than their normal work to “reveal your errors”.
      - Without forcing issues, plant mental “seeds” with Socratic questions and suggestions. With trainable coworkers, you can reason that a different method might be better.

- Conclusions for Students:
  - Systems Thinking assists ambitious workers in quickly learning how their early and later jobs fit within the overall business, which enables suggestions for process improvement (often seen by management as indication of potential for rapid advancement).
  - As students, you already have done planning and other work that often is part of Systems Engineering. You now have knowledge of the other methods to apply when they could be useful to you.

- Associated Project Support:
  - The Project Management Institute (PMI) is a more business oriented organization than the International Council on Systems Engineering (INCOSE), with separate focus on financial contract compliance and resources allocation as part of the project planning,
  - Standard Project Management functions overlap those of System Engineering in areas of project tasks definition, the less technical customer interface, and Risk Management.

- Sources of Further Information:
  - The LA Chapter of the International Council on Systems Engineering (INCOSE) is active, but is primarily oriented to defense systems suppliers. (The Inland Empire chapter was disbanded a few years ago as its defense oriented membership base shrank.)
  - Telelogic (now part of IBM) has information on DOORS, a useful Requirements Management Tool.

- More Sources of Further Information:
  - Much of information in this Seminar is from the free tutorials on the presenter’s website, so Richard Botting, Seminars CSE CSUSB, was given a pdf copy to distribute on request to interested Seminar attendees.
  - Internet searches provide other information.

- Tutorial Presented By:

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