Extending the Systems Engineering Methodology to Include Supportability Engineering

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Abstract

Systems' engineering has always been an essential part of developing integrated solutions. From its' earliest inceptions, systems engineering dealt with providing a solution that balanced performance and operational requirements at the lowest life cycle cost. As an art form, systems' engineering was based upon the methods and processes of individuals. As the tools, methodologies and philosophies of systems engineering evolved, it was transformed from an art to a science. This transformation is demonstrated in evolution that occurred through IEEE 1220, EIA 632, and EIA 731.

While many of the attributes of these guidance documents map in to understood design areas such as hardware, software, and ease of manufacture, they do not clearly map into areas such as support strategy, impact to total ownership cost, maintenance planning and technology refresh cycles. These later actions fall under the discipline of supportability engineering. The systems engineering model contains numerous opportunities for supportability linkage, however the supportability hand-offs were undefined when the systems engineering standards were released. This is because systems engineering guidance documents were being written at the same time supportability engineering was evolving to a standalone entity. The result is the documents have a strong interface, but without the necessary details to effectively integrate the disciplines.

This paper describes the interconnections and key linkages that need to be addressed to flow information between supportability engineering and systems engineering, and the further evolution of the systems engineering process through assimilation of supportability engineering.

What is Supportability Engineering

Supportability engineering defines the degree to which the system and the planned logistic resources meet system peacetime readiness and wartime utilization.

Supportability Engineering is functionally a subset of systems engineering, and is performed during the concept exploration and early systems development phases of a program when the system design is in its formative stage. The initial supportability analyses focus on the relationship between functional requirements (defined by the systems engineer), operational readiness, existing force structure, the desired mission profile, and mobilization. The analyses expand to associate a cost goal for each of the functional requirements. As the design matures, the analyses become more discrete.

For example, the company needs to design a computer that can quickly add up numbers. The supportability engineer likes to use an abacus; it is already fielded, requires no maintenance, and has a 20+ year life expectancy. The design engineers want to build a super computer with parts that should be available in three years. The systems engineer provides feedback and guidance in both directions, and leads the economic and non-economic factors to trade-off design alternatives, resulting in a product that not only meets the performance requirements, it meets the operational tempo in a cost effective manner for the User.

The readiness and supportability characteristics of a system are identified by the supportability engineer and are used in the systems engineering process in the determination of design requirements. These analyses are performed starting in the early design phases and continued throughout the design process to assist in determining the optimal balance between functional performance, readiness, and the acquisition of a supportable system (Ref. 1).

Why Do We Need Supportability Engineering

Supportability engineering is needed to define and develop an optimized support posture for the system, perform trade studies as part of the systems engineering process, and ensure that the characteristics are incorporated into the design.

The resulting product of the supportability/systems engineering process is to develop a life cycle balanced solution. Supportability engineering works as part of the design team to identify, to the greatest level of discretion, cost drivers, maintenance drivers, and potential supportability factors of the system design that influence optimization for the user. The supportability engineer develops a support strategy that will embrace and serve the designed product throughout its intended service life. The support strategy includes all aspects of supportability from cradle to grave including design characteristics for supportability, optimized ownership cost, usage by the ultimate customer, and disposal with environmental impact planning.

Inputs and tools provided by the supportability engineer to the systems engineer include:

a) Strategic logistics
b) Development of the acquisition support strategy plan
c) Cost As an Independent Variable (CAIV)
d) Life Cycle Cost (LCC)
e) Reliability Centered Maintenance (RCM)
f) Risk planning
g) Software Support Engineering
h) Total Ownership Cost (TOC)

For example, the systems engineer is looking at a design alternative for a liquid cooled computing system. The trade-off is between the performance of a liquid cooled versus air-cooled solution. From a supportability perspective, liquid cooling has numerous scheduled maintenance actions, unscheduled maintenance that may bringing the entire system off line, and an operational support requirement for the fielded life of the system. The supportability engineer works with the systems engineer to evaluate different concepts on how this equipment will be used operationally, how to support it, and trading off with the systems engineer for performance versus usability. The supportability engineer performs LCC, RCM, and supportability engineering trade-off analyses to provide the systems engineer with inputs to identifying the optimal solution.

Extending Systems Engineering to Include Supportability Engineering

A primary goal shared by systems engineering and supportability engineering is the satisfaction of the customers' need at an optimized total ownership cost (see figure 1). This shared goal is the basis for the initial involvement and analysis performed by the supportability engineer during concept exploration and through design development. Based on the functional requirements developed by the systems engineer, the supportability engineer will establish a preferred support strategy evaluating all aspects of product support (Ref. 2).

There are key functions that supportability engineering performs as a member of the systems engineering team: (Ref. 3)

a) To identify supportability and logistics constraints in the Operational Requirements Document (ORD); to define the resultant logistics support requirements for each design alternative

b) Optimization of logistics factors to down-select to the preferred design alternative

c) Assist in the decomposition of the supportability aspects of the design to create cost-effective/supportable detailed design decisions

d) Identify and recommend test and testability; plan logistics support for the product/system during developmental engineering tests and during all early field operational tests.

e) Identify all necessary items of support to ensure that the system definition and procurement includes both the system/product/service and all requisite items of support for each element.

f) Provide the system to the customers in the right place, at the right time, and in the right quantities through the execution of a good support plan and fielding plan

g) Improve the system through the inevitable change/modification process

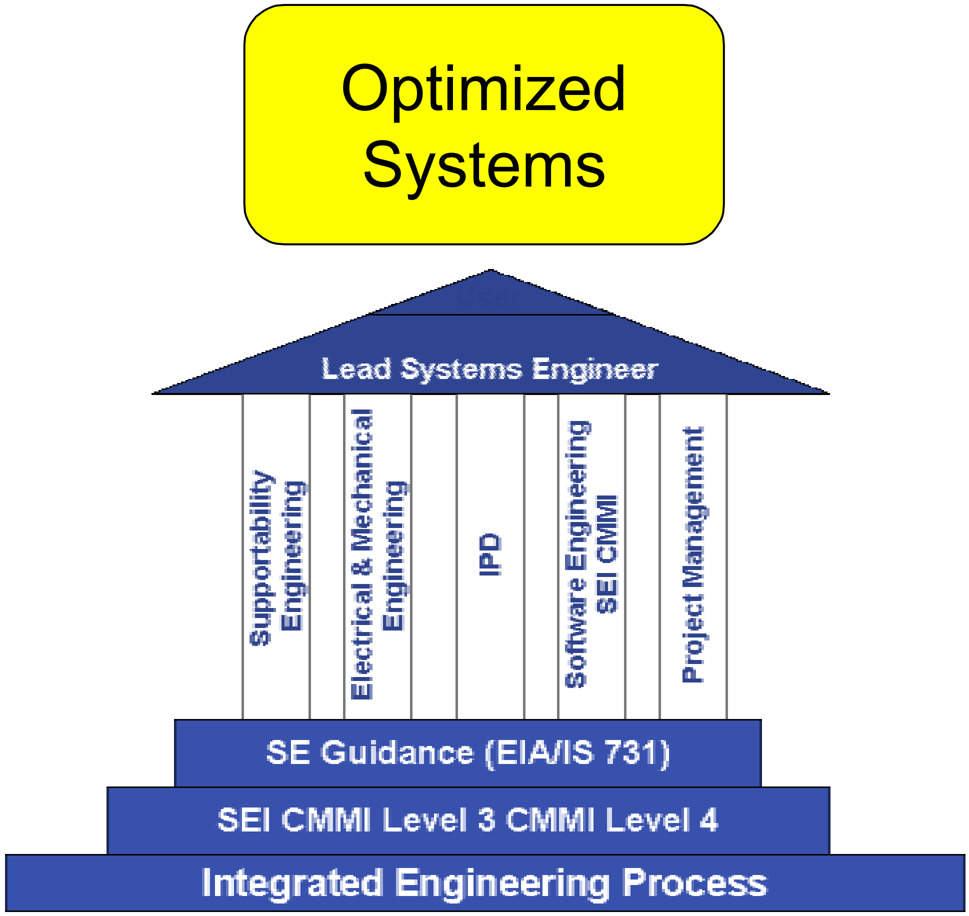

Figure 1. Supportability and Systems Engineering

The supportability engineer uses the initial analyses to create a framework for the logistics products to be developed during the later part of the design and the early production phases. These products include user training, technical documentation for maintenance in the field and at non-OEM sites, spares procurement, support and test equipment requirements, and technology refresh cycles. For example, a design that accommodates remote support may avoid the need for expensive on-site visits by field engineers. Another example is the use of on-board computer based training (CBT) to significantly reduce the amount of direct training that users require on complex products (Ref. 2).

The clearest way to show how supportability engineering needs to interweave with systems engineering is to start with a typical program. An example of United States Department of Defense (US DoD) program phases is summarized in Figure 2. This figure, taken from the INCOSE Systems Engineering Handbook (Ref. 4), also shows twenty-one key program tasks, which are conducted during a typical program life cycle. The tasks shown here are from a Systems Engineering process perspective.

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PHASE O	I	II	III
CONCEPT EXPLORATION (CE)	PROG. DEFINITION & RISK REDUCTION (PD&RR)	ENGINEERING & MANUFACTURING DEVELOPMENT (EMD)	PRODUCTION, FIELD-ING/DEPLOY, & OPNL. SUPPORT (PFD&OS)
1. SYSTEM ANALYSIS 2. REQTS. DEFINITION 3. CONCEPTUAL DESIGNS 4. TECHNOLOGY & RISK ASSESSMENT 5. PRELIM. COST, SCHED. & PERF. OF RECOMMENDED CONCEPT	6. CONCEPT DESIGN 7. SUBSYS. TRADEOFFS 8. PRELIMINARY DESIGN 9. PROTOTYPING, TEST, & EVALUATION 10. INTEGRATION OF MANUFACTURING & SUPPORTABILITY CONSIDERATIONS INTO DESIGN EFFORT	11. DETAIL DESIGN 12. DEVELOPMENT 13. RISK MANAGEMENT 14. DEVELOPMENT TEST & EVALUATION 15. SYSTEM INTEGRATION, TEST, & EVALUATION 16. MANUFACTURING PROCESS VERIFICATION	17. PRODUCTION RATE VERIFICATION 18. OPERATIONAL TEST & EVALUATION 19. DEPLOYMENT 20. OPERATIONAL SUPPORT & UPGRADE 21. RETIREMENT 22. REPLACEMENT PLANNING

DISPOSAL

EVOLUTIONARY REQUIREMENTS DEFINITION

Figure 2. Systems Engineering Process Phases

Phase 0 - Concept Exploration

Supportability engineering begins with systems engineering during the concept phase. There are three significant tasks performed by supportability engineering, (a) development of a support strategy, (b) participation in the system cost effectiveness analysis, and (c) identification of logistic risks.

a) Development of a support strategy: the concept phase generally begins with a user need. The systems engineer begins to translate the user need with the development team to form a series of required functions. It is during this phase that the user has also indicated a mission profile. The mission profile is basically the answer to "why build the product". The User has a general concept of what the intended product will be used for, how the product should be used, and what problem or need the fielded item will solve. These questions will determine the availability, deployment, and mobility of the item. The support strategy needs to support these goals of the customer over the intended service life of the product. A Support Strategy report is developed to include support approached for achieving a successful fielded life, and the associated expected cost for each characteristic of support.

b) Participation in the system cost effectiveness analysis: For supportability engineering cost effectiveness includes deployment analysis, operational analysis in the field, supportability analysis, training analysis, disposal analysis, life cycle cost analysis, and total ownership cost analysis (Ref. 4). Two of the key supportability engineering analyses associated with cost effectiveness are life cycle cost (LCC) and total ownership cost (TOC). Life cycle cost can be viewed as a snapshot in time of the cost of a fielded product. The LCC includes costs associated with initial Research, Development, test and evaluation (RDT&E), production and deployment (fielding, and operation support costs (O&S). Total Ownership Cost takes the LCC and adds to it by including costs associated with item management by the customer, program management by the Original Equipment Manufacturer (OEM), and other extraneous cost factors not typically associated with the ownership of a product. To distinguish between LCC and TOC, look at LCC as a noun (a fixed picture), and look at TOC as a verb, a constantly changing summation of actual costs and projected/predicted parametric costs. LCC is more readily used for initial trade-offs in selecting design characteristics or in the determination of short term cost drivers. TOC is better used for determining cost impacts that may lend themselves toward trends.

c) Identification of logistic risks: the greatest risk associated with logistics is the failure to bring supportability engineering on board as part of the design team. Supportability analysis performed after the fact merely documents design shortcomings, as opposed to supportability influencing the design (Ref. 5). Associated with supportability and logistics are program related risks, and environmental risks. Program risks include addressing interchangeability, COTS technology refresh cycles, DMS related issues, impacts to TOC and LCC, and designing without consideration for maintenance time or related resources. Environmental risks include operation and disposal of systems, and impacts and assure sustainability of these systems.

Phase 1: Program Definition & Risk Reduction

Supportability engineering contributes by (a) determining supportability design-to requirements (SDTRs), (b) performing trade studies based on SDTR measures of effectiveness, (c) establishing the initial Logistics Supportability planning, and (d) refining the support concept selection.

a) **Determining supportability design-to requirements (SDTRs):**
SDTRs are design characteristics that reduce the supportability impact to the total ownership cost. They may result in a reduced maintenance task time, easier access to failed parts, elimination of a potential piece of special (new) support equipment or tool, or use of a product that has a long industry life and will push our the impact of diminishing manufacturing sources (DMS). SDTRs are determined through analyses such as comparative task analysis, field performance data by other contractors on other products, and lessons learned.

b) **Performing trade studies based on SDTR measures of effectiveness:**
Visualize and model logistics scenarios to provide the systems engineer with alternatives during trade-offs. Tradeoffs include COTS versus new design support cost estimates; also, today's products are more reliable and this had reduced the relative importance of maintenance and repair. On the other hand, the complexity of equipment has often increased, particularly if it is software-based. This has raised the relative importance of aspects of product support such as user training and telephone support (Ref. 2). Consequently, designers need to consider how they can make support easier because of the costs involved; for example, software support costs are typically 6% of revenues in the software industry (Ref. 6). Cost optimization; perform baseline comparative analysis to assist in the selection of COTS or to determine if a new design is required. Trade-off analyses may also include determination of existing support & test equipment for FD/FI (fault detection/fault isolation) to the COTS equipment, or development of robust test equipment to support extended deployment scenarios. Cost optimization exercises and analyses

can include technological opportunities and standardization impacts. The results of cost optimization are fed back through to the systems engineer and may result in changes to the functional requirements baseline.

c) **Establishing the initial logistics supportability planning:**
During Phase I supportability engineering performs a reliability centered maintenance (RCM) analysis. RCM analysis is a rigorous analytical process, which emphasizes traceability, justification, and cost effectiveness of preventive maintenance requirements through auditable documentation practices. RCM is a preamble to a FMECA, which is typically developed during the Phase II part of the program.

d) **Refining the support concept selection:**
The support strategy is based on an initial desired support concept. Defining the support concept is an iterative task that is performed many times as the design evolves and matures. To initially substantiate the preferred support strategy, a preliminary level of repair analysis (LORA) is performed. The LORA takes preliminary design characteristics that are either specified, desired, estimated or projected, and through a series of algorithms models the end item through seven different maintenance outcomes. The costs associated with those outcomes is then estimated based on parametric entries, providing the user with a selection of support concepts. There are trade-offs between the lowest cost maintenance support concept and the highest cost maintenance support strategy. These trade-offs begin with the LORA outputs, and are leveraged against non-economic factors such as preferred deployment and mobility goals of the user. The results of the LORA and the preliminary life cycle cost analysis are used as updates to the support strategy report. These outputs can also be used to determine initial goals for Design to Cost and TOC.

Phase II: EMD

Supportability engineering contributes by (a) maturing supportability design-to requirements (SDTRs), (b) developing detailed mitigation plans for identified areas if risk, (c) identification of supportability candidates and line replaceable units, and (d) transitioning the results of the analyses to the supportability engineers for documentation of the support concept, identification of support resources, and determination of detailed maintenance tasks.

a) **Maturing Supportability Design-to Requirements:**
The Supportability Engineer continues to iterate the initial analysis as the design evolves to determine and mitigate any characteristic that might contribute toward increasing the overall cost of ownership. It is understood that there are design requirements and functional aspirations of the design that will override the cost effectiveness of a design trait. But it is still important for the systems engineer to have the cost impact available to him/her for input to the overall systems engineering trade-off and physical/functional requirements determination.

b) **Developing mitigation plans for identified areas of risk:**
As the design matures, areas of risk are going to change. New areas may surface, and initial risk areas may become larger or smaller contributors to the overall design risk. The most visible risks will also be reflected in Design To Cost (DTC) and Cost As an Independent Variable (CAIV) analyses. To mitigate associated risks, the supportability engineer performs iterations on the DTC using CAIV to isolate drivers.

It is understood that there will always be a cost driver in every design that is critical to the performance and functional requirements of the end item.

c) **Identification of Supportability Candidates and Line Replaceable Units:** Supportability engineering performs the initial analyses and determine through iterations of the Level Of Repair Analysis (LORA) and Life Cycle Cost (LCC) which line replaceable units are repair candidates and require analysis by the supportability engineer.

d) **Transitioning the results of the analyses to the logistician for documentation of the support concept, identification of support resources, and determination of detailed maintenance tasks:** The supportability engineer will reach a point of completion in Phase II and hand-off the effort to the logistician. This is the point where the analyses are no longer part of the systems engineering design phase, and are more a part of the operations and support (O&S) phase.

Summary

The systems engineering model contains numerous linkages to supportability. The supportability interconnections begin in the concept phase and continue throughout the life of the system. As part of the overall systems engineering process, supportability engineering provides the expertise to address supportability as a design characteristic in the front-end concept phase, to assist in determination of design characteristics as they relate to supportability of the fielded system, and to ensure that the customer has a highly supportable system at an affordable ownership cost.

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Biography:

Michele Hanna has over 20 years of industry experience. Her experience includes logistic support analysis, maintainability for spacesuits and CB environmental design support, life cycle cost analysis, repair level analysis, reliability centered maintenance, numerous proposals, business development trade studies and total ownership cost including RTOC analysis. Platform experience includes B-1B, OV-10D, spacesuits, and CB environmental habitats, F-14, F-16, F-22, JSF.

Mrs. Hanna was a member of the CALS Industry Steering Group for LSA/LSAR for three years and a contributing author for MIL-STD-1388-1A Notice 3 & 4, MIL-STD-1388-2B, Base & Notice 1 (Contributing Author), MIL-HDBK-1388, Draft (Contributing Author), AECMA 1000D & 2000M for European Logistics/CALS (Contributing Author), and AECMA 1000D & 2000M Acronym Cross Reference Matrix (Author).

She is a published author including "CALS & Spares Acquisition/Logistics Support Analysis" (Contributing Author), and New Directions for Logistics Engineering (Author-SOLE Presentation).

Mrs. Hanna has a B.S. in Logistics from Ohio State University and is currently pursuing a Master of Science in Systems Engineering AT NTU. She is employed as a Supportability Engineer at Lockheed Martin Navel Electronics and Surveillance Systems (NESS), Moorestown NJ.