U.S. DoD Legacy SE & Implications for Future SE Implementation

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Abstract. This paper presents a high-level, simplified view of systems engineering to establish a common context for discussing systems engineering environments. It examines often unstated bases and assumptions upon which systems engineering implementation in the U. S. Military is based, and offers observations regarding factors that deserve consideration in implementation of systems engineering outside of the military domain.

INTRODUCTION

Many engineering managers and systems engineers whose successful practice of systems engineering began in the United States military and/or aerospace environment have voiced frustrations in applying systems engineering in the commercial environment. Part of this frustration arises from a failure to define what SE is intended to do, and where it fits within the existing organization. Other factors contributing to this condition include a lack of awareness of underlying bases and assumptions that form a part of the military/aerospace infrastructure. Inherent differences in the values used to validate products emerging from the military versus commercial/industrial environments have a substantial impact on systems engineering implementation. Initial criteria must be developed to determine the viability of applying systems engineering (and the degree to which it is appropriate) in a given program and/or project, and to help identify potential risk factors in implementation. Recognition and agreement regarding: (1) the underlying bases and assumptions found in a given infrastructure; (2) inherent values held by the enterprise; and (3) set of initial criteria/risk factors to determine project viability are essential factors in successful implementation of systems engineering in a commercial/industrial environment.

WHAT DOES SYSTEMS ENGINEERING DO, AND WHERE DOES IT FIT?

The discipline of systems engineering participates in the solving of complex problems using activities, relations among the activities, tools and people in order to provide a system - or a 'system of systems' - which deliver fulfilled needs to our customers. To establish the context for this paper, a highly simplified view of a SE process is presented as shown in Figures 1a and 1b.

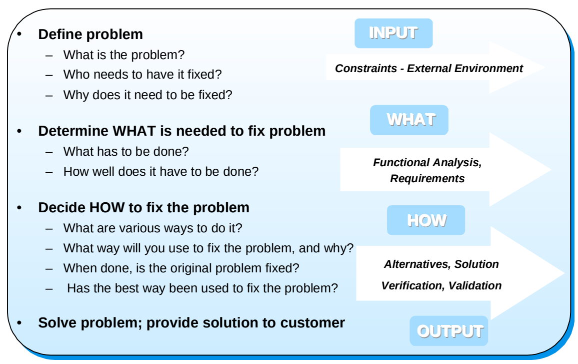

Figure 1a. Systems Engineering - A Macro Process

The reason for a simplified view is to establish a common basis for the discussion of a SE environment. It is natural

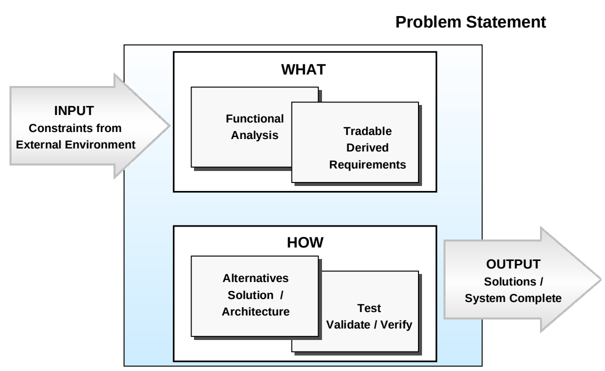

Figure 1b. Systems Engineering - 'Notional' Format

that a given knowledge domain would choose to adapt and/or tailor a more elaborate SE process, and would choose to name or word it differently than that chosen here.

This process establishes a **boundary**, an **input** from outside that boundary, an iterative examination of **what** is needed for the system and **how** to deliver that need, and an **output** from the system to the outside environment.

One assumption made herein is that most SE processes are applied in an iterative fashion over the time duration of the system, in its knowledge domains, and its application of logic.

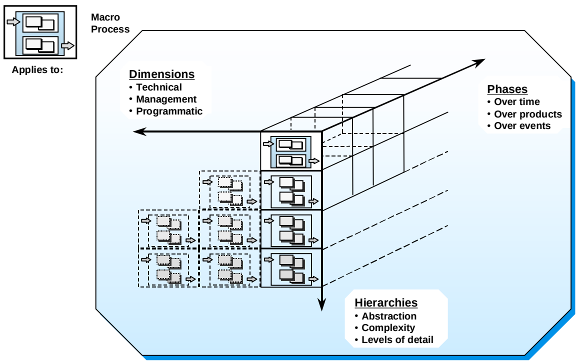

Figure 2. The Nature of a Systems Approach
Multi-Phased, Hierarchical, Multi-Dimensional
(over Time   Logic   Domains of Knowledge)

Figure 2 is a notional depiction of a SE process being applied repeatedly through a full spectrum of knowledge domains, logical hierarchies, and over time. To focus on a system's environment - rather than on the way people are organized to deal with that environment - it is further assumed that the question of where program/project management ends and systems engineering begins is irrelevant. For the purposes of this paper, critical information for successful implementation of a system is essential to the success of both program/project management and systems engineering.

THE MILITARY/AEROSPACE INFRASTRUCTURE

Factors contributing to apparent difficulties in successful implementation of systems engineering in the commercial/industrial environment include the differences between the underlying bases and assumptions reflected in the military/aerospace infrastructure and those found in the commercial/industrial domain. To more fully understand these bases and assumptions, a brief overview of the military/aerospace "systems" approach to develop, produce, deploy and operate new systems is essential. This approach is clarified by an examination of the historical[1] United States Department of Defense (US DoD) Major System Acquisition (MSA) Process, and some of the documents that have been consistently generated as a part of that process. The inherent logic of the US DoD MSA process, and a brief overview of acquisition activities performed in each of their developmental steps provide some insights regarding elements which may be present in the commercial and/or industrial domain**.**

The logic behind the US DoD MSA process is described in Figure 3, "Major Program Justification – U. S. Military." A comprehensive justification is required in the DoD acquisition process to initiate major programs: a major potential program is formed, initial funding is received to proceed, and a Program Manager and a Program Executive Officer is assigned to begin. Acquisition programs are based on and justified by validated mission needs. Mission needs are generated as a direct result of continuing assessments of current and projected capabilities required to carry out national policy. A mission need may be to establish a new operational capability, or to improve an existing capability. The mission may also reflect a desire to exploit an opportunity to significantly reduce system ownership costs, or to significantly improve operational effectiveness of an existing system.

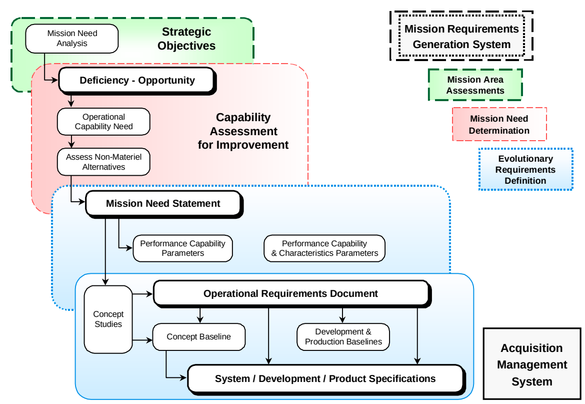

Figure 3. Major Program Justification - U. S. Military

US DoD JUSTIFICATION ACTIVITIES

The main justification activities, reflected in Figure 3, are:

- **Mission (or Enterprise) Requirements Generation System.** The continuous evaluation of current system capability in the context of changing organizational policies and objectives. The process that identifies the needed improvements in mission capability.
- **Evolutionary Requirements Definition**. The results of the Mission Need Analysis is documented in the Mission Need Statement (MNS) which identifies and describes the mission need in terms of non-system specific objectives and general capabilities. Performance capability and characteristics, derived from the MNS are developed and refined in the Operational Requirements Document (ORD). Operation requirements are evaluated at each phase of program development.

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[1] As a result of current acquisition reform activities in the United States military/aerospace community, these processes are being changed and redefined. The initial reference is from the DoD5001.2

- **Acquisition Management System.** The acquisition management system tracks and controls the application of the phases of the MSA process to ensure all required system capability and function is provided.

INTEGRATED PROGRAM SUMMARY (IPS)

Once a validated mission need is established, the program is initiated and the acquisition process begins. Information accumulated prior to initiation of the DoD MSA Process includes an initial decision document called an Integrated Program Summary.

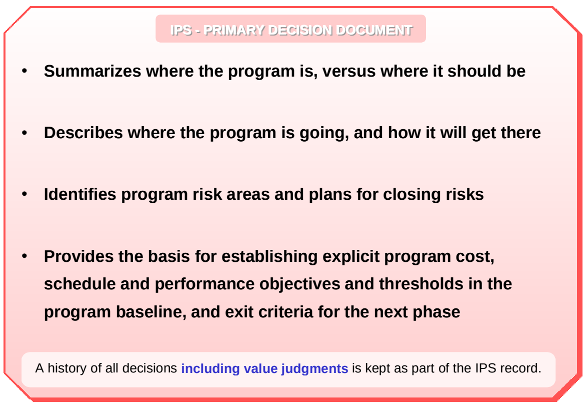

Figure 4. Integrated Program Summary (IPS) & Appendices

The Integrated Program Summary (Figure 4.) is expanded by program staff during the initial phase of DoD program/acquisition definition, is continuously updated as concepts are fleshed out, and assumes increasing importance as each milestone is met and another program phase is begun. As the primary decision document, an Integrated Program Summary - with its appendices - is used to facilitate top-level acquisition milestone decision making. A history of all decisions *including value judgments* is kept as part of the IPS record. The IPS provides a comprehensive summary of program structure, status, assessment, plans and recommendations by the Program Manager and the Program Executive Office:

- Summarizes where the program is versus where it should be,
- Describes where the program is going and how it will get there,
- Identifies program risk areas and plans for closing risks,
- Provides the basis for establishing explicit program cost, schedule and performance objectives and thresholds in the stand-alone acquisition program baseline and program-specific exit criteria for the next acquisition phase.

IPS APPENDICES

Seven appendices to the IPS provide more in-depth program detail to decision makers (see Figure 5, "Integrated Program Summary Appendices"

Appendix A. “Program Structure and Schedule” describes the program phases and event timeline.

Appendix B. “Program Life-Cycle Cost Estimate Summary” provides the current estimate of total program life-cycle cost. The cost estimate is given by each major phase of system acquisition and operation.

Appendix C. “Acquisition Strategy Report” outlines the acquisition strategy that will be used to ensure the development of competitive prototypes and competitive alternative sources of supply are used for the system acquisition.

Appendix D. “Risk Assessment” describes the mission, technology, design, engineering, support, manufacturing, cost , and schedule risks for all known or potential risks..

Appendix E. “Environmental Analysis” describes the methodology and procedures for analyzing the systems environmental impacts and integrating that information with other considerations in the program management and acquisition process.

Appendix F. “Affordability Assessment” develops program cost data and compares it to other long term budget requirements and recommends the best way to provide the needed system capability within the stated budget constraints.

Appendix G. “Cooperative opportunities document”

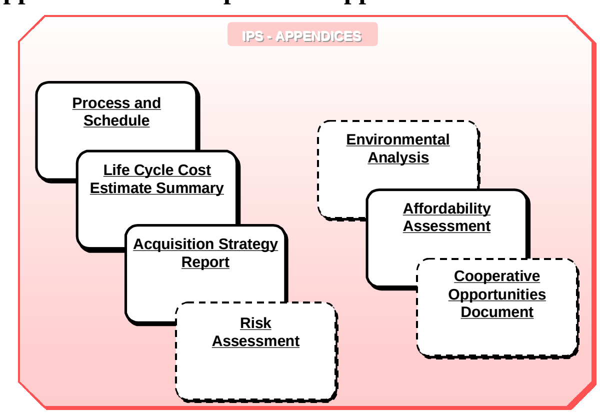

Figure 5. Integrated Program Summary Appendices

describes the current and future opportunities available to reduce cost and increase system effectiveness by cooperating with other programs that are doing similar things.

It should be noted that Appendices A, B, C, and F (Structure and Schedule, Life-Cycle Cost Estimate, Acquisition Strategy, and Affordability Assessment) are started to provide a basis for Phase 0 - that is, this preliminary information is gathered as a basis for initiating the formal US DoD MSA Process.

THE US DoD SYSTEM

The US DoD system acquisition process covers the total mission. The system itself includes:

1. The prime mission equipment,
2. The individuals that will operate and/or maintain the system,
3. The logistics support structure for the systems, and
4. The other elements of operational support infrastructure within which the system must operate.

Total system performance and cost of ownership are considered when addressing the constraints imposed by the requirements generation, planning, programming and budgeting processes, and also as part of cost, schedule and performance trade-offs performed by the systems engineering function.

US DoD OVERALL ACQUISITION PROCESS

The US DOD acquisition process (see Figure 6, "Overall Acquisition Process") has five phases and five major milestones that provide a mechanism for comprehensive management and progressive decision making associated with the "system acquisition" process. *The first step in this process is the determination of mission need. This determination is completed by the US DoD, and can be considered Phase "-1" because it happens before Phase 0.* A validated mission need (completed by the US DoD) represents the successful completion of Milestone 0, which is the entry to Phase 0.

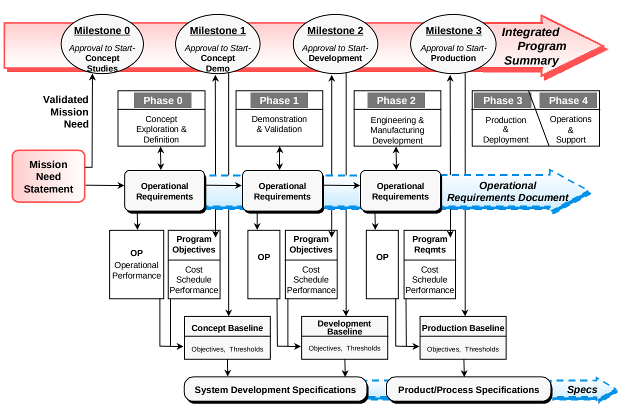

Figure 6. Overall Acquisition Process

Phase 0. "Concept Exploration and Definition" studies alternative concepts to identify the most promising solutions to validate mission needs. Work performed in this phase is primarily completed by a contractor, or several contractors, working on a **cost-plus basis**.

Phase I. "Demonstration and Validation" uses the results from the concept studies and evaluates them in terms of the acquisition strategy, cost, schedule, performance objectives and projected "affordability constraints." Work performed in this phase is primarily completed by a contractor, or several contractors, working on a **shared risk basis**.

Phase II. "Engineering and Manufacturing Development" designs and develops the selected system using the techniques outlined in the "Systems Engineering Standard." This standard provides for the tracking and integration of the following areas: work breakdown structure, reliability and maintainability, computer resources, human factors, system safety, system security, quality and other engineering specific concerns. *System specifications or "A-specs" are usually found in this phase of US DoD program development.* Work performed in this phase is primarily completed by a contractor, or several contractors, working on a **fixed fee basis**.

Phase III. "Production and Deployment" produces the system. Work performed in this phase is produced by contractors, and then deployed out to the field for the operation and support activities described in Phase IV.

Phase IV. "Operations and Maintenance" is the final phase, which produces a discrete new system and operational capability to the program.

These phases, and the relative authority and responsibility associated with each phase, make the role of systems engineering in the military/aerospace infrastructure more clear.

ROLE OF SE IN U.S. DoD

The important and vital role of SE (in the US DoD Major System Acquisition process) *is met by satisfying five basic objectives*:

1. Ensures that a project is completed on time, within budget and meet all life-cycle requirements;
2. Guides the definition, development and documentation of all life-cycle constraints and requirements necessary to meet mission needs;
3. Balances the system related products and processes to achieve an efficient solution to all user needs in each phase of the system life-cycle;
4. Delivers a complete set of documentation that thoroughly describes the system and its production and operation;
5. Provides appropriate cost, schedule, performance and risk data with which major high-level program management and control decision documents are prepared.

The systems engineering role, however, is subordinate and responsive to the overall project management and control process. Within the traditional DoD context, systems engineering is an essential part of program management and control. Systems engineering does not normally impact the selection of the program structure and schedule, program affordability assessment, program acquisition strategy and many other major operational aspects of a US DoD major systems acquisition. Most of these activities are already included as a transparent part of the existing infrastructure. Most systems engineers - whose initial exposure to SE is at the specification level - are not aware of this major set of assumptions and decision bases that predicate the work they are completing at a more detailed level in system development.

ADDRESSING SE OUTSIDE the DoD:

Once the systems engineer has moved outside of the DoD environment, SE implementation needs to be considered in the context of the entire infrastructure and the system environment. This is often a different context than that used by many systems engineers in their DoD work. The boundaries of the new system, along with a comprehensive examination of the system and its environment, should be carefully analyzed and described - noting major anomalies and impacts. The environment includes existing decision-making structures, acquisition/funding processes, project and/or program management, and additional factors that may impact system success.

1992 – U.S. Department of Energy

One of the most notable recent SE implementations was initiated in 1992 at the Department of Energy's Hanford Site in Richland, WA as a part of their Tank Waste Remediation Project. As reported by B.G. Morais and M Grygiel , systems engineering was introduced into a culture devoted to environmental cleanup that was previously focused on the production of weapons grade thermonuclear materials. The management and control structure that was needed to address classified and defense concerns was not prepared and/or adequate to deal with regulator and public involvement necessitated by the regulatory environment that surrounds Hanford's environmental cleanup. As they learned more about the existing culture and environment, it also became clear that no comprehensive decision-making authority and process was in place for this system. Little agreement was held regarding criteria for determining how well the operation of cleanup should be performed.

To deal with the gaps in the system environment, Morais and Grygiel used a high-level workshop attended by the DOE, its Contractors, and stakeholders from the community to establish a common framework and context in which tank waste cleanup could be addressed. A high level view of an SE process was presented; mission objectives were developed; value measures were created to eventually rank alternatives; operational scenarios were established. Then the iterative process of determining functions, requirements, alternatives, and tests for success was initiated.

Several notable conclusions emerged from this work and were stated in Morais' and Grygiel's paper. (1) Several key interface factors had not been finalized resulting in a need to establish a set of enabling assumptions so that work could proceed. Functioning under these assumptions results in risks that affect mission completion. (2) Substantial cultural and organizational change was continuing. The rate of change and need for applicable information was exceeding the length of time needed to perform and finalize analyses. (3) The establishment of the objectives and requirements from the Hanford cleanup mission and the larger mission of Environmental Restoration and Waste Management were not present during the early phases of the tank waste remediation process. This resulted in some redirection and revision of the sets of Alternatives as the process matured.

1999 – Eastman Kodak Company

In "Application of Systems Engineering Principles in Development of the Advanced Photo System", G. A. Mason, et. al., described the extensive efforts and accomplishments of Kodak in developing their innovative new photo system. Every aspect of their photographic system changed – from actual components to the way that the customer interacts with the product. Kodak needed to carefully manage that change, and decided to use systems engineering principles to do so. In different terms, this decision can be viewed as an initial mitigation of risk – and a beginning to a typical programmatic risk assessment.

Four key areas were identified that needed to be addressed by the management process during this change.

1. Providing an overall process for development and verification of system requirements, using a top-down approach that views the system as a whole and provides an orientation towards the life-cycle of the system.
2. Integrating existing development management processes by emphasizing the system environment that these processes exist within.
3. Integrating widely scattered technology, design, manufacturing and management efforts using "front-end" analysis of contributions to system performance.
4. Providing a framework for managing system level negotiations with our joint development partners and internal organizations.

It is interesting to note that the last three of these four areas are not necessarily assumed to be under the purview of the "classic" practice of systems engineering. Each of these same three areas are normally found in the DoD acquisition infrastructure in which classic SE is performed.

Acquisition Strategy and the Environmental Analysis portions of an Integrated Program Summary (IPS) address the objective listed as Number 2 – "Integrating existing development management processes by emphasizing the system environment that these processes exist within." Number 3 – "Integrating widely scattered technology, design, manufacturing and management efforts using "front-end" analysis of contributions to system performance" – is initially found as a part of Acquisition Strategy and Cooperative Opportunities within the IPS. It also is largely considered within the Operational Requirements when validating the Mission Need (as a part of the performance capability assessments), often prior to initializing SE activities on the Program. "Providing a framework for managing system level negotiations with our joint development partners and internal organizations" is a vital part of the Acquisition Strategy of the IPS. Also, it is intrinsic to the well-defined decision structure and framework that exists in the U.S. Military.

It is likely that careful consideration of factors not automatically practiced as a part of "military DoD-style" SE contributed substantively to the success of the Advanced Photo System efforts at Kodak.

1999 – Extended Enterprise in Aerospace Sector

In "Designing an Optimal Product Introduction Process for an Extended Enterprise in the Aerospace Sector", Ben Clegg, Alison Boardman, John Boardman, and Rachel Mason-Jones provided insights regarding the complexity encountered by multiple organizations when using an extended enterprise – comprising systems of systems - to tackle complex new aerospace products. A primary advantage of such joint product development is to allow systems expertise and commercial risk to be shared. The key disadvantage is that product lead-time and costs tend to rise with the increase in project management complexity. The main thrust of their research examined when and how individual systems become effectively bound to make up a single system.

One of the primary objectives by the participating companies in the extended enterprise was the hope that a process for product introduction would be developed that has *joint* ownership by them all. As each of the various models used by the companies was reviewed, a number of characteristics were noted that needed to be common within the development of the new process. These observed characteristics included:

- Stage and review gates that were defined differently in each company,
- Supply chain timing and operational implementation that conflicted with certain practices of concurrent engineering and principles,
- The boundaries and timing of the PIP (e.g., when is it initiated, should it include new capability acquisition activities, when is it complete, …) need to be established,
- Identifying links (either in a 'liaison' or collaborative' capacity) between the companies.

Other differences that were noted between the companies will undoubtedly have impacts on the eventual success of an extended enterprise. One area was in the description and focus of system boundaries – wherein (1) 'internally focused' activities neglected efforts for external supply base communications and (2) 'engineering focused' activities neglected financial and commercial implications of new product introduction. Another area of contrasts was in acquisition and funding practices as exercised by the different companies. The existing financial basis of a company, its overall acquisition strategy and long term investment capital reserves will substantially impact the relative risk the company is willing to bear as well as the kind of contracting strategies it can deploy. One more area of needed agreement between extended enterprise companies was in the timing of, and incorporation of, higher level system change in the PIP – so that manufacturing and engineering can respond with risk mitigation for change.

This research paper describing the extended enterprise in the aerospace sector has established numerous and important criteria that will need to be incorporated into successful implementation of the product introduction process, and in systems engineering.

2001 – GAO … Better (Weapon) System Outcomes

In their recently released report "BEST PRACTICES, Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes", the U.S. General Accounting Office (GAO) provided recommendations on best practices based on nine case studies – six from the U.S. military, and three from major commercial programs. Although these recommendations were directed to the Secretary of Defense, they are widely regarded as being applicable across major commercial programs.

These GAO recommendations address issues related to realigning the mechanics and incentives of requirements setting and program approval processes with the need to match customer expectations and developer resources *before weapon system programs are started.* The GAO recommends for executive action that:

1. Systems engineering be utilized to align customer requirements and contractor capabilities prior to program initiation,
2. The major systems acquisition process be changed to reduce the pressures that encourage setting high and

inflexible requirements to win the competition for program approval,

3. It be required, as a condition for starting a new weapon system program, that sufficient evidence exists to show there is a match between a weapon system's requirements and the resources the program manager has to develop that weapon.

The principal findings from the GAO include:

1. Timely match of requirements and resources is critical to product development outcomes. Key to the successful cases was the ability to make early trade-offs either in the design of the product or in the customer's expectations to avoid outstripping the resources available to product development.

- Early matching of customer expectations and developer's resources is critical to program success,
- Trade-offs are critical to matching customer expectations with developer resources before starting product development,
- When matching did not occur before program launch, developers were forced to add unplanned resources.

2. Several factors enable customer's needs and developer's resources to be matched before program launch.

- Systems engineering tools are critical for identifying gaps between developer's resources and customer's expectations [SE...lays the factual foundation for pragmatic negotiations],
- Flexibility in setting requirements is key to closing gaps between customer expectations and developer resources,
- Balance in the roles of the customer and product developer makes for effective trade-offs.

3. Characteristics of DOD's acquisition process make it hard to match needs and resources before program launch.

- Current process puts requirements setting and systems engineering on opposite sides of the launch decision,
- Incentives of current process create pressure on product requirements,
- More successful weapon system programs have departed from the normal process,
- Constructive changes in DOD's policy not enough to match customer expectations with developers' resources.

Comments from the DOD in general agree with these recommendations and findings. Similar to the activities required for a DoD systems engineer to transition to the commercial arena, this report suggests a structural re-alignment in the DOD system acquisition process that moves their process closer to commercial practices.

CONCLUSIONS

This paper established a high-level, simplified view of systems engineering as a common context for discussing systems engineering environments. The underlying bases and assumptions upon which the practice of systems engineering in the U. S. Military depends are far reaching. Successful SE implementation in commercial enterprise depends heavily on the ability to determine and recognize which factors are already a part of the existing environment or infrastructure in which the new/improved system is planned – and those that are not. For systems engineers whose experience is largely on DoD systems, it is important to be aware of these factors before initiating SE in the private commercial sector. The most critical are those that have been addressed within the overall Acquisition Infrastructure – especially the Integrated Program Summary and its appendices. Careful consideration of the system boundaries and a description of the environment of the system space should be made prior to acquisition, purchase and the decision to proceed. As significant risks to the technical program are attributable to the lack of a decision framework, a functional management process that includes a clear decision-making process is mandatory. Further, the recent GAO report recommends an initial decision-making process, prior to program initiation, that matches customer requirements and resource capabilities as a program cost and schedule risk reduction mechanism

REFERENCES

Clegg, Ben, Board, Alison, Boardman, John, Mason-Jones Rachel, ‘Application of Systems Engineering Principles in the Development of the Advanced Photo System,’ 9th Annual Symposium of INCOSE, Brighton, England, 1999.

Mason, Gregory A., McGrath, William E., Rutter, Christine K., Sherwood, W. Brian, Silva, Fernando G., Spense, John P., Tsao, How J., ‘Designing an Optimal Product Introduction Process for an Extended Enterprise in the Aerospace Sector,’ 9th Annual Symposium of INCOSE, Brighton, England, 1999.

Morais, Bernard G., Grygiel, Michael, ‘Application of Systems Engineering into an Ongoing Operation,’ 4th Annual International Symposium of INCOSE, San Jose, CA, 1994.

U.S. GAO-01-288, “BEST PRACTICES, Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes,” March 2001.

U. S. DoD Directive 5000.1, “Defense Acquisition,” February 23, 1991.

U. S. DoD Directive 5000.2, “Defense Acquisition Management Policies and Procedures,” February 23, 1991.

BIOGRAPHY

Joseph J. Simpson. Joseph J. Simpson’s interests are centered in the area of complex systems including system description, design, control and management. Joseph has professional experience in several domain areas including environmental restoration, commercial aerospace and information systems. At Westinghouse Hanford Company, Joseph was responsible for the conceptual and preliminary design of a requirements management and assured compliance system. Mr. Simpson developed a successful research proposal to NASA Langley on "Meta-Semantics and Object Models for Engineering Management" while working for the Boeing Company in 1999. While working in the internet domain, Joseph developed and deployed test-bed software essential to a major web-based commercial product. Mr. Simpson has recently joined the Phantom Works at the Boeing Company.

Joseph Simpson has a BSCE and MSCE from the University of Washington, is a member of INCOSE and IEEE, and has obtained various information and computer system certifications.

Mary J. Simpson. Mary Simpson's experience and interests focus on engineering systems solutions to complex problems encountered in organizations, processes, and systems interactions. As the principal author of the DOE's Strategic Plan (1996) at Hanford Site, and the principal author of DOE's Mission Direction Document - which became a formal part of their performance-based contracting mechanism, Mary successfully applied strategic planning, domain analysis, and high-level modeling in the evaluation and integration of complex systems. Mary Simpson applied strategic engineering and process management analysis to her work with executive management at Boeing Commercial Airplanes as well as with their major integration and re-engineering initiatives. Recently, Mary has joined Battelle, at Pacific Northwest National Laboratory, as Chief Systems Engineer.