Systems Engineering: An alternative management paradigm?

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Abstract. This paper[1] examines role of systems engineering in the current management paradigm, and looks at the difficulty of establishing a body of knowledge for systems engineering. The paper then resolves the difficulty by showing that systems engineering is an alternative management paradigm to the 20th Century Taylor paradigm of "Scientific Management[2]".

INTRODUCTION

We are living in an age of transitions. One of these is the transition from hardware-based systems to software-based systems. While Information Technology (IT) underpins the civilization in the early years of the 21st Century, the current systems and software acquisition and development paradigm is characterized by mind-boggling complexity, a turbulent transition from function-based designs to object-oriented designs, cost and schedule overruns (CHAOS 1995, OASIG 1996), and project failures (Capers Jones 1996). One reason for this state of affairs is that IT acquisition and development is currently performed in an industrial age management paradigm based on the work of F. W. Taylor who system engineered his manufacturing organization to develop the optimal process at the start of the 20th Century. This paradigm is breaking down in the systems acquisitions and software development of the late 20th Century and early 21st Century.

The process of the conversion of a set of vague, varying and changing user needs into delivered systems and software via a process that can take months or even years, is the toughest challenge facing the IT profession in these initial years of the 21st Century. People who can lead the implementation of the IT systems and software acquisition and development process within the cost and schedule constraints are scarce. These people are becoming known as systems engineers and the approach they use is systems engineering.

Thus while the world is turning to systems engineering to solve the problems of developing and maintaining the software based systems underpinning our civilization, systems engineering

Is a vague term with many different interpretations. As such, many systems engineers cannot clearly articulate the functions and benefits of systems engineering (Kasser and Shoshany 2000).

Covers a broad spectrum of activities (Kasser and Massie 2001) and consequently, it has been extremely difficult to establish a systems engineering body of knowledge (SEBOK); something that is critical to the future of systems engineering.

THE NEED FOR A SEBOK

The lack of a SEBOK is having a detrimental effect on systems engineering as evidenced by

Poorly implemented systems engineering with consequent cost and schedule escalations as well as unnecessary expenditures (Kasser and Williams 1998). Among the many examples of anecdotal evidence, Newland (1998) mentions the systems engineer with major responsibilities for a shipyard's overseas Combat Systems integration who had absolutely no idea of any of the recognized systems engineering principles.

The continual discussion of fundamental concepts without closure and moving on to the application of the concepts to the real world. A typical example is the discussion on poorly written requirements and their effects, which has not progressed much beyond Hooks (1993). The effect of poorly written requirements on costs and schedules needs to be minimized not discussed!

The continual discussion on the differences between systems engineering and project management. Most of these discussions focus on the technical role of the engineers and the administration and organizing role of the manager. The discussions conveniently ignore the fact that the managers make the decisions and the systems engineers

[1] This work was partially funded by the DSTO Centre of Expertise Contract

[2] F.W. Taylor system engineered his organization to split the work between management and labour. Management was supposed to plan and design the work, while labour was to implement it in the predetermined one best way.

hold the knowledge necessary for making an informed decision. One of the root causes for the breakdown of the Taylor paradigm is that we are now separating the knowledge holders from the decision-makers. The discussion and conflict terminate with the realization that systems engineering and project management perform the same functions but in different management paradigms.

The rediscovery and reinvention of concepts long adopted in overlapping disciplines[3]. As an example, LaPlue L. et al. (1995) discuss the development of a methodology for specifying requirements that describe the behavior of a system and its interaction with its environment. In fact they reinvented the environmental and behavioral models of the Ward and Mellor (1985) software development methodology. This situation escalated project costs since the methodology existed and could have been used rather than reinvented.

The lack of an understanding of fundamental concepts, which is then masked by the excuse that something cannot be done by conventional approaches and a new and complex approach is needed with the requirement for funding the research and the postponement of the delivered implementation. Another example is the term "System of Systems." Real systems engineers understand the hierarchical concept of meta-systems, systems and sub-systems. And when you understand that concept, you can see that the acquisition of what has become known as a "System of Systems" is just an uncoordinated ad-hoc multi-phased time-ordered parallel-processing evolutionary process (Kasser 2002). Another example is the concept of Cost as an Independent Variable (CAIV), which is a way of complicating *just a part* of the concept of designing budget tolerant systems using the Cataract approach proposed by Denzler and Kasser (1995). Moreover, to repeat Kasser (1996), "*excessive complexity is a symptom of an underlying problem within the foundation of the current paradigm*." Thus complex solutions to any problem are always inherently less than optimal and are the antithesis of the products of true systems engineering.

Coining new words due to the lack of understanding that words and concepts already exist. System of systems was discussed above. However, to be fair, systems engineering is not alone in doing this. For example software engineering has recently discovered the technique of "abstracting" or hiding the insides of a component from the designers who integrate the component with other components. Hardware and systems engineers have long been familiar with the concept of a "black box".

Poor Quality in the papers presented in the annual symposia of the INCOSE. There can be no metric for the competency of systems engineers without a SEBOK (Kasser 2000) and hence, no metric for the qualifications for reviewers of papers submitted to the annual International Symposium of the INCOSE. The volunteer reviewers may accept papers that should be rejected on the grounds that the content is incorrect or past its "use by" date. While papers that are past their "use by" dates are of interest to beginners who are ignorant of, or do not have access to previous publications, they should not be published as discovery papers. They could however be published as Case Studies reaffirming findings and principles already known. Moreover, papers containing incorrect information have a greater potential for harm; because others read them and assume that what they are reading is correct and may build on them. Look at the proceedings of the last few Symposia. You will see the same type of papers published each year. There seems to be little movement forwards. Scan the citations at the end of the papers, and see how many citations are to work published in earlier symposia proceedings. There are very few citations, and of those, the majority of such citations are authors citing their own previous publications as the basis for the continued work described in the current paper. It would be interesting to also determine how often papers published in the INCOSE symposia are cited in other refereed journals.

ORGANIZATION OF THE SEBOK

If systems engineering is an alternative management paradigm, then the SEBOK has to be extensive. Kasser and Massie (2001) proposed that it needs

Both depth and breadth at the same time.

To overlap a number of engineering and management disciplines.

Hitchins' Five Layer model. Kasser and Massie also suggested that a suitable framework for organizing a SEBOK could be based on the five-layer model proposed by Hitchins (2000). The five layers are

Layer 5 – Socioeconomic - the stuff of regulation and government control.

Level 4 - Industrial Systems Engineering, or engineering of complete supply chains/circles.

Level 3 - Business Systems Engineering - many businesses make an industry. In this layer, systems engineering seeks to optimize performance somewhat independent of other businesses.

Level 2 - Project or System Layer - many projects make a Business. Western engineer-managers operate at this layer, principally making complex artifacts.

Level 1 - Product Layer - many products make a system. The tangible artifact layer. Many engineers and their institutions consider this to be the

[3] Specific examples have not been referenced from the recent INCOSE symposia proceedings to avoid personalizing the issue.

only "real" systems engineering.

Hitchins further states that the five layers form a "nesting" model, i.e. many products make a project, many projects make a business, many businesses make an industry and many industries make a socioeconomic system. Clearly, these statements are only approximate since-

A socioeconomic system has more in it than just industries.

A business has more in it than just projects, and so on.

- Actual organizations may divide the work in different ways resulting in either sub-layers, or different logical break points.

The five layers imply that the content of the SEBOK is more than the material published in INCOSE symposia and journals. Systems engineers have to be cognizant of what is being published in non-INCOSE conferences and journals in several fields including economics, requirements engineering, engineering management, TQM, business, and software engineering. The nature of the activities in each of the five layers is such that

- Systems engineers operating in one level use a different vocabulary to those operating in another level, hence, among other manifestations, the multitude of definitions of systems engineering (Kasser and Massie 2001).

The SEBOK could contain almost the entire technical and managerial bodies of knowledge.

SYSTEMS ENGINEERING AS AN ALTERNATIVE PARADIGM

The major roadblocks hindering the development of a comprehensive SEBOK can be bypassed by the recognition that systems engineering is a different way of doing things with respect to the current Taylor paradigm of Scientific Management namely an alternative management paradigm. Systems engineering is a return to an older management paradigm that was used for the construction of projects such as the ancient pyramids, and the 19th Century canals and railroads. Systems, which, within the scope of the tools and technology of their time, presented problems that were just as complex as the problems we face today. This older paradigm can be defined as "*a set of activities which control the overall design, development, implementation and integration of a complex set of interacting components or systems to meet the needs of all the users*". This sentence just happens to be a Defence Evaluation and Research Agency (DERA) definition of systems engineering (DERA 1988).

Alternative paradigms. Kuhn (1970) writes that an alternative paradigm is a reconstruction of the field from new fundamentals, a reconstruction that changes some of the field's most elementary theoretical generalizations as well as many of its paradigm methods and applications. The field under discussion is "*acquiring and delivering systems and software that meet the changing needs of the user on time and within budget*". If systems engineering is a different management paradigm for this field, then to meet Kuhn's requirement for an alternative paradigm it has to

Resolve conflicts that cannot be readily resolved within the current paradigm.

Incorporate management and other activities that are currently performed by non-systems engineers who may be competing (or overlapping) with systems engineers.

Systems engineering seems to do both. Some examples (in chronological order of publication) are

- Eisner (1988) lists a general set of 28 tasks and activities that is normally performed within the overall context of large-scale systems engineering. The full range of activities is commonly called 'specialty skills' because some people spend their careers working in these specialties. Thus according to Eisner systems engineering overlaps at least 28 engineering specialties.
- Lewis (1992) provides case studies in software independent verification & validation (IV&V). Yet the words "IV&V engineers" could be replaced by the words "systems engineers" and the cases would be just as appropriate in a class on systems engineering instead of a class on IV&V.
- Deming (1993, 30) laments the failure to manage the organization as a system. He advocates replacing Management by [individual component] Objectives (MBO) by studying the theory of a system and managing the components [setting the objectives] for optimization of the aim of the system. Deming (1993, 50) further states that "we are living under the tyranny of the prevailing style of management. Most people imagine that this style of management has always existed, and is a fixture. Actually, it is a modern invention, a trap that has led us into decline."
- Roe (1995) in discussing the role of the systems engineer and project manager states that the knowledge and skills of system engineering are the same as those of project management in the areas of management expertise, technical breadth and technical depth. The difference in application, according to Roe, is that the system engineer has more technical breadth, while the project manager has more management expertise. Roe concludes with "to perform effectively, the project manager must be a system advocate. He must learn the mul-

tidisciplinary approach and embrace the systems engineering methodology. The project manager and the systems engineers share common objectives, i.e., to plan, design, and deliver a system that meets the customer's needs. Thus, they must avoid conflict and work cooperatively to attain the project's goals."

- Deevy (1995, 25) writes that management consulting has become a major growth industry with American companies now spending over 7 billion [dollars US] each year on outside advice. Thus Deevy seems to imply that engineers are expected to know how to engineer, physicians are expected to be competent practitioners of medicine, yet the current management paradigm has reached the stage where it does not expect managers to know how to manage.
- Martin Cobb stated "We know why projects fail, we know how to prevent their failure --so why do they still fail?" This statement has become known as Cobb's Paradox (Voyages 1996).
- Roe (1996) writes "Integrated Product Development (IPD) is becoming a fact of life for companies doing business with the government, and for those who have found that it provides an edge in the modern global market. Success stories abound. But it has not come easy to any organization. Each has found it necessary to make fundamental changes and to convince upper management that the rewards of undergoing the cultural shock of reengineering the organization will more than justify the pain. Lessons have been learned and are still being learned and applied to readjust the process. New management techniques, coupled with aggressive application of systems engineering, will prove to be key elements of IPD."
- Sheard (1996) described twelve roles of the systems engineer that are occasionally or frequently assumed to constitute the practice of systems engineering. According to her, some of the roles fit naturally as [system development] life cycle (SDLC) roles; others fit the program management set of roles, while still others are not normally thought of in either group.
- Kasser (1996b) analyses the functions performed by systems engineers and shows that there seems to be no unique body of knowledge to systems engineering. He states that all of the activity performed by systems engineers, apart from possibly requirements and interfaces, are also performed by other types of engineers.
- Mooz and Forsberg (1997) write that systems engineering and project management should be integrated. They state that in many project environments, system engineering and project management are managed separately. This situation is aggravated by the discipline segregation by universities and by the corresponding professional organizations. As a result of this separateness, project managers futilely try to manage cost and schedule without managing technical content while the technical providers, ambivalent to the cost and schedule consequences, pursue superior technical solutions.
- Eisner (1997, p156) expands Eisner 1988 and discusses 30 tasks that form the central core of systems engineering. **The whole area of systems engineering management is covered in just one of the tasks**. Eisner states that not only must a Chief Systems Engineer understand all 30 tasks; he or she must also understand the relationships between them, which is an enormously challenging undertaking that requires both a broad and deep commitment to this discipline as well as the supporting knowledge base.
- Bottomley et al. (1998) studied the roles of the systems engineer and the project manager and identified 185 activities and their competencies (experience and knowledge). Their findings included:
    - No competency was assessed as being purely the province of systems engineering.
    - There is no sharp division between the two disciplines (systems engineer and the project manager) even at the level of individuals.
- Hitchins (1998) develops four litmus tests for systems engineering. He states that the conclusion to be drawn from the application of the litmus tests to some everyday industrial practices is that many practices which present themselves as systems engineering are either inappropriately, titled, or are, perhaps, only part of a much richer story. Even classic systems engineering is seen to have some limitations in practice. Hitchins' penultimate sentence states "[systems engineering] *is a philosophy and a way of life*".
- Brooks and Mawby (1998) recognize systems engineering and project management as separate disciplines, both of which regard decision making as their territory. They add that conflicts of this type are often reinforced by a traditional functional organization creating barriers between management and engineering so that any projects conducted in that environment will benefit from the full potential of an integrated approach to systems engineering and project management.
- Robson (2001) discusses the paradox in which the tribes [of the various work disciplines] need to adopt a systems engineering approach, and, "the challenge is to achieve this without

the provocation of the 'systems engineers are taking over the world'!"

The overlap in, and the difficulty of allocating, the roles of systems engineers, can be overcome in the manner of overcoming any paradox, namely by a change of perspective or paradigm.

In conventional systems engineering terminology, there is a system (an organization) that no longer can provide the capability to meet the needs of its customers. Its evolutionary changes seem to have reached the point of diminishing returns and perhaps way beyond. Adding layers of complexity is not the solution. It is time for a replacement system. The first stage in the process of replacing the system is to recognize the need for a replacement. Kasser (1996b) seems to the first paper (within the systems engineering community) that recognizes the situation and questions the role of systems engineering within the current management paradigm. Kasser states

- "Systems engineering is a discipline created to compensate for the lack of strategic technical knowledge and experience by middle and project managers in organizations functioning according to Taylor's 'Principles of Scientific Management.'
- Most of today's systems engineers really appear (work as) to be Requirements and Interface Engineers. They have the responsibility to validate the requirements since there's little point in building a system which conforms to requirements if the requirements are incorrect. Perhaps those are two missing 'ilities' in the current paradigm.
- Project management, Business Process Reengineering (BPR), concurrent engineering, TQM and theoretical systems engineering all seem to be attributes of the same function; namely *producing a product to (the correct) specifications by an organization within the constraints of resources, budget and schedule*. Remember MIL-STD-499A was written for systems engineering **management** and MIL-STD-499B changed the focus to systems analysis and **control**. This overlap or duplication seems to be due to defects in the current organizational structure, and in the case of systems engineering, the transition in technology from hardware to software.
- We need a new organizational paradigm to simplify the organization such as the one proposed at the *9th Annual National Conference on Federal Quality*, (Kasser 1996) and within that paradigm, there still is a need for someone to have a strategic perspective of the entire system."

Transition is taking place. Campbell (1960) wrote that changes which change the rules of the game and require people to shift their perspective are resisted. It is an emotional issue and cannot be settled by logic. Kuhn (1970) wrote that changes which require people to unlearn what they already know is correct are resisted very strongly. Consequently, it is nigh impossible for managers to unlearn what they know is the correct way to manage. So the failure of the process improvement initiatives which require managers to unlearn what they know is the correct way to manage (paradigm), based on their years of experience on the job, does not come as a surprise to anyone familiar with Kuhn's work. Yet the recent books on improving management all state that management should unlearn something they do now and change to a different way of doing things. Unwillingness to unlearn is a major cause of resistance to change. No wonder that Drucker (1985) stated that a paradigm shift takes about 25 years, namely the time it takes for the unwilling to unlearn proponents of the old paradigm to retire.

The systems organization is beginning to appear. For example, Crosby (1984, 10) stated that organizations have recognized the need for a drastic change in their way of doing things. Some organizations have almost made the paradigm shift. As companies struggle to boost efficiency and become more market responsive, they have stripped out layers of management, broadened the remaining span of control and employed technology. Up front planning ensures quality. The trend in enlightened management is to delegate the decision making and control to the employees doing the actual work. Employees are taught how to analyze and solve Quality problems with minimal management supervision, and in some instances, the lines between workers and middle management blur and even vanish (Kanter 1987, 60). Organizations still use the term "management", yet the functions performed by these managers map into the definition of the functions performed by systems engineers. **Surely the next logical step must be to eliminate managers completely, thereby solving Cobb's paradox, and adopt the systems engineering paradigm of management.** As Drucker (1980, 226) wrote "*the form which management will take may be quite different tomorrow. The restraints, the controls, the structure, the power, and the rhetoric of management may change drastically*", which means changing their corporate culture.

Thus other organizations will suffer upheavals in making the paradigm shift. Not every organization is going to be able to make the paradigm shift. Many will fade away like the 381 that companies dropped out of the Fortune 500 listings between 1955 and 1990.

CONCLUSIONS

The conclusions of this paper are

- The lack of a SEBOK is detrimental to systems engineering, consequently one must be established quickly.
- However, a comprehensive SEBOK covering all five layers of systems engineering many never be established because it would have to contain almost the entire technical and managerial bodies of knowledge for hard systems as well as the body of knowledge relating to soft systems.
- The difficulties in placing the role of the systems engineer within the current management paradigm and the scope of the SEBOK seem to confirm the view that systems engineering is a different management paradigm to that of the Taylor based organizational paradigm.
- The world is in the process of a transition from the Taylor based organizational paradigm to the systems engineering paradigm of management.

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