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Systems Engineering: Myth or Reality

Joe Kasser

The Anticipatory Testing Corporation

POB 3419, Silver Spring, MD., 20918.

Telephone 301/593 3316, fax 301/593 2624

E-mail jkasser@iee.org

Abstract. Each year at the **National Council of Systems Engineering** (NCOSE) symposium lots of dedicated people spend a lot of energy assessing, measuring and educating people about an incomplete body of knowledge (systems engineering). The incompleteness is due to the lack of a definition of what that body of knowledge is supposed to cover. Now every systems engineer knows that it is important to capture all the requirements as early as possible in the program, so why have the systems engineers not defined systems engineering (SE)? **This situation led me to hypothesize that there was no such thing as systems engineering (after all, if the experts in NCOSE can't come up with one, then there isn't one).**

This paper analyzes the functions performed by systems engineers, shows there seems to be no unique body of knowledge to SE, which explains why the NCOSE experts have failed to define SE. The paper then looks outside the SE box for the reasons for the failure, and provides a surprising conclusion.

DEFINING SYSTEMS ENGINEERING

Systems engineers have had a problem, not only explaining what they do to other people, but also defining it amongst themselves. For example, at (NCOSE 1994), presenter after presenter opened their presentation with a definition of SE. and each definition was different. However, when each presenter continued by describing the functions performed by systems engineers, they talked about ***planning, organizing, directing and measuring*****; the traditional functions of management.** When asked what systems engineers did, their answers were also different. Now, as (Mackey[2], 1994) pointed out, SE was developed in the communications industry to meet the networking challenges of the 1950's and may even have begun in Germany in the 1940's. So for more than 40 years, no systems engineer has come up with a definition of SE that systems engineers can agree upon. The question is

> ***"What is there about Systems Engineering that defies definition"?***

In an attempt determine the nature of the problem the proceedings published at (NCOSE 1994 and 1995) were scanned to determine if their subject matter could provide an answer. The results are shown in

Table 1.

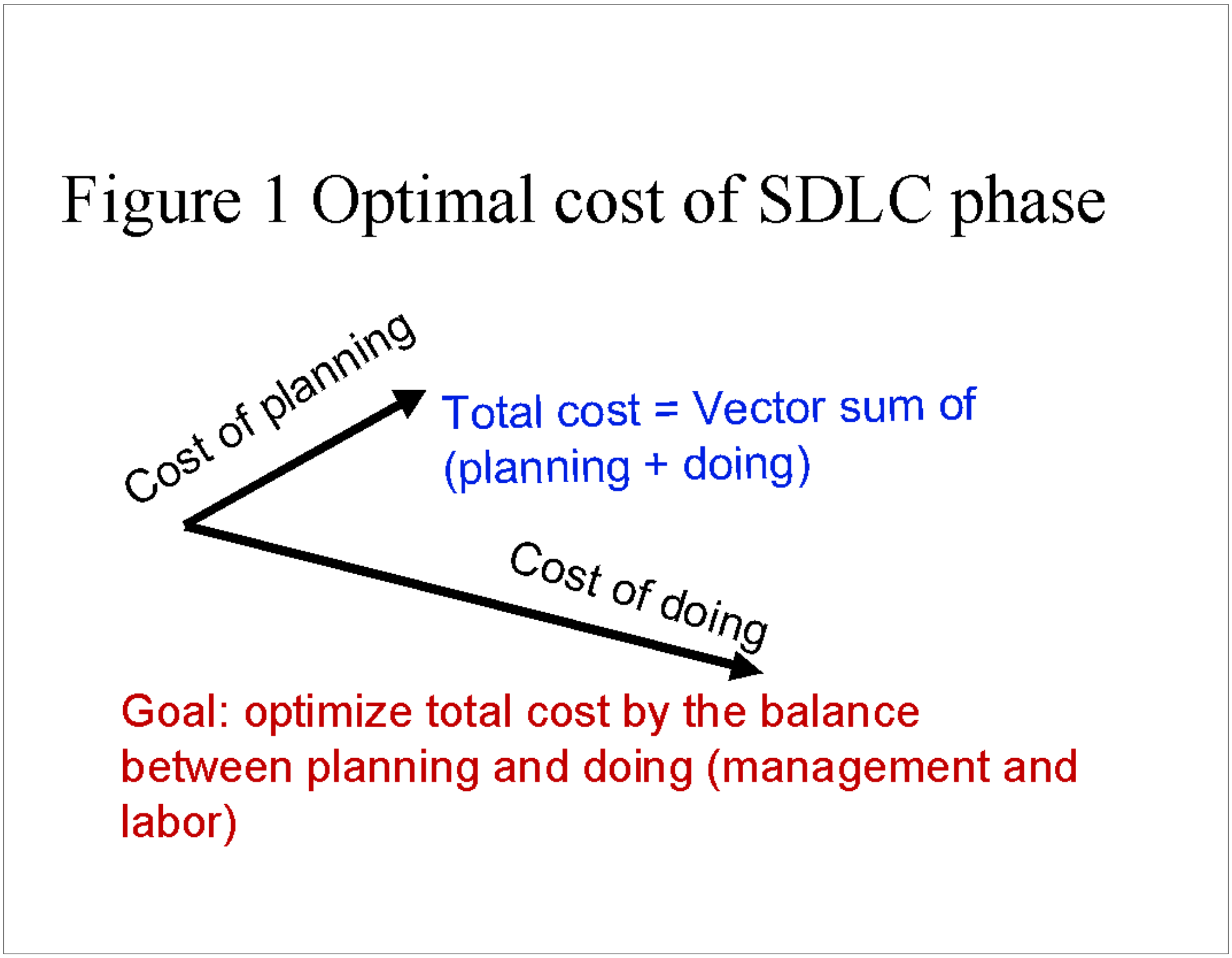
Table 1 Topics of NCOSE proceedings

Topic discussed	**1994**	**1995**
Requirements	31	24
Architecture/design	9	7
Analysis	1	0
Build/integrate	1	1
Test	0	0
Operations and maintenance	0	1
"ilities"	0	3
Methodology and models	43	43
Concurrent engineering and IPTs	0	11
Risk Management	4	11
Management	8	9
Organization and tools for SE	21	13
TQM and metrics for SE	14	8
ISO 9000	0	2
People and teams	1	11
Ethics in SE	0	1
Reengineering	1	0
Total	**134**	**146**
Papers in proceedings	**147**	**139**

Everyone seemed to agree that SE is performed throughout the Systems Development Life Cycle (SDLC) which spans the range of product inception, through design, development, operations and obsolescence. The number of papers on methodology and process showed there is no "standard" process for SE. While papers in other engineering conferences tend to focus on applications (outward), the (NCOSE 1994 and 1995) papers focussed on:

- SE methodology and process (inward).
- The early phases of product inception, namely "requirements engineering".

SE seems to be in the state electrical engineering was in before the adoption of "Ohms's law'.
An attempt to identify such an "Ohm's law" in terms of cost elements was then initiated. The approach was to consider the activities in the SDLC that pertain to planning as "delays" and the activities involved in working as "leading". These are the analogs to capacitance (lags) and inductance (leads). Then for any phase in the SDLC, the optimal cost to perform the phase is the "right mix" of planning and doing as shown in Figure 1. This attempt failed since all the activities identified overlapped those of "project management".



SYSTEMS ENGINEERING AND MANAGEMENT

Project Management. According to (Kezsbom et al. 1989, 6) project management is defined as

> *"the planning, organizing, directing, and controlling of company resources (i.e money,materials, time and people) for a relatively short-term objective. It is established to accomplish a set of specific goals and objectives by utilizing a fluid, systems approach to management by having functional personnel (the traditional line-staff hierarchy) assigned to a specific project (the horizontal hierarchy)".*

Kezsbom's systematic approach to project management requires the break down and identification of each logical subsystems component into its own assemblage of people, things, information or organization required to achieve the subobjective (Kezsbom et al., 1989, 7).

The role of the Systems Engineer. The role of the systems engineer is to ensure the delivery of the best working system that can be built within the constraints of schedule, budget and resources. As such, systems engineers:

- Have the responsibility for the global technical design, optimal implementation and proper verification of the system over the entire SDLC [Kasser 1995].
- Manage subcontractors, requirements, prepare plans for systems engineering and risk management (Brekka et al. 1994).

For systems engineers to be the only functional skill which fulfills this role, they must have a unique body of knowledge.

The SE Body of Knowledge. Looking around, reviewing experience and the literature, apart from "requirements and interface engineering" there is no unique body of knowledge for SE. All the 'ilities' are careers in themselves, and have their own literature. According to (Roe 1995) the knowledge and skills of SE are the same as those of project management in the areas of management expertise, technical breadth and technical depth. The difference in application is the system engineer has more technical breadth, while the project manager has more management expertise.

The traits of systems engineers. (Hall, 1962, 16-18) provided the following specifications or traits for an "Ideal Systems Engineer". The specifications are grouped in several areas:

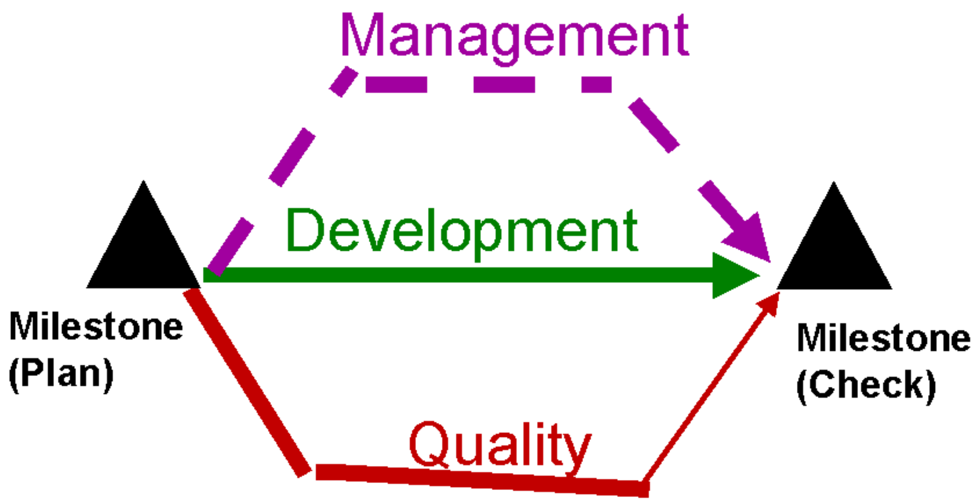
- An ability to see the big picture.
- Objectivity.
- Creativity
- Human Relations
- A Broker of Information
- Education - Graduate training in the relevant field of interest (application), as well as courses in probability and statistics, philosophy, economics, psychology, and language.
- Experience in research, development, systems engineering and operations.

Hall concludes by stating that as the ideal is not available, mixed teams of specialists and generalists are used.

OUTSIDE THE BOX

The Environment Model. Consider the environment in which SE is performed, namely the organization. The current organization is configured in a hierarchical structure. The division of work between manager and worker within our corporate organizational structure is based on "Scientific Management" (Taylor 1911), and we have further added "Quality" as another area of endeavor as shown in Figure 2. Yet, these days, Taylor's:

Figure 2 Three streams of work



- **Assumptions are no longer valid** - Taylor's paradigm was for an organization in which the workers did not want to work (Theory X). Today most organizations are Theory Y and the workers want to get the job done.
- **Rules for the division of labor are not being followed** - Taylor split the work into a partnership between brain and brawn. Taylor assumed managers knew more about the work than did the worker. According to Taylor, managers are supposed to plan and direct activities, while the workers do the work. Yet today much of management has little idea of the technical aspects of the work and consequently little idea of the technical impact of their decisions.

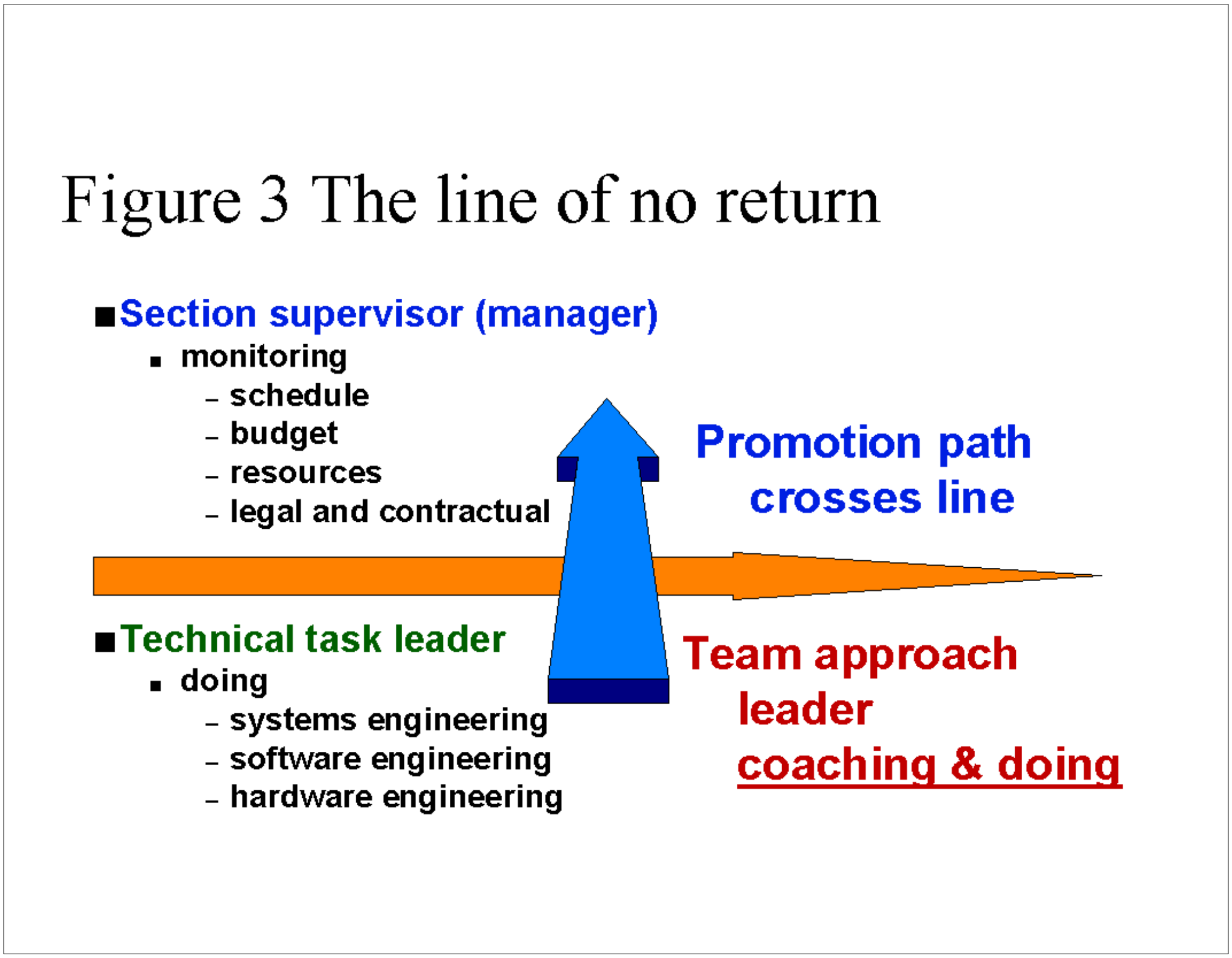
The optimal management method is said to be Management By Walking Around (MBWA) (Peters and Austin 1985). Yet (Deming 1986, 22) wrote

> *"MBWA is hardly ever effective. The reason is that someone in management, walking around, has little idea about what questions to ask, and usually does not pause long enough at any spot to get the right answer".*

Juran as quoted by (Harrington, 1995, 198) stated that 80 to 85% of all problems are caused by management.

We spend a lot of organizational energy mitigating the effect of poor management instead of on productive work. This working around ineffective managers leads to excessive complexity within the organization. For example, we create jobs which compensate for the lack of skills in management. One such job is the 'facilitator' who keeps meetings on track, a second example may be the 'systems engineer'. Excessive complexity is a symptom of an underlying problem within the foundation of the current paradigm (Kasser 1996). Other symptoms that the Taylor organizational paradigm is defective are:

- The ineffective use of promotions since financial rewards are equated with greater degrees of control. We tend to promote a good technical person into a poor manager. Once the line in Figure 3 is crossed, there is no retreat within the organization, and good technical people may be lost to the organization. This particular path also leads to the impression that managers are more important than the technical personnel who produce the products which bring in the revenue.
- The adoption of project management and other sub-organizations which cross the boundaries of management, development and quality (Integrated Process Teams (IPT) and concurrent engineering).
- Our symbology uses boxes for a hierarchical organization structure and circles for a process. Truly a case of attempting to insert a square peg into a round hole.
- The report producing and information filtering functions of middle management have largely been replaced by technology (Rodgers et al. 1993).



CONCURRENT ENGINEERING, TOTAL QUALITY MANAGEMENT, et al.

Concurrent Engineering. Looking at industry today, Hall's mixed teams seem to be called IPTS and are working in the context of "concurrent engineering" which has existed as a recognizable topic since the mid 1980's. According to (Gardiner 1996) the aim of both concurrent engineering and SE is

> *"to provide a good product at the right time .. suitably free of defects and ready when the customer*

> *wants it*".

Total Quality Management (TQM) . The International Organization of Standards (ISO) 8402:1994 definition of Quality is:

> *"the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs"*,

in other words 'requirements' or what the customer really wants and the degree of conformance to same'. The ISO definition of TQM is:

> "*management approach to an organization, centered on quality, based on the participation of all its members and aiming at long-term success through customer satisfaction and benefits to all members of the organization and to society*."

Customer satisfaction is based on producing a quality product at a cost the customer is willing to pay. So, when, in early 1996, the International Council of Systems Engineers (INCOSE) finally published a definition of SE as:

> "*an interdisciplinary approach and means to enable the realization of successful systems*."

INCOSE seems to have reiterated the statement in (NASA, 1992, 7)

> "*TQM is the application of SE to the work environment*".

This is not so surprising because many of the tools used for TQM are the same as for systems engineering, but with different names. (NASA, 1992 , 7) also stated

> *"Statistical process control is akin to the use of technical performance and earned value measurements"*.

The Conference. A conference is itself a system by definition. Consider the process to prepare and produce a conference for 800 systems engineers one year from today (the product). This need is analyzed and a set of requirements developed for the:

- Date of the conference.
- Constraints imposed by available resources.
- Number of session tracks.
- Number of sessions.
- Anything else needed.

These requirements are analyzed, alternative implementations proposed, decisions made based on evaluation criteria. A location is picked. Sessions are developed, and publicity generated. As time goes by, a call for papers is published, papers are received and evaluated, conference registrations are received and processed. One day the conference begins and the pace really heats up as 800 people have to be provided with the full services of a conference in real-time. Several systems are in action and interacting including the preparation and presentation of the:

- Sessions.
- Proceedings.
- Meals.
- Accommodation.

Name the process described in this section. Is it conference management or SE?

THE TEMPORAL PERSPECTIVE

Engineers were hard at work designing and building from the pyramids, war machines and irrigation systems, of pre-history to the canals and railroads of the 19th century. Those systems in their day were just as complex as the systems we design and build today. They had the same constraints of resources, budget and schedule. So why:

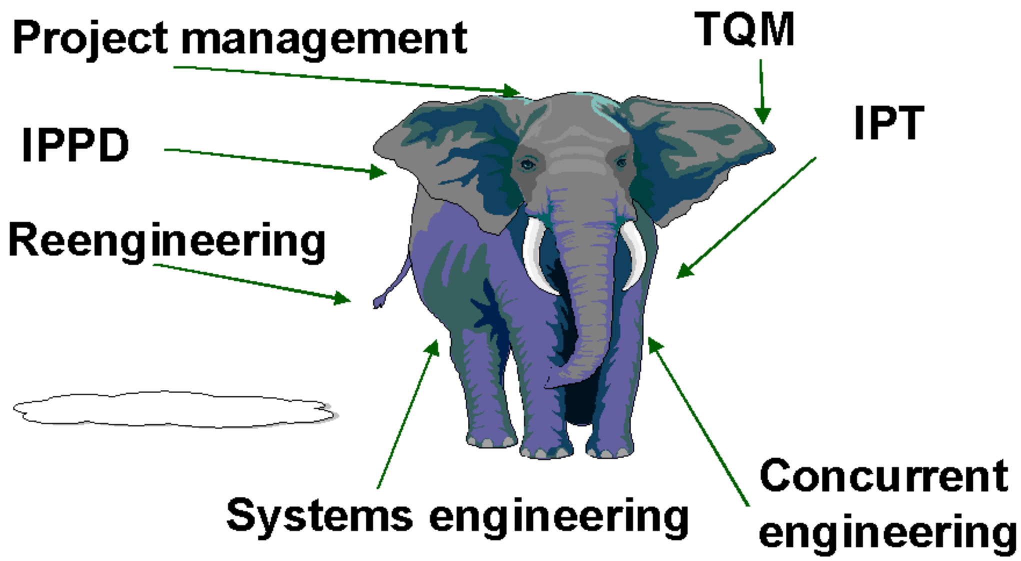
- Have the concepts of TQM only been recognized as having been around for 25-35 years?
- Has SE only been recognized as a discipline since the 1950's?

The last 50 years have also seen a transition (not yet completed) from hardware based systems to software based systems. For example, the job advertisements in the media now tend to focus on the software skills needed by applicants for SE positions. SE may be an artifact of this transition.

CONCLUSIONS

SE 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 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 SE 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 SE, 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.

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BIOGRAPHY

Joe Kasser combines systems engineering with management skills and expertise. He has spent the last 20 years applying total quality management to systems engineering, and has achieved the cost-effective implementation of international and domestic aerospace, communications, and solar power systems. He is a recipient of NASA's Manned Space Flight Awareness (Silver Snoopy) Award for quality and technical excellence. He is also an Institute of Certified Professional Manager's (ICPM) Certified Manager and a recipient of the ICPM's 1993 Distinguished Service Award. He is the author of *Applying Total Quality Management to Systems Engineering*. He led the design, building, and installation of a network of 600 microprocessors, such that it was installed half way around the world and worked first time with only a single hardware discrepancy report. He saved NASA $1.5 million. He is currently working on his systems engineering doctoral dissertation at The George Washington University, and another book with the provisional title *There's No Place for Managers in a Quality Organization*.