Yes systems engineering, you are a discipline

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"It ain't what you don't know that gets you into trouble. It's what you know for sure that just ain't so." - Mark Twain 1835-1910.

Abstract Systems engineering is currently characterized by conflicting and contradictory opinions on its nature. The paper begins by describing the evolution of systems engineering in the National Council on Systems Engineering (NCOSE)/ International Council on Systems Engineering (INCOSE) and the difficulty in defining and differentiating systems engineering as a discipline. The paper then identifies and discusses six different and somewhat contradictory camps or perspectives of systems engineering. After identifying the cause of the contradictions the paper suggests one way to reconcile the camps is to dissolve the problem to distinguish between the activity known as systems engineering and the role of the systems engineer with a return to the old pre-NCOSE systems engineering paradigm. The paper then continues by testing the hypothesis and shows that systems engineering is a discipline that can be differentiated from other disciplines. However, it is not a traditional engineering discipline.

Systems engineering in NCOSE/INCOSE

Systems engineers have had a problem, not only explaining what they do, to other people but also defining it amongst themselves since the early 1990's. The baseline for this research however began at the 1994 symposium of the NCOSE, where presenter after presenter opened their presentation with a definition of systems engineering 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 controlling; the traditional functions of management (Fayol, 1949) page 8). When asked what systems engineers did, their answers were also different. These observations in 1994 triggered a research program into the nature of systems engineering and its overlap with project management which began with an analysis of the activities or functions performed by systems engineers. The initial research showed that there seemed to be no unique body of knowledge to systems engineering and that all of the activities performed by systems engineers, apart from possibly requirements and interfaces, were also performed by other types of engineers (Kasser, 1996). The paper concluded with "*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*". Subsequent research into the nature of systems engineering included a literature review of text books published between 1959 and 2009 starting with (Goode and Machol, 1959) as well as the proceedings of all the international symposia of the INCOSE since 1991. Findings from this research determined (Kasser and Massie, 2001; Kasser and Hitchins, 2009) that:

- The role of the systems engineer in the workplace depends on the situation. This is because the role of the systems engineer has evolved over time so that it is different in practically every organisation and has various degrees of overlap with the roles of project managers and personnel in other disciplines.
- Definitions and descriptions of systems engineering comprise different interpretations of the broad raft of activities that systems engineers might undertake according to their role in the workplace.

This multichotomy exists because different people have chosen or perceived different meanings of the term ‘systems engineering’ for almost 60 years. Consider the following comment from 1960 “*Despite the difficulties of finding a universally accepted definition of systems engineering, it is fair to say that the systems engineer is the man who is generally responsible for the over-all planning, design, testing, and production of today’s automatic and semi-automatic systems*” (Chapanis, 1960) page 357). (Jenkins, 1969) page 164), expanded that comment into twelve roles (activities performed by a person with the title systems engineer) of a systems engineer and seven of those roles overlapped the role of the project manager (activities performed by a person with the title project manager). Since that time, systems engineering has evolved and some of the evolution in systems engineering can be seen in the very little overlap between the twelve roles documented by (Jenkins, 1969) and the twelve systems engineering roles documented by (Sheard, 1996).

The six camps in systems engineering

An analysis of the different views of/opinions on/worldviews of (Checkland, 1993) systems engineering in the early years of the 21st century identified the following somewhat overlapping camps (Kasser and Hitchins, 2011): Life cycle, Process, Problem, Discipline, Systems thinking and non-systems thinking, and Enabler. Consider each of these camps:

Life cycle camp

Some systems engineers seem to have an understanding of the early stage systems engineering activities that take place in the concept definition stage of a solution system acquisition[1]. The majority however has no idea that the concept definition phase even exists, they don’t understand what happens in that phase and they think that systems engineering in the acquisition domain begins with the requirements analysis phase. The early stage campers tend to be the old timers; while the others tend to be those systems engineers educated in the last 20-30 years in the paradigm based on the United States Department of Defence (DOD) where the whole set of activities performed in early stage systems engineering were removed from “systems engineering”[2.] In this paradigm, requirements are but one of the inputs to the ‘systems engineering process’, see (Martin, 1997) page 95; (Eisner, 1997); (Wasson, 2006) page 60; (DOD 5000.2-R, 2002), pages 83-84) for typical examples.

Process camp

Some systems engineers, particularly in INCOSE and the US Department of Defense, are

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[1] The solution system is acquired to remedy a problem.

[2] This removal was documented in DOD 5000.2-R, "Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs," US Department of Defense, 2002.

process-focused. For example, (Arnold, 2000) quoted (MIL-STD-499B, 1993) and (IEEE 1220, 1998) stating "*a single process, standardizing the scope, purpose and a set of development actions, has been traditionally associated with systems engineering*". The process-focused systems engineers' mantra is to apply "the systems engineering process" and all will be well. These are the campers who tend to insist that organisations must modify themselves to follow a particular process standard in accordance with the United States Department of Defense 5000 Guidebook Section 4.1.1, which states that the successful imp*lementation of proven, disciplined systems engineering processes results in a total system solution that is robust to changing technical, production, and operating environments; adaptive to the needs of the user; and balanced among the multiple requirements, design considerations, design constraints, and program budgets".* However, these campers can't seem to see the big picture and don't seem to realise that not only does the "systems engineering process" map into the ubiquitous general problem solving process but there is also currently no single widely agreed upon "systems engineering process" since over the years, the "systems engineering process" has been stated in many different and sometimes contradictory ways, including:

- The (MIL-STD-499B, 1993), (EIA 632, 1994) and (IEEE 1220, 1998) processes;
- The lists of processes in ISO/IEC 15288 (Arnold, 2002);
- The waterfall process (Royce, 1970);
- The V "model" representation of the waterfall process;
- The spiral, incremental and evolutionary models;
- System Lifecycle functions (Blanchard and Fabrycky, 1981);
- State, Investigate, Model, Integrate, Launch, Assess and Re-evaluate (SIMILAR) (Bahill and Gissing, 1998);
- The basic core concepts accepted by most systems engineers (Mar, 2009);
- A systems engineering approach to addressing a problem (Hitchins, 2007).
- The INCOSE Handbook (Haskins, 2011).

These campers fail to realize that the reason why these documented processes are different is that they were developed by some entity at some point in time for a specific situation and *need to be tailored* for other specific situations. It is the systems engineer designs (Biemer and Sage, 2009), architects (Kasser, 2005) or customizes the process that will be used to realize the solution system[3]. These campers also ignore:

- The literature on excellence which focuses on people and ignores process; see (Peters and Waterman, 1982; Peters and Austin, 1985) and (Rodgers, et al., 1993) for typical examples.
- The axiom "garbage-in-garbage-out" (GIGO) which although originally was applied to computer data, holds true for all types of processes.
- Attempts to warn against "overemphasis on the institutionalization of processes rather than the value or effectiveness of the effort" (Armstrong, 1998).

In the last few years, the process camp has produced Model Based Systems Engineering (MBSE) by applying 21st century technology in their 20th century systems engineering process paradigm. MBSE in its current form:

- is an attempt to return to the early stage systems engineering activities performed in the 1960's and 70's , and,

[3] Perhaps this is because process architecting tends to be overlooked because process architecting is generally not taught in systems engineering classes which tend to assume a process exists and start from there. Process architecting however is taught in project management classes as a part of creating project plans.

- ignores the potential of the integrated information environment to produce interdependent third and fourth generation systems engineering and project management tools that could improve on the current paradigm and reduce the probability of project failures by adding expert system and artificial intelligence functionality to the tools[4]; a potential that was demonstrated at the Systems Engineering and Evaluation Centre at the University of South Australia in the early years of the 21st century (Kasser, et al., 2002; Cook, et al., 2001; Kasser, 2000; 2002).

Problem camp

The problem solving camp can be traced back at least as far as 1980 (Gooding, 1980). These campers maintain the tradition of the pre-NCOSE systems engineers and focus on the problem and identifying the best solution available given the constraints at the time (Hitchins, 2007). Some of these campers also address carrying out that process to realize the solution system; see (Bahill and Gissing, 1998) for an example. This is why, as mentioned above, their "systems engineering [problem solving] process" overlaps the various versions of problem solving process, See (GDRC, 2009) and (OVAE, 2005) for typical examples of the problem solving process.

Discipline camp

Systems engineering meets the requirement for a discipline proposed by (Kline, 1995) page 3, who wrote "*a discipline possesses a specific area of study, a literature, and a working community of paid scholars and/or paid practitioners*". However, as noted above, all the elements of the current INCOSE approach to systems engineering overlap those of project management and other disciplines which make it difficult to identify systems engineering as a distinct discipline for tackling complex problems. For examples, see:

- (Jenkins, 1969; Brecka, 1994; Roe, 1995; DSMC, 1996; Sheard, 1996; Johnson, 1997; Watts and Mar, 1997; Bottomly, et al., 1998; Kasser, 1996) for just a few examples of the different overlaps between systems engineering and project management.
- (Emes, et al., 2005) who discussed overlaps between systems engineering and other disciplines.
- (Eisner, 1988) who listed a general set of 28 tasks and activities that were normally performed within the overall context of large-scale systems engineering. He calls the range of activities 'specialty skills' because some people spend their careers working in these specialties. Thus according to Eisner in 1988 [the role of][5] systems engineering overlaps at least 28 engineering specialties.
- (Eisner, 1997) page 156), who expanded (Eisner, 1988) and discussed 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*". INCOSE President John Thomas expands on this role in his presentations on the need for systems engineers with moxie, see (Thomas, 2011) for one example.

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[4] As a simple example in smartening up requirements management tools, Tiger Pro contains the functionality to detect and correct some types of errors in requirements (Kasser, et al., 2003).

[5] Author's interpretation.

- (Goode and Machol, 1959) according to (Hall, 1962), page 20), make no distinction between 'systems engineering' and 'engineering design' or even 'design' and use the terms interchangeably. (Archer, 1965) defined design as *"a goal-directed problem solving activity"*. (Fielden, 1963) defined 'engineering design' as *"the use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform prespecified functions with the maximum economy and efficiency*" and (Matchett and Briggs, 1966) defined 'design' as *"the optimum solution to the sum of the true needs of a particular set of circumstances"*. (Bahill and Dean, 1997) in discussing the requirements in the 'systems engineering process' call it the 'system design process' and use the terms 'design' and 'solution' interchangeably. And, (Hari, et al., 2004) provided an example of the various activities performed in new product design that overlap those of systems engineering.
- The UK Defence Evaluation and Research Agency (DERA) definition of systems engineering is "*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*" (DERA, 1998). Controlling activities are project management activities, development and testing activities are engineering activities.
- According to (Kezsbom, et al., 1989), page 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, et al., 1989), page 7'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 sub-objective.
- (DOD, 1996) defined Integrated Product and Process Development (IPPD) as *"a management process that integrates all activities from product concept through production/field support, using a multifunctional team, to simultaneously optimize the product and its manufacturing and sustainment processes to meet cost and performance objectives"*. Looking at industry today, (Hall, 1962)'s mixed systems engineering 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 Systems Engineering is *"to provide a good product at the right time ... suitably free of defects and ready when the customer wants it*".
- Configuration Management is defined as "*a field of management that focuses on establishing and maintaining consistency of a system's or product's performance and its functional and physical attributes with its requirements, design, and operational information throughout its life*" (MIL-HDBK-61A, 2001). There are two types of configuration audits within configuration management:

  - Functional configuration audits– which ensure that functional and performance attributes of a configuration item are achieved, and
  - Physical configuration audits - which ensure that a configuration item is installed in accordance with the requirements of its detailed design documentation.

  Configuration audits can occur either at delivery or at the moment of effecting a change. These audits are commonly known as verification and validation or testing in the systems engineering community.

The discipline camp tends to account for the overlap by viewing systems engineering as a meta-discipline incorporating the other disciplines and hold that systems engineering needs to widen its span to take over other disciplines.

Systems thinking and non-systems thinking camps

The systems thinking camp tends to be systems engineers who can view an issue from several perspectives e.g. (Evans, 1996; McConnell, 2002; Rhodes, 2002; Martin, 2005; Selby, 2006; Beasley and Partridge, 2011), while the non-systems thinkers tend to have a single viewpoint. The non-systems thinkers also generally exhibit the 'biased jumper' level of critical thinking (Wolcott and Gray, 2003). In addition, there is a domain systems view of the role of systems engineers/engineering as well. Examples are network systems engineers/engineering, control system engineers/engineering, communications systems engineers/engineering, hydraulic systems engineers/engineering, transportation systems engineers/systems engineering, etc.

Enabler camp

In the enabler camp, systems engineering is the application of systems thinking and critical thinking. Moreover, it can be, and is, used in all disciplines for tackling certain types of (complex) problems; see "*[systems engineering] is a philosophy and a way of life*" (Hitchins, 1998).

Reconciling the camps

Each camp is focused on the role of the systems engineer in the workplace and each camp has a different version or vision of that role. As long as these camps were isolated, there was no problem; it is when these different roles are compared that the confusion, complexity, contradictions and overlaps with other disciplines appears. The situation is indicative of the early stages of a discipline much like the state of chemistry before the development of the periodic table of the elements or the condition of electrical engineering before the development of Ohm's Law and later the development of electrical motors before Maxwell's equations were discovered. For systems engineering to become a discipline, these camps must be reconciled or unified.

There are four ways of remedying or dealing with a problem, namely solving, resolving, dissolving or absolving the problem (Ackoff, 1978) page 13), where only the first three actually remedy the problem. The four ways are:

- **Solving the problem** is when the decision maker selects those values of the control variables which maximize the value of the outcome.
- **Resolving the problem** is when the decision maker selects values of the control variables which do not maximize the value of the outcome but produce an outcome that is good enough (satisfices the need).
- **Dissolving the problem** is when the decision maker reformulates the problem to produce an outcome in which the original problem no longer has any meaning.
- **Absolving the problem** is when the decision maker ignores the problem or imagines that it will eventually disappear on its own. Problems may be intentionally ignored because they are too expensive to remedy, or because the technical or social capability needed to provide a remedy is not known.

The chosen approach to reconciling the camps is to dissolve the problem by making a change in the paradigm. This approach redesigns the system containing the problem or changes the perspective from which the problem is viewed, to produce an innovative solution. The current systems engineering paradigm is based on the role of the systems engineer in the workplace, namely what the systems engineer does recognizing that what the systems engineer does is different in each organization. The approach to reconcile the camps is to distinguish between two systems engineering paradigms:

- systems engineering - the role (SETR) being what systems engineers do in the workplace , and
- systems engineering - the activity (SETA) that can be performed by anyone.

SETA is the set of activities known as systems engineering, while SETR is a role or job description of the systems engineer. (Kasser and Palmer, 2005). Having made the distinction, the following criterion was used to determine if an activity does or does not belong in the set of activities known as SETA (Kasser and Hitchins, 2009; Kasser, et al., 2009):

- If the activity *deals with parts and their interactions as a whole*, then it is an activity within the set of activities to be known as SETA.
- If the activity *deals with a part in isolation*, then the activity is not an activity within the set of activities to be known as SETA but is part of another set of activities ('something else'), e.g., engineering management, software engineering, etc.

SETA is a return to Hall's definition of "*systems engineering as a function*[6] *not what a group does*[7]" (Hall, 1962) page 11. Hall added "*By recognizing the scope of the function it becomes possible to dissect it, to understand its problems and to reconstruct it to make it more efficient than it is today*".

Kuhn wrote 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 (Kuhn, 1970). If SETA is an alternative systems engineering paradigm to SETR, then to meet Kuhn's requirement for an alternative paradigm it has to resolve conflicts that cannot be readily resolved within the current paradigm, namely reconcile the camps.

Testing the hypothesis

The hypothesis that SETA is a systems engineering paradigm was tested by posing the following research questions:

1. Is there another set of activities (equivalent to SETA) that can be considered as a discipline that is used in other disciplines and domains?
2. Can SETA as a discipline be differentiated from other disciplines?
3. Can the traditional SETR view of systems engineering be described in terms of SETA?

Consider each research question in turn.

1. Another set of activities.

Is there another set of activities that can be considered as a discipline that is used in other disciplines and domains? The answer to the question is yes. Mathematics is considered both as a discipline and as a set of tools used in many if not all disciplines and domains. For example, operations research is based on mathematics, managers commonly use spread sheets, and humanity uses the ubiquitous digital calculator to perform mathematical calculations many situations.

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[6] Activity.
[7] Role.

2. Differentiation of SETA as a discipline

Can SETA as a discipline be differentiated from other disciplines? The answer to the question is yes which resolves the issue of differentiating systems engineering from other disciplines, something which cannot be done in the current INCOSE paradigm. SETA is often used in the form of applying systems thinking and critical thinking (Kasser and Mackley, 2008; Kasser, 2009) in the ubiquitous generic problem-solving-solution-realization process.

Mathematics is an enabling discipline which provides a set of tools and techniques for tackling certain types of problems. Similarly SETA is not a traditional engineering discipline but can also be considered as an enabling discipline, providing a set of tools and techniques, comprising activities that deal with parts of a system and their interactions as a whole, which are used to identify underlying problems and realize optimal solutions via the systems engineering problem solving process. This is a change in perspective with respect to the current INCOSE discipline camp which looks outwards from systems engineering. In the discipline camp, SETR is or should be taking over other disciplines. The enabler camp looks at systems engineering from the outside. From this outside perspective, SETA is an enabling discipline used in those other disciplines and professions.

Moreover, the SETA discipline is a return to the pre-NCOSE systems engineering paradigm for managing complexity and innovation as documented by the literature of the time including (Goode and Machol, 1959) and (Hall, 1962), when 'systems engineering' (SETA) was a tool used by, or synonymous with, 'design' (Goode and Machol, 1959; Hall, 1962; Fielden, 1963; Archer, 1965; Matchett and Briggs, 1966; Jones, 1970) page 115) and 'systems engineers' (SETR) performed SETA using systems engineering tools (Wilson, 1965; Alexander and Bailey, 1962; Chestnut, 1965) such as:

- Probability,
- Single thread – system logic,
- Queuing theory,
- Game theory,
- Linear programming,
- Group dynamics,
- Simulation, and
- Information theory

3. Traditional activities

Can the traditional SETR view of systems engineering be described in terms of SETA? The answer is yes.

From the big picture perspective, SETA and non-SETA are subsets of the whole set of workplace activities performed in the problem-solving-solution-realization process which covers the entire activity from the time an issue is raised (which in turn becomes a problem which then needs a solution) to the time of disposal of the solution system when it no longer satisfies the need. This set of activities may be partitioned into different mixes of subsets in various ways such as by profession and discipline (project/engineering management, systems engineering, engineering, new product design, etc.) and by time (the phases in the system lifecycle). These SETA and non-SETA activities can be also be grouped into the following three interdependent streams of work which merge at predefined milestones during the system development lifecycle (SDLC) as shown in Figure 1.

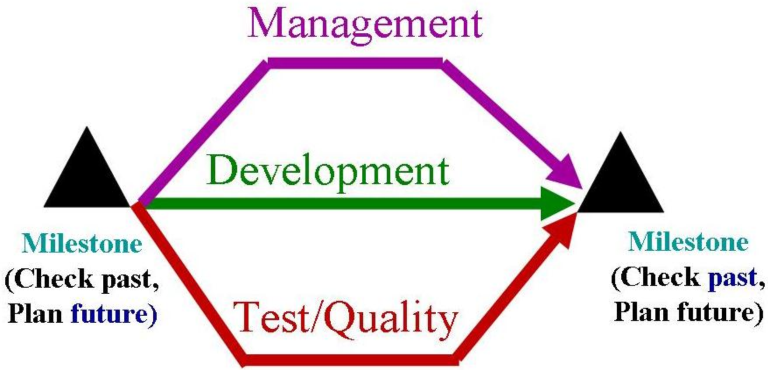

Figure 1 The three streams of work to realize a solution to a problem between two milestones

- **Development,** the activities which identify the correct problem and develop the optimal solution system.
- **Management,** which performs the necessary planning, organizing, directing, controlling, staffing and reporting activities to ensure that resources (equipment and personnel) are available when needed within the constraints of schedule and budget.
- **Test/Quality,** which performs the prevention, testing, configuration control, quality and process improvement activities.

Due to the various ways in which SETA and non-SETA have been allocated to personnel[8] performing SETR and non-SETR, in any specific organisation at any specific time, a specific SETR will perform a mixture of SETA and non-SETA in one or more of the three interdependent steams of work. For example, one instance of SETR might perform systems architecting in the development stream while another may perform systems engineering management in the management stream and a third perform system integration. At the same time non-SETR personnel, such as designers or project managers might be performing different mixtures of non-SETA and SETA. This situation also explains why there seem to be a lot of people in industry doing SETA without being aware of the term 'systems engineering'.

SETR has traditionally been associated with Defence and aerospace due to their conflation. (MIL-STD-499B, 1993) defines a total systems approach for the development of defence systems. Section 1.1 of the standard states that "*the systems engineering process is applied iteratively through the system life cycle to translate stated problems into design requirements*". Yet the systems engineering process described in the standard is just a version of the latter part of ubiquitous generic problem-solving-solution-realization process stated in engineering language. SETA can thus be considered as an enabling discipline used in the problem-solving-solution-realization process performed in the domain of acquiring and developing Defence systems. ISO/IEC 15288 (Arnold, 2002) also contains a list of processes used in the domain of acquiring and developing systems which overlap all three streams of work. Each of those processes contains SETA and non-SETA.

Discussion

Systems engineering has been associated with Defence and aerospace due to their conflation. SETA is often used to perform design, yet Love argues "*the central activity of designing is*

[8] The word 'personnel' is used to avoid the semantically loaded terms engineers, systems engineers, project manager, etc.

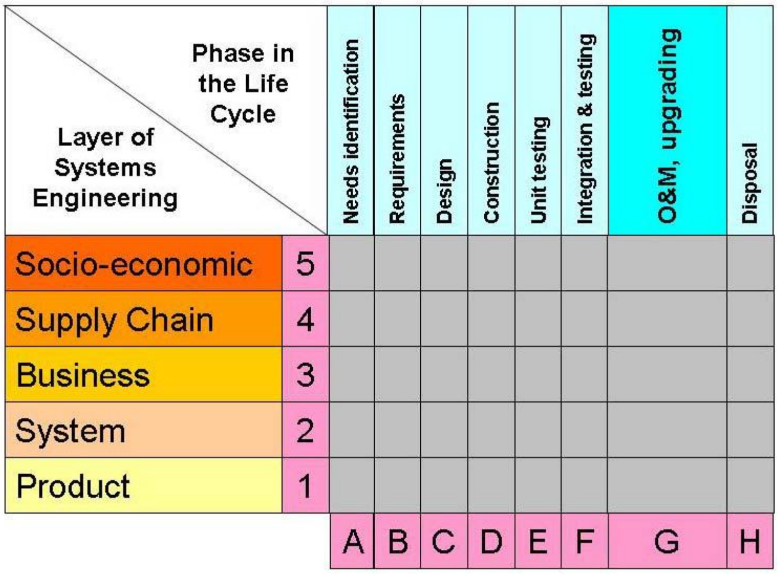

Figure 2 The HKM Framework for understanding systems engineering

'epistemologically different' from the application of systems methods, techniques, and approaches and perspectives". It [his paper] *suggests the uncritical conflation of the activities of designing and systems analysis seriously compromises theoretical and practical developments in both Systems and Design and this has led to confusion in both fields and to the development of extensive, unnecessary and over-complex theories targeting an epistemologically irresolvable problem.*" (Love, 2003). Overly complex theories are a symptom of a flaw in the paradigm. There is a need to differentiate SETA from the system acquisition and development lifecycle currently conflated with systems engineering.

Systems engineering began as SETA and evolved into SETR (Hitchins, 2007; Kasser, et al., 2009). The SETR paradigm, led by the discipline camps looks outwards from systems engineering in an effort to expand SETR into a meta-discipline. The SETA paradigm on the other hand, looks inwards at systems engineering from the outside and sees SETA as an enabling discipline applied inside those other disciplines. SETR is performed in all columns of the Hitchins-Kasser-Massie Framework (HKMF) for understanding systems engineering (Kasser, 2007) shown in Figure 2. However, in any one layer, most of SETA tends to be performed in Column's A and B; the activities involved in figuring out the problem and determining and specifying the optimal solution system to be realized. Most of the activities in columns C, D and E are non-SETA performed by engineers, designers and testers. Some SETA does occur to ensure that the system level specifications are met and to deal with the emergent properties. SETA picks up again during systems integration and the commissioning of the solution system in the field phases of the SDLC. In addition, if the subsystems are complicated enough they may have their own set of SETA and non-SETA. For example, in the Apollo program, there was an overall set of SETA for the entire mission; yet the realization of each of the subsystems was non-SETA engineering as far as the entire mission was concerned. However, the realization of the Lunar Module and the Apollo Lunar Surface Experiments Package (ALSEP) and the other tier one subsystems each needed SETA and non-SETA activities. And within the ALSEP, realization of the central station and each of the scientific experiments required SETA and non-SETA activities irrespective of the job title (SETR) of the person who performed the activities.

SETA does not actually produce a tangible product. SETA produces documents, namely the plans, specifications, reports, etc. during the SDLC. The non-SETA activities including engineering actually produce the solution system.

The SETA/SETR paradigms provide for agreement on SETA[9] and the recognition of the reasons for the different roles of the systems engineer. The lifecycle camp views SETR over the entire problem-solving-solution-realization process. The process camp views SETR in the latter part of the system lifecycle documented in the various standards applied to systems engineering (Honour and Valerdi, 2006; Haskins, 2011), and the problem camp views SETR as a problem solving role anywhere in the problem-solving-solution-realization process.

The SETA/SETR paradigms also provide a solution to the problem of developing a manageable systems engineering body of knowledge (SEBoK). SETR has evolved over time so that it is different in practically every organisation and has various degrees of overlap with the roles of other disciplines. This makes differentiating systems engineering from the other roles in the workplace extremely difficult and has resulted in the discipline camp calling systems engineering a meta-discipline that embodies the others. It also complicates developing a manageable SEBoK, since in order to be complete the contents of the SEBoK-SETR would have to cover the knowledge needed in the different SETR in practically every organisation and the knowledge needed in the disciplines where the overlaps occur. SETA on the other hand, can readily be determined in an objective manner by examining the activities in all three streams of work in the SDLC in each column of the HKMF, sorting out the SETA and creating a SETA-SEBoK with traceability to each area in the HKMF. Moreover, additional research can tag each of the areas of the HKMF with required competencies.

Personnel known as systems engineers (SETR) often perform a mixture of SETA and engineering. SETA in all three streams of work incorporates the mental activities of applying holistic thinking (the combination of systems thinking, analysis and critical thinking) to remedying problems (Kasser and Mackley, 2008; Kasser, 2009). This is the way post-independence Singapore was systems engineered, by personnel in public health, housing, Defence, transportation, etc. and is the essence of the SETA paradigm irrespective of SETR and domain. The people who do SETA do it as a way of life (Hitchins, 1998) whether they are, or are not, known as systems engineers (SETR). For example, SETA is used when:

- **Cooking a meal.** The meal emerges from both the process and the combination of, and the interaction between, the ingredients. The best ingredients will not save a meal that was over-cooked or under-cooked.
- **Diagnosing an illness.** Good physicians consider the symptoms holistically in the context of the physiology of the patients and their environments.
- **Organising a conference.** The conference emerges from the combination of, and interaction between, the location, speakers, reviewers, delegates, and other entities.
- **Solving crimes.** Detectives, upon investigation, find a variety of clues which (should) lead to the perpetrator

And the personnel who perform these activities are not known as systems engineers. This is not surprising since the need for systems thinking in tackling problems has also long been recognised outside the systems engineering community: for example "*when people know a number of things, and one of them understands how the things are systematically categorized and related, that person has an advantage over the others who don't have the same understanding"* (Luzatto, circa 1735). Ford discussed looking at the value chain of products transported by the railroads as a system, in order to solve the transportation problem of his time (Ford and Crowther, 1922), pages 230-231). Other examples are Crosby's

[9] The INCOSE Fellows accepted the definition in 2009, see (Kasser and Hitchins, 2009).

"completeness" (Crosby, 1979), Deming's "system of profound knowledge" (Deming, 1993), and Senge's "fifth discipline" (Senge, 1990); all state the need for systems thinking, and the benefits to be gained therefrom.

Conclusions

Systems engineering can be considered as being two paradigms:

1. **SETR:** systems engineering performed by personnel known as systems engineers. Examples are network systems engineering, control system engineering, communications systems engineering, etc. In many instances the type of system is dropped from the title. This systems engineering overlaps other disciplines and the exact role depends on the situation.
2. **SETA:** the problem identification and solution realization activities on a system at the system level in accordance with the activity definition (Kasser and Hitchins, 2009). This systems engineering is an enabling discipline like mathematics.

Separation of the SETA and SETR paradigms:

- Resolves the conflicts and contradictions in the current state of systems engineering; in addition:
    1. The traditional activities known as systems engineering can be described in terms of SETA and SETR.
    2. SETR is the job title for a person who performs a mixture of SETA and non-SETA.
    3. SETA is an enabling discipline that is used in other disciplines and domains.
    4. SETA as a discipline can be differentiated from other disciplines.
- Resolves issues due to the overlap between systems engineering and project management.

Irrespective of what they are called[10], personnel leading projects should be Type Vs (Kasser, et al., 2009) with sufficient knowledge and experience in the problem, solution and implementation domains to be able to make informed decisions and understand the advice of experts in each domain. They should also be people who apply SETA all the time, namely it is their way of life.

Author's biographies

Joseph Kasser has been a practicing systems engineer for 40 years and an academic for about 14 years. He is a Fellow of the Institution of Engineering and Technology (IET), an INCOSE Fellow, the author of "*A Framework for Understanding Systems Engineering*" and "*Applying Total Quality Management to Systems Engineering*" and many INCOSE symposia papers. He is a recipient of NASA's Manned Space Flight Awareness Award (Silver Snoopy) for quality and technical excellence for performing and directing systems engineering and other awards. He holds a Doctor of Science in Engineering Management from The George Washington University. He is a Certified Manager and holds a Certified Membership of the Association for Learning Technology. He also started and served as the inaugural president of INCOSE Australia and served as a Region VI Representative to the INCOSE Member Board. He gave up his positions as a Deputy Director and DSTO Associate Research Professor at the Systems Engineering and Evaluation Centre at the University of South Australia in early 2007 to move to the UK to develop the world's first immersion course in systems engineering as a Leverhulme Visiting Professor at Cranfield University. He is currently a Visiting

[10] The term engineer-leader is used in Singapore to indicate that the person needs proficiency in both systems engineering and project management.

Associate Professor at the National University of Singapore.

Derek Hitchins retired from full time academic work in 1994 on medical grounds, and is now a part-time consultant, teacher, visiting professor and international lecturer. Formerly, he held the British Aerospace Chairs in Systems Science and in Command and Control, Cranfield University at RMCS Shrivenham. Prior to that, he held the Chair in Engineering Management at City University, London. Derek joined the Royal Air Force as a Cranwell apprentice and retired as a wing commander after 22 years, to join industry. His first industry appointments were as the System Design Manager of the Tornado F3 Avionics, Technical Co-ordinator for UKAIR CCIS, and UK Technical Director for the NATO Air Command and Control System (ACCS) project in Brussels. He subsequently held posts in two leading systems engineering companies as Marketing Director, Business Development Director and Technical Director before becoming an academic in 1988. His current research is into system thinking, system requirements, social psychology & anthropology, Egyptology, command & control, system design and world-class systems engineering. He has published three systems engineering books: "*Putting Systems to Work*", John Wiley & Sons, in 1992; "*Advanced Systems Thinking, Engineering and Management*," Artech House, 2003; and, “*Systems Engineering: A 21st Century Systems Methodology*,” John Wiley & Sons in 2007/2008. He inaugurated the IEE’s PG M5 — Systems Engineering. He also started the UK Chapter of INCOSE and was its inaugural president. He is an INCOSE Fellow, an INCOSE "Pioneer" and a Charter Member of the Omega Alpha Association.

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