Overview of the Systems Approach

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This knowledge area (KA) considers how a systems approach relates to engineered systems and to systems engineering (SE). The article Applying the Systems Approach considers the dynamic aspects of how the approach is used and how this relates to elements of SE.

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Systems Approach and Systems Engineering

The term systems approach is used by systems science authors to describe a systems "*thinking*" approach, as it pertains to issues outside of the boundary of the immediate system-of-interest (Churchman 1979). This systems approach is essential when reductionist assumptions (the notion that the whole system has properties derived directly from the properties of their components) no longer apply to the system-of-interest (SoI) and when emergence and complexity at multiple levels of a system context necessitate a holistic approach.

The systems approach for engineered systems is designed to examine the "*whole system, whole lifecycle, and whole stakeholder community*" as well as to ensure that the purpose of the system (or systemic intervention) is achieved sustainably without causing any negative unintended consequences. This prevents the engineer from "*transferring the burden*" (in systems thinking terms) to some other part of the environment that unable to sustain that burden (Senge 2006). This also deters issues involving *sub-optimization* that could occur when whole systems are not kept in

mind in achieving the purpose of the system (Sillitto 2012).

The systems approach (derived from systems thinking) and systems engineering (SE) have developed and matured, for the most part, independently; therefore, the systems science and the systems engineering communities differ in their views as to what extent SE is based on a systems approach and how well SE uses the concepts, principles, patterns and representations of systems thinking. These two views are discussed in the following sections.

Systems Science View

As discussed in the Systems Science article, some parts of the systems movement have been developed as a reaction to the perceived limitations of systems engineering (Checkland 1999).

According to Ryan (2008):

> **Systems engineering has a history quite separate to the systems movement.** *Its closest historical link comes from the application of systems analysis techniques to parts of the systems engineering process . . . The recent popularity of the SoS buzzword in the systems engineering literature has prompted* **the expansion of systems engineering techniques to include methods that can cope with evolving networks of semi-autonomous systems. This has led many systems engineers to read more widely across the systems literature, and is providing a re-conceptualization of systems engineering as part of the systems movement, despite its historical independence. This is reflected in the latest INCOSE hand-book [INCOSE 2011, page 52], which states "the systems engineering perspective is based on systems thinking", which "recognizes circular causation, where a variable is both the cause and the effect of another and recognizes the primacy of interrelationships and non-linear and organic thinking—a way of thinking where the primacy of the whole is acknowledged.** (emphases added)

Thus, for many in the systems science community, systems thinking is *not* naturally embedded in either SE definitions or practice.

Systems Engineering View

Many SE authors see a clear link between SE and systems thinking. For example, Hitchins (Hitchins 2007) describes generic models for the application of systems thinking to engineered system contexts. He suggests that these could form the foundation for descriptions and standards for the practices of SE. Hitchins also proposes a set of *guiding principles which have been the foundations of SE, apparently since its inception* (Hitchins 2009):

- **SE Principle A: The Systems Approach** - *"SE is applied to a system-of-interest (SoI) in a wider systems context"*
- **SE Principle B: Synthesis** - *"SE must bring together a collection of parts to create whole system solutions"*
- **SE Principle C: Holism** - *"Always consider the consequences on the wider system when making decisions about the system elements"*
- **SE Principle D: Organismic Analogy** - *"Always consider systems as having dynamic "living" behavior in their environment"*
- **SE Principle E: Adaptive Optimizing** - *"Solve problems progressively over time"*
- **SE Principle F: Progressive Entropy Reduction** - *"Continue to make systems work over time, through maintenance, sustainment and, upgrade activities."*
- **SE Principle G: Adaptive Satisfying** - *"A system will succeed only if it makes winners of its*

success-critical stakeholders, so the lifecycle of a system must be driven by how well its outputs contribute to stakeholder purpose"

Hitchins considers principles A-D as pillars of SE that identify key aspects of systems thinking which should underpin the practice of SE. Principles E-G consider the dynamics of SE life cycle thinking, the *why*, *when* and *how often* of SE.

The following sections consider the systems approach to engineered systems against four themes.

1. Whole System

The system coupling diagram (Figure 1), describes the scope of a systems approach to engineered systems (Lawson 2010).
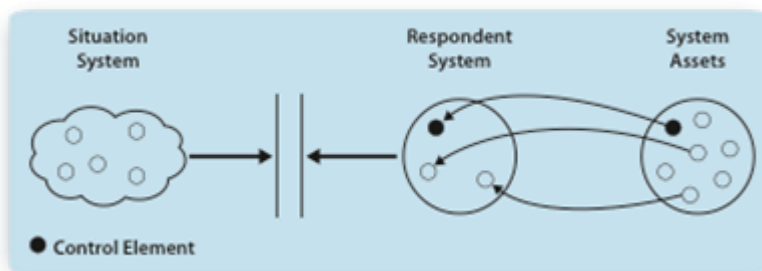
Figure 1. System Coupling Diagram (Lawson 2010).
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- The **situation system** is the problem or opportunity either unplanned or planned. The situation may be natural, man-made, a combination of both, or a postulated situation used as a basis for deeper understanding and training (e.g. business games or military exercises).
- The **respondent system** is the system created to respond to the situation. The parallel bars indicate that this system interacts with the situation and transforms it to a new situation. Respondent systems have several names:, project, program, mission, task force, or in a scientific context, experiment.
- **System assets** are the sustained assets of one or more enterprises to be used in response to situations. System assets must be adequately managed throughout the life of a system to ensure that they perform their function when instantiated in a respondent system. Examples include: value-added products or services, facilities, instruments and tools, and abstract systems, such as theories, knowledge, processes and methods.

Martin (Martin 2004) describes seven types of system, or *"the seven samurai of systems engineering,"*, all of which, system developers need to understand to develop successful systems:

- the context system
- the intervention system
- the realization system
- the deployed system
- collaborating systems
- the sustainment system
- competing systems

Martin contends that all seven systems must be explicitly acknowledged and understood when engineering a solution for a complex adaptive situation.

These views, and others, describe one aspect of the systems approach when applied to engineered

systems; in addition, it is applicable to understanding a problem, it organizes the resolution of that problem, and creates and integrates any relevant assets and capabilities to enable that solution.

2. Whole Lifecycle

Ring (Ring 1998) provides a powerful framework for the continuing management and periodic upgrade of long-life and *"immortal"* systems. It also accurately represents the *"continuous"* or very rapid product launch and refreshment cycle driven by market feedback and constant innovation that is seen in most product and service system consumer markets.
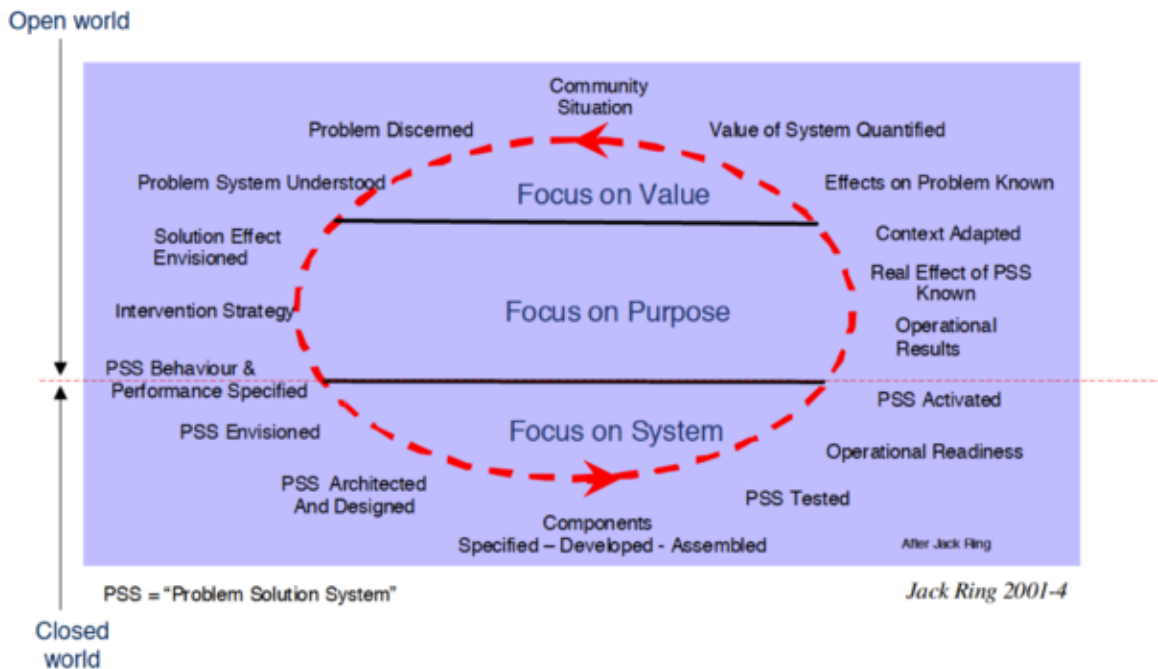
Figure 2. Ellipse Graphic (Ring 1998). © 1998 IEEE. Reprinted, with permission, from Jack Ring, Engineering Value-Seeking Systems, IEEE-SMC. Conference Proceedings. All other rights are reserved by the copyright owner.

Enterprise systems engineering may be considered in multiple concurrent instances of this model for different sub-sets of enterprise assets and services, in order to maintain a capability to pursue enterprise goals in a complex and dynamic external environment.

The dynamic nature of this cycle and its relationship to Life Cycle thinking is discussed in the article Applying the Systems Approach.

3. Whole Problem

The article Identifying and Understanding Problems and Opportunities considers the nature of problem situations. It discusses the relationship between hard system and soft system views of problems and how they relate to engineered systems. Engineered systems are designed to operate with and add value to a containing social and/or ecological system. The scope of problems is captured by frameworks, such as Political, Economic, Social, Technological, Legal and Environmental (PESTLE) (Gillespie 2007) or Social, Technical, Economic, Environmental, Political, Legal, Ethical and Demographic (STEEPLED).

The idea of a wicked problem (Rittel and Webber 1973) is also discussed. These problems cannot be quantified and solved in a traditional engineering sense.

Sillitto (Sillitto 2010) describes a lifecycle model in which the decision as to what parts of problems can be *"solved"* and what parts must be *"managed"* is the first key decision and emphasizes the need for a solution approach that provides flexibility in the solution to match the level of uncertainty and

change in the problem and stakeholder expectations. It is now normal to view a problem as one that "*changes over time"* and to promote the belief that value is determined by the perceptions of key stakeholders.
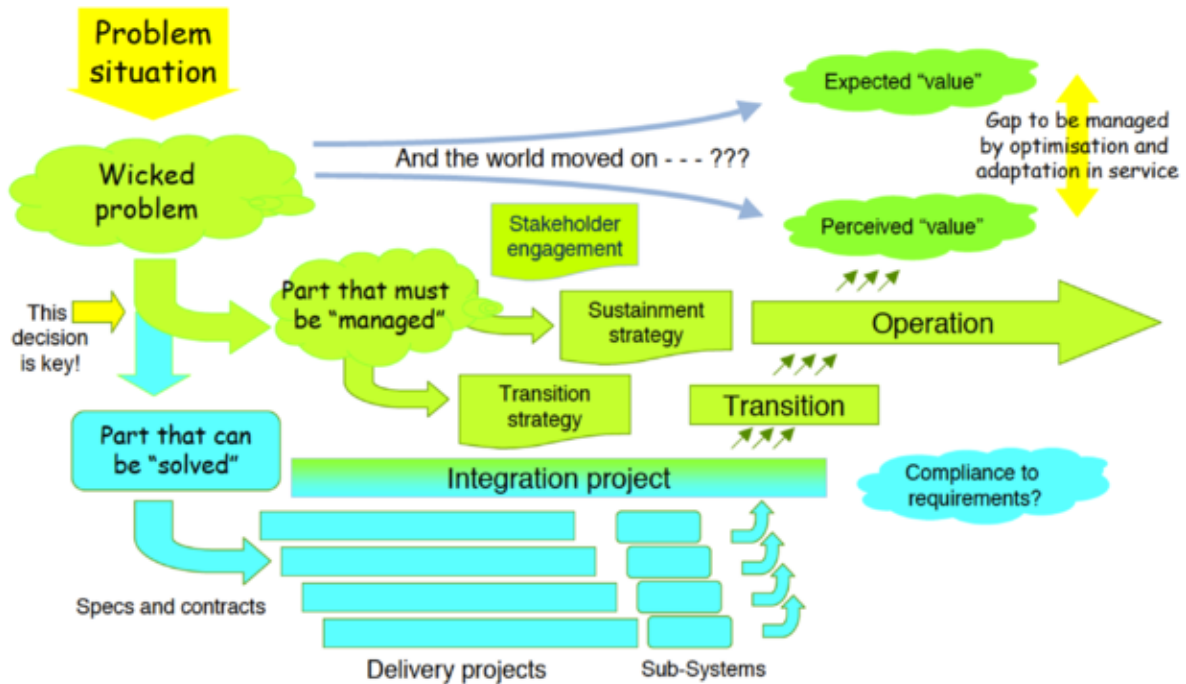
Figure 3. Engineered vs Managed Problems (Sillitto 2010). Reproduced with permission of Hillary Sillitto. All other rights are reserved by the copyright owner.

Thus, a systems approach can be useful when addressing all levels of a problematic situation, from individual technologies to the complex socio-technical issues that come about in the area of engineered systems development.

4. Multi-Disciplinary

As discussed by Sillitto (Sillitto 2012), the methods and thinking applied by many practicing systems engineers have become optimized to the domains of practice. While systems thinking concepts, patterns and methods are used widely, they are not endemic in SE practice. As a result, SE practitioners find it difficult to share systems ideas with others involved in a systems approach. Part 4: Applications of Systems Engineering describes traditional (product based) SE (Lawson 2010) and examines this against the SE approaches that are applicable to service, enterprise, and system of systems capability. These approaches require more use of problem exploration, a broader solution context, and a purpose driven life cycle thinking.

SE and Systems Approach

From the above discussions, there are three ways in which SE could make use of a systems approach:

- in its overall problem- solving approach
- in the scope of problem and solution system contexts considered
- in the embedding of systems thinking and systems thinking tools and in all aspects of the conduct of that approach

The current SE standards and guides, as described in Part 3: Systems Engineering and Management, encapsulate many of the elements of a systems approach. However, they tend to focus primarily on the development of system solutions while the wider purpose-driven thinking of a full systems approach (Ring 1998) and the wider consideration of all relevant systems (Martin 2004) are embedded in the acquisition and operational practices of their application domains.

The inclusion of systems thinking in SE competency frameworks (INCOSE 2010) represents a general move toward a desire for more use of systems thinking in SE practice. There is a wide stakeholder desire to acquire the benefits of a systems approach through the application of SE, particularly in areas where current SE approaches are inadequate or irrelevant. Hence, there is a need for a better articulation of the *systems approach* and how to apply it to non-traditional problems.

Synthesis for SEBOK

The systems approach presented in the SEBoK uses the following activities:

- identify and understand the relationships between the potential problems and opportunities in a real worldreal-world situation
- gain a thorough understanding of the problem and describe a selected problem or opportunity in the context of its wider system and its environment
- synthesize viable system solutions to a selected problem or opportunity situation
- analyze and choose between alternative solutions for a given time/cost/quality version of the problem.
- provide evidence that a solution has been correctly implemented and integrated
- deploy, sustain, and apply a solution to help solve the problem (or exploit the opportunity)

All of the above are considered within a life cycle (glossary) framework which may need concurrent, recursive (glossary) and iterative applications of some or all of the systems approach.

When the systems approach is executed in the real world of an engineered system (glossary), a number of engineering and management disciplines emerge, including SE. Part 3: Systems Engineering and Management and Part 4: Applications of Systems Engineering contain a detailed guide to SE with references to the principles of the systems approach, where they are relevant. Part 5: Enabling Systems Engineering provides a guide to the relationships between SE and the organizations and Part 6: Related Disciplines also offers a guide to the relationship between SE and other disciplines.

More detailed discussion of how the systems approach relates to these engineering and management disciplines is included in the article Applying the Systems Approach within this KA.

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