Managing complexity: The Nine-System Model

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Abstract. Systems engineering has been defined as "*the science of designing complex systems in their totality to ensure that the component subsystems making up the system are designed, fitted together, checked and operated in the most efficient way*" (Jenkins, 1969). This paper documents research that reviewed three existing models for managing the complexity of the system development process in the INCOSE literature and found that while these models drew different systems of interest (SOI) from different perspectives they were unable to manage complexity in any practical manner. This paper then presents a Nine-System Model that can be used to manage complexity. This Nine-System Model builds in best practices and, being self-similar, can be applied in any level of the systems hierarchy. The nine systems in the model comprise situations, processes and socio-technical systems in a clearly defined interdependent manner. The application of the Nine-System Model is illustrated in two examples. The paper then compares the four different models, and uses the Nine-System Model as a framework to relate the MIL-STD-499 (MIL-STD-499A, 1974), EIA 632 (EIA 632, 1994), IEEE 1220 (IEEE 1220, 1998) and the ISO/IEC 15288 (Arnold, 2002) Standards, the SIMILAR process (Bahill and Gissing, 1998), Hitchins' version of systems engineering (Hitchins, 2007) and the problem-solving process and shows that each is a subset of the Nine-System Model. The paper concludes with a summary of the key benefits of the Nine-System Model.

1. Introduction

Systems engineering has been defined as "*the science of designing complex systems in their totality to ensure that the component subsystems making up the system are designed, fitted together, checked and operated in the most efficient way*" (Jenkins, 1969). However, in the ensuring 45 years, instead of performing systems engineering as defined by Jenkins, systems engineers seem to have been busy creating more and more complex models and processes. This observation can be mapped into the holistic approach to problem solving (discussed in Section 3.3) as the undesirable situation, where:

- **The undesirable situation** is the failure of systems engineering to manage the complexity of the systems development environment.
- **The future desirable situation** is systems engineering successfully managing the complexity of the systems development environment.
- **The solution** is a theory of how to manage complexity and a set of tools for managing complexity based on the theory.
- **The problems are:**
  1. To understand the reasons why systems engineering has not been able to manage the complexity of the systems development environment in a repeatable manner.

2. How to develop a theory for managing complexity and the tools for managing complexity based on the theory.

This paper:

- Discusses three previous existing approaches to managing complexity found in the INCOSE literature.
- Shows that while the existing models made a contribution to the body of knowledge they do not go far enough.
- Discusses how each model draws a boundary about a different System of Interest (SOI) within an environment and partitions the SOI into different subsystems.
- Hypothesises a theory that complexity can be managed (but not reduced) by applying a set of rules for grouping/aggregation/synthesis.
- Proposes and provides examples of a self-similar framework model of nine systems, the Nine-System Model, usable to manage complexity in any level of the hierarchy by intertwining situations, systems and processes in an interdependent but clearly defined manner.
- Shows how the Nine-System Model relates to the system engineering Standards, i.e. MIL-STD 499 (MIL-STD-499, 1969), EIA 632 (EIA 632, 1994) and IEEE 1220 (IEEE 1220, 1998), and the problem-solving process.

2. Previous proposed approaches to manage complexity

Since complexity cannot be removed, it must be managed. Given the problem of managing complexity, the first activity was to research the INCOSE literature to identify previous attempts to manage complexity. This section discusses the following three models for managing complexity in the systems development context found in the INCOSE literature.

- The Seven Samurai (Martin, 2004).
- The Whole System Model (Adcock, 2005; Mackley, 2008).
- The Systems Project (Paul and Owunwanne, 2006).

2.1. The Seven Samurai

Martin's approach to managing the complexity follows the problem solving version of systems engineering by starting with a problematic or undesirable situation (Schön, 1991) and ending with a solution system that remedies the problem. Martin stated that "*the seven different systems must be acknowledged and understood by those who purport to do systems engineering*" (Martin, 2004). Martin likened his seven systems to the seven samurai in the 1954 film (Kursawa, 1954) because just as the seven unemployed samurai became heroes by saving a poor village under attack, according to Martin, when his seven systems are employed with proper consideration and enthusiasm they will become the heroes of your systems development project. Martin's seven samurai systems are:

S1. *The context system* is where the problem (P1) resides; namely, the "as-is" situation. Aspects of the *context system* must be analysed to determine the underlying problem.

S2. *The intervention system* provides the solution to a real or perceived problem in the context system. The *intervention system* is created by the *realization system*. However, once deployed in the *context system*, the *intervention system* becomes the *deployed system*.

S3. *The realization system* consists of all the resources to be applied in causing the *intervention system* to be fully conceived, developed, produced, tested, and deployed. Martin adds that this system is often known as an Enterprise.

S4. **The deployed system** which evolves from the *intervention system* and interacts with *collaborating systems* to accomplish its own functions. While the *deployed system* is intended to be the same as the *intervention system*, there generally are differences for various reasons, intentional or otherwise. Once deployed, the system will often change the original *context system* into a **modified context system** (S1')[1] and might cause a new or modified problem (P2).

Figure 1 Seven Samurai Systems

S5. **The collaborating systems** interact with the deployed system in the modified context system.

S6. **The sustainment system** provides services and materials to keep the *deployed system* operational, e.g. fuel, energy, spare parts, training, customer hotline, maintenance, waste removal, refurbishment, retirement etc. in many instances, the *realization system* may need to modify or even develop parts of the *sustainment system*.

S7. **The competing systems** which may also solve the original problem or parts of it and competes for resources used by the *deployed system*.

Martin's SOI shown in Figure 1, is the seven samurai systems and the 15 interactions between them.

2.2. The Whole System Model

The Whole System Model (Adcock, 2005; Mackley, 2008) shown in Figure 2 views the problem of managing complexity from two different perspectives; lifecycle and process, considering the SOI as five linked systems within "*the bounded system whose lifecycle is under consideration*":

S1. **Operational system (OS):** Entities involved in provision of system mission, objective, strategies and plans.

S2. **Support system (SS):** Entities involved in maintaining the OS with supply of required resources.

S3. **Development system (DS):** The process and associated equipment/tools required for creation, development and certification of the OS design throughout its lifetime.

Figure 2 The Whole System Model

S4. **Production system (PS):** Process and equipment/tools required to create a validated and reproducible OS from the system design.

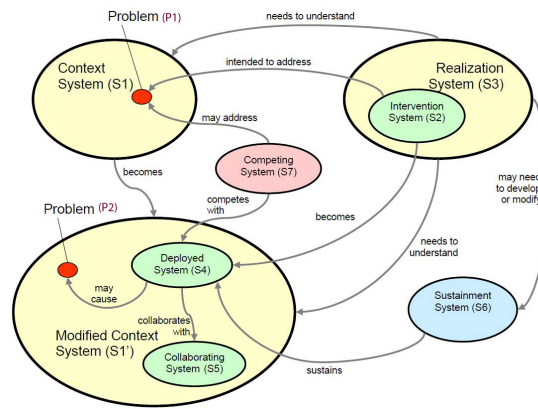[1] This could be considered as an eighth system.

S5. ***Containing system (CS):*** The related systems and the environment in which the other four systems interact, often known as the acquisition system.

According to Adcock, the Whole System Model illustrates the scope of related system and enabling system relationships which might apply to a given SOI, depending upon which part of the whole system it is from.

2.3. The Systems Project

The Systems Project (Paul and Owunwanne, 2006) shown in Figure 3:

- "*is a framework for packaging and conducting all of the systems engineering activities associated with developing/managing the product system, the producing system, the Existing System (if there is one in place, if applicable [I/A]), and the Maintenance and Support System through the life cycle of the product system.*
- Manages the complexity by viewing the SOI from the process perspective.
- Involves the simultaneous development/ manage-ment of as many as four in-dependent but related sys-tems. These related sys-tems shown in Figure 3, encompassed in the SOI are:
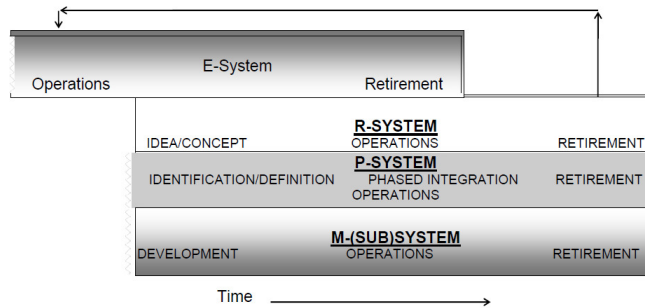

Figure 3 The Systems Project

S1. ***The Existing System ("E-System")*** is the system which may be in place and which will be retired upon implementing the R-System.
S2. ***The Required System ("R-System")*** is the system that is being developed to satisfy a need, alleviate an existing problem situation, or respond to an opportunity.
S3. ***The Producing System ("P-System")*** is the system that produces the *R-System*. The *P-system* comprises the businesses, individuals, manufacturing plants etc. that must be managed and coordinated to produce and deploy the *R-System* and the *M-System* and decommission and remove the *E-System* when it is replaced by the *R-System*.
S4. ***The Maintenance and Support System ("M-System")*** which supports the R-Sys-tem through its life cycle.

If the *R-System* is a new system, there may not be an *E-System* in place. If there is an *E-System*, then, when deployed, *the R-system* becomes the new *E-system* and the entire develop-ment cycle repeats itself.

2.4. Discussion

The authors of each of the models drew different SOIs from different perspectives to develop their models. The systems addressed by the models, used as the basis for comparison, shown in Table 1 are derived from the holistic problem solving process shown in Figure 4. They are not derived from the systems engineering Standards because the Standards only document the activities performed by different groups at different times in different locations. As such there is no way to ensure that the set of systems is complete using a Standards-based reference. When the models are compared in Table 1 it can be seen that:

- Each model is a different set of systems.
- Each system may be an organization, situation, process or technological system.

Table 1 Comparison of the three models

Systems addressed by the models	Seven Samurai	Whole System Model	Systems Project
Existing "as-is" **situation**	Context (S1)	-	-
Existing **system** in "as-is" situation	-	-	E-system
Process to develop conceptual solution system	-	-	-
Conceptual solution **system** at time development begins	Intervention (S2)	-	R-System
Process to plan transition from existing situation to situation in which the solution system will be deployed	Implied in Realization (S3)	Implied in Production	Implied in P-System
Process to realize solution system	Realization (S3)	Production	P-System
Resources to be applied to realize the solution system	Realization (S3)	Development	P-System
Solution **system** at and after time of deployment	Deployed (S4)	Operational	R-System
New situation after solution system has been deployed	-	-	-
Adjacent **systems** operating in association with the solution system at and after time of deployment	Collaborating (S5)	-	-
System or systems that keeps the solution system operational at and after deployment	Sustainment (S6)	Support	M-System
Process to determine situation after deployment of solution system contains no undesirable elements	Realization (S3)	Production	P-System
Alternative solution systems	Competing (S7)	-	-
Enterprise and environment	Realization (S3)	Containing	-

- Each model is incomplete since other models may contain systems that the model does not.
- Systems present in one model may not be present in another model.
- Each model invokes the temporal perspective (considers the time to realize the solution system) but in different ways.
- The situation after the solution system has been deployed is not considered in any of the three models, although Martin does refer to it as a *modified context system* (S1').

So while the models represent some aspects of the complexity of the situation they do not provide much help in managing the overall complexity. A new theory is needed.

3. A new theory for managing complexity

Maier and Rechtin stated what needs to be done by providing the following rules for reducing complexity (Maier and Rechtin, 2000) page 6):

- Abstract the system at as high a level as possible.
- Progressively reduce the level of abstraction.

This paper now hypothesises that those rules can be expanded into a theory that complexity can be managed (but not reduced) by applying the following rules for grouping/aggregation/synthesis:

1. Use a definition of a system incorporating a temporal dimension (Section 3.1).
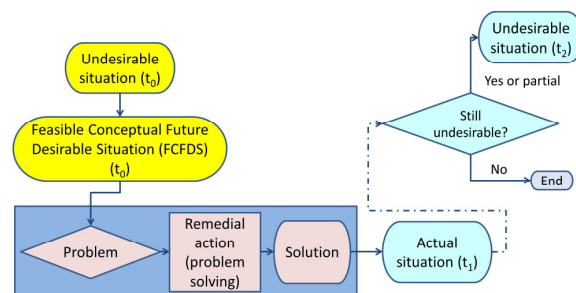

Figure 4 Holistic systems approach to managing problems and solutions

2. Use the principle of hierarchies (Section 3.2).
3. Partition the system into less than 7±2 subsystems at any level in the hierarchy in accordance with Miller's rule (Miller, 1956) to facilitate human comprehension.
4. Maier and Rechtin stated that poor aggregation and partitioning increases complexity, so partition the subsystems for maximal internal cohesion and minimal coupling between subsystems (Ward and Mellor, 1985).
5. Design the subsystems to be self-regulating (homeostasis).
6. Optimize the system interaction at the subsystem interfaces (Kasser, 2011).
7. Abstract (hide) non-relevant information at any level in the hierarchy to facilitate understanding the system by using more than one perspective to view the SOI where each view abstracts out non-pertinent information to that perspective. See Section 4.1 for an example.
8. Use the holistic systems approach to problem solving (See Section 3.3).

Since space limitations preclude discussing each of the rules herein, consider the following subset of the rules.

3.1. Defining the SOI

Defining the SOI can be considered as the first step in the process of managing complexity. The literature contains many definitions of the word 'system'; Webster's dictionary, for example provides 51 (Webster, 2004). The common denominators in the 22 definitions of a system listed by Kasser (Kasser, 2013b) pages 178 - 179) can be summarized by the elements shown in Figure 5

Figure 5 The elements of a system

(Flood and Jackson, 1991) which omits an important aspect of a system, left out of all the definitions, namely that a system changes over time.
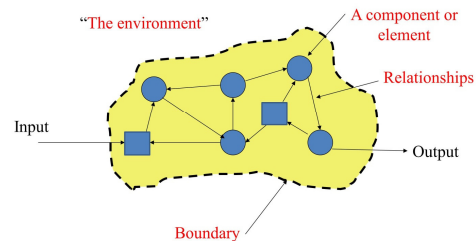
Looking at a system, a template definition that nudges the systems engineer towards best practices is "*A system is an abstraction from the real world of a set of objects, each at some level of decomposition, at some period of time, in an arbitrary boundary, crafted for a purpose*" (Kasser, 2013a) pages 251 to 252). This definition of the SOI allows the same SOI to be considered as two different systems if each system is a snapshot taken at a different time. This is not a new concept; examples of the consideration of the same system at different times include:

- Martin's Seven Samurai which treat the system being developed and the deployed systems as separate systems (Martin, 2004) as discussed in Section 2.1.
- Business Process Reengineering's use of the "as-is" and "to-be" views or models of an enterprise as separate entities/systems.

3.2. The principle of hierarchies

The principle of hierarchies has been discussed in the literature as shown by the following three quotations. "*All complex structures and processes of a relatively stable character display hierarchical organisation regardless of whether we consider galactic systems, living organisms and their activities or social organisations*" (Koestler, 1978) page 31).

"*Once we adopt the general picture of the universe as a series of levels of organisation and complexity, each level having unique properties of structure and behaviour, which, though depending on the properties of the constituent elements, appear only when those are combined into the higher whole, we see that there are qualitatively different laws holding good at each level*" (Needham, 1945) cited by (Koestler, 1978) page 32).

Wilson wrote "*The English philosopher Herbert Spencer appears to be the first to set out the general idea of increasing complexity in systems (Spencer, 1862). The term itself was first used by the English biochemist (and scholar of Chinese science) Joseph Needham (Needham, 1937). The following quotation from a Web source provides an insight into the fundamentals of the theory (UIA, 2002):*

(a) *The structure of integrative levels rests on a physical foundation. The lowest level of scientific observation would appear to be the mechanics of particles.*

(b) *Each level organizes the level below it plus one or more emergent qualities (or unpredictable novelties). The levels are therefore cumulative upwards, and the emergence of qualities marks the degree of complexity of the conditions prevailing at a given level, as well as giving to that level its relative autonomy.*

(c) *The mechanism of an organization is found at the level below, its purpose at the level above.*

(d) *Knowledge of the lower level infers an understanding of matters on the higher level; however, qualities emerging on the higher level have no direct reference to the lower-level organization.*

(e) *The higher the level, the greater its variety of characteristics, but the smaller its population.*

(f) *The higher level cannot be reduced to the lower, since each level has its own characteristic structure and emergent qualities.*

(g) *An organization at any level is a distortion of the level below, the higher-level organization representing the figure which emerges from the previously organized ground.*

(h) *A disturbance introduced into an organization at any one level reverberates at all the levels it covers. The extent and severity of such disturbances are likely to be proportional to the degree of integration of that organization.*

(i) *Every organization, at whatever level it exists, has some sensitivity and responds in kind"* (Wilson, 2002)

3.3. The holistic problem-solving approach

The holistic problem solving process (Kasser, 2013b) pages 284-285) is shown in Figure 4. Unlike the traditional approach to problem-solving which begins with a problem and ends with a solution, the holistic approach takes a wider perspective and begins with an undesirable situation (Schön, 1991) at some time (t_0) which has to be converted to a Feasible Conceptual Future Desired Situation (FCFDS). The process begins when the observer becomes aware of an undesirable situation that is made up of a number of related factors. A project is authorized to do something about the undesirable situation. The problem solver tries to understand the situation, determine what makes the situation undesirable and then create a vision of a FCFDS. The problem then becomes one of how to transition from the undesirable situation to the FCFDS. Once the problem is identified, the remedial action is taken to create the solution system which will operate in the context of the FCFDS. This remedial action takes the form of the acquisition of suitable commercial-off-the shelf (COTS) system if available or the system development process (SDP) to develop a solution system. Either system will be operational in the situational context of the FCFDS. Once realized or acquired, the solution system is tested in operation in the actual situation existing at time t_1 to determine if it remedies the undesirable situation. However, should the remedial action take time, the undesirable situation may change from that at t_0 to a new undesirable situation existing at t_2. If the undesirable situation at t_2 is remedied, then the process ends; if not, the process iterates from the undesirable situation at t_2.

4. The Nine-System Model

The Nine-System Model:

- Is based on the problem-solving approach to systems engineering in accordance with IEEE 1220 which stated that "*the systems engineering process is a generic problem-solving process*" (IEEE 1220, 1998) Section 4.1).
- Manages complexity by abstracting out all information about the SOI that is not pertinent to the issue at hand.
- Views the SOI from several perspectives rather than one or two as in the previous models.
- Is an application of the theory that complexity can be managed (but not reduced) by applying a set of rules for grouping/aggregation/synthesis.
- Is a self-similar framework model usable in any level of the hierarchy.
- Encompasses aspects of the seven samurai (Martin, 2004), Business Process Reengineering (BPR), Checkland's Soft Systems Methodology (Checkland and Scholes, 1990), Hitchins' approach to systems engineering (Hitchins, 2007) and the SIMILAR process (Bahill and Gissing, 1998)
- Incorporates the MIL-STD-499 (MIL-STD-499A, 1974), EIA 632 (EIA 632, 1994) and IEEE 1220 (IEEE 1220, 1998) Standards.
- Incorporates the seven principles for systems engineered solution systems (Kasser and Hitchins, 2011).
- Provides a template incorporating built-in best practices that conform to the 'A' paradigm of systems engineering (Kasser, 2012).
- Is a conceptual model since as the *Temporal* perspective shows, all the systems do not coexist at the same time.
- Comprises the following situations, processes and socio-technical systems in a clearly defined interdependent manner:

S1. The undesirable or problematic **situation.**
S2. The **process** to create the FCFDS.
S3. The FCFDS that remedies the undesirable **situation**.
S4. The **process** to <u>plan</u> the transition from the *undesirable or problematic situation* (S1) to the FCFDS (S3).
S5. The **process** to <u>perform</u> the transition from the *undesirable or problematic situation* (S1) to the *FCFDS* (S3) by providing the *solution system* (S6) according to the plan developed in the *planning process* (S4). S5 could be the SDP or an acquisition process if a suitable COTS system is available.
S6. The solution **system** that will operate within FCFDS[2].

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[2] The adjacent and supporting systems are not separate systems in this model because they are considered as subsystems or adjacent systems of the *solution system* (S6). If they are:

1. **Subsystems:** they are purview of the systems engineer of *solution system* (S6) in the same manner as any other subsystem and can be seen in the *Structural* and *Functional* HTPs of the *solution system* (S6).
2. **Adjacent systems:** they show up in the *Big Picture* perspective of the *solution system* (S6); their operational interactions and interfaces are seen in the *Operational* perspective of the *solution system* (S6). However, since S6 and the adjacent systems are subsystems of the metasystem operating in S7, the specification of the nature of the adjacent systems are the purview of the system engineer of that metasystem in the same way as the specification of the nature of the subsystems of S6 is the purview of the system engineer of the *solution system* (S6).
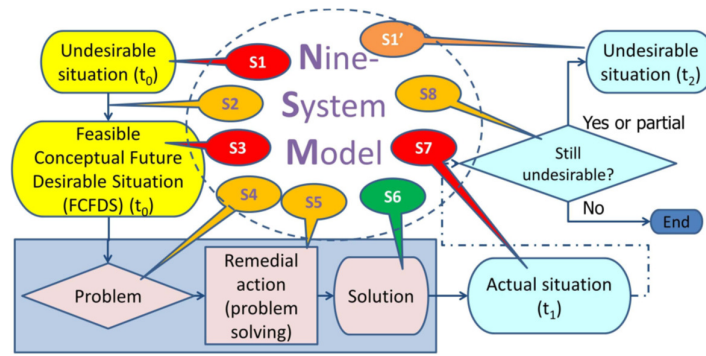
Figure 6 Mapping the nine systems to the holistic problem solving process

S7. The actual or created *situation*.

S8. The process to determine that the realized solution remedies the <u>evolved</u> *undesirable situation*.

S9. The *organization*(s) containing the processes and providing the resources for the operation and maintenance of the processes. S9 is also often known as the Enterprise.

Each of the nine systems must be viewed from each of the Holistic Thinking Perspectives (HTP) as appropriate (Kasser, 2013b). The Nine-System model is not shown in a single figure, instead perceptions from the following HTPs are provided:

- **The Operational perspective** shows how the nine systems map directly into the holistic problem-solving process shown in Figure 4 annotated in Figure 6, kicking off at time t_0. S1 is the undesirable situation. S2 is the process implied in Figure 4 and Figure 6 that develops the FCFDS (F3). Once the FCFDS is approved, S4, the process that plans (creates) the realization process (S5) and solution system (S6) begins. S4 terminates at the System Requirements Review (SRR). The realization process (S5) realizes the solution system
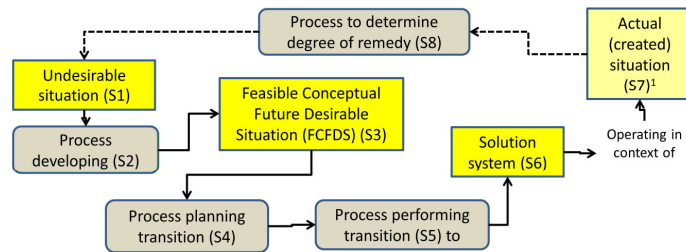

Figure 7 The Nine-System Model (*Functional* perspective)

(S6). Once realized, the *solution system* (S6) is tested in operation in the *actual situation* existing at time t_1 (S7) to determine if it remedies the *undesirable situation*. However, since the solution realization process takes time, the *undesirable situation* may change from that at t_0 to a new *undesirable situation* existing at t_2. If the *undesirable situation* at t_2 is remedied, then the process ends; if not, the process iterates from the undesirable situation at t_2 and the actual situation (S7) becomes the new undesirable situation in the next iteration of the process (S1').

- **The Functional perspective** shown in Figure 7 shows the relationships between the situations, systems and processes. The *process* to plan the transition from the *undesirable or problematic situation* (S1) to the FCFDS (S3) and the **process** to realize the transition from the *undesirable or problematic situation* (S1) to the *FCFDS* (S3), S4 and S5, constitute two parts of the system realization process.

- **The Structural perspective** shown in Figure 9 shows the relationship between the process systems and the *solution system* and the organization(s) containing the process systems and *solution system*. For example, this perspective provides the organisation charts in S9 for staffing the process systems (S2, S4, S5 and S8) and the Product Breakdown Structure for the solution system (S6).
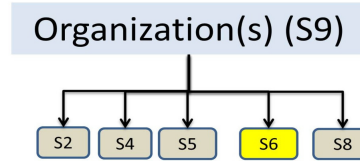- **The Temporal perspective** shown in Figure 8 shows how the systems relate in time. The nine systems do not coexist at the same point in time; the relationship follows the problem-solving process shown in Figure 4, kicking off at time t_0. S2 is the process that develops the FCFDS (F3). Once the FCFDS is approved, S4, the planning process to create the realization process (S5) and solution system (S6). S4 terminates at the SRR. The realization process (S5) realizes the solution system (S6). Once realized, the *solution system* (S6) is tested in operation in the *actual situation* existing at time t_1 (S7) to determine if it remedies the *undesirable situation*. However, since the solution realization process takes time, the *undesirable situation* may change from that at t_0 to a new *undesirable situation* existing at t_2. If the *undesirable situation* at t_2 is remedied, then the process ends; if not, the process iterates from the undesirable situation at t_2 and the actual situation becomes the new undesirable situation.
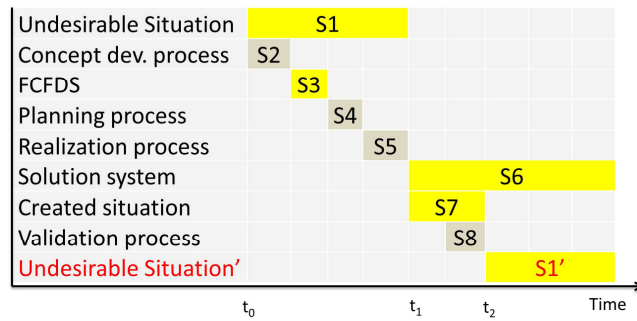
Consider each of the nine systems as follows:

Figure 9 The Nine-System Model (*Structural* perspective)

Figure 8 The Nine-System Model (*Temporal* perspective)

4.1. S1. The undesirable or problematic situation

The *undesirable or problematic situation* is a snapshot of the SOI that exists at a point in time (t_0) of one or more socio-technological systems working together. This system, known as the "as-is" situation in BPR, provides the baseline when an entity with the appropriate authority initiates a project to remedy the *undesirable or problematic situation*, by developing something that will convert the undesirable situation to a *FCFDS* (S3). This situation can be described from the HTPs on the perspectives perimeter (Kasser, 2013b) rather than in one single graphic. For example:

1. **The Big Picture perspective** includes information about the adjacent systems.
2. **The Operational perspective** includes the operational interactions and interfaces between the situation and the adjacent systems.
3. **The Functional perspective** includes the interactions between the systems that are functioning in the situation.
4. **The Structural perspective** includes the structure, technology and physical nature of the systems in the situation.
5. **The Temporal perspective** includes a history of how the situation arose.

6. **The Generic perspective** includes information about the similarity of the situation to other situations.
7. **The Continuum perspective** includes information about (pertinent) differences between the situation and other situations.
8. **The Quantitative perspective** includes numerical information associated with the situation.
9. **The Scientific perspective** includes the conclusions inferred from the analysis of the information in the above eight descriptive perspectives about:
    a. The causes of the undesirable situation. If the stakeholders cannot agree on a single problem statement, they may be able to provide a consensus on the most acceptable *FCFDS* (S3).
    b. Ways to remedy the undesirable situation that could lead to the FCFDS.

4.2. S2. The process to create the FCFDS

The concept development process to create the *FCFDS* (S3) is divided into three streams of activities (management, development/production and testing/Quality) occurring within milestones (Kasser, 1995) and contains the following sequential activities (*Functional* perspective):
1. Bounding the SOI and analysing the *undesirable situation* (S1) from the eight descriptive HTPs.
2. Conceiving a number of potential conceptual solution options in the form of *FCFDS*. This activity is best performed as independent parallel tasks so that each *FCFDS* is not influenced by another *FCFDS*.
3. Identifying ideal solution selection criteria.
4. Performing the trade-off studies to determine the preferred FCFDS.
5. Producing the Concept of Operations (CONOPS) that describes solution system and the context and environment (*FCFDS*) in which the *solution system* (S6) will operate and how that operation is anticipated to occur.

This process (S2):

- Is performed in the context of, and uses resources provided by, the organization system (S9).
- Takes place in the early stages of the solution system realization process and corresponds Steps 2, 3, 4, 5 and 6 in the Hitchins' approach to system engineering shown in Figure 10 (Hitchins, 2007) Figure 6.2).
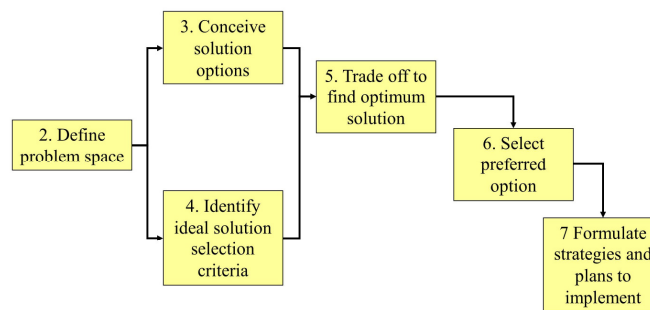

Figure 10 A systems engineering approach to problem solving

- Is where most of the mathematical and analytical tools of systems engineering (Khisty and Mohammadi, 2001) are employed.
- Studies S1 and S3 using systems engineering tools such as (Wilson, 1965; Alexander and Bailey, 1962; Chestnut, 1965):

    - Probability,
    - Single thread – system logic,
    - Queuing theory,
    - Game theory,

- Linear programming,
- Group dynamics,
- Simulation, and
- Information theory.

- Is divided into three streams of activities (management, development/production and testing/Quality) occurring within milestones (Kasser, 1995).

The *Structural* perspective of S2 and other processes provides the organisation chart.

4.3. S3. The FCFDS that remedies the undesirable situation

The *FCFDS* (S3):

- Is created at this time based on the principle of working back from the answer (Ackoff, 1999).
- Is the BPR "to-be" situation.
- Can be documented using the eight descriptive HTPs in an iterative manner. This overcomes the defect in the current paradigm in which the functional view precedes the physical view in theory but cannot do so in practice (Halligan, 2014).
- Is the context and environment that will incorporate the *solution system* (S6) as conceptualized at time t_0 but actually deployed at time t_1. Can be documented using the descriptive HTPs in the manner used in Section 4.1.
- Is a hypothesis until validated once the *solution system* (S6) is operating in its context (S7) by the *validation process* (S8).
- Can be considered as S1 in which the:

  1. Causes of the original *undesirable or problematic situation* (S1) have been eliminated.
  2. Potential modifications and improvements to the original *undesirable or problematic situation* (S1) have been conceptualized.

4.4. S4. The process to plan the transition from the undesirable or problematic situation to the FCFDS

The process to plan the transition from the 'as-is' *undesirable or problematic situation* (S1) to the 'to-be' created situation (S7) based on realizing the *FCFDS* (S3) is a set of activities that:

1. Convert information in the CONOPS and FCFDS (S3) into a matched set of specifications for the *solution system* (S6), the subsystems of S6 and their infrastructure.
2. Create the *process* (S5), to realize and install the *solution system* (S6) in accordance with "*the systems engineer creates a unique process for his or her particular development effort*" (Biemer and Sage, 2009) page 153).
3. Produce the Systems Engineering Management Plan (SEMP) and the Test and Evaluation Master Plan (TEMP).
4. Take place in Step 7 in Figure 10.
5. Are performed in the context of, and uses resources provided by, the *organization system* (S9).
6. Are divided into three streams of activities (management, development/production and testing/Quality) occurring within milestones (Kasser, 1995).
7. Generally terminate with a System Requirements Review (SRR).

4.5. S5. The process to perform the transition

The process to perform the transition from the *undesirable or problematic situation* (S1) to the to be created situation (S7) based on realizing the *FCFDS* (S3) by providing the *solution system* (S6) according to the SEMP and TEMP developed in the *planning process* (S4):

- Is often called the systems engineering process when the *SDP* is used to develop a new system, but can also be a COTS acquisition process.
- Is divided into three streams of activities (management, development/production and Development Test and Evaluation (DT&E) occurring within milestones.
- May require several iterations when the requirements are dynamic and changing rapidly.
- May only require a single iteration when the requirements are stable.
- Must be able to cope with changes in/to the need/problem at any point in the process. For example, in the Apollo program, the need (and hence the requirements) did not change during the SDP, and the operational life of each iteration of the manned element of the system was short; measurable in days. Each Apollo Lunar Surface Experiments Package (ALSEP) however had a much longer life span. Other early successful projects such as the transcontinental [United States of America] television microwave relay system (Hall, 1962) and the Semiautomatic Ground Environment (SAGE) project, a computer and radar-based air defence systems created in the United States of America in the 1950s (Hughes, 1998) page 15) were also not subject to changing needs. However, today's S5 must be able to cope with changes in the situation which are manifested as changes in the needs before the *solution system* (S6) is delivered.
- Is performed in the context of, and uses resources provided by, the *organization system* (S9).
- Is where the following systems engineering tools (Jenkins, 2005) are used:
  - Databases,
  - DOORS,
  - CORE,
  - Drawing tools,
  - PowerPoint,
  - Visio,
  - Word processors,
  - Spreadsheets,
  - Etc.
- Is one of focuses of Model-Based Systems Engineering (MBSE); namely the integrated database environment (Kasser, 2013c)

4.6. S6. The Solution system that will operate within FCFDS

The *solution system* (S6):

- Does not have to be technological or even a new acquisition.
- Is first partitioned into two major subsystems, the mission and support subsystems described in the CONOPS (Kasser and Hitchins, 2011). The support systems for the solution system can be either subsystems or adjacent systems depending on the situation. For example, the support system providing training can be an adjacent system, and some of the maintenance functions can be performed by a subsystem which for this purpose would be the organization. If they are:

1. ***Subsystems:*** they are purview of the systems engineer of *solution system* (S6) in the same manner as any other subsystem and can be seen in the *Structural* and *Functional* HTPs of the *solution system* (S6).
2. ***Adjacent systems:*** they show up in the *Big Picture* perspective of the *solution system* (S6); their operational interactions and interfaces are seen in the *Operational* perspective of the *solution system* (S6). However, since S6 and the adjacent systems are subsystems of the metasystem operating in S7, the specification of the nature of the adjacent systems are the purview of the system engineer of that metasystem in the same way as the specification of the nature of the subsystems of S6 is the purview of the system engineer of the *solution system* (S6).

- Lies somewhere along a continuum that stretches from 'fully automatic technological' to 'manual with no technology'; and may be a modification of an existing system, a change to an existing process, tactics, doctrine, policy, or training or some combination.
- Needs to be realized in such a manner that upgrades reflecting changing needs during its operational phase can be incorporated without major perturbations.
- Must be viewed from at least the following HTPs:

    o ***Operational perspective*** which shows what the system does (Scenarios) by describing the interactions with adjacent systems and the metasystem.
    o ***Functional perspective*** which show the internal mission and support functions.
    o ***Structural perspective*** which shows the technology and physical components.
    o ***Quantitative perspective*** which shows the numbers associated with the functions and other properties of the system (costs, reliability, etc.)

- Is one of focuses of MBSE (Kasser, 2013c).
- Operates in the context of, and uses resources provided by, the *organization system* (S9).

If the *solution system* (S6) will operate in a competitive market, then Martin's competitive systems represent the actual and potential competitors and belong to the purview of the systems engineers in the marketing department of the *metasystem* which for this purpose would be the *organization* (S9).

4.7. S7: The Actual or created situation.

The *actual or created situation* (S7) exists once the *solution system* (S6) has been deployed. S7:

- Is the realization of the *FCFDS* (S3).
- Is the situation at the time solution system (S6) is realized (t_1).
- Contains the *solution system* (S6) and adjacent systems operating interdependently.
- May only partially remedy the original *undesirable or problematic situation* (S1).
- May not remedy new undesirable aspects that show up during time taken by *realization process* (S2 and S5).
- May contain unanticipated undesirable emergent properties from the *solution system* (S6) and its interactions with its adjacent systems.
- May be realized in partial remedies.

4.8. S8. The Process to determine that the realized solution remedies the <u>evolved</u> undesirable situation

This *validation process* (S8) sometimes known as Operational Test and Evaluation (OT&E) determines if the *solution system* (S6), operating in its context, remedies the new <u>evolved</u>

undesirable situation at t_1. While this process if often thought of as the last stage of the SDP, when the SOI is viewed from the Temporal HTP, it can be seen that once the *solution system* (S6) is deployed and operational in the context of the *created situation* (S7), S8 evolves into the change control process that:

- Triggers a new iteration of the Nine-System Model to modify/upgrade the *solution system* (S6). In this instance, S7 becomes the new undesirable situation (S1') at time t_2 as shown in Figure 8.
- May lead to the disposal phase of the system lifecycle should the *solution system* (S6) no longer remedy the undesirable aspects of the evolved situation (S7).

This process is performed in the context of, and uses resources provided by, the *organization system* (S9).

4.9. S9. The Organization(s) containing the processes.

S9 is the organization or organizations containing the processes and providing the resources for the operation and maintenance of the processes. S9 is also often known as the Enterprise which may be made up of more than one organization. However as they are instances of a single generic type of system, they can be treated as such. Each organization can itself be portioned into subsystems often known as departments and the Nine-System Model applies to each department in a self-similar manner. For example, consider the human resources (HR) department of the fictitious Federated Aerospace, which supports staffing the projects and other departments. From the perspectives of the HR department, the nine systems are:

S1. ***Undesirable situation:*** a lack of competent, motivated staff in projects and other departments
S2. ***Process to develop the FCFDS:*** one of the corporate personnel management processes.
S3. ***FCFDS:*** projects fully staffed with competent personnel and retaining staff.
S4. ***Process to <u>plan</u> the transition to FCFDS:*** hiring and prevention of leaving processes.
S5. ***Process to <u>perform</u> the transition to FCFDS:*** HR personnel management system (hiring, training, etc.).
S6. ***The solution system:*** the HR department personnel management system.
S7. ***The created situation:*** projects fully staffed with competent, motivated personnel and retaining staff.
S8. ***Process to verify:*** one of the corporate quality management processes.
S9. ***The organization:*** Federated Aerospace.

5. Examples of the Nine-System Model

Consider the following examples of the Nine-System Model to assist in gaining insight as to the capabilities of the model:

1. The National Aeronautics and Space Administration (NASA) Moon Landing program.
2. An unmanned aerial vehicle.

5.1. NASA Moon Landing program

The NASA Moon Landing program was probably the most complex project ever tacked in human history up to and including the 1970s. Consider the Nine-System Model at the highest level of the hierarchy of systems that comprised the program. The nine systems were:

S1. ***Undesirable situation:*** the perception that the Soviet Union was ahead of the US in space.
S2. ***Process to develop the FCFDS:*** NASA's early stage systems engineering.

S3. *FCFDS:* the perception that the US was ahead of the Soviet Union in space.

S4. *Process to plan transition to FCFDS:* NASA's early stage systems engineering.

S5. *Process to realize transition to FCFDS* took place in the Manned Space Flight development activities in NASA, the Defense Contract Administration Services (DCAS) and the private contractors.

S6. *The system* operating in the FCFDS at the highest level of the hierarchy can be considered as the following three subsystems (Kasser, 2013b) pages 225-226) :

- o *The Earth subsystem* containing the NASA manned spacecraft centers and headquarters.
- o *The Lunar subsystem* which was empty before the first landing and then contained an increasing number of Apollo Lunar Surface Experiments Packages (ALSEP). Two astronauts were part of this subsystem while they were on the Lunar surface.
- o *The interface subsystem* which contained the spacecraft, astronauts (three while in transit, one when in Lunar orbit) and the communications subsystems.

S7. *The created situation:* after Apollo 11 landed on the moon.

S8. *Process to verify:* Public opinion polls.

S9. *Organizations:* NASA, DCAS and its contractors.

5.2. An unmanned aerial vehicle

An unmanned aerial vehicle (UAV) is a piece of equipment that performs a variety of missions and provides an example of the model at an intermediate level in the hierarchy of systems. The Nine-System Model applied to a military UAV contains the following nine systems:

S1. *Undesirable situation:* a need for accurate and timely information about something happening in a remote location.

S2. *Process to develop the FCFDS:* one of the early stage system engineering activities.

S3. *FCFDS:* receipt of accurate and timely information about something happening in a remote location.

S4. *Process to plan transition to FCFDS:* one of the early stage system engineering activities.

S5. *Process to realize transition to FCFDS:* the military acquisition process that would develop or purchase a UAV and supporting systems (Ground control, data processing, etc.).

S6. *The solution system:* the UAV.

S7. *The created situation:* the UAV and adjacent systems operational and providing the accurate and timely information about something happening in a remote location.

S8. *Process to verify:* the operational test and evaluation process.

S9. *Organizations:* the contractor organisations in which the UAV is developed or purchased from and the military organisation in which it operates.

6. Managing complexity via the application of the Nine-System Model at various levels in the system hierarchy

The Nine-System Model applies at every level in the hierarchy of systems as shown in Figure 11, Figure 12, Figure 13 and Figure 14 where:

- Figure 11 displays the lowest level of the hierarchy of this set of systems. This figure shows a radar system (S6) which will operate as a subsystem in the context of its meta-system (S7), the aircraft.

- Figure 12 shows the next level of the hierarchy, the aircraft (S6) which is a subsystem of the airfield (S7).
- Figure 13 shows an adjacent or sibling system to the aircraft; a hangar (S6) which is also a subsystem of the airfield (S7).
- Figure 14 shows the next level of the hierarchy, the airfield (S6) which is a subsystem of the Air Defence System (ADS) (S7). Note that these hierarchical views shown in Figure 11, Figure 12, Figure 13 and Figure 14 are reductionist if used on a stand-alone (single view) basis as pointed out in Figure 14 because the hierarchical view does not show the metasystem (S7).
- In any of the four figures, Figure 11, Figure 12, Figure 13 and Figure 14:
    - Each system has its own nine systems.
    - Each system is described by its eight descriptive HTPs.
    - S6 and its adjacent systems are subsystems of S7.
    - S7 perceived from this view is a S6 to the systems engineers working on it.
    - All information not pertinent to the points being made in the discussion, e.g. the organizations (S9), has been abstracted out.

- Each systems engineer only needs to be concerned with their subsystems, S6 and S7 and manage the rest of complexity in the following manner:
    - *Subsystems:* they are purview of the systems engineer of S6 in the same manner as any other subsystem.
    - *Adjacent systems:* they show up in the Big Picture perspective of S6; their operational interactions and interfaces are seen in the Operational perspective of S6. However, since S6 and the adjacent systems are subsystems of the metasystem operating in S7, the specification of the nature of the adjacent systems are the purview of the system engineer of that metasystem operating in S7, in the same way as the specification of the nature of the subsystems of S6 is the purview of the system engineer of S6.

The partitioning of information in the HTPs associated with each system chunks the information to mask the complexity and allows it to be managed. The descriptive HTPs provide templates for describing each of the nine systems. For example:

- Horizontal views:
    - Appropriate support systems as adjacent systems in the *Big Picture* and *Operational* and perspectives.
    - All systems at the same level in the hierarchy will have the same metasystem and a slightly different list of adjacent systems.

- Vertical views:
    - Appropriate show support system as subsystems in the *Functional* and *Structural* perspectives.
    - Provide traceability from system to subsystem.

These templates could be built into future systems engineering tools and provide similar functionality to that provided by today's requirements management tools.

Kasser, Zhao and Mirchandani provide another example of using the Nine-System Model to manage stakeholders' areas of concern in the context of the pre-System Requirements Review (SRR) activities in the Multi-Satellite Operations Control Center (MSOCC) Data Switch Replacement Project (Kasser, et al., 2014).
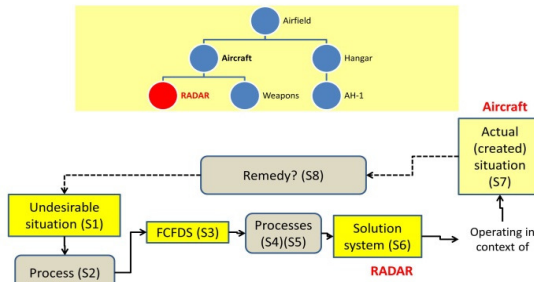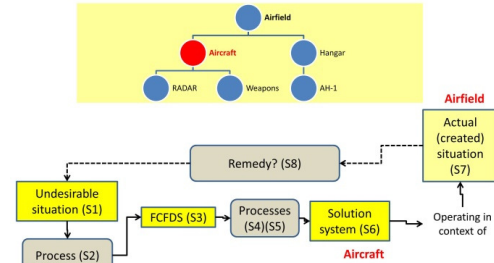
Figure 11 Radar as a subsystem of an aircraft

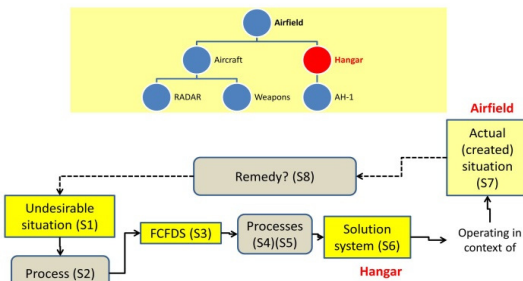Figure 12 Aircraft as a subsystem of an airfield

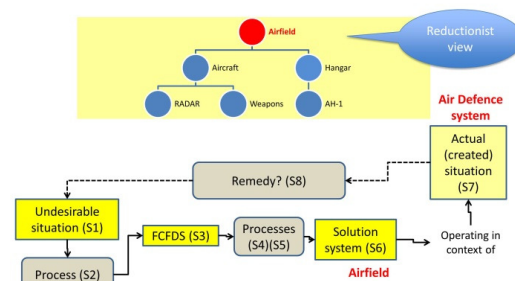Figure 13 Hangar as a subsystem of an airfield

Figure 14 Airfield as a subsystem of the ADS

7. Discussion

The section:

- Compares the Nine-System Model with the existing Seven Samurai, the Whole System Model and the System Model.
- Uses the Nine-System Model as a framework to relate the MIL-STD 499 (MIL-STD-499, 1969), EIA 632 (EIA 632, 1994), , IEEE 1220 (IEEE 1220, 1998) and ISO/IEC 15288 (Arnold, 2002) Standards, the SIMILAR process (Bahill and Gissing, 1998) Hitchins' version of systems engineering (Hitchins, 2007) and the problem-solving process.
- Shows how the nine systems dissolve three paradoxes in systems engineering.
- Shows how BPR relates to systems engineering.
- Summarizes the key benefits of the Nine-System Model.

7.1. Comparing the four models

When the Nine-System Model is compared with the three existing models in

Table 2, the Nine-System Model:

- Is seen as being more comprehensive.
- Has well-defined interfaces between the systems as shown in Figure 7 and Figure 9.

7.2. Relating the Nine-System Model to the MIL-STD 499, EIA 632, IEEE 1220 and ISO/IEC 15288 Standards, the SIMILAR process and the problem-solving process

This section shows how the Nine-System Mode relates to MIL-STD 499, EIA 632 and IEEE 1220 Standards, the SIMILAR process, Hitchin's version of systems engineering and the problem-solving process.

Table 2 Comparison of the four models

Systems addressed by the models	Seven Samurai	Whole System Model	System Model	Nine-System Model
Existing "as-is" **situation**	Context (S1)	-	-	S1
Existing **system** in "as-is" situation	-	-	E-system	Subsystem of S1
Process to develop conceptual solution system	-	-	-	S2
Conceptual solution **system** at time development begins	Intervention (S2)	-	R-System	S3
Process to plan transition from existing situation to situation in which the solution system will be deployed	Implied in Realization (S3)	Implied in Production	Implied in P-System	Explicit in S4
Process to realize solution system	Realization (S3)	Production	P-System	S5
Resources to be applied to realize the solution system	Realization (S3)	Development	P-System	S5
Solution **system** at and after time of deployment	Deployed (S4)	Operational	R-System	S6
New situation after solution system has been deployed	-	-	-	S7
Adjacent **systems** operating in association with the solution system at and after time of deployment	Collaborating (S5)	-	-	In HTPs of S6
System or systems that keeps the solution system operational at and after deployment	Sustainment (S6)	Support	M-System	Adjacent to or subsystem of S6
Process to determine situation after deployment of solution system contains no undesirable elements	Realization (S3)	Production	P-System	S8
Alternative solution systems	Competing (S7)	-	-	S3
Organization, enterprise and environment	Realization (S3)	Containing	-	S9

7.2.1. *MIL-STD-499*

The purpose of the MIL-STD 499 (Systems Engineering Management) Standard (MIL-STD-499, 1969) was to provide a set of criteria for people writing plans. Its updated version MIL-STD 499A (Engineering Management) (MIL-STD-499A, 1974), was developed to assist Government and contractor personnel in defining the system engineering effort in support of Defense acquisition programs. These activities take place in S4.

7.2.2. *EIA 632*

EIA 632 (Processes for Engineering a System) defines five groups of processes for engineering a system (EIA 632, 1994), namely EIA 632 focuses on S5 (to produce S6).

7.2.3. *IEEE 1220*

The focus of the IEEE 1220 Standard for Application and Management of the Systems Engineering Process is on the engineering activities necessary to guide product development (IEEE 1220, 1998) namely, IEEE 1220 focuses on S5 (to produce S6) with some coverage of S4 and the enterprise in which S4 and S5 are taking place (S9).

According to IEEE 1220, "*the systems engineering process is a generic problem-solving process*" (IEEE 1220, 1998) Section 4.1). The IEE 1220 version of the systems engineering process, based on the shortened problem-solving process; the section inside Figure 4 that starts with a problem and ends with a solution; has produced the 'B' paradigm of systems engineering which begins with the requirements phase in the system lifecycle (Kasser, 2012)Systems engineers need to use the holistic approach managing problems and solutions shown in Figure 4. IEEE 1220's replacement of the problem-solving process by the term systems engineering process seems to have led to today's focus on process; specifically the development process. Had the standard instead stated that 'systems engineers apply the problem-solving process' the focus of systems might have remained as the original focus on managing complex problems (Jenkins, 1969).
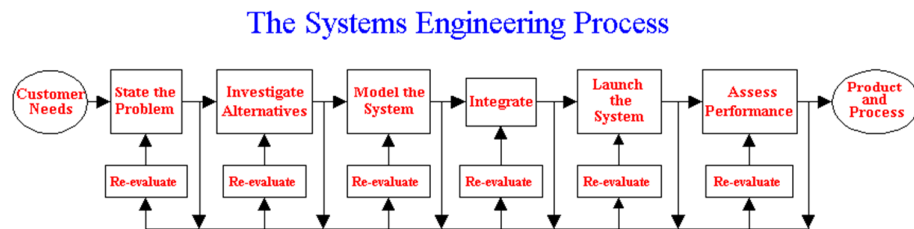

Figure 15 The SIMILAR process

7.2.4. *The SIMILAR process*

The SIMILAR process (Bahill and Gissing, 1998):

- Shown in Figure 15 focuses on three aspects of systems engineering; requirements definition, architectural design and testing and verification.
- Follows the 'B' paradigm of systems engineering so that the requirements definition for the solution system (S6) activities and architectural design of the solution system (S6) activities take place in S5 and testing and verification take place in S8.

7.2.5. *ISO/IEC 15288*

ISO/IEC 15288 (System engineering – System life cycle processes) (Arnold, 2002) focuses on the processes that span the conception of the idea through the retirement of a system within the context of the enterprise (S4, S5 and S9).

7.2.6. *Hitchin's version of systems engineering*

Hitchins' version of systems engineering in Figure 4 (Hitchins, 2007) page 173) is based on the problem-solving process but only ranges from identifying the problem to formulating the strategies and plans for realizing the solution system (S6) namely, S1, S2, S3, and S4. As far as Hitchins is concerned, activities in S5 and S8 constitute engineering rather than systems engineering.

The comparison is summarized in Table 3 which clearly shows that the Standards, the SIMILAR process and Hitchins focus on different systems within the Nine-Systems Model.

Table 3 Focus of the Standards, MBSE problem-solving and the nine systems

System	MIL-STD-499	EIA-632	IEEE 1220	ISO/IEC 15288	Hitchins (2007)	SIMILAR	MBSE	Problem-solving process
S1					X			X
S2					X			X
S3					X		X	X
S4	X		Partial	X	X			X
S5		X	X	X		X	X	X
S6		X	X			X	X	X
S7								X
S8						X		X
S9			Partial	X				

7.3. Dissolving three paradoxes found in the current systems engineering paradigm

The Nine-System Model dissolves the following paradoxes in the current paradigm:

- The systems engineering tools paradox.
- The reductionist paradox.
- The roles paradox.

7.3.1. The systems engineering tools paradox

The tools paradox arises due to the different descriptions of system engineering tools in the literature. For example, in the 1960's systems engineering tools included (Wilson, 1965; Alexander and Bailey, 1962; Chestnut, 1965):

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

Yet by, 2005 systems engineering tools were (Jenkins, 2005):

- Databases
- DOORS
- CORE
- Drawing tools
- PowerPoint
- Visio
- Word processors
- Spreadsheets
- Etc.

The paradox can be dissolved by recognising that the focus of systems engineering changed in the US Department of Defense (DOD) when the DOD moved early stage systems engineering out of systems engineering into Cost as an Independent Variable (CAIV) and the early stage activities in S2 were to be performed by Integrated Product and Process Development (IPPD) teams rather than by systems engineers (DOD IPPD, 1998), (DOD 5000.2-R, 2002), pages 83-

84). Thus the systems engineering tools of the 1960s' are used in S2 to apply to S1 and S3 while the systems engineering tools of 2005 are used in S5.

7.3.2. *The reductionist paradox*

Reductionism has been considered as poor practise in systems engineering (TBD), yet current system views are inherently reductionist. Consider Figure 16 as an example. The top level of the system is Federated Aerospace. The figure is reductionist because Federated Aerospace is a subsystem of its metasystem. The paradox is dissolved by the Nine-System Model which considers Federated Aerospace and its metasystem as two of the nine systems. As such, Figure 16 would not be acceptable in the nine-system paradigm since it lacks links to the metasystem and adjacent systems.
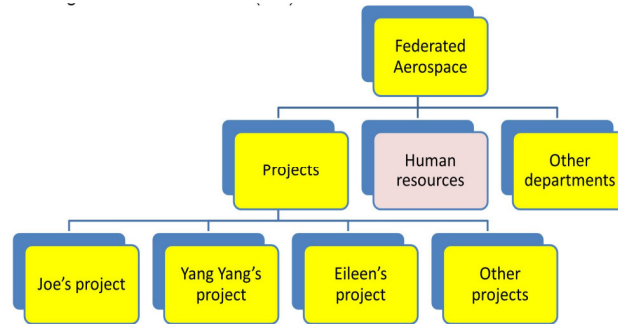
Figure 16 Structural view of Federated Aerospace

7.3.3. *The roles paradox*

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). However, the twelve systems engineering roles documented by Sheard (Sheard, 1996) have very little overlap with those of Jenkins. The paradox may be dissolved, by observing that systems engineering has evolved since 1969 when it was concerned mainly with S1 to S4 as observed by Jenkins and 1996 when the INCOSE version of systems engineering was concerned mainly with S5 and S6 as observed by Sheard.

7.4. Unifying BPR and systems engineering

BPR uses the 'as-is' view of S1 together with the 'to-be' view of S3 to determine the solution system in the same manner as the 'A' paradigm of systems engineering (Kasser, 2012). Hence BPR can be considered as an application of a methodology used for reengineering businesses. Systems engineering applies the same methodology in for solving complex problems particularly in the defence and aerospace domains.

7.5. Benefits of the Nine-System Model

In summary, the Nine-System Model:

1. Is founded on a theory based on aspects of problem solving and system engineering.
2. Links into the existing problem-solving and process paradigms.
3. Builds Best Practices into systems engineering.
4. Discourages the current reductionist and isolationist views of a system by means of the built-in metasystem (S7).
5. Encourages testing of solution system (S6) in context of the created situation (S7).

6. Abstracts out complexity and consequently opposes today's tendency to make things more complex.
7. Contains clear boundaries and lines of demarcation between the nine systems.
8. Shows that Development Test and Evaluation (DT&E) takes place as one of the streams of work in S5 and Operational Test and Evaluation (OT&E) takes place in S8. Hence by definition adoption of the Nine-System Model incorporates those activities as Best Practice.
9. Includes aspects that tend to be ignored in current paradigm, such as:
   a. Planning the realization process.
   b. The concept that the top level system is something else's subsystem as in an airfield is part of an ADS as shown in Figure 14.
10. Can be used to clarify the confusion arising from different perspectives of systems engineering in the literature by showing how the Standards, the SIMILAR process, problem solving and Hitchins' version of systems engineering relate to each other.

8. Summary

This paper documented research that reviewed three existing models for managing the complexity of the system development process in the INCOSE literature and found that while these models drew different SOIs from different perspectives they were unable to manage complexity in any practical manner. This paper then presented a Nine-System Model that can be used to manage complexity. This Nine-System Model builds in best practices and, being self-similar, can be applied in any level of the systems hierarchy. The nine systems comprise situations, processes and socio-technical systems in a clearly defined interdependent manner. The application of the Nine-System Model was illustrated in two examples. The paper then compared the four different system models, and used the Nine-System Model as a framework to relate the MIL-STD-499 (MIL-STD-499A, 1974), EIA 632 (EIA 632, 1994), IEEE 1220 (IEEE 1220, 1998) and the ISO/IEC 15288 (Arnold, 2002) Standards, the SIMILAR process (Bahill and Gissing, 1998), Hitchins' version of systems engineering (Hitchins, 2007) and the problem-solving process. The paper concluded with a summary of the key benefits of the Nine-System Model.

9. Biographies

Joseph Kasser has been a practicing systems engineer for more than 40 years and an academic for about 16 years. He is a Fellow of the Institution of Engineering and Technology (IET), an INCOSE Fellow, the author of *"Holistic thinking: creating innovative solutions to complex problems", "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 has performed and directed systems engineering in the UK, USA, Israel and Australia. 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 Associate Professor at the National University of Singapore.

Yang-Yang Zhao is currently an Associate Professor in the Norwegian Institute of System Engineering at Buskerud and Vestfold University College. She received her Ph.D. degree from the National University of Singapore in June 2013, previously having earned a master's degree in System Design and Management there in July 2009. She received her first master's degree in Engineering Management from the City University of Hong Kong then worked as a research assistant at its Department of Manufacturing Engineering and Engineering Management. Her research interests include system engineering, technology management and innovation strategy, and her work has appeared in the Journal of System Engineering, the Journal of Technology and Engineering Management, Total Quality Management and Business Excellence Journal and refereed international conferences.

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