Application of systems engineering to the public service systems (PSS): identifying areas of concern

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Abstract. Systems engineering has been successfully applied to large scale complex systems in the defense and telecom industry since the 1960s and later in the information technology (IT) industry. However, the value of systems perspective in solving complex social systems (for the purpose of this paper used to denote the same as public service systems -PSS) problems has yet to be experimented with. The Department of Industrial and Systems Engineering (ISE) at the National University of Singapore (NUS) has tried making some initial attempts and inroads into this area recently. As part of the launching of the Executive Systems Engineering and Management program ISE has been organizing short seminars and workshops. This paper summarizes some of the initial experiences and findings of the ISE faculty in interacting with some public service systems agencies/communities on the topic of application of systems thinking in their domain. The author is one of the faculty members involved in such initiatives with the public service systems.

Keywords. Systems thinking, public service systems, systems engineering.

1 Introduction

In the earlier years of systems engineering (1960s and the 70s) authors were considering systems where the cost functional which was being minimized (maximized) was dollar cost, energy, fuel, or time. Little consideration was given to the type of environment these systems were to operate in and little attention was given to assign a cost to such factors as water pollution, air pollution, noise pollution, or social disturbances. Most engineers considered the non-machine aspects of the problems to be out of the realm of engineering.

The later years’ in the 80s on have demonstrated to the world systemic global problems such as global warming, epidemics like HIV, SARS etc., global terrorism, financial crises very convincingly concluding that there exists a complete spectrum of man-machine-environment problems needing solutions. Review of these problems will reveal they are indeed system problems in nature and therefore should be amenable to the same analytical tools as are used to solve problems in the defense, aerospace or process control areas.
Organizations have time and time again shown concern about lack of such competence in systems engineering and systems thinking. The National Defense Industrial Association’s (in the United States) Systems Engineering Division (NDIA) Task Group Report of 2006 states that the quantity and quality of systems engineering expertise is insufficient to meet the demands of the government and the defense industry. (Bunting and Jain, 2010)

Systems engineering deals with design, development, and implementation of systems that deliver utility and significance. Systems engineering is a life cycle approach to engineering design - the integration of numerous technical and non-technical disciplines toward the development of new products, systems and services. (Jain, and Chandrasekaran, 2008) Success in the market place requires holistic design rigor and engineering rigor of the highest order – never the one without the other. Systems engineering is the discipline that helps bring these two objectives together. Engineers need the systems/holistic perspective as well as the tools, and methodologies of systems engineering to be able to effectively formulate and solve complex problems. For example, engineers should learn how to define problems in response to a need or a technological opportunity, determine customer or stakeholder requirements, formulate alternative concepts and select an optimal one, etc. (Jain, et. al, 2009)

**Life Cycle Perspective:** Systems engineering has been defined in several different ways – each having its own flavor. The International Council of Systems Engineering (INCOSE) defines it as an interdisciplinary approach and means to enable the realization of successful systems. NASA views it as a robust approach to the design, creation, and operation of systems. It is the management of technology that controls a total system life-cycle process, which involves the definition, development, and deployment of a system that is high quality, trustworthy, and cost-effective in meeting user needs (Sage, Armstrong, 2000). It is an appropriate application of a combination of the mathematical theory of systems and behavioral theory in a useful setting appropriate for the resolution of complex real world problems of large scale and scope (Sage, 1980).

Some standards such as Mil-Std 499A, IEEE-Std 1220 and ISO 15288 have also proposed the definition of SE. The Mil-Std defines it as the application of scientific and engineering efforts to: “(i) transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test, and evaluation; (ii) integrate related technical parameters and ensure compatibility of all related, functional, and program interfaces in a manner that optimizes the total system definition and design; and (iii) integrate reliability, maintainability, safety, survivability, human, and other such factors into the total technical engineering effort to meet cost, schedule, and technical performance objectives.” SE is a generic problem solving process which provides the mechanisms for identifying and evolving product and process definitions of a system. (IEEE-Std 1220).
The life-cycle perspective of SE becomes very evident from the above definitions. A SE perspective enables systems (whether physical, social, virtual or otherwise) to be designed, built, and operated in a manner that serves the needs of their stakeholders and can be maintained and supported effectively throughout their life cycle.

Seeing wholes and relationships: Systems thinking highlights that our actions are interrelated to other people’s actions in patterns of behavior and are not merely isolated event. Just as market price is an outcome of many individuals’ buying and selling behaviors at different prices. It helps us sense as well as appreciate our connection to a wider whole. (Senge, 1990) It helps us see wholes. As shown in Figure 1 systems thinking has been proposed as the “fifth discipline” for building learning organizations, together with four other, namely, personal mastery, mental models, shared vision, and group learning. Learning organizations are those that develop a continual collective learning by putting all their members in a position to learn together while supplying them with the instruments for such collective learning.

![Figure 1: Systems Thinking: The Fifth Discipline](image)

Systems thinking warns us that a problem must not be identified with the evident symptoms that require urgent measures because the symptom is not the problem. It is in the structure of the system and its dynamics. In order to solve “the” problem it is not enough to remove the symptom. That would only mean settling for short-term symptomatic solutions. We need to get away from analyzing problems from this reductionist perspective – A leads to B. Most of our public service systems deal with problems that inherently have multi-dimensionality. Usually the problems are a culmination of interaction of several things and establishing straight forward causality is almost impossible. For example, our inability to understand the complicated nature of managing the aging population in countries like Japan and Singapore. Systems thinking allows us to understand these problems from the parts, the whole, and the interactions between the parts and whole, between the whole and its environment.
The advantage of systems thinking derives from the leverage effect – seeing in what way the actions and changes in the structures can lead to long-lasting, meaningful improvements. Often the leverage effect follows the principle of the economy of means, according to which the best results do not come from large-scale efforts but from well-concentrated small actions. Our non-system way of thinking causes significant specific damage because it continually leads us to concentrate on low leverage effect changes. We correct and improve the symptoms but such efforts are limited to improving short-term factors, while worsening the situation in the long run. (Senge, 1990)

Public Service Systems, Social Systems: Some examples of the kinds of systems that we include in this category are: sustainable solutions for problems on urban living and design of future cities, health care, education, city and regional planning, energy and transportation, infrastructure, water and environmental etc. Policy and planning issues related to these are becoming issues of increasing concern to policy makers. Any sub optimal decision has far-reaching and serious societal implications.

All of these are characterized by complexity of structure and interactions between elements that comprise them. A social system is complex because the system emergence cannot be easily explained by cause-effect relations. The unpredictability of emergence comes from uncertainty in elements interactions and self-organization in a system. An SCS is the most complex system because its elements have human-centric functions and therefore highly unpredictable outcome of exogenous inputs to the SCS. (Yasui, 2011) The characteristics that define these public service social systems are as follows:

1. Mission critical systems: These systems support mission criticality.
2. Multiplicity of stakeholders: They require to represent the shared views of all the diverse groups of stakeholders.
3. Complex relationships within its part and outside in its environment: They cannot be described through ‘cause and effect’ relationships.
4. Several interactions within the system are implicit, and subtle: Many of these are not articulated in any form. There needs to be an implied sensitivity to address such dependencies and interactions.
5. Lead to human, social, and environmental impact when they fail. High social consequence issues should be high priority such as mission losses – significant consequences in society, economy, and future societal research.
6. Massive “snowball effect” due to unknown emerging interactions and unintended consequences.
7. Harmful effects cannot be ignored. Due to the nature of complexity of structure and ubiquitous nature of their impact the possibilities of failures cannot be overlooked. Their failure has a far reaching impact resulting in unacceptable losses of human, system, and environment. An example of very complex dependencies of such a system is the north-east ‘black-out’ in 2003 in the US.
8. Long term impacts: These systems have a long term impact on the social, environmental, and humans and in turn are impacted by and evolve in
response to the interactions with the social, environmental, and human elements of their context, for example, the medical insurance schemes or the social security system in the US.

Areas of Interest and Concerns: In the author’s engagement with the public service systems recently some areas of concern that have emerged relevant for the application of systems engineering are the following:

The major concerns emerged as the lack of understanding of SE applicable for such PSS and obtaining the ‘buy-in’ from within the organizations. There is a need to create an awareness and recognition that SE has applicability and value to these PSS organizations. The other major concern was on integration of processes, platforms, data, and technologies across the different departments and functions in these PSS organizations.

Another area of concern is obtaining and analyzing stakeholders’ requirements and customers' requirements keep changing. In the public service systems domain this area is the most challenging. The policy implications of new requirements take time to ‘read up’ and research. “PSS needs to focus on areas such as, policy development and systems thinking, and applications of systems thinking to shape organizational behavior”.

Knowledge within the organizations is in silos. Also there is a lack of enough people specialized in supporting the application of systems engineering. There is a lack of awareness of the relevant SE tools and their deployment. Also training on SE in these PSS organizations needs to be strengthened.

Management demand ‘immediate answers’ and there is not enough time for systems engineering. Sometimes there is the pressure to follow the pre-determined direction by higher management.

Often organizations do not have an understanding of what is SE, how to apply it and how to obtain stakeholders buy-in. Constraints also come due to the need to overcoming self-interest of the individual department and lack of knowledge of system efficiency. Integration of cross-department processes and interactions between departments is necessary to design and implement any SE initiatives. Many of the SE initiatives remain unattended due to a perception of technology limitation and lack of appropriate engineering knowledge.

Understanding the complexity and ‘confidentiality of system model’ is required for integrating with other system, safety, and with legacy systems. Sometimes bureaucracy and rigid frameworks of the PSS comes in the way of collection of data and responsibility and accountability issues.

Current training areas in these PSS organizations related to SE topics were noted as: process improvement, business process re-engineering, change management, technical training, competitive training, root cause analysis to determine failure root
causes, "basic systems thinking", software application, system subsystem design, 
optimization of systems for cost reduction/energy savings, optimized contingency for 
operation and maintenance of system/network, operations requirements, systems 
thinking, environmental testing, design for deployment etc.

**Contributors to problem solving at the PSSs:** Keeping in mind the unique nature of 
the context in which the PSSs operate and unique nature of the services they provide 
to their stakeholders, the usefulness of a systems perspective and their expectation of 
value from SE application will have to be analyzed and ascertained. It will involve an 
analysis into how problems are formulated, evaluated, and solutions implemented. 
Figure 2 is a representation of the factors influencing the systems boundary definition 
of a PSS and the different players and their roles.

![Figure 2: System Boundary Definition: Key Players and Their Roles](image)

**Sources of motivation:** will involve ascertaining who contributes (ought to 
contribute) the necessary sense of direction and ‘values’? What purposes are to 
be served? Whose purpose is it? Basically, the motivation behind the purpose 
of the system being analyzed.

**Sources of control built into the system:** will involve an analysis of the power 
and authority structure inherent in the system. Who contributes (ought to 
contribute) the necessary means, resources, and decision authority? Who has 
(ought to have) the power to decide?

**Sources of expertise assumed to be adequate:** Who contributes (ought to 
contribute) the necessary competence, skills and the necessary knowledge of 
‘facts’? Who has (ought to have) the know-how to design, operate, and 
manage the system?

**Sources of legitimation to be considered:** Who represents (ought to represent) 
the concerns of the affected stakeholders? What is the process of self-analysis 
and correction? Who contributes the necessary sense of self-reflection and 
responsibility among the involved? How do the involved deal with the 
different perspectives of the affected stakeholders? How are the conflicting 
and/or contradicting interests and needs of the stakeholders balanced and 
traded-off?
Conclusion: This paper is just a beginning of hopefully some serious work that awaits to be done in the area of application of systems engineering to the PSSs. Presently the PSSs are skeptical about what systems engineering means for them, how will it be applied and what value will it bring to them. The case of a well-established and profitable practice of SE in the defense and aerospace domain has not successfully translated into its acceptance in other complex environments. PSSs are very ripe for SE application due to their service intensive nature, multiple and often contracting stakeholders, resource constraints, and an environment which is mostly complex and ridden with uncertainty. The way forward is to make some small inroads and gain the trust of a few PSSs and establish the credibility and meaningfulness of the application of SE in the PSSs domain. That will go a long way in obtaining the willing support of such institutions and agencies.

References


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