Systems Engineering Approaches for Indian Public Health

Dr. Venkata Srinivas Dangeti[1]

Abstract

The Indian Public Health system exhibits attributes similar to artificially engineered complex systems. The multi-dimensional nature of these attributes, such as variable access to health facilities in rural vs urban settings; paucity of public funds dedicated for the betterment of healthcare; a clear fragmentation in the quality of care provided by public health systems and private hospitals; and several interacting components within the health system such as patients, hospitals, trained practitioners; as well as other interfacing parameters with direct impact on health, such as literacy, sanitation, drinking water facilities - closely mirror the complexity observed in any artificially designed systems and products such as a computer, aircraft, medical devices, etc. By juxtaposing the common system-level attributes, patterns, and constraints observed in the design of such artificial systems, and employing systems engineering-based modeling approaches, better solutions can be incrementally and efficiently deployed for public health.

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A system is a combination of elements that interact to produce the desired output. An example of a system is a human body which is a complex organization of several sub-systems such as the respiratory system and the circulatory system with a great degree of interdependence and interconnection between the participant sub-systems. The human body exhibits an astonishing and marvelous amount of complexity rendered by its overall architecture, which includes the detailed spatial location of various organs whose functionality is satisfactorily manifested due to specialization achieved by various cells, which are the result of the differentiation and development plan of the embryo. This complex architectural manifestation at the scale of sub-systems is seeded by an amazing amount of commonality at the level of cells and tissues, where there is a high level of homogeneity. We constantly witness these attributes of modularity and inter-dependencies as one views any given system at different scales. Such a complex natural system such as a human body is an end-product of millions of years of evolutionary fine-tuning achieved by blind biological mechanisms. A methodology that considers such varied scales of analyzing the system is direly needed to make it amenable for understanding and then effectively intervening in the case of diseases.

Similarly, with the unprecedented growth in technology and the need for the development of a multitude of complex artificial man-made systems, including electromechanical devices such as medical devices, spacecraft, computers etc., there was a definite need to approach the development using thorough and systematic approaches for product development. The primordial elements that make up the endeavor of such complex product developments include a combination of people, processes, and their design. Similar to natural systems, the design and development of com-

[1] Systems Engineer and Researcher, New York, United States of America.
Email:venkatas.dangeti@gmail.com

plex systems require a meticulous understanding of the requirements which are statements for capturing the needs of the system, which can be decomposed to evaluate the needed architecture and design of the intended product. Some of the complexity in the design of any successful product comes from the lack of clarity in the capturing of the needed requirements which generate ambiguity and leads to incorrect evaluation of the trade-offs between various possible designs for the design and development of the product.

Getting a firm grip in dealing with complexity requires varied approaches than just employing the traditional view of statically breaking the system into subcomponents and attempting to understand each subsystem and drawing broad, sweeping conclusions on the properties of the whole system. Such reductionist approaches are ill-suited to getting in terms with any complex systems. In stark contrast to such approaches, Systems Engineering approaches that have been employed across several industries in complex product development, which involves geographically diverse development teams, a vast number of components in some cases running into several thousand which need to be assembled to achieve the desired whole, are greatly suited for managing the complexity.[1,2] The manufacturing of an aircraft system with millions of parts that are assembled at different locations at various stages and finally assembled at a different site is a classic example of using such system engineering processes. The successful approach of systems engineering to the development of such complex systems stems from the already existing realization of the inadequacy of traditional reductionist approaches as well as knowing the emergent properties of systems such as reliability, integrity, modularity etc., which don't simply arise due to the static addition of sub-systems but due to multi-variant dynamic nature of interactions that need to be designed with full consideration of trade-offs for every design choice.

Systems Engineering encompasses a broad purview of multiple approaches including requirements engineering, architecture development, design considerations, successful verification, and validation to achieve the intended end-goal of the system. The definition of what can be considered a system and sub-system is entirely chosen arbitrarily based on the amount of control one can exert on the design and development of the system. One can also consider a system to be a part of a larger ecosystem. The system boundaries that emanate between two systems and between multiple sub-systems within a large complex system are drawn to effectively model the innate complexity that might arise due to the varied nature of interactions. As an example, a natural system like the human body can be considered one large system with multiple sub-systems such as respiratory, circulatory, endocrine, and others. Every cell of the human body can be considered a system that interacts with other cells in a tissue which is a sub-system of an organ. At the same time, the interactions that can occur between the human body and the environment can be considered a system of systems or be a part of a larger ecosystem.

As discussed above, Systems theory and approaches have been successfully employed for a better understanding of natural systems as well as for the development of complex artificial systems such as an aircraft system. The public health system offers a rich fertile ground for the application of systems theory and principles for not only better understanding the complexity but also providing avenues for the application of the systems engineering principles for effective policy design by governments.[3] Similar to such complex artificial systems, it exhibits a staggering complexity by the virtue of a billion-plus population with diverse health needs, a substantial diversity in access to advanced medicine in rural poor settings compared to rich urban areas, inadequacies in the allocation of budgets dedicated for health, as well as lack of adequately trained resources willing to work in such resource-starved settings. All these systematic problems are compounded by the multi-dimensional nature of health in general which can be directly attributed to the overall standard of life. It will be ideal to strategically look at such specific problems in healthcare policy and employ systems-based engineering approaches for better solutions.

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