**What is Systems Engineering?**

While discussing the definition stated as [1] systems engineering is an interdisciplinary field of engineering and engineering management that focuses on how to design, integrate, and manage complex systems over their life cycles. At its core, systems engineering utilizes systems thinking principles to organize this body of knowledge. The individual outcome of such efforts, an engineered system, can be defined as a combination of components that work in synergy to collectively perform a useful function, this is more like defining what systems engineering is without realizing whether this investigates, evaluates, expands, or brings about an argument into the minds of someone reading it for the first time. This essay is an attempt to break down concepts and dive into understanding what systems engineering really could mean using a top-down approach.

Systems engineering is all about the process that is required or utilized to develop a robust functional system. A system is a set of entities and their relationships whose functionality is greater than the sum of individual entities. A system can be made up of a series of systems or subsystems. A subsystem here can be an actual discrete system with complete subsystems underneath it or they can also be the lowest component level where there is nothing to describe as a system within it. For example, a screw is a component and any mechanical machine is a system. Systems engineering as a process is the same for any engineer. Be it a black box device for an electrical engineer or writing a program for a computer science engineer. For all system engineers, there must be a requirement irrespective of the field. These requirements lead to functions which is the core aspect of systems engineering from a broad overview. Once onto functions, getting down to functional analysis is the next part to understand which components need to be created or, if any, which pre-existing components can be utilized. To understand this, one may consider the example as to why redefine a switch to make a keyboard when there are already so many designs of switches available.

Systems engineering broadly tells us how complex projects can be developed that efficiently meet objectives. With efficiency, it is inclined towards minimizing unnecessary work, catching errors early, and effectively communicating among all of the key participants. One can understand it in a way that systems engineering is a process to develop something too complex to be designed and built as a single monolithic entity. It starts from an ill-defined idea and then putting form to it and understanding the interactions among itself as well as the world as a whole keeping the needs in check. The needs are from stakeholders (high-level objectives), project management (risk, schedule, budget, etc), and engineering specialists. Systems engineering works to describe a system that is compatible with all of the above needs. Complex systems are co-evolving multilayer networks. A complex system has many elements or entities that are highly interconnected or interwoven. The certain properties essential to complex systems are emergence and power laws, self-organized criticality, collapse and boom phases, phase transitions, edge of chaos, and path-dependent processes. The goal of complex systems is to understand the dynamical systemic outcomes of interconnected systems and ultimately control and design systemic properties like the economy, ecology, cities, climate, financial system, and social processes. The understanding of a complex system is reached out in a quantitative, predictive and ultimately in an experimentally testable manner. Many complex systems are sensitive to details in their internal setup. Concepts that may seem to be extremely robust and effective in a non-complex system may lose their predictive power when confronted with a complex system.

To understand complex systems, one may plunge into understanding the brain as a complex system and how complex are nervous systems in themselves. [3] An average human brain weighs about 1.4 kilograms and is about the size of your fist. However, it is responsible for every thought, feeling, taste, action, memory, or everything a human will ever do in his life. The world we live in is extremely complex in itself. The brain continuously receives input from this complex world through senses that detect light, odor, temperature, pressure, sound, waves, vibration, and so on. The brain converts information from the outside world to construct the world that we see, feel, taste, and hear. It determines what is most important for us at any given moment and that is what we perceive. It creates a conscious percept to the world inside our heads to allow us to operate in this complex world. All that we are is due to this amazing complexity of our brains. The average adult human being has 86 billion neurons. If each neuron of a single human brain were laid end to end they could be wrapped around the earth twice over. Each neuron can have as many as 10000 synapses connecting it functionally to other neurons. Therefore, a typical brain will have over 100 trillion connections or synapses. If we could map a connection every second, it would take more than 3 million years to map the human brain and this is without considering the switches at each connection, nor its function. Neuronal communication adds to the further complexity of our brain. The most common form of communication between neurons involves chemical transmission via a vast array of chemicals and receptors. Different combinations of chemicals and receptors can result in either excitation or inhibition of the neuron. Simply put, they act as switches turning the neuron on or off and increasing the incredible complexity of the neuronal architecture and function well beyond our expectations! So, an interesting question to ask is whether the complexity of our brain is what makes us human. The complexity doesn’t seem to distinguish our brains from those of other animals. For example, elephants have larger brains which are therefore more complex. The complexity of the brain and the nervous system is unimaginable. Every brain is unique and there are currently over 7 billion different models functioning today. The quote by the nuclear physicist George Edgin Pugh sums up how complex a human brain is. [4] It goes as, “If our brains were simple enough for everyone to understand them, we’d be so simple that we couldn’t”.

This brief study justifies how complex a system can get and how every system has an architecture but there is even more to it. Of course, the process is not a linear progression but is iterative among the engineering specialist, stakeholders, and project managers. Often, the needs of these groups conflict with each other and it is through trade studies, architecture descriptions, and requirements that could be resolved. New problems arise when the decomposition of the system into components takes place. Simplifying the complexity and splitting the system functionally, logically, and physically would form a part of it. Ensuring that these systems meet the needs of higher systems and making sure that they are compatible among themselves are other challenges faced by a system engineer. The architecture descriptions, reviews, and trade studies are all the additional parts of what is expected of a system engineer. Following systems engineering approach gets essential for complex systems. [2] For example, while designing a car door a strong structure, hinge, latch, a mechanism to open it from both sides is not all that is needed. A window to see through the door, an electric switch to operate the window, or a child lock maybe some of the other things needed. If so, one may have to bring an electrical engineer to work. Just in case there is a need for sensors in the window, they may then want a software engineer to manage the safety element. So, this simple work and rework cycle can be expensive and time-consuming. This may still be a simple problem to figure out the needs but as the project and needs get complex, that is where a system architecture is required thus justifying the need for systems engineering. Although, there may be many more aspects to define what systems engineering is, the general breakdown of definition, how complex systems can get, a case study on how complex a system can get, the need of systems engineering, and problems faced in its absence may suffice to place you as an erudite in a room full of systems engineers.

References: -

[1] <https://en.wikipedia.org/wiki/Systems_engineering>

[2] <https://www.mathworks.com/products/system-composer.html?s_eid=PSM_15028>

[3] <https://www.coursera.org/lecture/analysing-complexity/the-complexity-of-brains-7K7Ig>

[4] <https://quoteinvestigator.com/2016/03/05/brain/>