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Systems Thinking: An Analysis of Key Factors and Relationships

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Abstract

Today's work environment presents engineers with complex challenges that demand holistic approaches. Systems thinking provides ways to think about a problem and its solutions using "whole system" perspectives. There have been multiple studies that identify the key elements that comprise systems thinking. These studies have resulted in the identification of sets of individual systems thinking traits, elements, and characteristics. In this paper, the authors further explore and analyze individual systems thinking elements as well as the relationships between the various elements. The authors will present and discuss a model that illustrates the relationships between the elements related to individual systems thinking.

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1. Introduction

Systems thinking is the ability to think about a system as a whole, rather than only considering the parts individually. It perceives the world as a complex system and supports the understanding of its interconnectedness and interrelationships [1]. There are many definitions of systems thinking. In his book, The Fifth Discipline, Peter

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Senge [2] defines systems thinking as a discipline for seeing wholes. He further defines systems thinking as a “framework for seeing interrelationship rather than things, for seeing patterns of change rather than static snapshots” [2]. Davidz [3] builds further upon the notion of interrelationships, and interdependencies. She defines systems thinking as the “analysis, synthesis and understanding of interconnections, interactions, and interdependencies that are technical, social, temporal and multi-level” [3]. Moore, Dolansky, Singh, Palmieri and Alemi [4] identify some of the same concepts as Senge and Davidz in their definition of systems thinking. Moore, Dolansky, Singh, Palmieri and Alemi’s [4] complete definition of systems thinking is “the ability to recognize, understand, and synthesize the interactions, and interdependencies in a set of components designed for a specific purpose. This includes the ability to recognize patterns and repetitions in interactions”. The ability to understand interrelationships is a recurring theme in all of these definitions.

Systems thinking perceives the world as a complex system and supports the understanding of its interconnectedness and interrelationships [5]. It builds upon the idea that a system is greater than the sum of its parts and therefore should be studied holistically. The use of it allows us to better understand and develop successful complex systems and is integral to systems engineering. Systems engineers use systems thinking to understand the factors, relationships and feedback behaviors in a system. It is used to consider a problem and its solutions in a “whole system” manner. Systems thinking has been applied in many different domains including healthcare, sustainability, defense, project management, education, and in the service sector, among many others.

Systems thinking is a critical skill set used by competent systems engineers [5]. Systems engineering competency models identify systems thinking as a foundation for performing systems engineering. These models define a set of core competencies in the systems engineering workforce. The Systems Engineering Competency Framework (SECF) [6] has a quantifiable set of competencies for systems engineering and includes systems thinking. Another model, the Systems Engineering Competency Taxonomy (SECT) presented by Squires, Wade, Dominick and Gelosh [7] also identifies systems thinking as a core competency for a systems engineer.

Further breaking down systems thinking leads to the distinction between systems thinking in an individual and in a team composed of individuals. Individual systems thinking (IST) is based upon the ability of an individual systems engineer to demonstrate systems thinking. Collaborative Systems Thinking (CST) as defined by Lamb [8] is “an emergent behavior of teams resulting from the interactions of team members and utilizing a variety of thinking styles, design processes, tools and communication media to consider the system, its components and dynamics towards executing systems design”. CST is referred to as team systems thinking (TST) by the authors of this paper, and is the result of several individuals working together as in concert rather than the individual alone. Both IST and TST include various characteristics, abilities, skills and traits needed to accomplish systems thinking. While TST is also important, the purpose of this paper is to explore IST elements as well as the relationships between various elements of IST.

2. Individual Systems Thinking Elements Background

Multiple studies identify traits, elements and characteristics required for IST [3,4,9,10]. In Moti Frank’s Capacity for Engineering Systems Thinking (CEST) [9], elements are identified based on extensive literature reviews along with observations of successful systems engineers by peers and supervisors from two separate studies. Frank validated the initial element list that includes cognitive characteristics, capabilities, traits and behaviors by comparing his list with similar lists of characteristics and traits from two other authors, Frampton, Thom and Carroll [11] and Di-Carlo and Koshnevis [12]. The resulting elements include 38 cognitive characteristics, capabilities, traits and behaviors used to measure (CEST) in individuals.

Stave and Hopper [10] conducted an extensive literature review of systems thinking characteristics and came up with seven characteristics of a systems thinker. These include recognizing interconnections, identifying feedback, understanding dynamic behavior, and differentiating types of variables and flows, using conceptual models, creating simulation models, and testing policies. Building upon these characteristics, Stave and Hopper [10] provide a taxonomy that includes measures and objectives for each of these seven characteristics.

Moore, Dolansky, Singh, Palmieri and Alemi [4] developed the Systems Thinking Scale (STS) scale as a way to measure the systems thinking capability needed by professionals in the health care industry. These researchers consulted with eleven experts in the fields of systems thinking and continuous improvement as part of their study.

The results were validated by healthcare professionals and later further validated using psychometric testing. The thirty question STS scale uses six dimensions of systems thinking: sequence of events, causal sequence, multiple causations possible, variation of different types, feedback, and interrelations of factors.

Davidz [3] has also conducted extensive research in the area of systems thinking and its role in systems engineering. She used pilot interviews, field studies, interviews with subject experts, and surveys in order to identify systems thinking elements. Davidz categorized the results of one of the surveys into a hierarchy that groups the different systems thinking characteristics and traits. Many of the characteristics and traits identified in Davidz's work overlap with the elements identified in research from Moti Frank [9], Stave and Hopper [10], and Moore, Dolansky, Singh, Palmieri and Alemi [4]. The specific term "element" is used throughout the rest of this paper in reference to the set of characteristics, capabilities, traits and behaviors identified from these studies.

3. Individual Systems Thinking Elements

The authors of this paper analyzed the IST elements identified in multiple studies [3,4,9,10]. The previously identified elements were compared and contrasted and a set of guidelines were established to assist in identifying key IST elements. The guidelines considered the frequency of element occurrence in the survey responses in some of the previous studies. The first criterion used in the analysis was to compare the complete set of elements from Frank's [9] research with the elements from the research of Davidz [3], Stave and Hopper [10], and Moore, Dolansky, Singh, Palmieri and Alemi [4]. In order for the element to be included in the set of key IST elements, it had to be first in Frank's list of elements as well as in at least one of the other research studies [3,4,10]. Frank's systems thinking elements are used as the base in the first criterion because he validated his research against other researchers. He also provided detailed background information for each element. In addition, as part of the first criterion only Davidz's elements that had greater than or equal to five survey responses were included. A minimum requirement of five survey responses identifying an element was used to avoid cases where the survey question may have been interpreted incorrectly. A separate criterion was to include elements from Davidz's work that had greater than or equal to ten responses regardless of whether or not the element existed on Frank's list. A quantity of ten was used in this case because it represents a reasonable quantity in relationship to the rest of the responses in the survey.

Table 1 shows the identified key IST elements. The analysis resulted in twenty-one elements. In cases where the specific element name differed between the researchers, the authors of this paper adapted the element name to fit the needs most suitable to their research [3,4,9,10].

Table 2 presents a few of the definitions developed for each of the elements identified in Table 1. The definitions were created using background information from various authors who identified systems thinking elements including Frank [9], Stave and Hopper [10], Moore, Dolansky, Singh, Palmieri and Alemi [4], and Davidz [3] along with information found using a further literature review for each definition. The definitions were created because, in many cases, previous work identified only particular aspects of each of the definitions of each element. Some of the resulting definitions contain segments from multiple researchers' background information to create a definition more suitable to the authors of this paper. In other cases, the authors of this paper had to come up with definitions themselves as some existing information related to each element was descriptive and not a definition.

The definition of "understanding the whole system" was adapted from the background information and definition in Frank's [9] research. Aristotle contributed to the definition with the concept that a whole system is greater than the sum of its parts. The definition of "understanding interconnections" was developed using a hybrid of the Webster dictionary's definition of understanding [13] and the background and a definition from the research of Stave and Hopper [10]. The definition of "consider and use multiple perspectives" uses a modified version of descriptive information from Frampton, Carroll, and Thom [14]. The original description, "In addition, they had to be able to consider issues from a range of perspectives and points of view, to understand them and to draw upon appropriate concepts and values in arriving at a critical assessment of them." [14], was leveraged since it was included in Frank's [9] background information. The authors referenced both Frank [9] as well as Frampton, Carroll and Thom [14] to create a modified definition. Definitions were created in a similar manner for each of the other eighteen elements.

Table 1. Individual Systems Thinking Elements

Behl and Ferreira Element Name	Frank Element Name [9]	Davidz Element Name [3]	Stave and Hopper Element Name [10]	Moore, Dolansky, Singh, Palmieri and Alemi Element Name [4]
Understanding the whole system	Understand the whole system	Think broadly/big picture		
Understanding interconnections	Understand interconnections		Recognizing interconnections	Interrelations of factors, patterns of relationships
Thinking creatively	Thinking creatively	Creativity, Out of the box		
Not getting lost in the details	Understanding systems without getting stuck on the details, Tolerance for ambiguity and uncertainty	Not detail focused		
Consider and use multiple perspectives	Understand the system from multiple perspectives	Multiple perspectives		
Curious	Curious	Curiosity		
Asks good questions	Asks good questions	Asks questions, Inquisitive (Desire to question)		
Analytical	Analytical	Analytical, Logical		
Create, build and use models	Create, build and use simulations		Creating simulation models	
Good interpersonal skills	Good communication and interpersonal skills	Strong interpersonal skills		
Good listening skills		Listening		
Good communication skills	Good communication and interpersonal skills	Communication		
Have self confidence	Have self confidence	Self confidence,		
Disciplined	Disciplined	Disciplined, structured/methodical, organized		
Abstract thinking		Abstract thinking		
Initiative/Motivation		Initiative/Motivation		
Systems engineering education		Education		
Wide and varied experience		Wide and varied background, Experience, Wide range of interests		
Outgoing/Extrovert		Outgoing/Extrovert (not an introvert)		
Tolerance for uncertainty	Understanding systems without getting stuck on the details, Tolerance for ambiguity and uncertainty	Tolerance for uncertainty, tolerance for ambiguity		
Open minded		Open minded		

Table 2. Individual Systems Thinking Element Definitions

Element Name	Definition
Understanding the whole system	Understanding the whole system means comprehending the system holistically, taking into consideration all its elements, subsystems, assemblies and components.
Understanding interconnections	Understanding interconnections means having the knowledge and ability to understand relationships and interdependencies between system elements at various hierarchical levels of the system, along with the results of interactions between system elements.
Consider and use multiple perspectives	Considering and using multiple perspectives means understanding the system from diverse and several points of view.

4. Individual Systems Thinking Element Relationships

Each identified IST element is an important and integral component of systems thinking. However, important relationships also exist between the elements. Individual IST elements can contribute to other IST elements. The authors analyzed the relationships between the various IST elements. Figure 1 illustrates the identified relationships between IST elements. Only a subset of the elements is shown and discussed due to conference paper page limitations.

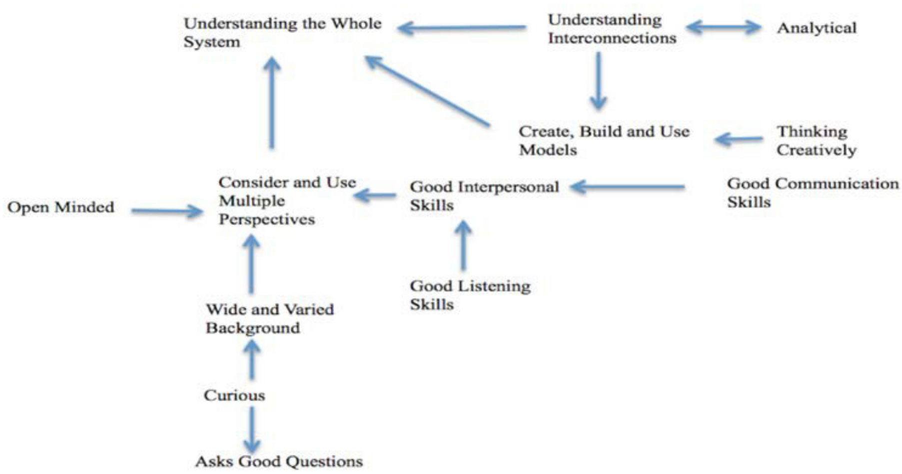

Fig. 1. Individual Systems Thinking Element Relationships

In "understanding the whole system", a systems engineer requires "understanding interconnections" and "consider and use multiple perspectives". "Consider and use multiple perspectives" allows the systems engineer to take into account different stakeholder viewpoints such as the end user, the design team, the support team and the executive team, among others. The different viewpoints along with the understanding of all interconnections will give the engineer the ability to develop a more complete view of the system. A number of elements contribute to "consider and use multiple perspectives" and include having a "wide and varied background" and being "open minded". Having a "wide and varied background" means that the engineer can leverage their experience and education to be able to see the problem from many points of view. The engineer must also keep an open mind ("open minded") and be willing to consider various ideas. Being "curious" allows the engineer to take the initiative in getting many different experiences and the interest to "ask good questions"

The systems engineer will leverage the ability to "create, build and use models" in "understanding the whole system". "Thinking creatively", including the ability to put things together in new ways, is important in order to "create, build and use models". This is due to the need to, at times, think outside the box when creating models.

"Understanding interconnections" is a contributing factor for "create, build and use models" because without it, the engineer would not be able to clearly understand all of the interfaces of the system. The contributing factor for "understanding interconnections is "analytical". This is a bi-directional relationship between "understanding interconnections" and "analytical" because both elements contribute to each other. Being "analytical" allows the systems engineer to logically look at all of the interconnections and having a clear understanding of those interfaces allows the systems engineer to analyze them. Another contributing factor to "consider and use multiple perspectives" is "good interpersonal skills". A systems thinker would develop "good interpersonal skills" by relying on their "good communication skills" as well as "good listening skills".

5. Conclusions and Future Work

Systems thinking is the ability to think about a complex system in a holistic way and not just the parts individually. Elements from the research of Frank [9], Stave and Hopper [10], Moore, Dolansky, Singh, Palmieri and Alemi [4], and Davidz [3] and were used as the basis to analyze IST elements. Key IST elements were identified and further defined. The authors of this paper also examined and analyzed the relationships between each of these IST elements. These relationships identify important associations between the elements. While this paper focuses on IST, it is also important to understand TST, as systems engineers often work in teams. Understanding how the team interacts as a whole will help to further understand how to optimize systems engineering efforts on projects. The authors will leverage the analysis presented in this paper in future research to explore the relationships between IST elements and project success.

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