Systems Engineering Decision-making: Optimizing and/or Satisficing?

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***Abstract*—Not all systems are the same: consequently they need different management approaches. The varied typology of systems is not always universally recognized. One way in which systems can vary is in terms of complexity; and there is increasing awareness about growing complexity in systems across a number of literature domains. Complexity is now an evolving topic in systems engineering (SE). However, traditional SE has tended to address all systems with the same approach, moving from the premise that activities and their interrelationships are linear and measurable. Recently there has been a paradigm shift in the way systems are understood, with the recognition of their nonlinear and emergent properties. Traditionally optimization has been the primary method of decision-making. When dealing with complexity, true optimization is not always possible: therefore satisficing was introduced. Selecting and applying these two very different approaches is proving to be a challenging task for engineering practitioners. This paper explores SE decision-making in dealing with different types of systems with various degrees of complexity and proposes a decision-making methodology which can assist engineering managers with the selection of optimizing versus satisficing in a given situation or problem space.**

Keywords—optimizing; satisficing; top-down management; governance; systems engineering (SE); system of systems (SoS).

I. INTRODUCTION

Management/leadership decision-making has been extensively investigated, using a variety of categorizations. The work of Simon in the field is well-known; for example, Simon [1], in writing about the steps involved in decision-making moving from finding and attending to problems, being aware of the alternatives, and then evaluating those alternatives and selecting one. Simon stressed the centrality of decision-making and rationality to human endeavors including economics, management and psychology. Maximizing utility or optimization derives from the concept of bounded rationality; but human decision-making is often not quite this clear-cut, and thinking is not always logical [2]. Often there are decision making dilemmas in which none of the choices available are really satisfactory. Simon's theory of bounded rationality suggests that decision-makers often use a simplified model of the world, based around the concept of satisficing; deciders accept a satisfactory but not optimal result. Thus it is not accurate to imagine that decision-makers decide in a fully rational way with a strict search for optimization. Rationality is bounded due to constraints such as complexity, incomplete information, limited capacity of the decision-maker, limited time available and the decider's objectives.

Others, for example Maldonato [3], have written about the impact of bounded-ness on rationality and the fact that rationality is just an ideal. Cady [4] applied two fundamentally different views of decision-making (the rational view and the naturalistic view) within complex health systems. Thus the rational view requires that the senior leader decision-maker explores all of the available alternatives and then choose the best possible option to achieve the best outcome. In order to do this, the decision-maker needs to have a full knowledge and understanding of all of the various alternatives and be able to assess those alternatives effectively. This is the decision-making arena for simple contexts, for example an assembly, where the environment changes only slowly and there are no external inputs; "RDM [rational decision-making] is frequently prescribed as the ideal for implementing C2 [command-and-control] systems" [5]. On the other hand, the naturalistic decision-making style takes account of real-world constraints and also the capacities of the person or team making the decision [6]. The decision-maker does not have perfect information and the decision making process therefore needs to be collaborative. In summary, optimizing is the process of listing all of the available alternatives, assessing each one, and then choosing the best one. Satisficing, on the other hand, is the decision process used when it is not feasible to list all of the available alternatives and choose in an orderly fashion due to the dynamic nature of the situation, unclear boundaries and emergence: rather, it is necessary to choose a good enough option which satisfies a previously set benchmark.

II. SYSTEM COMPLEXITY

Much early systems research employed conceptual or analytical methods and focused on scheduling optimization, based on the view that system components and their interrelationships are fixed and measurable. However times have changed, and there is a growing body of knowledge to suggest that systems are becoming more and more complex and that various systems contain different degrees of complexity [7]. Several typologies of systems have been explored but there is still no one universally accepted typology. The concept of 'system' was initially recognized by Bertalanffy [8] in 1934. Originally stand-alone systems were the focus of exploration by researchers and practitioners in various domains. However due to technological advances and the further involvement of the human factor, the complexity of systems has increased and this has led to the concept of

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systems of systems to deal with multiple integrated complex systems working together to achieve a common objective [9-11]. One of the typologies proposed for classifying systems recognizes the four main types; assembly system, traditional system, SoS and chaotic state [12]. Similarly, in the domain of project management, systems can be viewed as occurring along a dimension of simple, complicated, complex and chaotic [13]. Thus Snowden and Boone [14] presented four levels of complexity; simple, complicated, complex, and chaotic and these have been utilized by several writers to describe the new approaches necessary given increasing levels of complexity and the need for frameworks to help managers select the most appropriate action given the context in which they find themselves [15]. It has been suggested that simple and complicated systems are rather similar, both being concerned with the 'knowns' domain. At the other end of the spectrum, complex and chaotic systems are both concerned with 'unknowns' where it is not possible to know and understand all features of the situation.

As system complexity increases towards the complex/chaotic end of the dimension, or towards flexible and chaotic state systems, the decision-making approach of managers needs to evolve. A reductionist approach based upon linking causes or strategies with clear outcomes becomes less appropriate when the issues are far less clear and constantly changing. Nonlinear cause and effect relationships and greater unpredictability and emergence make the situation unsuitable to this type of decision-making. In particular, the ability to find the best result for a given option decreases, but the appropriateness of finding a good enough approach via satisficing increases. When a system is simple or complicated, it is cost-effective and efficient to manage it using optimization. In this case it is feasible to list out the various options available, rank them all and choose the best option. When the system is becoming complex it is impossible to optimize [16]. As previously stated, there are several typologies of system of systems, and one of these is the typology of four main groups: assembly system, traditional system, system of systems and chaotic state, as presented in Figure 1 below.

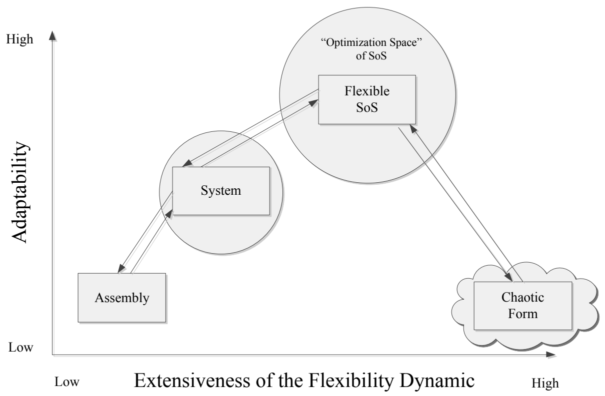

Fig. 1. A typology of systems. Adopted from Gorod, et al. [12]

According to Mansouri, et al. [17], different types of systems can be explained as follows:

- **An Assembly** is defined as "a collection of components and modules in one unit, performing a single function" [18]. Examples would be electronic devices such as cell phones and laptops [19]. This type of system or activity belongs to the domain of 'known knowns'. VanBeurden, et al. [15] described the simple domain as "…one in which cause and effect relationships are mostly linear, empirical and agreed upon". This level is also called deterministic since the variables and the way they interact among each other are known and observable. This evidence-based 'best practice' approach is widely accepted and has predictable outcomes. In this kind of domain or system, top-down management is the most appropriate management style [20]. In this kind of domain or system, top-down management is the most appropriate management style [20].

- **A Traditional System (complicated system)** is defined by the IEEE Standard 1220, as a "… set or arrangement of elements [people, products (hardware and software)] and processes (facilities, equipment, material and procedures) that are related, and whose behavior satisfies operational needs and provides for the life cycle sustainment of the products" [21]. Examples of such systems would be an airplane or an automobile [19].

- **A System of Systems (SoS)** is a more complex type of system whose flexibility dynamic lies more towards independence. These types of systems are network centric and evolve around decentralization. If a system is simple/complicated, there are linear dependencies between components and optimization is possible. However constituents of systems of systems are autonomous and heterogeneous, and optimization is not possible: relationships between constituents are often nonlinear, and causality is only recognizable in hindsight. One of the most important characteristic of a SoS is that it should be governable [22]. In cases of excessive system flexibility, systems tend to become chaotic. As Snowden [23] asserted of complex systems (SoS); "…the components and their interactions are changing and can never be quite pinned down. The system is irreducible". The complex domain evokes emergent properties necessary for innovation and global competiveness. Managers need to use methods to encourage emergent patterns to be revealed through engagement with a wide variety of participants. A highly collaborative approach with a diverse group of participants will produce the most useful outcomes. Examples would include mergers/acquisitions and many other contemporary business situations.

- **A Chaotic State** refers to a state in which flexibility is excessive to such an extent that it leads to a loss of governance. This will be followed by a serious decline in adaptability because the system is too dynamic, there are too many options, things change too fast, and the boundary is not clearly definable.

III. OPTIMIZATION

Optimization is a familiar concept across a number of domains. This approach is a very successful one for certain situations. Byron [24] described optimizing as implementing the best means towards the desired result, and following the steps of itemizing all available options, assessing each one and then selecting the best. Gonnering [25] commented that 'best practice' is appropriate only for simple situations. However optimization has its limitations. Thus Blustein [26] investigated optimization within the domain of parenting and argued that optimization (acting in the best interest of the child) could lead parents to be placed under a great deal of stress and limit their activities in other areas which would be of benefit to the wider society.

The reductionist viewpoint rests well with the idea of best practices and compliance with these. However within dynamic environments, optimizing to achieve best practice may not be a feasible approach. In this and the following section, the relationship between optimizing and two approaches towards leadership; top-down management and governance is examined. The term 'governance' refers to an influencing network which has high adaptability, a free flow of information between participants, and a high level of involvement of stakeholders in decision-making. This approach is entirely different from top-down management which focuses on commanding and controlling the system. The relationship between optimizing, system complexity and management and governance is demonstrated in Figure 2.

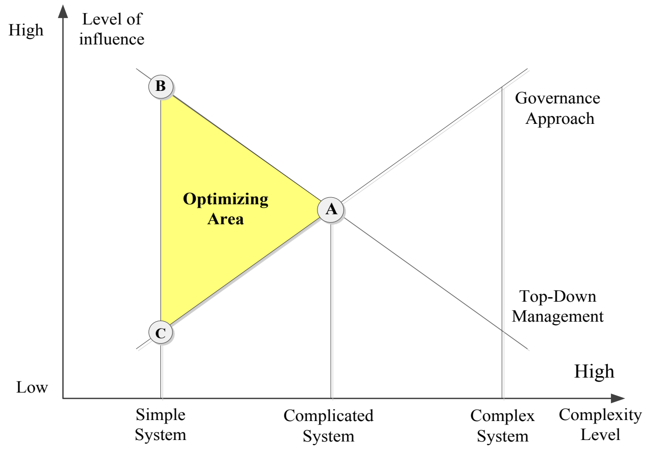

Fig. 2. The relationship between the optimizing area and system complexity level.

At the intersection point B in Figure 2, it is clear that top-down management is the most appropriate for simple systems (assemblies) since this management type has a strong influence on the effectiveness of the system. Simple systems have features of fixed scope, hierarchical structure and a strong controlling ability [27]. Thus simple systems can be broken down by dividing the main tasks into smaller components for implementation. In addition, the interactions among key stakeholders of simple systems are based on a hierarchical structure [17] from senior managers through to their subordinates at the middle and the lowest management levels. Managers leverage on their power in transferring their commands to followers, as well as being able to control risks related to time, cost and quality. A number of tools and techniques have been developed to support managers to operate simple systems such as configuration management tool, problem tracking tool and workgroup collaboration tool [28]. As a result, the traditional top-down management approach has great advantages when applied to simple systems [29]. On the other hand, a governance approach based on a network structure can provide indirect influences on a system through its regulations and policies. The governance approach is dynamic, adaptive, and can react rapidly and flexibly to changes in the environment [30], but this soft approach is not as efficient with assemblies because their scope is clearly defined and requires specific guidelines from managers; for example, detailed requirements for system operation regarding time, cost and quality.

In Figure 2, at the intersection point (A) between the top-down management curve and the governance curve, the influence level of top-down management is equal with that of governance, which means that both top-down management and governance can be applied in combination. This is the situation with complicated systems (traditional systems); their performance is optimized by using a combination of the top-down management style and the governance approach, because a complicated system consists of a number of simple systems. The interaction among components of complicated systems is varied due to changes coming from both the internal and external environments and this can lead to uncertainty factors arising during operating stages. Thus, while the top-down management style is used to manage simple tasks, a governance approach is useful in developing regulations and policies that can create soft influence on the operating processes of a complicated system, and both of these approaches can be undertaken at the same time.

The optimizing area concept is beneficial when considering the management area (ABC), as depicted in figure 2 where it is possible to seek the best and optimal solution for operating a simple system. This area is bounded by the intersection points between the top-down management line, the governance curve and a vertical line used to determine the complexity level of a system. In Figure 2, the less complex the system, the larger is the optimizing area and this area becomes smaller as the system becomes more complex. The combination of specific levels of top-down management and governance will depend upon the perception of the manager regarding the complexity level of a system. One way to assess the complexity level would be to use the five complexity characteristics of Gorod, et al. [12] (autonomy and dependence, belonging, connectivity, diversity and emergence), before selecting the appropriate features of management for a particular system.

IV. SATISFICING

Optimization is a very efficient decision-making method; it produces the best result considering all of the options, it is risk-averse and relatively easy to apply. However in certain types of complex situations there is no way to identify all of the available options due to rapid changes in the environment. Simon [31] presented a choice mechanism which allows us to identify a 'satisficing' path that permits satisfaction at a specified level of all needs. Simon [2] first described satisficing due to constraints as the 'good enough' approach which involves deciding upon a benchmark, beyond which any option will be assessed as being good enough. The decision-maker thus assesses available options until they find the first one which is good enough in the context of the benchmark. This idea has been taken up in many different contexts. Thus Blustein [26] described the satisficing approach towards childrearing as being the 'good enough' approach. Satisficing parenting is described thus; "….parents do not have an obligation to do what is best, but what is good enough…." [26].

This approach is much more suitable to a complex dynamic environment where optimization or seeking out the one best result cannot be achieved, as shown in Figure 3 below. There is no way to identify all of the available options as in optimization.

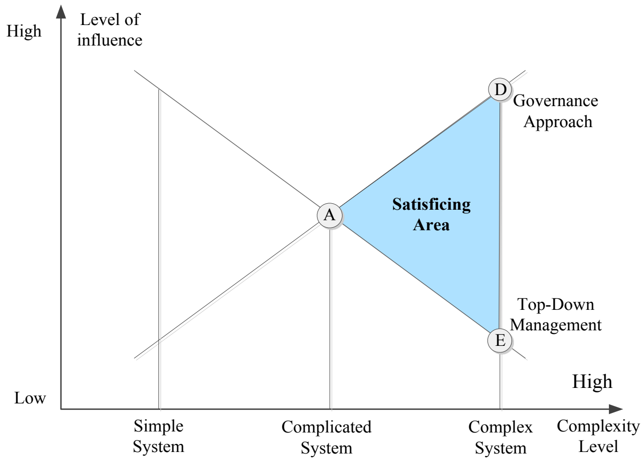

Fig. 3. The relationship between the satisficing area and system complexity level.

Given rapid changes in the external environment including technology, information systems, the increasing involvement of the human factor and globalization trends, systems are becoming more complex and the process of managing them needs to evolve from hierarchical to network-centric [17]. Figure 3 shows that the influence power of governance increases as complexity increases. The increasing levels of independence/autonomy signify the challenge of predicting the system scope. A complex system (SoS) includes a number of constituent systems which can work independently, but these systems still share the same mission [32]. There are numerous components in the main system and the interaction among these components does not follow any given rules. In other words, it seems impossible to identify the specific requirements used for system operation. In this circumstance, a top-down management approach is less efficient because this method of guidance focuses strongly on the details of the system and is inflexible in its implementation [33]. On the other hand, governance is appropriate in complex systems because it allows managers to create soft influence on the whole system through policy. Instead of concentrating on small parts or details and controlling these, governance tends to direct the whole system to ensure that it is flexible and can adapt to changes from the external environment [30] and to minimize negative impacts from systemic risks.

In Figure 3, the satisficing area is bounded by the management area (ADE) where it is possible to look for a 'good enough' option for system operation. The 'satisficing area' concept is a successful method for managing complex systems. Because these systems contain a number of uncertainties and numerous potential risks arising from the external environment, it is impossible to seek best solutions for system operation. The fundamental method of the satisficing approach is the use of governance to establish alternative options for complex system in particular contexts. Based on each option, benchmarks are established by the governing body to provide evaluating criteria for senior managers to make satisficing decisions. Depending on the complexity level of the system and the availability of resources, managers can select advanced features of governance to support their decision-making processes. The differences between optimization and satisficing are shown in Table 1 below.

V. OPTIMISATION AND SATISFICING

Although several researchers have considered the management features of the optimizing and satisficing approaches, there has been limited research in identifying the differences between these two approaches. Based on system considerations, Table I below presents some significant differences in the operation of optimization and satisficing.

TABLE I. OPTIMIZATION VS. SATISFICING

System considerations	Optimization	Satisficing
Point of view	Discrete and particular	Holistic [16]
Causality	Clear cause and effect	No clear causality
System constraints	Dependent variables	Both dependent and independent variables
Management styles	Top-down management approach [34]	Governance approach
Time frame	System life cycle [27]	Continuous [27]
Tools and techniques	Reductionism-based [28]	• Systems thinking based tools; • System modelling such as System dynamics (SD) and Agent-based modelling (ABM); • Others.
Stakeholders	Identifiable	Emergent
Solution options	Options known [24]	Options unknown unknowns.
Risk assessment	Traditional risk management	Systemic risk management [35]
Interaction	Linear	Non-linear
Output	'Best' solution [24]	'Good enough' option [16]
Structure	Hierarchical structure [17]	Network structure [17]
Approach	Process [27]	Methodology [27]
Decision-making	Top Down	Bottom Up

Thus, based on the differences between system dimensions of optimization and satisficing in particular contexts, managers can decide to select main dimensions to either find solutions which are the 'best option' or a 'good enough' option and then set up benchmarks used to evaluate options as they come.

In simple/complicated contexts, the system processes of optimization are depicted in Figure 4.

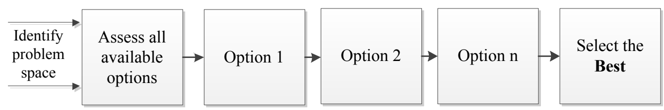

Fig. 4. Typical example of system optimization process

As Figure 4 illustrates, engineering managers can use an assessment process to consider all options in the problem space and select the best option to optimize system performance. This is a linear process. However, when systems are complex, the interaction processes between system stages are varied and continuous. Managers may face difficulties in assessing all available options, so a satisficing methodology can be used to deal with complex system decision-making as depicted in Figure 5.

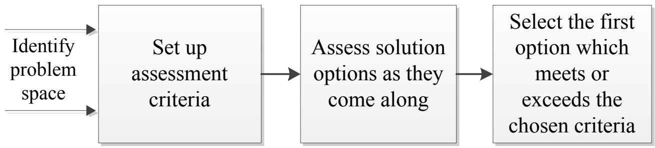

Fig. 5. System satisficing methodology.

As shown in Figure 5, based upon predefined assessment criteria such as quality, cost, time and risks, managers can set up assessment criteria to define a 'good enough' benchmark value which is used to select a solution option for the system. The first option which meets or exceeds the benchmark is selected and the outcome will be "good enough." Engineering managers can use features of the governance approach including policy, regulations and guidelines to create soft influence on the complex system, in order to adapt to changes arising from external environment.

VI. CONCLUSION

This paper has demonstrated the difference between optimizing and satisficing as decision-making methods and provided a comparative analysis. Historically, SE has tended to use the optimization approach as the primary method of decision-making. Recently, the satisficing approach has been introduced; but there is still concern about how systems engineers can make the choice between optimizing and satisficing under different circumstances. This paper proposes a methodology whereby decision-makers can select between optimizing and satisficing, in response to differing levels of complexity. It is intended that this method will increase SE's effectiveness in dealing with all types of systems. As part of future research, the authors are planning to create a decision-making index which will further assist decision-makers in the selection of optimizing and/or satisficing.

REFERENCES

[1] H. Simon, "Decision Making: Rational, Nonrational, and Irrational," *Educational Administration Quarterly,* vol. 29, no. 3, pp. 392-411, August 1, 1993 1993.

[2] H. Simon, "Rational choice and the structure of the environment," *The Psychological Review,* vol. 63, no. 2, pp. 129-138, 1956.

[3] M. Maldonato, "Undecidable Decisions: Rationality Limits and Decision-making Heuristics," *World Futures,* vol. 63, no. 1, pp. 28-37, 2007/01/01 2007.

[4] P. Cady, "A system of system lenses for leadership decision-making," *Healthcare Management Forum,* vol. 29, no. 1, pp. 8-11, January 1, 2016 2016.

[5] T. Grant, "Towards mixed rational-naturalistic decision support for command-and-control," in *International community on information systems for crisis response and management*, J. S. Landgren J, Ed. Goteborg, Sweden: The Netherlands Defense Academy, 2009.

[6] N. Keller, E. T. Cokely, K. V. Katsikopoulos, and O. Wegwarth, "Naturalistic heuristics for decision making," *Journal of Cognitive Engineering and Decision Making,* vol. 4, no. 3, pp. 256-274, 2010.

[7] W. B. Arthur, "Why do things become more complex," *Scientific American,* vol. 268, no. 5, p. 144, 1993.

[8] L. v. Bertalanffy, "Untersuchungen über die Gesetzlichkeit des Wachstums. I Allgemeine Grundlagen der Theorie, mathematische und physiologische Gesetzlichkeiten des Wachstums bei Wassertieren. Roux'Archiv für Entwicklungsmechanik 131, 613-652," *The relationships between gill surface area and growth performance in fish,* vol. 279, 1934.

[9] K. E. Boulding, "General systems theory-the skeleton of science," *Management science,* vol. 2, no. 3, pp. 197-208, 1956.

[10] M. C. Jackson and P. Keys, "Towards a system of systems methodologies," *Journal of the operational research society,* vol. 35, no. 6, pp. 473-486, 1984.

[11] R. L. Ackoff, "Towards a system of systems concepts," *Management science,* vol. 17, no. 11, pp. 661-671, 1971.

[12] A. Gorod, S. J. Gandhi, B. Sauser, and J. Boardman, "Flexibility of system of systems," *Global Journal of Flexible Systems Management,* vol. 9, no. 4, p. 21, 2008.

[13] J. Bakhshi, V. Ireland, and A. Gorod, "Clarifying the project complexity construct: Past, present and future," *International Journal of Project Management,* vol. 34, no. 7, pp. 1199-1213, 2016.

[14] D. J. Snowden and M. E. Boone, "A leader's framework for decision making," *Harvard Business Review,* vol. 85, no. 11, p. 68, 2007.

[15] E. K. VanBeurden, A. M. Kia, A. Zask, U. Dietrich, and L. Rose, "Making sense in a complex landscape: how the Cynefin Framework from Complex Adaptive Systems Theory can inform health promotion practice," *Health Promotion International,* p. 89, 2011.

[16] A. Gorod, M. DiMario, B. Sauser, and J. Boardman, "'Satisficing'system of systems using dynamic and static doctrines," *International Journal of System of Systems Engineering,* vol. 1, no. 3, pp. 347-366, 2009.

[17] M. Mansouri, A. Gorod, and B. Sauser, "A typology-based approach to adopting effective management styles for enterprise systems," in *Systems Conference, 2010 4th Annual IEEE*, 2010, pp. 300-305: IEEE.

[18] M. Jamshidi, "System of systems engineering-New challenges for the 21st century," *IEEE Aerospace and Electronic Systems Magazine,* vol. 23, no. 5, pp. 4-19, 2008.

[19] B. Sauser, "Toward mission assurance: a framework for systems engineering management," *Systems Engineering,* vol. 9, no. 3, pp. 213-227, 2006.

[20] V. Ireland, A. Gorod, B. White, S. Gandhi, and B. Sauser, "A contribution to developing a complex project management BOK," *The Project Management Association,* 2013.

[21] IEEE, *Standard for Application and Management of the Systems Engineering Process*. IEEE, 2005.

[22] B. Sauser, J. Boardman, and A. Gorod, M. Jamshidi, Ed. *SoS Management, in System of System Engineering - Innovations for the 21st Century*. Hoboken, NJ.: Wiley & Sons, 2008.

[23] D. Snowden, "Complex acts of knowing: paradox and descriptive self-awareness," *Journal of Knowledge Management,* vol. 6, no. 2, pp. 100-111, 2002.

[24] M. Byron, "Satisficing and Optimality*," *Ethics,* vol. 109, no. 1, pp. 67-93, 1998.

[25] R. S. Gonnering, "The Seductive Allure of 'Best Practices': Improved Outcome is a Delicate Dance between Structure and Process," *Available at SSRN 1753308,* 2010.

[26] J. Blustein, "Doing the best for one's child: satisficing versus optimizing parentalism," *Theoretical Medicine and Bioethics,* vol. 33, no. 3, pp. 199-205, 2012.

[27] A. Gorod, B. Sauser, and J. Boardman, "System-of-systems engineering management: A review of modern history and a path forward," *IEEE Systems Journal,* vol. 2, no. 4, pp. 484-499, 2008.

[28] INCOSE. (2000, 1 September). *INCOSE Tools Database* Available: https://oldsite.incose.org/ProductsPubs/products/SEtools/

[29] I. Nonaka, "Toward middle-up-down management: accelerating information creation," *Sloan Management Review,* vol. 29, no. 3, pp. 9-18, 1988.

[30] M. Mansouri, A. Gorod, B. Sauser, and S. J. Gandhi, "A Systemic Approach to Adopting Effective Management Styles Based on Typology of Systems," presented at the 30th Annual American Society of Engineering Management Conference, October 14-17, 2009.

[31] H. A. Simon, "Rational choice and the structure of the environment," *Psychological review,* vol. 63, no. 2, p. 129, 1956.

[32] H. Eisner, J. Marciniak, and R. McMillan, "Computer-aided system of systems (S2) engineering," in *Systems, Man, and Cybernetics, 1991.'Decision Aiding for Complex Systems,*

Conference Proceedings., 1991 IEEE International Conference on, 1991, pp. 531-537: IEEE.

[33] T. Pearce and J. Fortune, "Command and control in policing: A systems assessment of the gold, silver and bronze structure," *Journal of Contingencies and Crisis Management,* vol. 3, no. 3, pp. 181-187, 1995.

[34] G. A. Yukl, *Leadership in organizations*, 7th ed. New Jersey: Pearson education, 2010.

[35] S. J. Gandhi, A. Gorod, and B. Sauser, "A systemic approach to managing risks of SoS," *IEEE Aerospace and Electronic Systems Magazine,* vol. 27, no. 5, pp. 23-27, 2012.