

# The Voice of the Systems

The Journal Of The Israeli Systems Engineers

ISSUE NO.25 | January 2020

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INCOSE\_IL - THE ISRAELI SOCIETY FOR SYSTEMS ENGINEERING

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# The Voice of the Editor

Amir Tomer

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## Dear Readers,

ILTAM, our hosting organization, terminated its activity and from now on the Israeli Society for Systems Engineering, INCOSE\_IL, operates as an independent live and kicking organization. We all thank Moshe Salem for his most valuable contribution to INCOSE\_IL during the last two decades. As you can see, The Voice of the Systems not only continues to be published as usual, but we plan to expand it from a biannual journal to a kind of internet “blog”, in which everybody could take active parts as readers and writers (see frame below). The voice of the president – Dr. Ram Oron – explains the forthcoming changes.

This issue too is packed with materials: an article by Dr. John Gill and Dr. Avigdor Zonnenshain and an article by Sergey Tozik – both about Socio-Technical systems. An article by Alon Ben Moshe about design complexity and an article by Gadi Kravitz about analogic inference in systems engineering. It also contain reports from 3 major events: INCOSE-IS, the first HSI conference and the last Gordon Center seminar day.

I wish you pleasant reading.



**Prof. Amir Tomer, CSEP**

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The Editor

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# The Voice of INCOSE\_IL President

Ram Oron



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Dear Systems Engineering Community,

A new year is a new beginning. Starting in 2020, INCOSE-IL operates in a different format: Until 2019, we operated as a professional organization as part of ILTAM. Now we operate as an independent non-profit organization, based on ILTAM's infrastructure. This change was carried out in close cooperation with ILTAM's management, in light of our shared goal advancing the field of systems engineering in Israel.

I would like to take this opportunity and thank Moshe Salem, CEO of ILTAM, who has greatly contributed to advancing Israeli systems engineering, as well as the knowledge sharing among industries and between academia and industry. Moshe has many rights in the devolvement of systems engineering in Israel over the last two decades. Moshe led the way in holding many events and activities, such as conferences, meetings and seminars, and served as the living spirit behind them. Moshe's personal contribution and his cooperation with INCOSE-IL presidents along the years are significant factors in reaching a strong and vibrant systems engineering community that enables us being in the forefront of systems developments. On a personal level, I learned a lot from Moshe, I enjoyed it working closely with him, and I am sure that we will keep these relationships. Upon retiring from the position, I wholeheartedly wish Moshe all the best.

In addition, I would like to thank the members of the ILTAM presidency, led by INCOSE-IL past president Haim Richman, for their full support for INCOSE-IL continued activity and for supporting me as the leader of this activity. The ILTAM presidency has made sure to transfer a stable infrastructure that allows INCOSE-IL to smoothly continue operations. We have also received the blessing of the Technological Infrastructure Division in the Israeli Innovation Authority, and we are grateful for that.

INCOSE-IL new leadership consists of strong and diverse group of professionals. This group includes leading systems engineers from a variety of industries and from academia, together with active members who are passionate about systems engineering.

Our 2020 work plan consists of dozens of activity days, including afternoon sessions, interest groups, work groups, seminars, and courses. Technical domains shall focus on systems engineering and software-intensive systems. The program can be viewed on our new website [www.incoseil.org](http://www.incoseil.org). Of course, we shall continue serving as the Israeli chapter of INCOSE and we will maintain our ties with the academy and the professional organizations with whom we cooperate. We will also continue performing volunteering activities for the community and shall outline a strategic plan for INCOSE-IL for the years to come.

I urge you to support the INCOSE-IL by retaining and expanding membership, participating in activities, providing feedback that will allow us to improve our operations, and initiate additional activities.

Wishing us all a successful and fruitful year.



Sincerely,  
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President, INCOSE IL  
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# Opportunities and Challenges of Sociotechnical Systems Engineering

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The term Sociotechnical Systems was coined by Eric Trist, Ken Bamforth and Fred Emery in the 1950's and was based on their work with English coal miners at the Tavistock Institute in London. Originally, Sociotechnical systems in organizational development recognized the interactions between workers and (then current) technology in their workplace (extracted from Wikipedia, Oct 2019). In the intervening decades, the term has expanded to cover the social aspects of people and society in addition to the technical aspects of structure and process; i.e., the interrelatedness of social and technical aspects of systems deployed in society. In this current definition, humans are considered to be an integral part of the system as are hardware and software configuration items. In this modern construct, humans influence and are influenced by the performance of the physical systems we deploy. The intent of this paper is to clearly distinguish the unique elements of what constitutes Sociotechnical Systems Engineering (STSE) and a framework to integrate those elements. The proposed framework will then serve as the foundation for further discussion related to the opportunities and challenges associated with this evolving perspective on Systems Engineering (SE). The authors conclude that Systems Engineering in terms of its framework, practice and processes remain essentially intact. Furthermore, the application of a sociotechnical framework may unlock the potential for significantly greater improvements in our quality of life as well as the potential for lessening waste, inefficiency and undesirable emergent behaviors. It is also apparent that the outcomes we experience do not lie in our definition of Systems Engineering or Sociotechnical Systems Engineering as much as they may lie in our deeper motivations for doing either.

By most common definitions, a framework is the basic structure underlying a system or concept. Frameworks by their nature are intended to highlight unique and essential elements of a concept shedding light on how they are intended to connect and interact with one another – much like a Concept of Operations. In the interest of differentiating Systems Engineering from STSE, the authors offer the following as the basic elements of an SE framework; Requirements Derivation, Resources Management, Decision Making and the Application of Technical Knowledge in the pursuit of delivering a Working System; in short, the engineering of systems. This framework typically has many other characteristics and attributes associated with it, however, the essential elements that define the framework are few and vital. Absent any of the basic elements, effective Systems Engineering is not present. Figure 1 depicts the essential elements of traditional Systems Engineering in the context of many other attributes that are notionally associated with it, but not considered essential by the authors.

**Figure 1.** SE Framework Elements, Associated Characteristics and Attributes.



It is both interesting and relevant to briefly review how this SE framework has evolved over time as it provides insight into if and how the framework might evolve in response to Sociotechnical considerations.

We now find ourselves in what some refer to as the 4<sup>th</sup> Industrial Revolution (IR); The Internet of Things. This terminology is intended to differentiate our current epoch in technology application from former such epochs; the Rise of Computer Processing Systems (3<sup>rd</sup> IR), Integrated Systems (2<sup>nd</sup> IR), and the original Industrial Revolution (1<sup>st</sup> IR). These are important distinctions as both the challenges and opportunities associated with Systems Engineering are distinctly different for each epoch. Each epoch has, in turn, influenced the practice of and processes associated with effective Systems Engineering. Table 1 provides high level themes typically associated with each IR.

1 <sup>st</sup> IR; Mechanical Advantage	Human Force Multipliers
2 <sup>nd</sup> IR; Large and Interacting Systems	Commodities, Transportation, Utilities
3 <sup>rd</sup> IR; Ubiquitous Computing	Parallel Processing and Networking
4 <sup>th</sup> IR; Sociotechnical Engineering	Interactive/Data-Driven Infrastructure

A perspective offered by the authors is that the accomplishments of a given IR sets the foundation for the capabilities available in the next one. To wit, the 1<sup>st</sup> IR gave us the mechanical capability to tackle large systems of national importance. The 2<sup>nd</sup> IR established an integrated infrastructure that benefitted national interests and, indirectly, personal interests. The 3<sup>rd</sup> IR realized the benefits associated with the harnessing (collection and integration) of information and the 4<sup>th</sup> is associated with the ongoing development of information intensive applications that enable very powerful capabilities in terms of potential benefit or harm to the general public that interacts with what are now called Sociotechnical Systems. We (the authors) very broadly consider that the 1<sup>st</sup> IR delivered capabilities that increased the capacity of individual workers to be more productive. Subsequent IRs have enabled increasing integration of capabilities and, more precisely, horizontal integration of these capabilities in a way that large technical teams could collaborate in more meaningful ways to deliver new capabilities. The current 4<sup>th</sup> IR offers the promise and potential of enabling the broadest user base to participate in information centric applications with the intent of giving users insight and analytic capabilities previously available to only a few.

Which brings us to the definition of a Sociotechnical System. A Sociotechnical System is a system which is uniquely characterized by interactions between society’s complex infrastructure and human behavior itself. This distinction is seminal in our discussion about a framework because it acknowl-

edges a dramatic shift regarding how systems may be developed, by whom and for whom. The 4<sup>th</sup> IR delivers the power of information directly to anyone (technically schooled or not) who has an interest in developing an application that utilizes said information for that application's intrinsic purpose. In short, the 4<sup>th</sup> IR presents a great opportunity for the advancement of system capabilities by leveraging the power of information versus the application of a specific technology. And the capabilities inherent in Sociotechnical Systems may not reside solely with a Systems Engineer or formal design authority, but rather with individuals and organizations motivated by business models that value information over the direct consumption of physical resources to achieve the desired capability. A key tenet of Sociotechnical Systems is that information has become the most vital resource as opposed to the traditional resources typically consumed in the delivery of new capabilities.

Many suggested framework's exist today that attempt to accommodate the perceived complexities associated with Sociotechnical Systems Engineering. It is appropriate to provide a brief summary of the key aspects of these frameworks to set the foundation for comparison between them and the authors' proposed framework. The following section outlines only several of the many frameworks available which were selected by the authors (Gill and Zonnenshain) for their diversity.

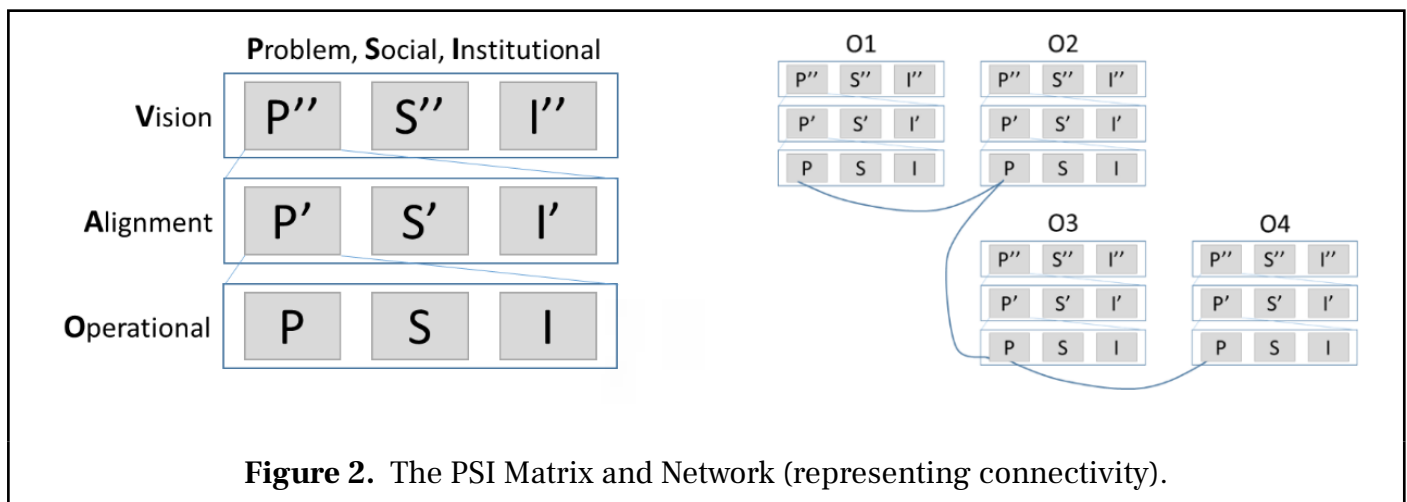
**DesignX:** Complex Sociotechnical Systems (Norman and Stappers, March 2016) promotes the idea that resolving a technical issue is not as difficult as implementing the solution because implementation is often challenged by changing conditions, political, social and cultural disruptions, economic and schedule turbulence, etc. A "DesignX" problem is beyond mere technical challenge and ventures into complex societal systems, such as transportation and health care. Delivering DesignX capabilities requires "tolerance" and offers the interesting perspective that success comes from satisficing versus optimization using an approach called "muddling through", a form of incrementalism championed by Lindblom (c. 1950). The DesignX authors promote a framework that is organized into three thrusts as follows;

<p><b>The Psychology of Human Behavior and Cognition</b></p> <p>System Design that Does Not Take into Account Human Psychology and Human Cognition: The Human Tendency to Want Simple Answers, Decomposable Systems and Straightforward Linear Causality</p>
<p><b>The Social, Political and Economic Framework of Complex Sociotechnical Systems</b></p> <p>Multiple Disciplines and Perspectives, Mutually Incompatible Constraints</p>
<p><b>The Technical Issues that Contribute to Complexity of DesignX Problems</b></p> <p>Non-Independence of Elements, Non-Linear Causal Relationships: Feedback. Long and Unpredictable Latencies, Multiple Scale Sizes and Dynamically Changing Operating Characteristics</p>

(Authors' note; The Framework above depicts three areas of primary interest, the framework elements, with a summary of the challenges that led to the element description as subtext; the challenges the framework is intended to address.)

The DesignX authors acknowledge that "design and implementation are not only the remit of designers, but will involve a creative collaboration between a variety of actors and stakeholders."

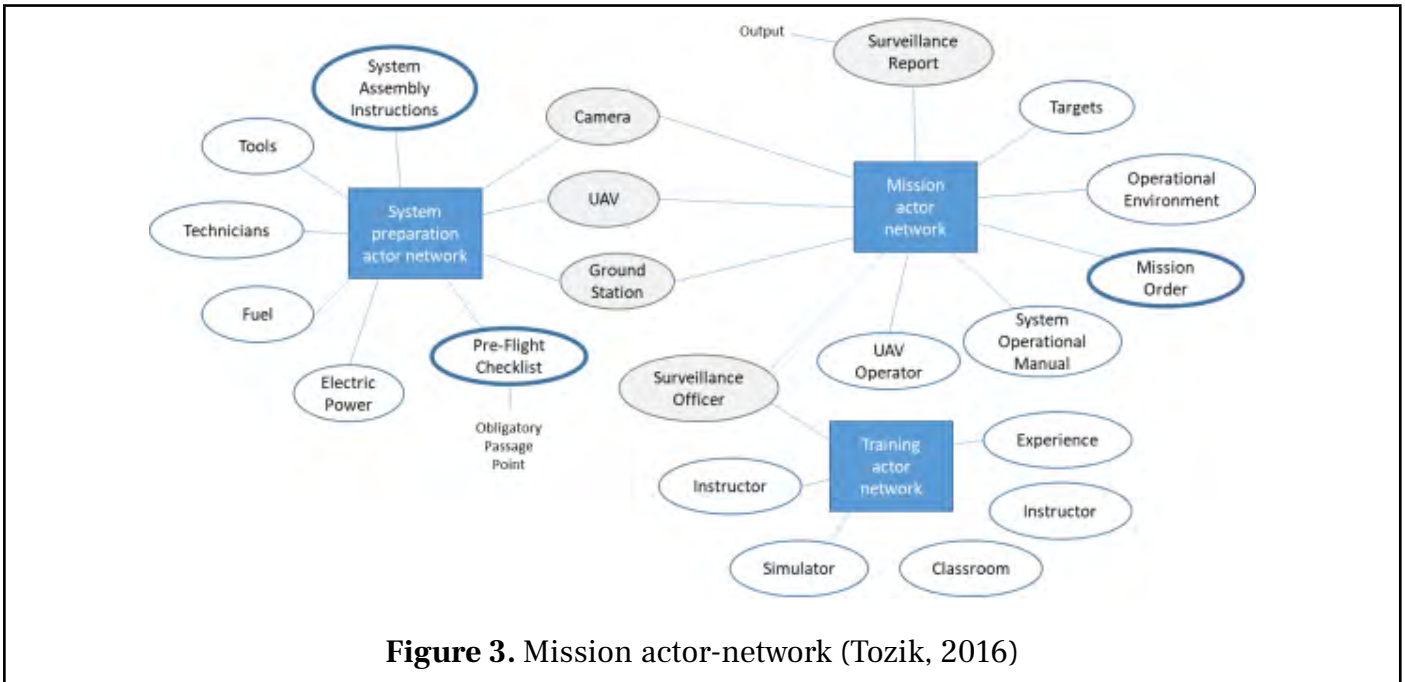
In The PSI Network Model for Studying Complex Design Scenarios (Reich and Subrahmanian, 2019) offers a recursive pattern to suggest a framework for studying complex (Sociotechnical) challenges. The basic pattern element is a PSI matrix (Figure 2) which posits the Problem, Social and Institutional challenges (PSI) in layers that reflect the Vision, Alignment and Operational focus of the individuals who must cooperate to realize the solution. The PSI matrix is subsequently extended in a network construct to accommodate larger challenges typically associated with System of Systems class initiatives. This attribute of the PSI approach is also depicted in Figure 2. Reich and Subrahmanian present several case studies to expose the potential utility of their framework, which demonstrate that “alignment” of the elements within the matrix can be correlated with project success. In short, a pervasive vision and common goals across teams that are populated with good communicators in key positions are essential elements of a successful project. The PSI matrix and network models offer the potential to plan for and/or monitor the health of a program using these indicators.



In A Subjective Toolbox for Sociotechnical Systems (Devaney, July 2019), the author proposes the integration of traditional objective perspectives with subjective perspectives as a means of promoting more human-centric systems engineering. The toolbox elements are Heuristics, Design Emphasis, Beauty, Empathy, Culture, Storytelling and Judgment. The author notes that the subjectivity associated with the elements he proposes has led to their suppression in strict (objective, data-driven) engineering approaches, yet, they appear to be essential elements in successfully coping with the types of challenges and opportunities being presented today as sociotechnical issues. Devaney also suggests that the perspectives provided are potentially most useful in the early stages of engineering (Architecture and Requirements Development) and the later stage of Validation, an interesting restatement of the finding that subjective techniques have been largely removed from the central process of engineering.

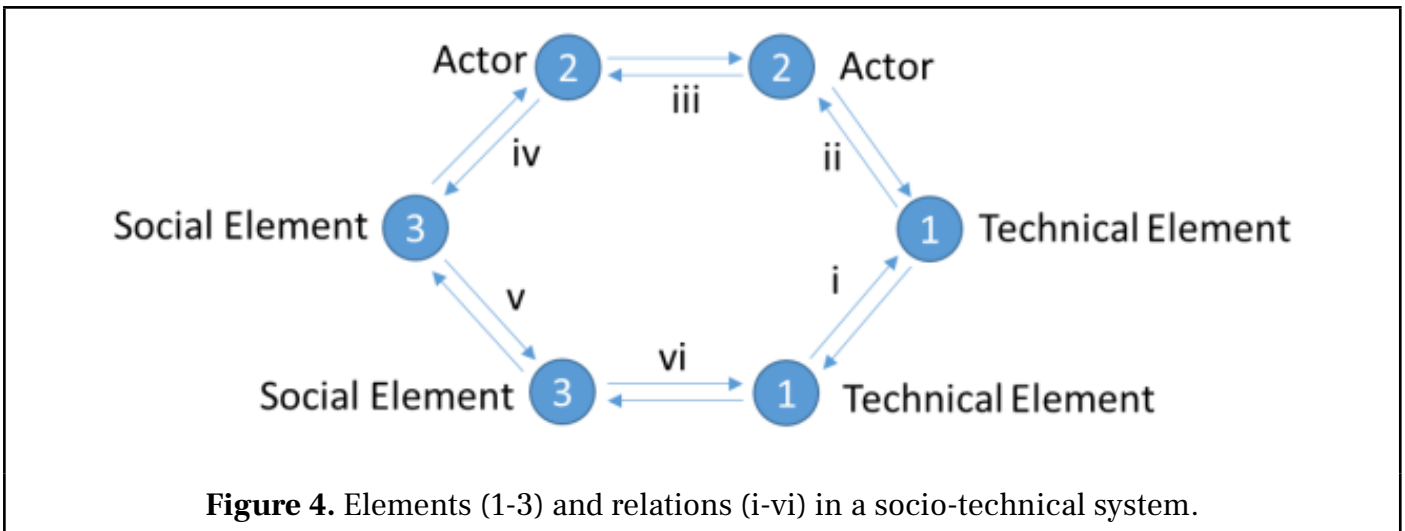
In Actor-Networks and Boundary Actors in Capability Integration Theory (Tozik, July 2016) the author presents a unified framework for the analysis of capability integration, maintenance and utilization as a construct of temporary actor-networks that integrate human and non-human actors; people, information, places, information, etc. The author asserts that through the enactment of temporary actor-networks, accumulated experience and decisions are carried through the development process and system usage as individuals, physical objects, documents and their basic associations evolve from one scenario to

the next. ANT describes technical products and social processes as the byproducts of heterogeneous networks of collaborating actors in an on-going, evolutionary process. Tozick asserts in his conclusion that capabilities typically emerge as a byproduct of traditional systems engineering processes, but that the Actor-Network Theory (ANT) is suitable for capability creation. Tozick recognizes that the proposed theory must be subjected to further scrutiny and rigorous testing before being further advanced as a workable approach to developing sociotechnical capabilities. Figure 3 depicts a Mission actor-network.



**Figure 3.** Mission actor-network (Tozick, 2016)

In Modelling Infrastructures as Socio-Technical Systems (Ottens, Franssen, Kroes and van de Poel, circa 2006), the authors clarify the distinction between System and Sociotechnical Engineering. Namely, that the concept of a system (IEEE Std. 1220-1998) accounts for humans as fulfilling subfunctions within the system. Humans relate with the systems at the man-machine interface. The IEEE standard ignores, or at least marginalizes, the social dimension of human involvement with the system. Intimate involvement by humans in sociotechnical systems is currently considered to be a key distinction of said systems. Ottens, et. al. (like Tozick) propose that sociotechnical systems can be represented and modelled using a framework that consists of Actors, Technical Elements and Social Elements as depicted in Figure 4.



**Figure 4.** Elements (1-3) and relations (i-vi) in a socio-technical system.

The relations depicted above can be characterized as physical, functional, intentional or normative. As noted in their conclusion, the inclusion of social elements, in both number and variety, increases the possible states of a system dramatically and often unpredictably.

In *Sociotechnical Systems Theory in the 21st Century: Another Half-Filled Glass?* (Eason, 2008), the author questions whether sociotechnical systems theory is still even relevant. He traces the origins of sociotechnical systems theory from its roots as an organizational theory applied to manufacturing jobs 50 years earlier through its current evolution as a means to characterize complex interactions between humans and (primarily) information and communications technology. He asserts that the theory has enduring relevance as it provides a way for us to understand the complex way in which people at work cooperate and use tools and technology to get their collective work done. Eason notes two aspects in particular regarding sociotechnical systems. The first being that changing one part of the system may improve its local performance but lead to dysfunction in another element or broadly throughout the system. The second being that the system is open by its nature, subject to changes in its environment and the quality and type of input it receives while delivering capabilities. He concludes by stating that the successful sociotechnical implementations will adapt over time and be flexible enough to allow users to obtain their desired capabilities, sometimes in ways not originally intended by design. Sociotechnical designers should seek to design subsystems holistically so as to achieve an integrated capability and be prepared to evolve them over time. Interestingly, he asserts that it is most common for sociotechnical system users to seek coping methods to deal with the stress of tight deadlines, rapid change and new demands, wherein they use available systems selectively in ways that allow them to overcome their challenges with work arounds. Typically, sociotechnical systems are implemented to deliver intended capabilities, but the truth of the implementation becomes visible over time as the new capability reveals new problems and opportunities.

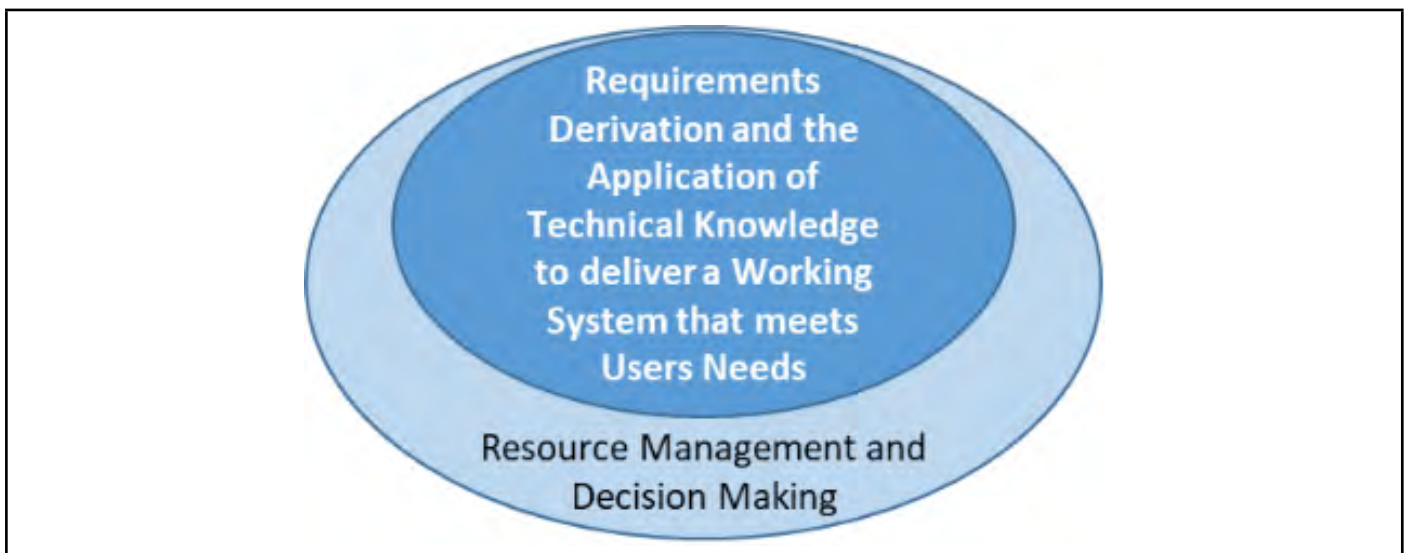
For those interested in learning more about sociotechnical systems, several resources provide thoughtful compilations of Sociotechnical Engineering foundational thinking. Notably; *Socio-Technical Systems: Transforming Theory into Practice* (Ngowi and Mvungi, March 2018), *Socio-Technical Systems: From Design Methods to Systems Engineering* (Baxter and Sommerville, August 2010) and *Managing and Engineering Complex Technological Systems* (Zonnenshain and Stauber, 2015).

Gill and Zonnenshain kept the following at the forefront of consideration while formulating the framework proposed in this paper; reduce the construct to its essential elements in the quest to expose the most basic principle(s) of Sociotechnical Systems Engineering, clearly expose what is new and/or unique in the framework and be able to clearly define its applicability (if any) in the face of the sociotechnical challenges we face today. On this basis, the authors offer the following thoughts regarding a Socio-technical Engineering framework.

Sociotechnical Systems Engineering (STSE) is a radical departure from the current IEEE definition of Systems Engineering in that STSE rigorously includes the human as a system element as opposed to relegating humans (users and maintainers) to being system elements that perform subfunctions. It does not, however, cause us to discard the existing SE framework. The resurgence of the notion that there is a dynamic and intimate relationship between society at large and the systems we deploy is to be expected considering the nature of the 4<sup>th</sup> IR which transfers capability conceptualization away from

a select few into the domain of those who have a novel idea and are willing to pursue it (development by the many...). The framework is to provide a viable means by which other concepts (Business Model Innovation, Quality, Environmental Considerations, Value Creation, etc...) gain a foothold in the system development process equal to that of the traditional technical, cost and schedule metrics by which product capabilities and project success is often measured. Lastly, we considered the very nature of our motivations for engineering systems, be they historical efforts or the class of challenges now being referred to as Sociotechnical.

Let us begin by reinforcing our current understanding of what we believe to be the basic tenets of the Systems Engineering process. In its purest form, many consider systems engineering to be the conduct of all technical and management activities required to bring a system into existence with the caveat that it provides value to a user. The essence of this perspective is visible in Figure 1 (re-visited below) which differentiates product development activities from the underpinnings of resource management and decision-making which are necessary for effective Systems Engineering, but not unique to it.



In this framework, it is reasonable to say that humans, even the future system users, are involved in the ongoing development process, but only peripherally. This peripheral engagement includes them being probed for requirements and preferences as well as their participation in formal reviews. They are largely separated from the inner workings of the development process owing, in part, to the presence and participation of the acquisition agent acting on their behalf. The point being (authors' observation) that there is an increasing distinction between those who develop systems and those who are stakeholders in its development. The motivations of those who engineer systems may be, and often are, very different from those who desire the system to begin with. This decoupling of the product being built from the social considerations and environment in which it will be employed often lead to a misalignment between the desired and delivered capabilities. To further expose this distinction, the authors offer the simple perspective that Systems Engineers are characteristically highly focused on cost, schedule and performance as they perform their project duties. They must expose and mature requirements, while architecting and designing a system that can also be built and tested within budgetary and schedule constraints if it is to ever even exist. The current approach to systems engineering in fact attempts to

lock down and codify any changes external to the design that might hinder its development. This reality of the process is done for good cause, but can lead to the delivery of systems whose capabilities do not meet the customers' needs as expressed in the original requirements – as often happens. Tradeoffs occur within highly constrained design spaces that lead to suboptimal products. The authors assert that this may be due to the reality that customers' needs and expectations typically change at a rate much faster than product development cycles can cope with. The proposed Sociotechnical Systems Engineering framework should then accommodate and, in fact, actively embrace the “other half” of the development team - including them in the development cycle in an effort to curb this progressive misalignment. The first element of the Sociotechnical Systems Engineering framework would then be “connective tissue” that ensures the active involvement of the customer and eventual user in some manner throughout the development cycle. It is our belief that the many decisions that confront development teams throughout the project would be better served by a team that considers the holistic project view rather than the arbitrarily limited view of the development teams; that being cost, schedule and performance. Figure 5 depicts the superset of elements considered to be essential in the Sociotechnical System Design framework. The essential elements of a traditional Systems Engineering framework are extended to include Analysis of the Perceived Sociotechnical Need, Sociotechnical Specification and Sociotechnical Validation. These elements arise from direct observation of the global environment in which the Sociotechnical systems are deployed.



**Figure 5.** Essential elements in a Sociotechnical Systems Development framework.

In fact, Figure 5 depicts several noteworthy aspects of the proposed framework. The depiction closes an “open loop” that exists in other frameworks (e.g., the Systems Engineering “V” model) wherein the development process is often shown as a sequence of steps executed over time with the customer making initial input and then awaiting the opportunity to validate the system that gets delivered. In the proposed Sociotechnical Systems Engineering framework, the customer, stakeholders and other team members often considered peripheral are brought to the “front line” of the development process so as to influence the ongoing development knowingly and immediately as development proceeds.

Additionally, this aspect of the evolving framework is also intended to remove the notion of the passage of time from the traditional development process and change the perspective to one of immediacy and holistic engagement of all stakeholders in the development process as it proceeds. The desire being that there will be less iteration and regression (backtracking) in response to discoveries as development proceeds owing to the availability and active participation of all stakeholders. This perspective is intended to reinforce the value of immediate feedback as the development process progresses vice the current approach of having a limited number of specialists review the evolving work products at formal reviews making suggestions that may or may not be implemented.

As proposed, the framework adds four elements to what was presented as the traditional (V-model) framework. Those elements are Sociotechnical Validation, a Sociotechnical Issue Statement, Sociotechnical Analysis and a Sociotechnical Specification. Each of these proposed elements are briefly defined below.

Sociotechnical Validation is our starting point for discussion as it is important to acknowledge and leverage the growing availability of big data with which one can clearly characterize the societal needs that require prioritized attention. There is a voluntary and sometimes compelling drive for individuals, groups, companies and large social entities to collect and broadcast data using emerging technologies. Scientific communities (E.g., NASA, the World Health Organization and the Environmental Protection Agency) not only collect and analyses such data, but make it publicly available. Likewise, there is a growing body of data associated with routine and administrative data collection (business-related, billing data, travel data, weather, utilities usage...) that constitutes a useful source of information; this body of information will continue to grow for the foreseeable future. When used objectively and effectively, big data will serve as a significant source of insight regarding sociotechnical needs. Take, for instance, any of the pressing concerns that appear to be facing us today; health issues, water shortage, pollution (in particular, plastic), Global Warming; drought and fires. A typical approach to resolving one of these challenges might involve containment of a local instance or the treatment of visible symptoms. A broader perspective sociotechnical approach might involve tackling an individual disease (E.g., Measles; Bill Gates) in an attempt to eradicate it completely. Regarding water shortage, one might look for methods to use less water in a given application or develop a more effective distribution system. In both instances (measles and water shortage), Mr. Gates has taken a step back to observe the issues from a sociotechnical perspective and attempted to resolve each by attacking the root causes vice treating the symptoms ([www.gatesfoundation.org](http://www.gatesfoundation.org)). His global perspective and holistic approach to resolving these issues is more focused upon the elimination of issues' causes rather than an after the fact application of simple treatment measures. The point is that sociotechnical issues are grand and global in nature and intended to address people's basic needs. Solving such issues typically requires that one view the issue from a global perspective and have the means to address the principal causes in a manner that does not exacerbate the primary issue or simply create a different issue in the process (make it someone else's problem). Likewise, a sociotechnical issue is one that will persist absent ongoing attention and management. This aspect of sociotechnical challenges distinguishes them from capability delivery (traditional SE) owing to the fact that one must consider the totality of the issue "in the moment" along with the enduring impact of the proposed solution; are we treating the symptom temporarily or resolving the root cause? In fact, the perceived onset of Sociotechnical Issues may, in itself, be a byproduct of traditional engineering's principal focus on delivering capabilities developed within the self-limiting

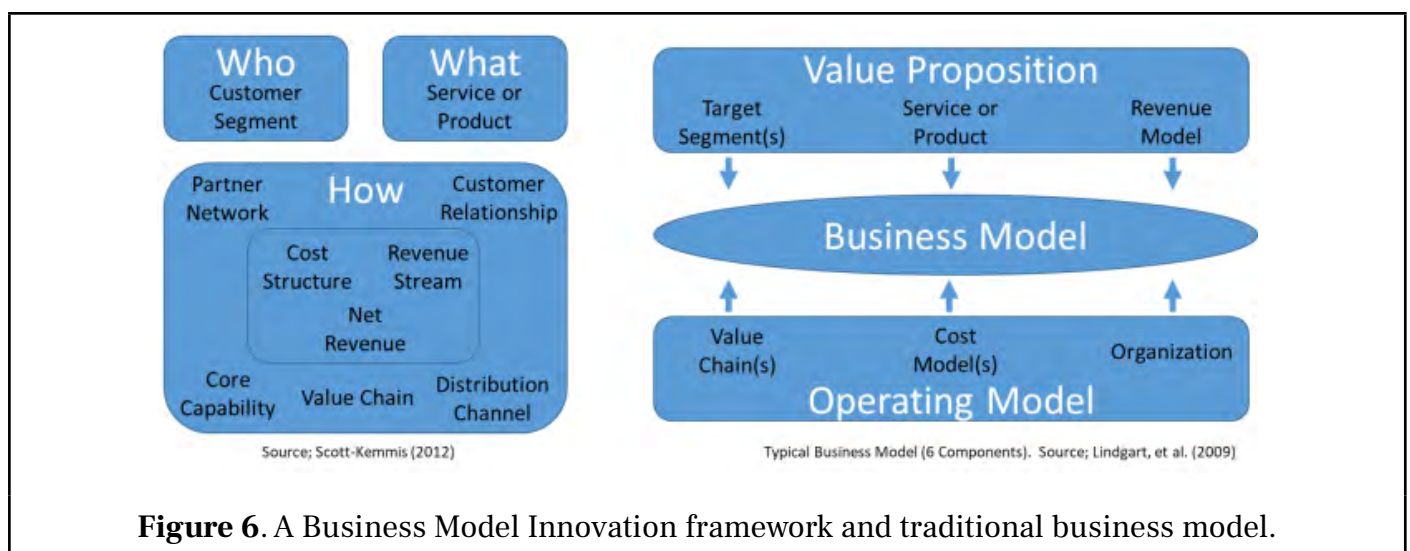
construct of a system boundary. The prior discussion is intended to reinforce the need for a global perspective and on-going attention to issues that matter the most to society at large. The emergence of big data, significant analytic capabilities and a companion capability to trend data over time unlocks the door for a Sociotechnical Engineer, or interested individual to identify, analyze and trend essential information related to the progression and resolution of an issue as time proceeds. The use of the term Sociotechnical Validation is intended to answer the questions “Are we doing the right things to lessen the negative impacts associated with the issue at hand, are we addressing the root causes of the problem?” The notion of global validation is intended to reflect the sociotechnical engineer’s willingness and ability to see beyond the system boundaries of traditional Systems Engineering so as to address to totality of the problem.

Perceived Sociotechnical Issue is the next element to consider. Perception is the key word here in the sense that human psychology would tell us that it is a rare event in which a human being can express in unequivocal terms the root cause of an issue to be resolved. A common truism is that “Perception is Reality”. Our language itself and most means of communications provide us ample opportunity to inject subjectivity in the messages we communicate. By our very nature, we are artful, interpretive and impressionable. Likewise, we are judgmental. It is in our DNA to reflexively decide that which is good from bad (safe from unsafe) in our lives as an inherited survival mechanism. Absent this ability to respond instinctively to unsafe circumstances, we could not have flourished as a species. It is this very mechanism that causes us to believe strongly our perceptions; even if they are not substantiated by facts. As noted previously, it is also a prominent attribute of modern engineering to remove most, if not all subjectivity from engineering activities. The authors believe strongly that definition of the Perceived Sociotechnical Need is an essential element of Sociotechnical Engineering because one cannot solve a problem until one knows the nature of the problem. Beginning with the perceived need, Sociotechnical Systems Engineers are well served to probe deeply and beyond the initial presentation of the “issues” to see the underlying mechanism(s). This takes thoughtful dialog and considerable insight to see and hear the underlying truth often hidden by subjectivity and interpretation. To an architect, this might look like the archeological spade work necessary to expose foundational issues that contribute to the presentation of the symptoms at hand. Likewise, this work is considered necessary to better understand which basic problem patterns exist for indeed, problems have patterns just as solutions do. The definition of the perceived Sociotechnical Issue is a critical and often underfunded aspect of engineering in the authors’ experience. Exploration of the deeper issues is not a discipline of traditional engineering and may well involve individuals with a different educational background and set of experiences than those of traditional engineers. In fact, the individuals directly exposed to the issues’ symptoms may be in a better position to describe the root causes than someone assigned to analyze the situation. To some engineers “It doesn’t exist if it cannot be measured”. However, there appear to be many attributes of sociotechnical issues that have no absolute measure, but exist nonetheless; delight, contentment, mistrust, frustration, anger.

Having identified the issue, it is now time to consider a deeper dive into the issue via Sociotechnical Analysis. Sociotechnical Analysis is the effort required to distill and clearly express the relationship between the parameters that have been shown to matter with regard to the issue at hand. This is the critical step of defining what the issue is as well as what it is not. Interestingly, this is where Big Data gets reintroduced into the framework in the sense that the data used to identify and characterize the issue to begin with may now be used to develop a model of the society wherein the issue presents

itself. Like any model (or analysis), it develops and matures over time with new data and algorithmic insights being used to improve the accuracy and utility of the model’s predictive capabilities. It is the authors’ belief that models of a society or its segments can become more accurate and useful over time just as we now rely on models of the weather for global environmental modeling and local weather prediction. Notionally, this would be the realm of the Sociotechnical Systems Engineer with System and Discipline-specific engineers performing in their traditional roles. To be clear, this type of analysis is not the usual, well-established methods of traffic network analysis and resource distribution, or a study of migration patterns from rural areas into the cities and elsewhere. Rather, it is the thoughtful contemplation and analysis of the bigger issues confronting society at large with a particular focus on satisfying the needs of the broader community while leveraging and optimizing available resources and capabilities; value optimization. Sociotechnical Analysis, in fact, actively includes many aspects of what is currently referred to as Business Model Innovation.

Business Model Innovation (BMI) is an alternative approach to traditional cost vs performance analyses conducted for engineering purposes. It is an approach fueled by disruptive technologies and the notion of business modeling wherein businesses are now keenly focused on increasing their profits by creating quality and delivering value to customers. BMI raises and addresses the fundamental questions about business purpose, what to produce, who the beneficiaries are and how to make money out of new innovations (products and services) that could be attractive to current and future customers. Herein lies the alignment of BMI with a Sociotechnical Engineering Framework; the notion of profit is replaced with one of value and the list of potential benefits is expanded from simple products into highly integrated services and experiences. Consequences matter as much as capabilities in Sociotechnical Engineering. In short, BMI is an effort to introduce an alternative measure of value in an integrated world, different than the traditional measures of profit and stock price. Figure 6 depicts an emerging BMI framework with its focus on three primary areas; the Who, What and How of value creation. Figure 6 includes a traditional business model comprised of a Value Proposition and Operating Model for comparison.



**Figure 6.** A Business Model Innovation framework and traditional business model.

Scott-Kemmis’ BMI is a relevant complement to the Sociotechnical Engineering framework proposed herein owing to its elevation of Who and What aspects of the development effort to the level of the How. It establishes and retains more balanced focus on a larger segment of the population (larger than the Target segment) and the societal network/relationships that are impacted by the product than the traditional (Lindgart) model. Likewise, the Scott-Kemmis model lends itself somewhat easily to the notion of Sociotechnical Validation because there are now more effective Measures of Performance

(MoP) and Measures of Outcome (MoO) that can be applied across the three focus areas (Who, What and How) with data being obtainable by leveraging the connectivity of the Internet of Things (IoT) and using modern data science methods to derive relevant information from the data.

The last new topic to be discussed in presenting the Sociotechnical System Engineering framework is Sociotechnical Specification. It is the authors' contention that this specification is not one that is authored for individual development efforts, but rather one that is adopted and embodied in the thoughts and decisions of the practicing Sociotechnical System Engineer. The notion of a Sociotechnical Specification resides within the well-established and time-honored Engineer's creed;

### **I pledge:**

- To give the utmost of performance;
- To participate in none but honest enterprise;
- To live and work according to the laws of man and the highest standards of professional conduct;
- To place service before profit, the honor and standing of the profession before personal advantage, and the public welfare above all other considerations.

In humility and with need for Divine Guidance, I make this pledge.

Adopted by National Society of Professional Engineers, June 1954

It is rather simple to see (author's opinion) where the mandates of Cost, Schedule and Performance imposed by the majority of project implementations have constrained our thinking, potentially limiting our success at meeting the intent of this code. Consider also the cottage industries of Requirements, Risk, Program, Process, Lifecycle, Cost, etc. Management applications that have developed within our technical communities to optimize these aspects of product development. These industries, coupled with the implied influence of IEEE Std. 1220-1998 (humans essentially interacting with systems at the subfunction level), have served to focus our technical efforts on things that we can control deterministically and algebraically. In sum, they appear to be influences that easily and effectively divert our focus from the essential tenets of the Engineer's creed. This seems to be especially true with respect to service before profit, honor and standing of the profession before personal advantage, and the public welfare above all other considerations. Organizationally, INCOSE appears to comprehend this as well and promotes Sociotechnical Engineering in their motto; A better world through a systems approach.

**We, the authors, believe there is more to Sociotechnical Specification than a simple motto. A Sociotechnical Specification encodes a set of beliefs. Take, for instance, the Laws of Robots (Asimov, 1942);**

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey orders given it by thuman beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

**Re-stated in a similar form, a Sociotechnical Specification might look like this;**

1. A Sociotechnical Engineer actively protects the needs of the many and the planet and shall not allow harm to come to either through inaction.
2. A Sociotechnical Engineer must seek to deliver the greatest social good from among all viable options and apply effort to the highest priority activities unless and until a higher value option presents itself.
3. A Sociotechnical Engineer must seek to curtail the promulgation of negative Sociotechnical activities with the same intensity, intellect and dignity with which they pursue the achievement of positive Sociotechnical activities.

Clearly, such a specification would require dialog and the insights of many (Sociotechnical) stakeholders to be reduced to essential principles. It suffices for us to state though that Sociotechnical Engineering is so distinctly separate from the tenets and practices of traditional System Engineering that it could, in fact, be defined by an overarching specification or set of beliefs. And those would complement the current practice of System Engineering by invoking a macroscopic worldview as opposed to the current microscopic capability perspective.

It is helpful to reiterate what differentiates Sociotechnical Engineering from Systems Engineering. Sociotechnical Engineering originated 60 years ago as a methodology for characterizing human interactions with tools in their workplace to optimize performance and has grown to encompass how societies interact with complex technologies in the world ecosystem of today living on the threshold of the 4<sup>th</sup> Industrial Revolution. Traditional systems engineering has been instrumental in advancing our capabilities to their current level, but the full and intimate integration of man and technology calls for a more holistic approach to engineering, one which acknowledges that every action we take and each design choice we make has a consequence on the lives we live and the environment in which we exist. A new framework is necessary to guide us to make choices that are wise for society at large as opposed to satisfying the “needs” of individuals who can fund development activities that may, in the long run, be very detrimental to overall quality of life.

The proposed Sociotechnical Engineering framework is a construct to help engineers deliver adequate solutions to the challenging issues we face in the 4th Industrial Revolution. It is an extension of the well-established V-Model framework to include four new areas of consideration for those who engineer systems. This framework acknowledges the system boundary as an artificial construct for the sake of designing the system, but Sociotechnical Validation extends the operational environment of the system to include the world we inhabit. This facet is intended to highlight the importance of minimizing the global impact of the systems we build primarily from the perspective of balancing the capability being delivered with the waste and byproducts that are produced by the system over its operational life. Likewise, Sociotechnical Validation takes the broader perspective that society as a whole is benefitting from the implementation as opposed to the narrower view of satisfying of a limited set of customers. Perceived Sociotechnical Need, the second facet, is included to extend the consideration of design teams to focus on issues well beyond technical considerations. The realm of the Sociotechnical engineer becomes one of understanding and resolving elements of design and implementation that lead to system deployment consequences that have no absolute measure, but exist and can lead to delight, contentment, mistrust, frustration or anger. Interestingly, Business Model Innovation and the resurgence of Quality in design processes have each begun to focus on these intangibles as important considerations in the product

and process design areas. The third framework facet, Sociotechnical Need Analysis is included as a means to develop the measures by which we will quantify the sociotechnical benefits of the systems we are designing and implementing new metrics to ensure that we are realizing those benefits as new capabilities are deployed. There is an inherent closed-loop approach to Sociotechnical Engineering in this framework which reinforces the obligation we incur as members of the engineering community; that is to more broadly assess the societal impacts of the design decisions we make and put more focus on reducing the detrimental effects of capabilities we deploy. Lastly, the inclusion of a Sociotechnical Specification is a codification of a belief system that guides Sociotechnical Engineers to design responsibly and for the benefit of society and our planet. The suggested specification is intended to elevate the importance of considering the long term consequences and societal impact of what we do as opposed to continuing our near-term focus on cost, schedule and performance as the primary measures by which we assess the success or failure of the capabilities we deploy.

It is now appropriate to highlight the perceived opportunities and challenges associated with Sociotechnical Engineering. As with any proposed change, there is always the momentum of the established infrastructure and processes that can inhibit adoption and implementation. Fortunately, the proposed framework is not offered as a practical extension of Systems Engineering, but rather a thoughtful complement that is intended to spur practicing systems engineers to consider more and all consequences of the design choices they make – those choices being influenced by more than cost, performance and schedule. The proposed framework has been constructed to allow diverse and integrated development teams to tackle more pervasive issues rather than delivering incremental improvements to existing capabilities. Boldly stated, the framework is intended to provide a means by which we can assess and address societal issues created by prior engineering efforts that have had long term deleterious side effects; Global Warming, resource exhaustion, pollution and the growing disparity between the proverbial “haves” and “have nots”. The framework is intended to broaden our perspectives as engineers as we continue to go about our efforts to deliver vital capabilities – with society at large in mind.

Another challenge is the perceived difficulty in changing the value criteria by which we assess the “goodness” of our efforts; the Cost, Schedule and Performance mantra. As noted earlier, Business Model Innovation and the increasing focus on Quality is an indication that these communities may be a step ahead of us as engineers in this regard. They are actively seeking and finding new approaches to satisfying customer needs in environmentally friendly, socially responsible ways that lessen the damaging impact of product deployment and capability use. The basic mechanisms are the same regarding analysis and assessment, but the span of parameters under consideration is becoming much more diverse and encompasses subjective considerations such as “the experience”, satisfaction, convenience, efficiency and more. The proposed Sociotechnical framework was conceived with this thought in mind in an effort to renew our commitment to meeting the needs of society in ways that may have been lost over the years. With the advent of the 4<sup>th</sup> IR, Sociotechnical Engineering has the opportunity to bring our considerable technical acumen to bear against issues of our own making. The framework represents an attempt to shift our attention and effort towards eliminating the issues that we created with traditional System Engineering motivations and move confidently into the 4<sup>th</sup> IR meeting a broader set of society’s needs and expectations with much less critical resource consumption.

The last challenge to be considered in this paper is the momentum associated with “We’ve always done it this way.” A simple statement that carries a tremendous amount of momentum. Fortunately,

and through purposeful thought, this framework has been developed to retain the processes, tools and typical data that we, as practicing systems engineers, are accustomed to dealing with. The aspects being offered for inclusion in the Sociotechnical framework are largely the domain of the non-technical stakeholders in the ongoing development of new capabilities; those individuals whose needs must also be included as new products get deployed. In this sense, the proposed framework may be viewed as an extension of our current practices to include stakeholders who were formerly and largely silent in the design process. Particularly, when it comes to the value proposition and cost v. benefit considerations that dominate the Need Statement and concept development phase of our capability development processes. The calculus of the decisions being made may change dramatically when the value proposition is updated to include the needs and consideration of formerly silent stakeholders. Thus, the proposed framework is not something new as much as it is a call to fulfill the responsibilities of our profession more responsibly than we may have to date. Take, for instance, the imminent opportunity we may have to embark upon commercial space travel. While it is now fiscally feasible (a market exists) for some number of individuals to experience space travel, is it the best expenditure of resources in the broader global context? We do not propose to answer this question, but rather to ensure that the question is asked.

This framework is intended to increase our scope of consideration regarding the parameters we consider while seeking solutions to Sociotechnical challenges in the 4<sup>th</sup> IR. We have presented an approach that incorporates a new perspective regarding which sociotechnical issues we choose to resolve. Step one, Sociotechnical Validation, is intended to help us identify and prioritize issues that need immediate attention or represent the most beneficial expenditure of resources – natural resources as well as our collective ingenuity and initiative. Herein may lie the greatest potential benefit of our proposed framework. The thinking that lead us to this new perspective may be easily extended one step further and dramatically increase the impact of our efforts. Instead of focusing our efforts on issue resolution, the framework can be used to explore effective methods of issue prevention; prevention beats prescription every time. While it may be considered heretic to decrease demand for certain products (based on our current economic models), a sociotechnical approach may well render a qualitative compulsion to use and allocate resources differently and for the benefit of a broader swath of society. E.g., consumption reduction may deliver a higher return on investment than waste reduction. The proposed framework could prove very useful in “tuning” production to just meet demand in an attempt to flatten consumption curves. Think in terms of the cost of the resources that get consumed inefficiently to provide a given capability versus the cost of consumed resources that provide no benefit whatsoever. Sociotechnical Engineering may provide a venue for identification of these wastes and, therefore, the opportunity to eliminate such wastes. This line of thought is firmly embedded in traditional systems thinking, Business Model Innovation and the proposed Sociotechnical Specification. It remains to renew our commitment to serving the needs of society and face the responsibility of the full consideration of all aspects associated with our profession, not simply the delivery of a capability within cost, schedule and performance constraints.

Clearly, it remains to test the potential value of this framework and explore its merits via rigorous analysis of sociotechnical data and the creation of metrics that can give us deeper insight regarding sociotechnical cost versus benefits. The authors strongly support further studies and research using the principles expressed herein to create new, measurable criteria by which we can assess the socio-

technical benefits. This is not an initiative unique to engineering disciplines but must include business modelers, sociologists, environmentalists, the voice of the non-customer (those stakeholders who may not be using the capability but are impacted by it nonetheless) and, potentially, government authorities. The compelling objective is to achieve better balanced solutions over a more expansive problem scope than typically defined by the artificial system boundary we impose for design expediency. We welcome all future efforts to evaluate the utility and value of a Sociotechnical approach to system engineering and suggest applying this framework to today's pressing issues such as Greenhouse Gases, Space Debris, Public Health and Transportation. We contend that lowering the Sociotechnical cost of delivering the same capabilities we currently enjoy is a long term higher return on investment than improving the efficiency by which we currently develop and deploy capabilities.

We arrive at a simple conclusion; Sociotechnical Engineering is Systems Engineering with a different Objective Function. The proposed framework is an extension, a natural complement to the Systems Engineering of today with an overlay of additional considerations that are intended to help us responsibly and effectively meet the challenges and opportunities presented to us on the threshold of the 4<sup>th</sup> Industrial Revolution (Kenett, Swarz, Zonnenshain, 2020). The additional considerations re-introduce sociotechnical considerations that have, over time, been minimized for various reasons in our development of modern systems (2nd and 3rd Industrial Revolutions) whose purposes were to advance man's capabilities and technical reach. We have arrived; we can build anything that we can imagine. The advent of the 4<sup>th</sup> Industrial Revolution and this framework herald the advent of a new perspective; at what sociotechnical cost? Uniquely different from sustainability (can we continue to do what we already do for an indefinite period?), the proposed Sociotechnical Engineering framework is a means of re-elevating our thinking to the level of "Are we developing systems that can meet the needs of society today with little to no adverse impact on our future well-being?" A noble and worthy pursuit for our discipline.

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**Dr. John Gill** is a servant leader who empowers his colleagues by helping them develop the knowledge, skills and confidence to tackle new and exciting challenges. He is an accomplished Engineering Director and Program Manager having led significant technical initiatives to develop and field Electronic Warfare Systems for the F-22 Raptor and F-35 Lightning II. At BAE Systems, John was the Chief Architect for an \$11B proposal to replace aging United States pilot training assets with modern aircraft and an integrated ground- and simulation-based training system. He was instrumental in guiding BAE Systems' transition from traditional, paper-based engineering processes to a model-based development environment. He is a co-owner and creator of a highly successful Veterinary Emergency and Referral Hospital in Westford, Massachusetts. John is one of the original sets of 18 people certified as an INCOSE Expert Systems Engineering Professional (ESEP). Today he is systems engineering director for SSCI.



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He is an active member of the Israel Society for Quality (ISQ). He was also the Chairman of the Standardization Committee for Management & Quality in the Standardization Institute of Israel. He is a Senior Adjunct Lecturer at the Technion - Israel Institute of Technology. He was a member of the Board of Directors of the University of Haifa. He is an active member of INCOSE and INCOSE\_IL (past president). He is a Fellow of INCOSE.

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# The challenge of Socio-Technical Integration

## [Abstract]

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### **Technology fielding as a socio-technical intervention**

All technological artifacts are developed in a shielded and controlled environment as "technology in a lab". Putting this technology into actual use and realizing stakeholders' benefits requires transforming it into "technology in use", by intervening in the pre-existing socio-technical fabric and changing existing routines. This process has many names – "fielding", "transition to operations", "service transition", "systems deployment", "technology assimilation" etc. – but its essence is independent of the monikers.

The challenge of socio-technical integration has birthed new professions such as Acquisition Officers in the Military, Technology Integrators in the Education, Clinical Engineers in the Healthcare and IT Managers in business corporations.

Curiously enough, scientific insight on the processes accompanying technology fielding does not come from Systems Science or Complexity Studies but rather from the Social Sciences, specifically from the discipline of Science and Technology Studies (STS).

### **Actor-Network Theory as a bridge between SE and STS**

Actor-Network Theory (ANT) is a school in the STS that does not assume a-priori existence of "social forces" that shape the groups and systems but rather focuses on the emergence of systems from their smallest components – people and objects.

From the ANT perspective, human and non-human actors come together to form aggregations (networks). The process of network emergence and stabilization is called "translation" and proceeds by interlacing several activities or "movements", such as "problematization" of defining and communicating network's goals, "interestment" of motivating the actors to support the creation of the network, "enrollment" of actors to assume specific roles in the network, and "mobilization" of actors to become totally integrated in the network. The stabilized network starts acting as a single entity, becomes "black-boxed" and may turn into an actor on its own.

### **Implementing ANT as a socio-technical integration technique (ANTegration)**

The insights of ANT provide us a set of techniques for managing socio-technical changes. The mission of sociotechnical integrator is to transfer ownership of the technology from the technology supplier's project or product manager to the operations managers of the buyer, by embedding the technological artifacts in the operational routines.

To succeed in their mission, the sociotechnical integrators must first become the "Obligatory Passage Points" for all the changes and then extricate themselves from the emerging sociotechnical routines. The integrators implement the problematization and interestment techniques by identifying key actors, understanding the personal benefits they will derive from the change and then motivating them to support the change.

The integrators implement the enrollment and mobilization techniques by organizing "integration events" that exercise new routines, build up the experience of the actors, and modify the behavior of both human and non-human actors, training and imprinting them to become better contributors to the new routines.



The complete article is on the hebrew side of the issue.

המאמר המלא נמצא בחלקו העברי של הגיליון

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# Measuring Design Complexity and Selecting a Design Concept [Abstract]

Alon Ben Moshe, Rafael

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In design activities, any technical application or customer need can be met by various solutions, some are more complex than others. Engineering design aim to achieve performance while minimizing (structural) complexity. On the other hand, simplistic solutions might reduce performance below accepted levels. The question is how can the designer choose an appropriate solution?

**We question the interaction between:**

- |   |
|---|
| (a) <b>Structural complexity (SC)</b> of systems that is a measure of product structure and measured by the number of model parts and their interactions; |
| (b) <b>functional complexity (FC)</b> that is a measure of system performance or the probability to successfully comply with functional requirements.     |

We assume that the linkage between SC and FC is a significant measure for design quality and want to explore this linkage, using three equivalent systems assessment. FC vs SC relationship is described and demonstrate the difference among these three designs, with a monotonic relationship of functional and structural complexities.



The complete article is on the hebrew side of the issue.

המאמר המלא נמצא בחלקו העברי של הגיליון

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# Analogical inference in systems engineering

## [Abstract]

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Analogical inference is very common in design process and system engineering. They are especially critical during systemic fault investigations and development of new products based on similar products or technologies. In these cases, analogical inference is not a trivial thing, and sometimes leads the engineers to the wrong conclusions. Many engineers, like most people, spontaneously (intuitively) use analogical inference and are not always aware of how the process works and the dangers inherent in it. This lack of knowledge, in many words, leads it to be reckless and wrong by analogy. Because I believe that some of the mistakes can be avoided by understanding the process of making analogous conclusions and knowledge of aspects and vehicles buried in it, in this article, I found it appropriate to briefly introduce the topic, hoping that this presentation would raise awareness among engineers and perhaps prevent them from drawing the wrong analogous conclusions.



The complete article is on the hebrew side of the issue.

המאמר המלא נמצא בחלקו העברי של הגיליון

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## Summary of the HSI 2019 Conference in Biarritz, France, Sept. 2019

Dr. Avigdor Zonnenshain, The Gordon Center for Systems Engineering/Technion

Prof. Avi Parush, The Faculty for Industrial Engineering/ Technion

Avi Harel, Ergolight

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On Sept. 11-13,2019 we actively participated in the first International conference on HIS - Human Systems Integration in Biarritz, France, which was organized by INCOSE. About 100 systems engineers and human factors engineers from various countries, who are applying different aspects of HSI in the industry and in the Academia, participated in the conference. The chairman was Prof. Guy Boy, who is serving also as the chairman of the HSI WG of INCOSE and was the keynote speaker of the Gordon Center day on June 2019 at the Technion.

Garry Roedler, the President of INCOSE, and Kerry Lunney, the President Elect, participated too.

We have presented a paper and moderated a panel and have created fruitful connections with the participants of the conference.

### **The main insights from the conference:**

- HSI is implemented in different ways in various organizations, with different contents and scale;
- There is a dilemma where to lead the HSI discipline from organizational and contents aspects. Our panel, about the development of HSI as a new discipline, gathered a lot of interest;
- It is valuable to lead HSI not as a special capability but as a core capability built within each organization and its people;
- The integration of AI (and other advanced technologies) with HSI was raised several times, around the questioned of what it includes and what are its benefits;
- The interesting research activities and outcomes in the areas of HSI should be shared and implemented in industry.



An extended review may be found on the Hebrew part of the issue.

סקירה מקיפה נמצאת בחלקו העברי של הגיליון

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# Summary of the INCOSE Symposium 2019

Prof. Dov Dori, The Faculty of Industrial Engineering, Technion, Israel

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**The 29th Symposium of INCOSE was held this year, July 2019, in Orlando, Florida. As usual it was well organized and included interesting keynote speakers, tutorials by experts, various papers and plenty activities of Working Groups.**

- The symposium started with several tutorials:
- Introduction to Systems Security Engineering - Mark Winstead et al.
- Developing Verification Requirements to Assure Project Success - Mark Powell
- Getting Ready for Industry 4.0 and IoT with Model-Based Systems Engineering - Dov Dori

Among the keynote speakers it is worth mentioning Prashant Dhawan, Co-Founder of Biomimicry, India, whose talk entitled “Biomimicry - A Bioinspired approach to Systems Thinking”. This talk raised thoughts among systems engineers about what they can learn from living systems and their evolution. Another interesting keynote talk was given by Capt. Winston Scott who was an astronaut on Columbia 14, entitled “To the Stars. The Sky Is No Longer the Limit”.

The Israeli Chapter got the Silver Chapter Circle Award:



In the detailed summary (in the Hebrew section of the journal) we have included reviews of several interesting papers from this symposium, such as:

- **Integrating Program/Project Management and Systems Engineering in Practice** by Heidi Ann Hahn, Los Alamos National Labs and Ann L. Hodges, Sandia National Labs
- **Agile Systems Engineering Life Cycle Model for Mixed Discipline Engineering** by Rick Dove, Paradigm Shift International and Bill Schindel, ICTT Systems Sciences

- **Use of SysML for the creation of FMEAs for Reliability, Safety, and Cybersecurity for Critical Infrastructure** by Myron Hecht and David Baum, The Aerospace Corporation
- **The Digital Twin Throughout the SE Lifecycle** by Matthew Hause, PTC
- **Systems Engineering: Transforming Digital Transformation** by Troy A. Peterson, System Strategy, Inc.
- **Systems Engineering-Software Engineering Interface for Cyber-Physical Systems** by Sarah Sheard, Mike Phillips, Software Engineering Institute and Michael E. Pafford, INCOSE Chesapeake Chapter
- **Evolution of the Helix Project: From Investigating the Effectiveness of Individual Systems Engineers to Systems Engineering Organizations** by Nicole Hutchison, Hoong Yan See Tao, Pamela Burke, Sergio Luna, Araceli Zavala, Suchita Kothari, Shikha Soneji and Jose Ramirez-Marquez, Systems Engineering Research Center (SERC), Stevens Institute of Technology
- **Famous Failures Revisited: A Focus on System Integration** by James R Armstrong, Stevens Institute of Technology
- **A Practical Study on How Proactive Quality Approach Can Improve System Development Process to Ensure System-Effectiveness and Performance** by Haokar Aziz and Rolf Qvenild, University of South-Eastern Norway
- **Can We Use Wisdom-of-the-Crowd to Assess Risk of Systems Engineering Failures?** by Georgios Georgalis and Karen Marais, Purdue University

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Detailed summary is on the hebrew side of the issue.

סקירה מקיפה נמצאת בחלקו העברי של הגיליון

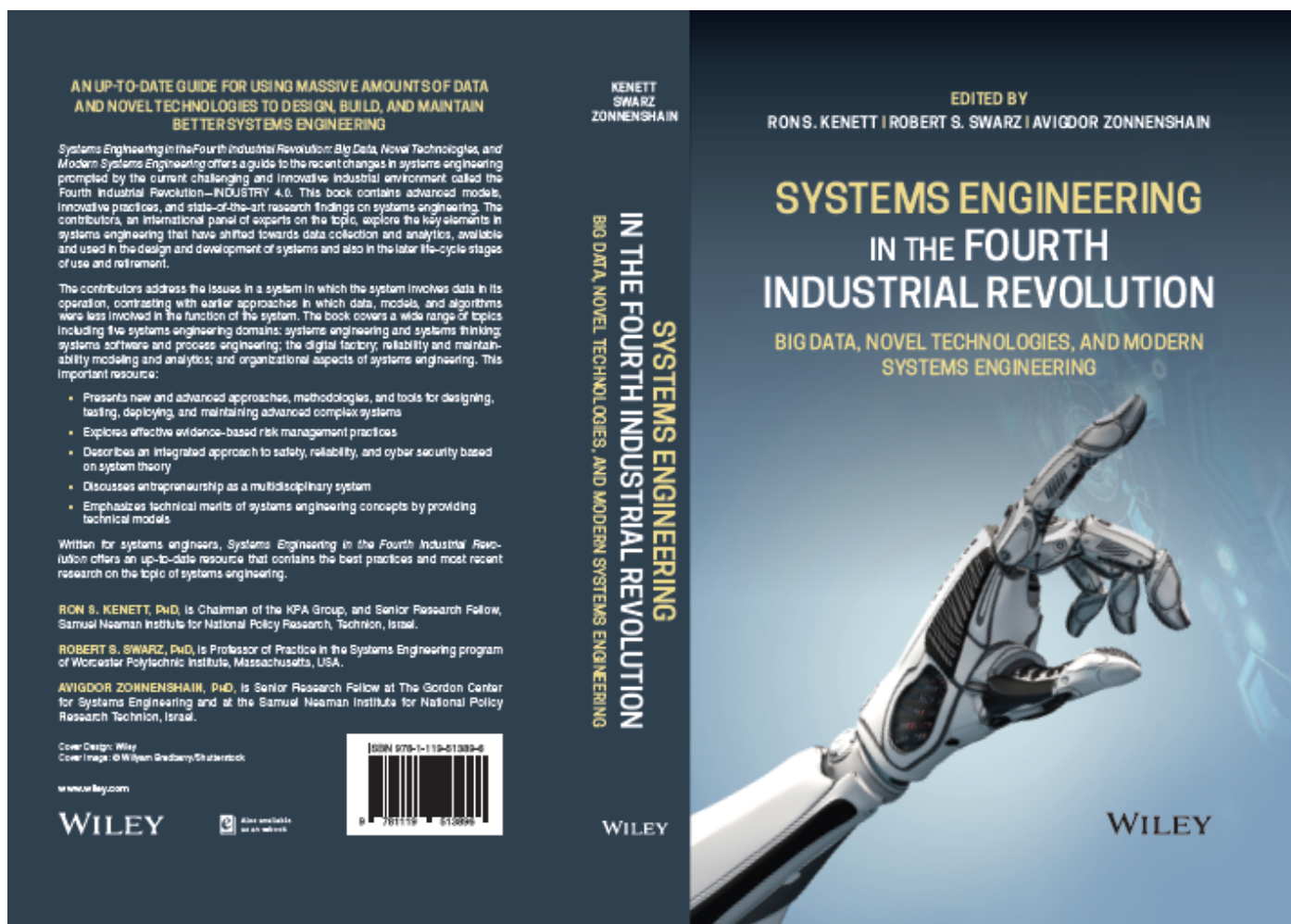
# SYSTEMS ENGINEERING IN THE FOURTH INDUSTRIAL REVOLUTION: BIG DATA AND NOVEL TECHNOLOGIES AFFECT MODERN SYSTEMS ENGINEERING

**Editors:**

Ron S. Kenett, KPA Group and Samuel Neaman Institute, Technion,

Robert S. Swarz, Worcester Polytechnic Institute,

Avigdor Zonnenshain, The Gordon Center for Sys. Eng. and Samuel Neaman Institute, Technion



This new book will be published by John Wiley and Sons in January 2020 (see link below). The book addresses topics of advanced systems engineering in response for the challenges and opportunities of the 4th Industrial Revolution.

<https://www.wiley.com/en-us/Systems+Engineering+in+the+Fourth+Industrial+Revolution%3A+Big+Data%2C+Novel+Technologies%2C+and+Modern+Systems+Engineering-p-9781119513896>

During the last decade, companies in advanced economies have experienced significant changes in engineering and manufacturing practices, processes, and technologies. These changes have the potential to create a resurgence in their engineering and manufacturing capabilities. This phenomenon is often referred to as the Fourth Industrial Revolution or Industry 4.0, and is based on massive digitization, big data analytics, advanced robotics and adaptive automation, additive and precision manufacturing (e.g., 3-D printing), modeling and simulation, artificial intelligence, and the nano-engineering of materials. This book addresses the topic from a Systems Engineering perspective. Rather than being based in scientific principles, Systems Engineering (SE) consists of a rich and useful set of principles, processes, practices, and lessons learned. The contributors to this volume provide a rainbow coverage of such topics.

What is a system? Virtually all the textbooks and courses on Systems Engineering (SE) begin by trying to define a system. The description usually involves some combination or variations of the following themes: (1) it's an engineered response to satisfy a need, (2) it possesses synergy (the whole is greater than the sum of its parts), (3) it is bounded (one can "draw a box" around it), (4) it has known internal functions, relationships, and interfaces, and (5) it has well defined and clearly understood external interfaces.

What has changed? Everything! Our notions of what a system is, and the characteristics of systems engineering, have served us well for the past 60 or 70 years, especially in the defense and aerospace industries. However, with the exponential increases in the amount of computational power, communications bandwidth, raw data, and addressable objects, things have changed! The Internet of Things and Big Data have changed our fundamental concepts of what systems are and how we do systems engineering.

System complexity has increased so much that it is not uncommon for systems to exhibit emergent behavior, occasionally with unintended consequences, i.e., the ability to perform functions that could not be imagined by examination of its component parts. Increases in communications bandwidth and the so-called Internet of Things obviate the boundedness of systems and of System of Systems (SoS). The vast amount of data presents enormous challenges to manage, store, analyze (and use!). Systems engineering (SE) is a discipline that promises to deal with complex issues in understandable and quantitative terms. The extended access to big data from sensors, together with concepts and technologies of the Fourth Industrial Revolution, offers an opportunity for SE to grow and expand. The bottom line is that SE should move from being focused on documents to an approach being driven by data (from D to D). This transition involves new and old disciplines such as computer simulations, statistically derived design and operational spaces, multivariate process control and monitoring, prognostic health management, complexity management and performance evaluation methodologies. The transition from Documents to Data poses a range of analytic challenges, including sophisticated predictive analytics and data integration accounting for information generated at various levels of form, resolution, and speed. Questions that need to be considered regard the evaluation of high level and detailed designs, setting up of test suites in parallel with system development and advanced support to decision making providing an indication of impact of alternative scenarios.

This book covers a wide range of domains with 22 chapters written by leading experts. These domains are:

1. Systems Engineering and System Thinking;
2. System Software and Process Engineering;

3. The Digital Factory;
4. Reliability and Maintainability Modeling and Analytics;
5. Organizational Aspects of Systems Engineering.
6. Some of the chapters are based on advanced and original research, and others report and present advanced practices and case studies.

The goal of this book is to share advanced models, innovative practices, and state-of-the-art research findings on systems engineering in the 4th Industrial Revolution era, with the professional community and with managers in industries and companies. Many of the methodologies of the current systems engineering body of knowledge were developed and practiced in the defense and aerospace industries. We target in this book industries that are affected by the 4th Industrial Revolution, like manufacturing, healthcare and life science, food and agriculture, communication and entertainment, smart transportation and cities, and more. We consider this an opportunity to introduce systems engineering into such new domains.

The book can serve as textbook and learning material in academic and professional training programs of systems engineering, and especially in programs on advanced systems engineering for the 4th Industrial Revolution. Also, this book can serve the curious systems engineers and managers who want to implement the new and innovative approaches presented in this book.

The chapters in the book present material that can stimulate research efforts and initiatives on the new methodologies and approaches for advanced systems engineering in the new and evolving ecosystem called Industry 4.0.

Final words: This book is a call for action to change the ways of doing systems engineering in order to meet the challenges and opportunities of the new technological era. It is designed as a resource to facilitate these actions for change and reform.

### **What professionals say about the book:**

Engineers will find this book insightful in addressing the enormous challenges of our future world dominated by data, complexity and increasing connectedness. Handling the velocity of change requires such a book for researchers, students and practitioner's alike.

Kerry Lunney, Engineering Director, Thales Australia and INCOSE President 2020-2021

We are on the path of conceptualizing and building multi-faceted systems in different levels of implementation that entail complex logic with many levels of reasoning in intricate arrangement, organized by web of connections and demonstrating self-driven adaptability which are designed for autonomy and exhibiting emergent behavior that can be visualized. System engineering research and practice need to rejuvenate itself to cope with these changes with a new perspective. This book provides answers to new questions that we face and directions to follow in creating new systems engineering practices for digital industrial revolution written by international authors of practicing systems engineering and academicians. It is a great book to read for understanding new systems engineering vision.

Prof. Cihan Dagli, DoD Systems Engineering Research Center-UARC, Founder and Director Systems Engineering Graduate Program, USA

This is a useful and timely book. The topics are well-chosen and they helped me to understand better the ongoing industry transformation and the role of analytics in it. I highly recommend it.

Dr. Emmanuel Yashchin, IBM Thomas J. Watson Research Center, USA

In this era of increasing complex systems, processes, and data, a system engineering perspective can serve us well to overcome the challenges and pursue the best opportunities afforded us in this fourth industrial revolution. This book compiles useful materials for dealing with complex systems with multi-disciplinary and data-based approaches. The need for a system engineering perspective is underscored by the fact that Industry 4.0 is disruptive to every industry that uses data. Still, some things remain the same—the importance of data in context, the usefulness of applied examples, the need to better anticipate the future to take best actions versus merely reacting to events as they occur, and the ability to build on our knowledge to further understand our world.

John Sall, Co-Founder & Executive Vice President, SAS Institute and JMP Business Division, USA

The book clarifies many questions and concerns that I personally had when working with dozens of manufacturing industry collaborators, such as the role of human and human factor in future machine learning dominated industrial environments. This volume will be very valuable for readers, especially engineers and students seeking to experience the real world, unstructured problems. It will equip them with effective tools for solution.

Prof. Ran Jin, Grado Department of Industrial and Systems Engineering, Virginia Tech, USA

This book will certainly enrich our system engineering (SE) literature collection, especially since it is focused upon “Industrie 4.0” the framework for “modern” SE. Modern SE will have to function in many ways different from “classical” SE and needs to question some of the “established” practices and in particular some of the associated processes. It is in this spirit that I welcome this new book, since it enters into some of the “Industrie 4.0” challenges and provides some SE answers which point in the right direction.

Prof. Heinz Stoeber, Space Systems Engineering, TU Delft, The Netherlands.

This book addresses a new challenge of our time, the development of Industry 4.0, which brings with it the combining of big data, complex objectives for efficiency and effectiveness of industrial systems, all in a context of continuous and rapid change. The chapters of the book lead the reader through understanding the nature of the special challenges of Industry 4.0 and providing guidance on how to do the work required to achieve, and provide assurance of achieving, the most desirable outcomes. The authors build on the existing tradition of systems engineering and lead the reader to understand how the existing methods of systems engineering can be adapted to enable achievement of the goals of Industry 4.0.

Dr Tim Ferris, Centre for Systems Engineering, Cranfield Defence and Security, Cranfield University, UK

Systems Engineering in the Fourth Industrial Revolution provides an important and timely perspective on how systems engineering must adapt to address the needs of evolving systems and technologies. This book explains how technological drivers such as the internet of things (IoT) and big data fundamentally change the nature of systems, and how we must rethink how to engineer these systems to address concerns such as resilience, safety, and security.

Sanford Friedenthal, SAF Consulting, former senior systems engineer at Lockheed Martin and Hughes Aircrafts, USA.

Reading this unique book, theory and practical examples, will enable those in the advanced fields to understand and recognize the new tools required in the modern engineering world. Insights related to development, maintenance, manufacturing, reliability, safety are needed for those who share the new world.

Prof. (Ret. B.Gen) Jacob Bortman, ME Department, Ben Gurion University of The Negev, Israel

The book offers a diverse set of chapters covering topics related to various aspects of “systems engineering meets big data”. This provides a wealth of information that will be useful not only to those in systems engineering, but also to researchers and practitioners in other big data fields.

Prof. Galit Shmueli, Institute of Service Science, College of Technology Management, National Tsing Hua University, Taiwan

We live in an increasingly interdependent world of ecosystems. Yet policymakers lack effective tools for 21st century systems thinking. This book, in 22 fascinating chapters, shows how data and technologies are impacting those who truly understand and apply systems thinking – systems engineers.

Prof. Shlomo Maital, The Samuel Neaman Institute, Technion, Israel

The book offers an impressive variety of 21st-century topics for interconnected software dominant systems, written by global leaders in these fields. I especially like that systemic concepts are first explained and then shown graphically along with tools that support their exploration, such as system thinking and the Conceptagon.

Sarah Sheard, The software engineering institute (SEI), Carnegie Mellon University, USA

The book presents a multi perspective insight unveiling the fundamental change in the contemporary nature of the term ‘system’. Such a revolutionary approach is needed to cope with both the complex structure of components, subsystems, systems, and systems of systems; and above all - the vast amount of data.

Prof. Arie Maharshak, President, ORT Braude Academic College of Engineering, Karmiel, Israel

Exciting book about Fourth Industrial Revolution era and changes around us. Kenett et al. are connecting several aspects of Industry 4.0, challenges, opportunities, benefits and efforts. The book is pointing out to the complexity and the need of collaborative efforts of all stakeholders of global policy to implement new and innovative technologies. This is an inspiring state-of-the-art book for academia and industry about systems, data, engineering, manufacturing, technologies and human aspects.

Dr. Julita Panek, Siemens Digital Industrie Pharma Central and Eastern Europe

The book represents pioneering movement which addresses audiences who is familiar with the systems engineering area and is interested to do a “leap jump”, and to be exposed to fascinating perspective which is dealing with the systems challenges of the 4th Industrial Revolution.

Giora Shalgi, The Samuel Neaman Institute, Technion and Former CEO of Rafael, Israel

The book explores and clarifies many important topics for the fourth industrial revolution, including why this is driving change in the focus areas for Systems Engineering. In particular, the book highlights the importance of Applied Systems Thinking as a way of bringing together different methods to improve the probability of a successful outcome.

Dr. Andrew Pickard, Systems Engineering, Rolls-Royce, USA

This must-read edited book highlights the essential elements of Industry 4.0 through a renewed look at the Systems Engineering discipline by leveraging the knowledge of a diversified group of leading scientists. The various contributions are well organized, insightful, present the current state of the art and transcend international boundaries completely.

Prof. Emeritus Ehud Menipaz, Department of Industrial Engineering and Management, Ben Gurion University, Israel

With the 4<sup>th</sup> Industrial Revolution, “a storm is coming”. It implies an enormous challenge for all engineering disciplines, especially for Software Engineering and Systems Engineering. To be able to deal with these challenges, this book provides the reader with a series of over 20 perspectives to consider. These perspectives range from Systems Thinking to Organizational Aspects, each written by a specialist in that field. Reading this book surely gives you insights for transforming your Systems Engineering efforts, so you’ll get ready to deal with the fourth industrial revolution challenges.

Paul Schreinemakers, INCOSE Technical Director, USA

The book “Systems Engineering in the Fourth Industrial Revolution” is a fresh collection of chapters providing a window to a new era of systems engineering. In contrast to the past 70 years where the pace of technology disruption was manageable by the adjustment of systems engineering tools; the pace in the last 10 years has called for revolutionary changes. The chapters in the book introduce a variety of issues including methods, tools, and perspectives that underlie this revolution. The book is an important introduction to this new era for every system engineer or those interested in the subject.

Prof. Yoram Reich, Faculty of Engineering, Head, Systems Engineering Research Initiative, Tel Aviv University, Israel.