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Assessing the Potential of IoT in Systems Engineering Discipline

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Abstract. Internet of Things (IoT) is becoming more and more important in many industry sectors and domains. Digital transformation is at the heart of business strategies nowadays and it begins with the executive mandate. There is a strong sense of urgency among executives as the threat of digitally enabled competitors remains high on the list of concerns. From the birth of IoT in 1999 to 2003, the number of devices grew to 500 million connected devices. By 2023, the forecast is for over 50 billion connected devices serving a population of 7.6 billion people (Dave 2011)

Metcalfe's Law reminds us that three interconnected components result in a maximum of three interconnections, but with four the maximum number of interconnections rises to six, and with ten components, designers must deal with 45! This law illustrates how so many connected devices will challenge the way system engineering is carried out now. IoT is NOT a distant future, it's happening now. As a system engineering professional we have to be ready for the kind of thinking and tools that will be needed to address such a level of complexity. The IoT is, in a sense, a hyper-scale System of Systems problem with multiple environments, requirements, governance structures and millions of stakeholders. So what tools can the SE discipline provide to manage this growing technology?

This exploratory research is targeted towards identifying the various IoT characteristics and their impact on System Engineering discipline. A methodology was developed to establish the relationship between the IoT characteristics and System Engineering elements (Design requirements). Matrix methodology also helped in identifying the positive and negative correlation between the IoT characteristics and its linkage with various systems engineering element. This investigative research could be used by System Engineering professional to understand the impact of IoT on the practice of Systems Engineering.

Introduction

Internet of Things (IoT) is a buzz word in the every industry now. There are both benefits and threat of adopting IoT in the industry. System Engineers are responsible for driving and inducting the technology change in the systems and adding/increasing value proposition to the products. IoT brings many complementing characteristics to the product/systems however there is no established methodology to link and leverage the characteristics with systems engineering elements. With this outline the objective of this paper is listed below.

1. Identification and definition of various IoT characteristics
2. Finding out High impact IoT characteristics in system engineering discipline
3. Map the IoT characteristics with System Engineering elements
4. Conclusion & Summary

IOT Characteristics

There are many IoT Characteristics, however 27 of them are identified through literature survey. These IoT characteristics general definitions and its Systems Engineering applications are outlined in Table 1.

Table 1: IoT Characteristics General Definition (Ramalingam, Christophe and Samuel 2017) & System Engineering Applications

SL. No.	**IoT Characteristics**	**General Definition**	**System Engineering Applications**
1	Interconnectivity	Anything that can be interconnected with the global information and communication infrastructure	System would choose which devices connect, and only the desired devices will connect, and excluding non-desired devices or links. For those devices that are connected, Systems Engineers would define the variety of behaviors and modes that each device brings to the system, as well as understanding how the system operates when needed devices aren't connected.
2	Heterogeneity	Devices can interact with other devices or service platforms through different networks	API's, common interfaces, etc. to allow connections with different networks.
3	Dynamic changes	The state of devices change dynamically, e.g., sleeping and waking up, connected and/or disconnected	The system should be aware of the environment, and when the device state needs to change (and the system having the ability to do so).
4	Things-related services	Capable of providing thing-related services within the constraints of things	Can the information gathered by a smart device be used to provide a value-added service? Business case for the data (and it may be across multiple users).

SL. No.	IoT Characteristics	General Definitions	System Engineering Applications
5	Enormous scale	The large number of devices that need to be managed and that communicate with each other	Aircraft-centered scales are much smaller than mobile phone. As air transport grows, so will the scale.
6	Safety	Safety of our personal data and the safety of our physical well-being	1) Is there any sensitive information that industry want to protect. 2) Prevent hacking of system.
7	Connectivity	Devices that enables network accessibility and compatibility	Networks used in Aerospace systems (MRO, ground operations, aircraft to aircraft - swarm control)
8	Intelligence	Both software & hardware provide “Intelligent Spark" that make a product experience smart	Machine learning of an aerospace system using IoT devices.
9	Sensing/Sensors	Provide the means to create experiences that reflect a true awareness of the physical world	What are existing sensors, are there sensors we need, and are they workable within the real world environment.
10	Expressing	Devices that allows us to output into the real world & directly interact with people & the environment	Human- Machine Interfaces. (How do humans transmit and receive information, and likewise with machines).
11	Energy Harvesting	Energy harvesting, power efficiency & charging infrastructure are parts of power intelligent ecosystem	Energy harvesting or scavenging has potential to power the full or partial sensor networks in smart systems
12	Computing/ Processor	Devices need a certain degree of computing power to relay and transmit gathered data to the cloud	System of interrelated computing devices have the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction
13	Quality & Reliability	IoT Devices need Quality & Reliability as it is operating in severe weather, unforgiving environments & hard to reach places	What aerospace grade devices are there, or do we design the system to not care?
14	Cost effectiveness	Disposable sensors at large volume need to be relatively cheap to implement	COTS impact, Volume Vs. Unit cost tradeoffs.
15	Consumption	Devices that are capable of producing operational data so that it can be consumed	How much data is being developed, and how much of it can the system digest without choking.

SL. No.	IoT Characteristics	General Definitions	System Engineering Applications
16	Conversion	Devices take the raw sensor data and convert it into contextualized meaning	Data analytics and matching it to the system context (i.e., how do we translate the device outputs into something that can be analyzed.
17	Centralization	Centralize the data and bring into one central location	Apply to different levels: System level centralization, airplane level, enterprise level.
18	Configuration	Channel the feedback from the cyber world into the physical world	Handling the fact that any new device can come in, and change the configuration of your system.
19	Cognition	Analytical process where we make sure we can apply context to the data in hand	Data analytics - can the system apply the context to the data that is received.
20	Coordination	Insight of IoT intelligence to start the process of better business logistics and scheduling	Using the data from the system to support enterprise processes (i.e. business planning, logistics, etc.,)
21	Deterministic	Time-Sensitive Networking for IoT	How do we handle latency in the system and between devices (RTOS) - does the device need to have an immediate response.
22	Mobility	The ability to get all of your job done wherever you are and whenever you need to.	Range of action and movement allowed by the system.
23	Security	The area of endeavor concerned with safeguarding connected devices and networks	System level security of the network; (keeping private data secured).
24	Miniaturization	Small, powerful devices which are even more powerful than the fastest enterprise computers	Affects product obsolescence (i.e. form factors of devices may change).
25	Composability	It means the design and development of hardware architecture, including within just the microprocessor itself	A highly composable system provides components that can be selected and assembled in various combinations
26	Standards	It is a document that specifies something that has the overwhelming support and agreement of the standards making body	Are there existing standards, and how to work with multiple standards what may not be compatible? Working with COTS protocols.

SL. No.	IoT Charac-teristics	General Definitions	System Engineering Applications
27	Protocols	A protocol is a particular set of rules for having a conversation between two computers to convey a specific set of information	Application of systematic methods to the development of communication protocols

Systems Engineering Elements

SEBoK (Systems Engineering Body of Knowledge) Figure 1 Shows the System Boundaries of Systems Engineering, Systems Implementations and Project/Systems management. In this research Systems engineering elements red color encircled items are considered to establish the relationship with IoT characteristics.

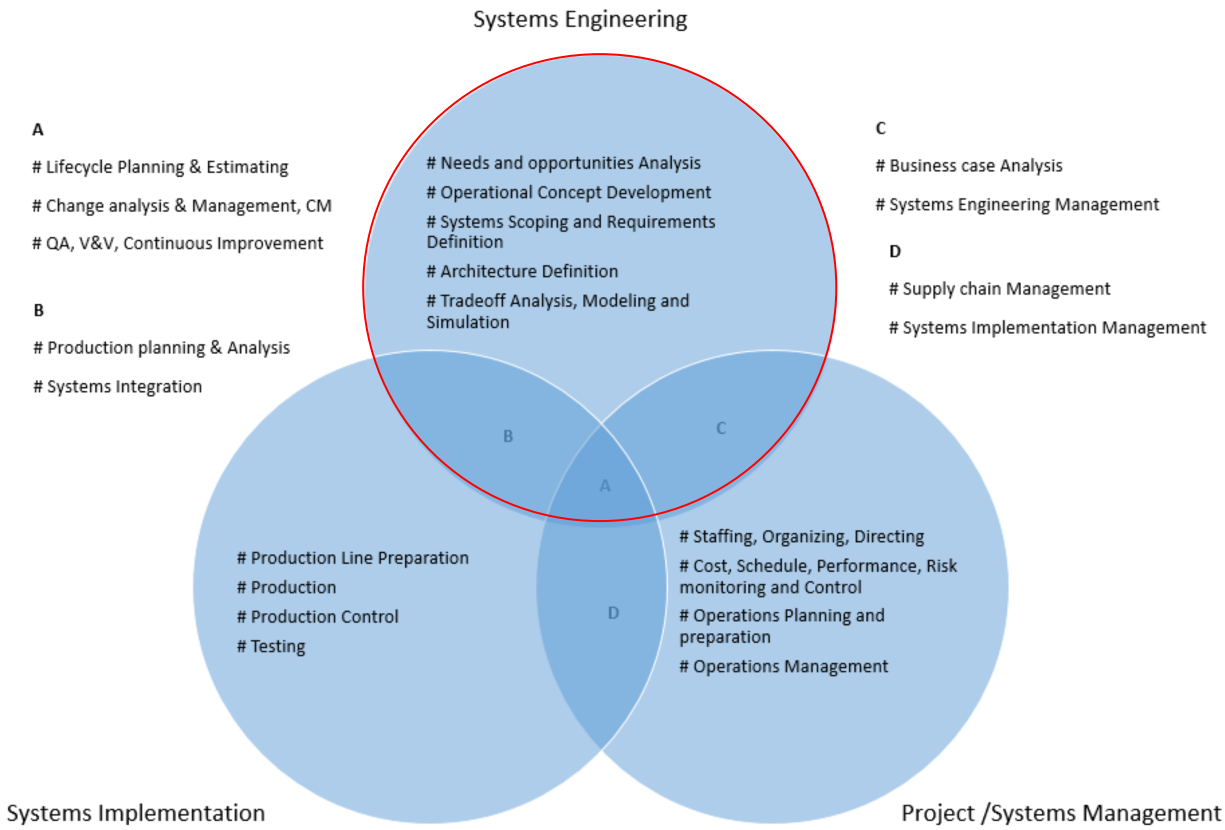

Figure 1. System Boundaries of Systems Engineering, Systems Implementation, and Project/Systems Management (SEBoK Original)

Survey to identify High impact IoT Characteristics

The authors conducted a survey from among the Systems Engineering community to identify the IoT Characteristics impacts on Systems Engineering. The pool of system engineering professionals participated in the survey with varied experience level and INCOSE certifications, see Figure 2.

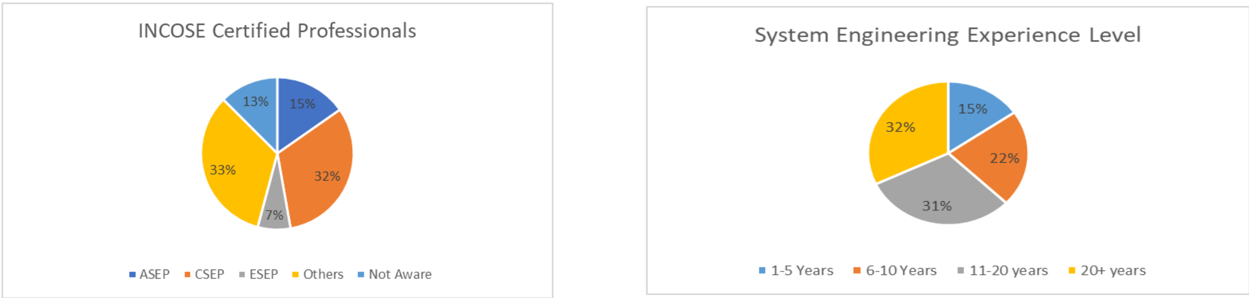

Figure 2. Survey Participants Details

High Impact IoT Characteristics: There are 7 IoT characteristics which scored equal or above 58% voting for High Impact. There are overall 15 characteristics scored 50% and above scoring for high impact. Characteristics such as Inter-Connectivity, Safety, Connectivity and Security scored high in the survey. These four key characteristics are very important for IoT implementation in any Systems without which value preposition of IoT may not be 100%.

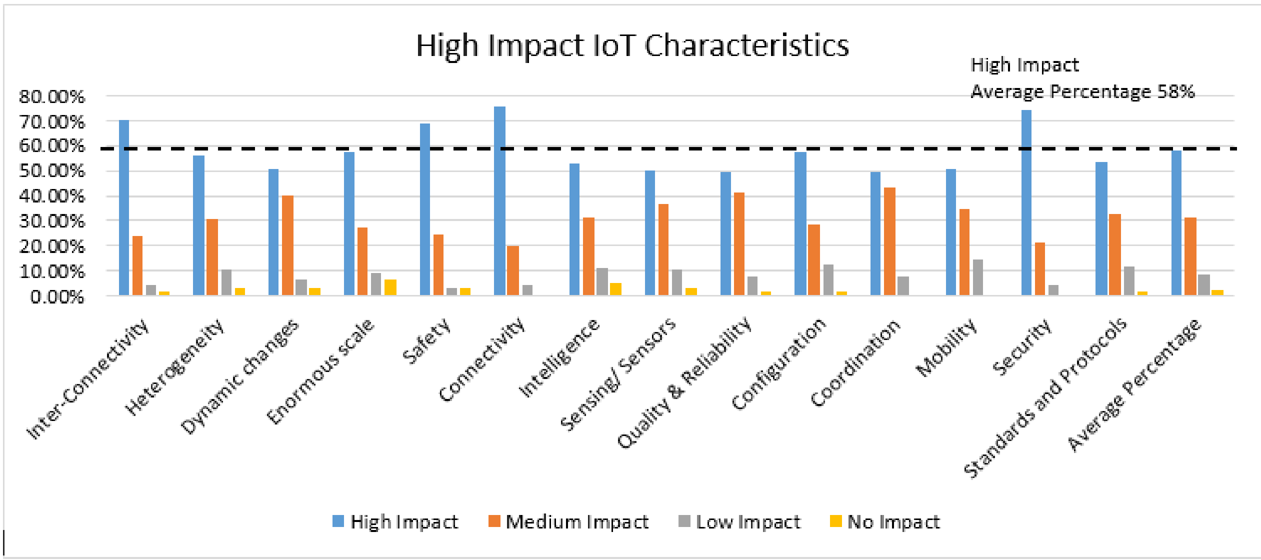

Figure 3. High Impact IoT Characteristics

Medium and Low Impact IoT Characteristics: There are 6 IoT characteristics which scored average 43% voting for Medium Impact. Things-related services, Cost effectiveness and Deterministic are high scoring medium impact IoT characteristics which needs to be assessed and implemented based on the value propositions.

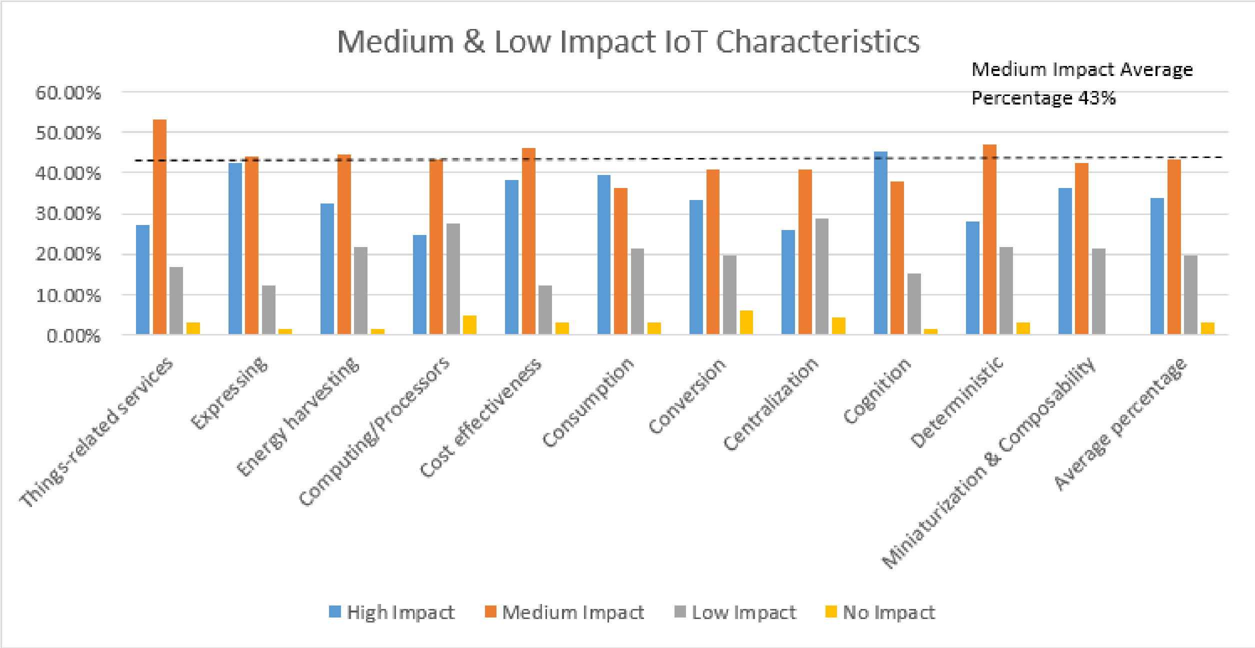

Figure 4. Medium and Low Impact IoT Characteristics

These two charts lists the IoT characteristics and its significance impact in the Systems Engineering discipline through survey. However the mapping between the SEBoK Systems Engineering Elements with IoT Characteristics will be helpful to understand the importance of characteristics and its relevance in Systems boundaries of Systems Engineering.

Mapping the IoT Characteristics with Systems Engineering Elements

'House of Quality' (HoQ), the basic design tool for the management approach known as Quality Function Deployment (QFD), originated in 1972 at Mitsubishi's Kobe shipyard site. Toyota and its suppliers developed it in numerous ways. HoQ is a kind of conceptual map that provides the means for inter-functional planning and communication. People with different industrial problems and responsibilities can work out design priorities while referring to patterns of evidence on the house's grid (John and Don 1988).

The house of quality as a part of QFD, identifies and classifies customer desires, identifies the importance of those desires, identifies engineering characteristics which may be relevant to those desires and correlates the two (desire and engineering characteristics). This process can be applied at any system composition level (e.g. system, subsystem, or component) in the design of a product and can allow for assessment of different abstractions of a system.

Customer attributes for systems engineering elements are listed on the left side rows of the matrix. Global IoT characteristics are listed in the top column of HoQ. Relationship matrix (Central portion) between systems engineering elements and IoT characteristics are established on a scale of strong, medium and weak relationships. Co-relationship matrix (Top Triangle) with potential positive and negative interactions between IoT characteristics has been identified. Too many positive interactions imply possible redundancy in IoT characteristics. Negative interactions suggest to consider the trade-offs in establishing target values for systems elements, see Figure.5 (Ramalingam, Christophe and Samuel 2018).

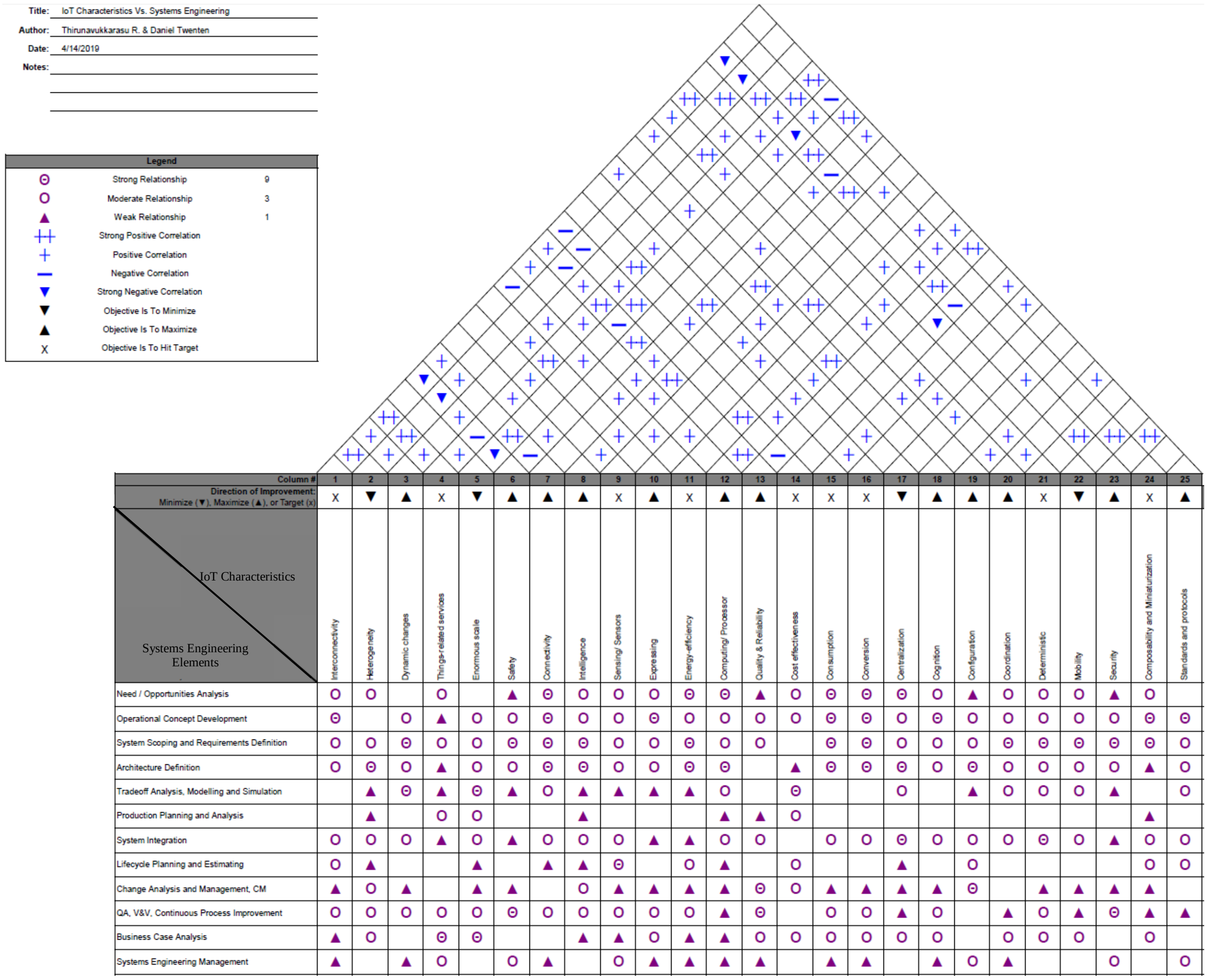

Figure 5. House of Quality (HoQ)

Mapping between the Characteristics and Systems Engineering Elements are established by interviewing the Systems Engineering professional. Survey results helped in identifying the high impact IoT Characteristics and interview helped in mapping those characteristics with Systems engineering elements. Systems engineering elements such as Operational Concept Development, System Scoping and Requirements Definition, Architecture Definition, System Integration and QA, V&V, Continuous Process Improvement are having 10 and more high impact IoT characteristics, See Figure 6.

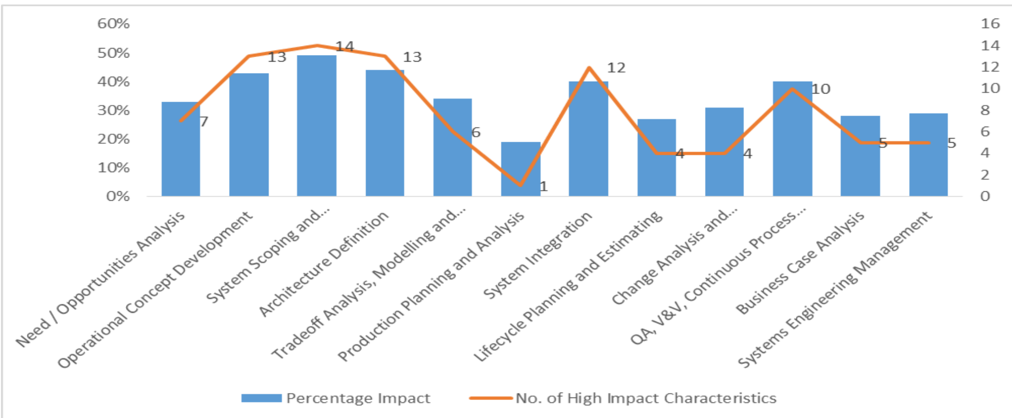

Figure 6. Mapping of High Impact IoT Characteristics and Systems Engineering Elements

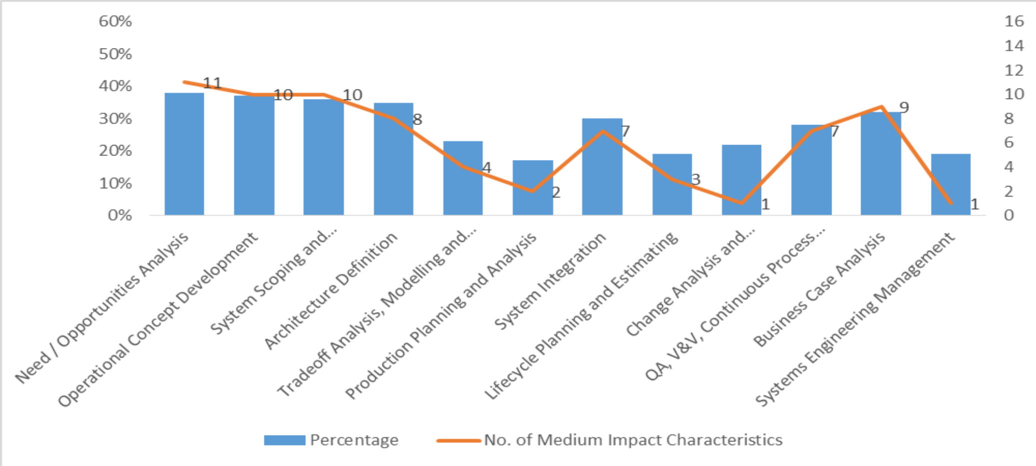

Figure 7. Mapping of Medium IoT Characteristics and Systems Engineering Elements

Systems Engineering elements such as Need / Opportunities Analysis, Operational Concept Development & System Scoping and Requirements Definition are having 10 and more medium impact IoT charactersitics, See Figure 7.

Conclusion

In this paper, the authors have established certain unique characteristics of IoT that could impact the key Systems Engineering concepts. IoT Characteristics such as Interconnectivity, Safety, Connectivity and Security will have largest impact on Systems Engineering methodologies related to the following SEBoK elements.

- Operational Concept Development
- System Scoping and Requirements Definition
- Architecture Definition
- System Integration
- QA, V&V, Continuous Process Improvement

This Investigative research would help future studies to develop more methodologies along the line of thought.

Summary

Literature survey helped in identifying the 27 IoT characteristics. In this paper, authors developed general definitions of IoT Characteristics and its systems engineering applications. Systems engineering professional survey results helped in grouping the High, Medium and Low impact characteristics. Utilized House of Quality to establish linkage between the IoT characteristics and Systems Engineering Elements. Focused interview with System engineering professional was helpful in identifying the characteristics which could impact the System Engineering elements. The methodology developed through this investigative research would help systems engineering professional to assess the impact of system engineering elements. Along with that this research helped in identifying the potential IoT skills for Systems Engineers to spearhead the IoT product development and manage the next generation products and systems.

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Biography

Thirunavukkarasu Ramalingam works at Collins Aerospace Global Engineering Center-India for 12+ years. As a Senior Technical Manager of Mechanical Systems strategic business unit, he is responsible for design and development of Aircraft Cargo Handling Systems & Hoist and Winch Businesses. He is a certified Lean Practitioner with proven track records. He holds a Bachelor degree in Mechanical Engineering and Master of Science in Mechanical systems design. He completed Aerospace MBA from Toulouse Business School, France and won best academic research paper award for 'Assessing the potential of IoT in aerospace'. This paper was published in 16th International Federation for Information Processing conference-2017. He also published paper titled 'How to find a Minimum Viable Product (MVP) in IoTA' at ERTS^2 2018 - 9th European Congress on "Embedded Real-Time Software and Systems", Jan-2018, Toulouse, France.

Daniel Tweten is a Pilot by interest and System Engineer by profession. Dan started his career with Boeing as Hydraulics Systems Engineer. He is currently works at Collins Aerospace as System Engineer for Cargo Handling Systems (CHS). He is FAA certified DER for Aircraft System and Equipment. He led various CHS programs to success including FAA STC. He holds Bachelor degree in Mechanical Engineering from North Dakota State University and he is completing Master of Science in Systems Engineering from Stevens Institute of Technology. He is holds an advanced graduate certificate in Project Management from Penn State University. He is an ASQ CQE.