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A Guide - Systems Engineering and Certification for Beginners

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***Abstract* - The main focus of this paper is to provide overview of Systems Engineering and Systems Concepts. This paper provides a primer to the foundational concepts of Systems Engineering within a framework for overall project success. We will focus on the classic Systems Engineering domains of requirements, behaviour, architecture and V&V. Rather than treating these in isolation, the fundamentals are positioned within a flexible system engineering process suitable for system development tasks across the complexity spectrum. While there is a place for process and documentation standards, our focus will be on eliciting the proper requirements, understanding the problem and solution domain, enhancing communication amongst the design team and the stakeholders, and satisfying the system need. It also provides the introduction to ASPICE and superimpose SE processes with ASPICE processes to provide a high-level knowledge on importance of Quality and Process aspects.**

***Index Terms* - SE (Systems Engineering), ASPICE, SEP Certification, Systems Concepts, Modeling and Simulation, Systems life cycle**

1.INTRODUCTION

Systems Engineering (SE) is an interdisciplinary field of engineering and management that focuses on how to design, integrate and manage complex systems over their life cycles [1]. This paper intends to impart basic introduction to the SE process and its various processes. The organization of this paper is constructed as follows. Section 2 provides an overview of SE. A brief introduction of SE concepts and definitions are given in Section 3, Section 4 describes in detail the system life cycle model. In Section 5, a complete overview of modeling and simulation is provided, Section 6 explains how ISO 15288:2015 standards can be applied throughout the SE life cycle. Section 7 gives an understanding of ASPICE in SE perspective. Section 8 gives an idea about certification available for SE, Section 9 provides conclusion and appropriate references are documented.

SE Handbook defines the discipline and practice of SE for students and practicing professionals alike; it provides an authoritative reference to understand the SE discipline in terms of content and practice. There are 10 chapters available in the SE Handbook. Chapter 1 provides purpose of SE Handbook, Chapter 2 details system life cycle and SE concepts, Chapter 3 describes life cycle model with six stages, Chapter 4 through 8 gives 15288:2015 processes, Chapter 9 explains Modeling and Simulation and Chapter 10 describes Specialty Engineering Activities.

2.SYSTEMS ENGINEERING OVERVIEW

SE is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the full system life cycle [1]. SE integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets customer needs [1]. SE offers greater control and awareness of the project requirements, interfaces, and issues and the consequences of any changes.

SE can be described as “big picture thinking and the application of common sense to projects.” through “a structured and auditable approach to identifying requirements, managing interfaces and controlling risks throughout the project lifecycle” [1]. There are two main objectives of the SE processes. 1) To build the right system, and 2) to build the system right. This means that SE addresses both the task of designing the system as specified and ensuring that the system truly fulfils the customer needs. To do this, SE employs a range of different processes which are defined in ISO 15288 [5]. These processes are tailored to the specific need of the company and the environment in which a particular system is developed.

3.SE CONCEPTS

Based on daily needs, the Systems Engineering Concept (SEC) combines practical experience and technical know-how with a systematic and practical approach to make the systems engineering discipline an integral part of the day-to-day work of the organisation.
The SEC is a concept which in detail describes the systematic methods for development of technical systems of any kind. It ensures a gradual maturing of the system requirements and system design, with continuous stakeholder involvement and system integration checks. The output is a thoroughly verified and validated system design that is documented in a stepwise manner as the design progresses. With the SEC, an organisation obtains both concrete actions and practical tools that enable any company to handle the complex business challenges of today. Listed below are some definitions of various SE concepts. Any system is described in the form of IPO diagram as depicted in Figure 1 [1].

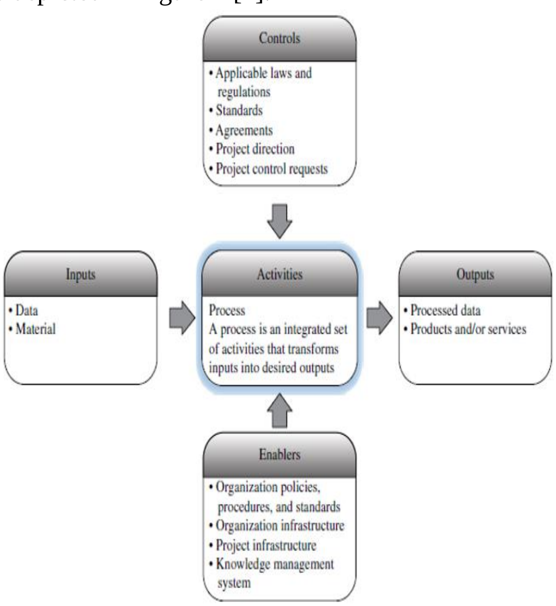

Figure 1: IPO Diagram – Input-Process-Output

System - A combination of interacting elements organized to achieve one or more stated purposes is a System [1].

Process - It is a set of interrelated activities which transforms inputs to outputs [1].

System Element - A system element is a discrete part of a system that can be implemented to fulfil specified requirements. A system element can be hardware, software, data, humans, processes, procedures, facilities, materials and naturally occurring entities (e.g., water, organisms, minerals), or any combination [1].

System-of-Interest - The system whose lifecycle in under consideration is called the System-of-Interest (SOI) [1].

System of Systems - SoS applies to a SOI whose system elements are themselves systems [1].

4.LIFE CYCLE MODEL WITH SIX STAGES

ISO/IEC/IEEE 15288 states: "5.4.1—A system progresses through its life cycle as the result of actions, performed and managed by people in organizations, using processes for execution of these actions" [5]. The life cycle model is the framework that helps to ensure that the system meets its required functionality throughout its life. Categorizing into different stages enables the organization in planning ahead of time, determine costs and staffing decisions, define goals, measure performance and validate points at each phase of the cycle to enhance the quality of the final product. Table 2 tabulates the life cycle stages and its purpose.
Every system life cycle consists of multiple aspects, including the business aspect (business case), the budget aspect (funding), and the technical aspect (product). Decision Gates (control gates, milestones, reviews) represent major decision points in the System life cycle. The systems engineer creates technical solutions that are consistent with the business case and the funding constraints. Primary objective of the Decision Gates is to ensure that the elaboration of the business and technical baselines are acceptable and will lead to satisfactory verification and validation (V&V). Table 1 tabulates the Decision gates with available decision options. "Life cycles vary according

to the nature, purpose, use and prevailing circumstances of the system" [1].

Table 1: Decision gates (Decision options)

Decision gates
Proceed with next stage
Proceed and respond to action items
Continue this stage
Return to preceding stage
Put a hold on project activity
Terminate project

Table 2: System Life cycle stages

Concept	Define problem space Decision options:
	1.Exploratory research
	2.Concept selection
	Characterize solution space
	Identify stakeholder's needs
	Explore ideas and technologies
	Refine stakeholders' needs
	Explore feasible concepts
	Propose viable solutions
Development	Define/refine system requirements
	Create solution description—architecture and design
	Implement initial system
	Integrate, verify, and validate system
Production	Produce systems
	Inspect and verify
Utilization	Operate system to satisfy users' needs
Support	Provide sustained system capability
Retirement	Store, archive, or dispose of the system

Concept stage plays a very crucial role in the development of a system. It is critical that in these early studies, a high-level, preliminary concept be created and explored. Clearly define the problem space, characterize the solution space, identify business or mission requirements and stakeholder needs and, while avoiding any design rework provide an estimate of the cost and schedule for the full-scale development [1]. Development stage begins with the output of the Concept stage which defines and realizes a system of interest (SOI) that meets its stakeholder requirements and can be produced, utilized, supported, and retired. The primary output of this stage is SOI. Key activates involve analyse, architect and design the System so that the System elements and their interfaces are understood and specified. Hardware and software interfaces are coded and evaluated [1]. Production stage of the system is produced or manufactured in this stage. Utilization stage of the system is operated in its intended environment to deliver its intended services [1]. Support stage of the services are provided in order to continue the system operation [1]. Retirement stage of the system and its related services are removed from operation [1].

5.MODELING AND SIMULATION

System model is used to represent a system and its environment. It may comprise multiple views of the system to support planning, requirements, architecture, design, analysis, verification and validation [1]. Simulation is the implementation of a model (or models) in a specific environment that allows the model's execution (or use) over time. Each of these models must be integrated to ensure a consistent and cohesive system representation. Some examples of system models may include the following:

- Functional model - system functions and their functional interfaces
- Behavioural model - overall behaviour of the system functions
- Temporal model - timing-related aspects of the architecture
- Structural model - system elements and their physical interfaces
- Mass model - mass-related aspects of the system
- Layout model - absolute and relational spatial placements of the system elements
- Network model - flow of resources among the applicable system functions or elements

Key activity is to facilitate the integration of M&S across multiple domains and disciplines and Model Management, Modelling Standards, Modelling Languages aid for the same. System models can also be used to specify the elements of the system.

Model Management - Model management includes change management techniques such as branch and merge where the Team is involved in different aspects of modelling [1]. Modeling Standards - System modelling concepts to be adhered for the respective system is defined. Modelling concepts enable communication / data exchange between the modelling elements [1]. Modeling Languages - Modeling languages are generally intended to be both human interpretable and computer interpretable and are specified in terms of both syntax and semantics. Figure 2 represents the SysML diagrams. The SysML from the OMG (Object Management Group) has emerged as an important modeling language for systems [1].

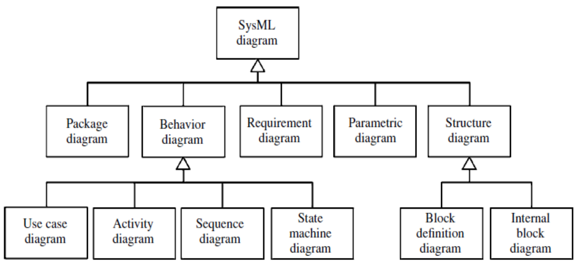

Figure 2: SysML Diagrams

- A package diagram (pkg) is used to organize the model into packages that contain other model elements, facilitates model navigation and reuse.
- A requirements diagram (req) captures text-based requirements, enables fine-grained traceability from requirement to requirement and between requirements and design, analysis, and verification elements in the model.
- System structure is represented using block diagrams:
- A block definition diagram (bdd) describes the system hierarchy and classifications of system elements.
- An internal block diagram (ibd) depicts the internal structure of a system in terms of how its parts are interconnected using ports and connectors, describing how the parts within the system are interconnected.
- Behavior is captured in use case, activity, sequence, and state machine diagrams.
- A use case diagram (uc) provides a high-level description of the system functionality in

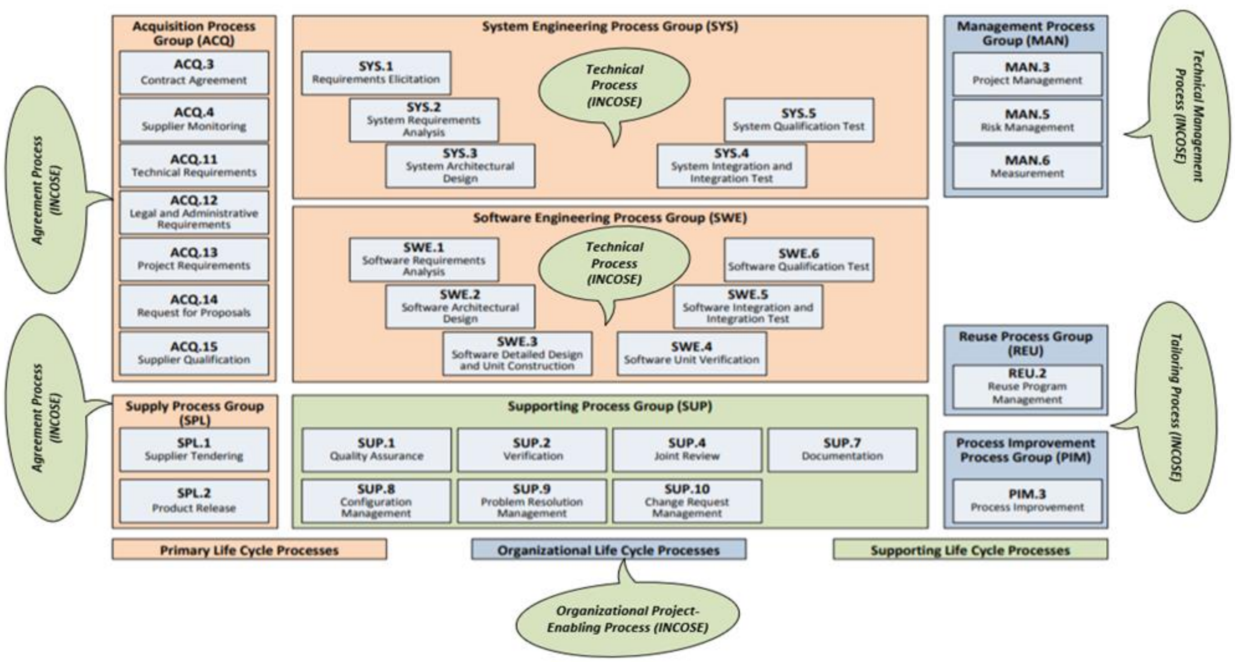

Figure 3: ASPICE + INCOSE Processes

terms of how users and external systems use the system to achieve their goals

- An activity diagrams (act) represents the transformation of inputs to outputs through a controlled sequence of actions
- A sequence diagram (sd) represents interaction in terms of the time-ordered exchange of messages between collaborating parts of a system
- A state machine diagram (stm) describes the states of a system or its parts; the transitions between the states; the actions that occur within states or upon transition, entry, or exit; and the events that trigger transitions.
- A parametric diagram (par) represents constraints on system property values as necessary to support detailed engineering analysis, these constraints

may include performance, reliability, and mass properties, etc.

6.15288:2015 PROCESSES

The ISO/IEC/IEEE technical processes and supporting process activities are invoked
throughout the life cycle stages of a system, as specified in Figure 3.

Figure 4: SE Processes

This is accomplished through the involvement of all stakeholders, with the ultimate goal of achieving customer satisfaction. ISO/IEC/IEEE 15288:2015 concerns those systems that are man-made and may be configured with one or more of the following system elements: hardware, software, data, humans, processes (e.g., processes for providing service to users), procedures (e.g., operator instructions), facilities, materials and naturally occurring entities.

7.ASPICE + SE INCOSE PROCESSES

Automotive Software Performance Improvement and Capability determination (ASPICE) as a standard provides the framework for defining, implementing and evaluating the process required for system development focused on software and system parts in the automotive industry [6]. ASPICE processes can be superimposed upon SE INCOSE processes [1] to emphasize on quality and process adherence perspective as depicted in Figure 3.

8.SEP CERTIFICATION DETAILS

INCOSE offers a multilevel SE professional certification program to provide a formal method for recognizing the knowledge and experience of SEs throughout the world. Three certification levels are available through INCOSE:

1. Associate Systems Engineering Professional (ASEP) Applicants are required to successfully complete a knowledge examination.
2. Certified Systems Engineering Professional (CSEP) requires a minimum of 5 years of practical SE experience, a technical degree (additional years of SE experience can be used in lieu of a technical degree), three professional references covering the candidate's cumulative years of experience, and successful completion of a knowledge examination.
3. Expert Systems Engineering Professional (ESEP) requires a minimum of 25 years of practical SE experience, a minimum of 5 years of professional leadership credits, a technical degree (additional years of experience can be used in lieu of a technical degree), and three professional references covering at least the most recent 10 years of experience. The ESEP award is based on panel review and approval.

9. CONCLUSION

This paper serve as an input for a SE beginner, SE practicing professional who aspire to gain SE knowledge and certification [3,4]. The important references are provided which guides through various links for SE exam preparation and application process [2].

10. ACKNOWLEDGEMENT

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