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Systems Engineering: Enabling Operations Management

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Abstract

Operations management entails performing essential activities for transforming inputs into outputs leading to creation of quality products and services. The proficient implementation of these activities can produce capable organizations able to withstand threats empowering enterprise survival in today's global marketplace. While proficiency strategies vary widely between and within industries, a strong organizational structure is paramount for realization. The development of such a robust corporate foundation necessitates meticulous planning, implementation, and execution of organizational and enabling constructs to ensure product and service deliverables. The employment of system engineering practices facilitates the establishment of this type of durable platform. A system engineering methodology incorporates a holistic approach to the design of quality products (or services) from cradle to grave. The approach includes vital enabling products, such as management and technical products, as well as end products. This chapter explores the systems engineering methodologies to enhance operations management.

Keywords: system engineering, operation management, system philosophy, system thinking, system lifecycle

1. Introduction

This chapter presents an overview of some systems engineering methodologies to enhance operations management. The appropriate application of these systems engineering methodologies reduces the risk associated with the introduction or modification of complex systems [1]. Risk reduction is typically an enterprise objective for new or modified product or service development and delivery. While the sources of risk are extensive and vary from one organization to another, the prevailing risk classifications are cost, time, and performance for system fulfillment.

Implementation of system engineering methodologies toward the management of enterprise operations will assist in this pursuit. Hence, the ultimate expectation of employing these system-engineering methodologies is increasing the likelihood of ultimately achieving customer satisfaction. Therefore, realizing customer satisfaction necessitates utilizing comprehensive measures to reduce risk and achieve system time, cost, and performance requirements [2].

This chapter reviews the dominate concepts of systems engineering and exemplifies the complimentary nature of system engineering to the operation management domain. The similarities between objectives render the system engineering holistic type tactics an excellent option to enhance the likelihood of reducing the before mentioned risk and meet operations management objectives of providing products and services to stakeholders.

Specifically, this chapter considers the systems engineering concepts of system philosophy, system lifecycle, system processes, system design, system analysis, and system management as a means of meeting operations management goals.

2. Systems philosophy

2.1. Systems thinking

The basis for the systems philosophy is the notion of system thinking, which stems from general systems theory. General systems theory considers the creation of logical basis to explain hierarchal relationships of systems throughout the environment [3]. The motivation for developing a general system theory branches from lack of common taxonomy serving the systems community [4]. While the system taxonomy still lacks cohesion across disciplines, the general system theory did establish a coalescing effect on system taxonomy.

To appreciate systems thinking requires the examination of two major governing worldviews. The first worldview is reductionism. A reductionism worldview looks to condense everything into minimal inseparable elements. The incorporation of the corollary notion of mechanism (cause and effect) leads to a worldview governed by analytical thinking. Analytical thinking attempts to explain the whole by the behavior of its parts. Analytical thinking was the preeminent approach during the industrial age [4].

The second worldview is expansionism. Unlike a reductionism worldview, an expansionism worldview considers the whole's behaviors through its connections between and with its surroundings. This expansionism worldview leads to synthetic thinking. Synthetic thinking attempts to explain whole as an integral unit. A synthetic thought philosophy is the basis for systems thinking [4].

While no universal system thinking definition exists, systems' thinking is the perceptual notion considering the entire system as an article focusing on its interaction with its environment. There are certain common critical elements for systems thinking, namely (1) synthetic thought, (2) expansionism (holistic focus), (3) interrelationships, (4) patterns, and (5) environment [5].

2.2. Systems defined

Analogous with the disjointed taxonomy prompting the establishment of the general systems theory is the existence of many system definitions. Here are several definitions of a system.

- *Definition 1:* “A system is anything evolved from elements that need to work together and that affect one another” [6].
- *Definition 2:* A system is “a collection of hardware, software, people, facilities, and procedures organized to accomplish some common” [7].
- *Definition 3:* A system is “any two or more entities interacting cooperatively to achieve some common goal, function, or purpose” [8].
- *Definition 4:* “A system is an interconnected set of elements that is coherently organized in a way that achieves something” [9].
- *Definition 5:* A system is “a number of elements in interaction” [3].
- *Definition 6:* “A system is a construct or collection of different elements that together produce results not obtainable by the elements alone” [10].
- *Definition 7:* “A system is a bounded physical entity that achieves in its domain a defined objective through interaction of its parts” [11].
- *Definition 8:* “A system is a set or arrangement of things so related or connected to form a unity or organic whole” [12].
- *Definition 9:* “A system is a set of interrelated components working together toward some common objective” [13].
- *Definition 10:* “A system is an integrated set of elements that accomplish a defined objective” [1, 14].
- *Definition 11:* A system is “a group of elements, either human or nonhuman, that is organized and arranged in such a way that the elements can act as a whole toward achieving some common goal or objective” [2].
- *Definition 12:* “A system is a set of elements so interconnected as to aid in driving toward a defined goal” [15].
- *Definition 13:* A system “is composed of separate elements organized in some fashion with certain interfaces among the elements and between the system and its environment. In addition, a system tends to affect its environment and be affected by it” [16].
- *Definition 14:* “A system is an assemblage or combination of functionally related elements or parts forming a unitary whole” [4].
- *Definition 15:* A system is “an integrated set of interoperable elements or entities, each with specified and bounded capabilities, combined in various combinations that enable specific behaviors” [17].

An assessment of these definitions reveals some commonalities. One way to view these commonalities is as components, attributes, and functional relationships. The components or elements are the parts of the system formed to constitute a whole, the attributes are the traits of these components, and the functional relationships are the joint component behaviors facilitating the system in fulfilling intended purpose [4].

While the preceding systems descriptions represent the essence of a system definition, some supplemental broad-spectrum system features encompass the embodiment of the systems definition. These features include (1) complex combination of resources, (2) hierarchical structure, (3) interactive subsystems, and (4) functional purpose. Collectively, these system features must react to a functional need [18].

2.3. Systems classification

When describing system forms, several instinctive contrasting system classifications materialize. These systems classifications include natural—manufactured, physical—conceptual, static—dynamic, and open—closed systems [18]. The following define the various system forms.

- *Nature System*: The nature system constitutes a system created by natural processes.
- *Manufactured System*: The manufactured system constitutes a system created through synthetic processes.
- *Physical System*: The physical system is a system assuming a physical construct.
- *Conceptual System*: The conceptual system exists in abstraction.
- *Static System*: The static system does not change state due to no operational or flow components.
- *Dynamic System*: The dynamic system does change state due to operational or flow components.
- *Closed System*: The closed system does not freely interact with its environment.
- *Open System*: The open system does freely interact with its environment [18].

While these system classifications are not all inclusive, the classifications establish a baseline for system identification. Often system boundaries transcend different classifications, such as manufactured—physical system or a dynamic—open system. Certain systems may be hybrid versions of contrasting systems. Consider a modified nature system where a nature system contains an embedded manufactured system, such as a flood control system or a prosthetic knee joint.

3. Systems engineering

3.1. System engineering defined

After over 60 years, many engineers still find themselves confounded by the discipline of systems engineering [19]. Like the definition of a system mentioned earlier, the widely variety

of system engineering feeder disciplines skews the perception of the system engineering discipline significantly. The definition of system engineering varies depending upon perspective. Here are several different definitions of systems engineering.

- *Definition 1:* “Systems engineering is a functionally-oriented, technologically-based interdisciplinary process for bringing systems and products (human made entities) into being as well as for improving existing systems” [4].
- *Definition 2:* “Systems engineering is the multidisciplinary application of analytical, mathematical, and scientific principles to formulating, selecting, developing, and maturing a solution that has acceptable risk, satisfies user operational need(s), and minimizes development and life cycle costs while balancing Stakeholder interests” [17].
- *Definition 3:* “Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems” [20].
- *Definition 4:* “Systems engineering is an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system” [21].
- *Definition 5:* “Systems engineering is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system” [10].
- *Definition 6:* “Systems engineering an interdisciplinary engineering management process that evolves and verifies an integrated, lifecycle balanced set of solutions that satisfy customer needs” [22].
- *Definition 7:* “Systems engineering is a management technology to assist clients through the formation, analysis, and interpretation of the impacts of proposed policies, controls, or complete systems upon the perceived needs, values, [and] institutional transactions of stakeholders” [23].
- *Definition 8:* Systems engineering is a “discipline that develops, matches, and trade off requirements, functions, and alternates system resources to achieve a cost-effective, life-cycle balanced product based upon the needs of the stakeholders” [7].
- *Definition 9:* “Systems engineering is the art and science of assembling numerous components together (including people) in order to perform useful functions” [6].
- *Definition 10:* “Systems engineering is the effective application of scientific and engineering efforts to transform an operational need into a defined system configuration through the top-down iterative process of requirements definition, functional analysis and allocation, synthesis, optimization, design, test, and evaluation” [24].
- *Definition 11:* Systems engineering is “the application of scientific and engineering efforts to: (1) transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test and evaluation, and validation; (2) integrate related technical parameters and ensure the compatibility of all physical, functional, and program interfaces in a manner that optimizes the total definition and design; and (3) integrate reliability,

maintainability, usability (human factors), safety producibility, supportability (serviceability), disposability, and other such factors into a total engineering effort to meet cost, schedule, and technical performance objectives" [25].

- *Definition 12:* "Systems engineering is an interdisciplinary activity that focuses more of systems properties than of specific technologies and has the overall goal of producing optimized systems to meet potentially complex needs. This focus includes specification of necessary systems properties (requirements), large-scale system organization principles (system architecture), definition of flow and events that travel between the system elements in its environment as well as between large-scale architectural elements comprising the system (interfaces) – and the selection of key approaches and technologies through optimization analysis (trade studies)" [26].
- *Definition 13:* "Systems engineering is the art and science of creating whole solutions to complex problems" [27].
- *Definition 14:* Systems engineering is an "interdisciplinary approach governing the total technical and managerial effort required to transform a set of stakeholders needs, expectations, and constraints into a solution and to support that solution throughout its life" [28].
- *Definition 15:* "Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer need and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. Systems engineering 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 the user needs" [1].

While the definitions vary, there are some mutual themes and approaches, namely (1) top-down approach, (2) lifecycles, (3) requirements, and (4) interdisciplinary methodology. The top-down approach is seeing the system in a holistic or big picture manner. The lifecycle lens considers the cradle to grave aspects of the system. The system requirements focus efforts on system development and post-development specification to meet customer expectations. The interdisciplinary nature ensures synergy of efforts throughout the system lifecycle with a reduction in risk [18]. System theory is the basis for systems engineering and consists of interdisciplinary analysis of complex system behavior transcending multiple disciplinary boundaries, such as social sciences, business, science, and engineering [29].

3.2. The engineered system

The result of the application of the systems engineering methodology is a manufactured or natural modified engineered system. Systems theories and thinking establish the underpinning of this approach of creating engineered systems to meet stakeholder's requirements. Well-designed engineered systems possess the following general properties [4].

- *Property 1:* Engineered systems functionality basis is stakeholder needs to realize specified operational objectives.
- *Property 2:* Engineered systems creation basis is to operate over the intended lifecycle from cradle to grave.
- *Property 3:* Engineered systems possess increasing design engagement throughout engineered system lifecycle until the disposal phase.
- *Property 4:* Engineered systems possess a synchronization resource apportionment.
- *Property 5:* Engineered systems consist of elements interacting to generate desirable system behavior.
- *Property 6:* Engineered systems consist of hierarchical elements externally influenced by familial systems and subsystems.
- *Property 7:* Engineered systems operate in the natural world in both desirable and undesirable ways [4].

Additionally, an engineered system contains not only the end product of interest. It also incorporates enabling products to support the end product throughout the end product’s lifecycle, such as development, production, maintenance, and disposal products [16].

3.3. The engineered system lifecycle

The systems lifecycle varies by organization and purpose. Jointly the International Organization for Standardization, International Electrotechnical Commission, and the Institute of Electrical and Electronic Engineers attempted to standardize the system engineering lifecycle in ISO/IEC/IEEE 15288 [28]. **Table 1** shows ISO/IEC/IEEE 15288 system lifecycle. The system lifecycle consists of five primary phases: (1) concept, (2) development, (3) production, (4) utilization and support, and (5) retirement [1, 28].

Table 2 shows a representative high-tech industrial system lifecycle. The system lifecycle consists of three primary periods: (1) study period, (2) implementation period, and (3) operations period. The study period consists of three main activities: (1) product requirements, (2) product definition, and (3) product development. The implementation period also consists of three primary activities: (1) engineering modeling, (2) internal testing, and (3) external testing.

| | | | | |
|---------|-------------|------------|-----------------------|------------|
| Concept | Development | Production | Utilization & support | Retirement |
|---------|-------------|------------|-----------------------|------------|

Table 1. ISO/IEC/IEEE 15288 system lifecycle.

| Study Period | | | Implementation Period | | | Operations Period | | |
|----------------------|--------------------|---------------------|-----------------------|------------------|------------------|-----------------------|---------------------------------|--------------|
| Product Requirements | Product Definition | Product Development | Engineering Modeling | Internal Testing | External Testing | Full-Scale Production | Manufacturing, Sales, & Support | Deactivation |

Table 2. Representative High-Tech Industrial System Lifecycle.

The operations period also consists of three primary activities: (1) full-scale production, (2) manufacturing, sales, and support, and (3) deactivation [1].

Table 3 illustrates the National Aeronautics and Space Administration (NASA) System lifecycle. The system lifecycle consists of two primary stages: (1) formulation and (2) implementation. The formulation stage consists of three primary phases: (1) concept studies, (2) concept and technology development, and (3) preliminary design and technology completion. The implementation stage consists of four primary phases: (1) final design and fabrication, (2) system assembly, integration, test, and launch, (3) operations and sustainment, and (4) closeout [10].

Table 4 illustrates the United States Department of Defense (DOD) system lifecycle. The DOD system lifecycle consists of three major phases: (1) pre-systems acquisition, (2) systems acquisition, and (3) sustainment. The pre-systems acquisition phase consists of concept and technology development activities. The system acquisition phase consists of two primary activities: (1) development and demonstration and (2) production and deployment. The sustainment phase consists of operations, support, and disposal activities [1, 22].

Table 5 depicts a generic system lifecycle for use to illustrate systems engineering deployment to enable operations management. The generic system lifecycle consists of two primary phases: (1) development and (2) post-development. The development period consists of five primary activities (1) definition, (2) design, (3) implementation, (4) integration, and (5) qualification. The post-development period consists of three primary activities: (1) production, (2) utilization, and (3) retirement [16].

| Formulation | | | Implementation | | | |
|-----------------|----------------------------------|--|----------------------------|---|--------------------------|----------|
| Pre-Phase A | Phase A | Phase B | Phase C | Phase D | Phase E | Phase F |
| Concept Studies | Concept & Technology Development | Preliminary Design & Technology Completion | Final Design & Fabrication | System Assembly, Integration & Test, Launch | Operations & Sustainment | Closeout |

Table 3. NASA System Lifecycle.

| Pre-Systems Acquisition | | Systems Acquisition | | Sustainment |
|------------------------------------|--|-------------------------------|--|-----------------------------------|
| Concept and Technology Development | | Development and Demonstration | | Operations, Support, and Disposal |

Table 4. DOD system lifecycle.

| Development | | | | | Post-development | | |
|-------------|--------|----------------|-------------|---------------|------------------|-------------|------------|
| Definition | Design | Implementation | Integration | Qualification | Production | Utilization | Retirement |

Table 5. Generic System Lifecycle.

Considering the generic system lifecycle as an exemplary for enabling operations management via systems engineering, necessitates a closer look at the activity and objectives of a generic system lifecycle. As the name implies, the development phase encompasses the activities involved in developing a system from original needs identification to commencing with production runs. **Table 6** catalogues the primary activity objectives during the development phase [16].

Likewise, with the development phase, **Table 7** catalogues the primary activity objectives during the post-development phase [16].

The engineered system lifecycle consists of both the development and post-development phases, as previously mentioned is inclusive of both the end project and the enable products encompassing the engineered system.

3.4. Systems engineering processes

ISO/IEC/IEEE 15288 indicates four distinct system lifecycle process groups, namely, agreement processes, technical processes, technical management processes, and organizational project-enabled processes [1, 28].

- *Agreement process group*: Since organizations are both originators and customers of systems, the agreement processes encompass the processes necessary to realize contracts between organizations. Agreement processes consist of two system lifecycle processes: (1) acquisition and (2) supply.
- *Technical process group*: The technical process group involves any technical activities utilized throughout the system lifecycle from cradle to grave to insure the system meets the stakeholder needs. Technical processes consist of 14 system lifecycle processes: (1) business or mission analysis, stakeholder needs and requirement definition, (3) system

| Activity | Objective |
|----------------|--|
| Definition | Formulate system operational concepts and create system requirements |
| Design | Develop technical concept and architecture for system. |
| Implementation | Create or purchase elements of system |
| Integration | Combine system components into a complete system. |
| Qualification | Perform prescribed and operational quality tests on integrated exemplar system |

Table 6. Development phase objectives of generic system lifecycle.

| Activity | Objective |
|------------------------|---|
| Production | Replicate completed system in applicable numbers |
| Operations and support | Operate system effectively in projected environment |
| Disposal | Dispose properly of system at end of useful life. |

Table 7. Post-development phase objectives of generic system lifecycle.

requirements definition, (4) architecture definition, (5) design definition, (6) system analysis, (7) implementation, (8) integration, (9) verification, (10) transition, (11) validation, (12) operation, (13) maintenance, and (14) disposal.

- *Technical management process group*: The technical management process group involves needed management activities related to asset allocation to discharge organizations agreements including programmatic measures. Technical management processes consist of eight processes: (1) project planning, (2) project assessment and control, (3) decision management, (4) risk management, (5) configuration management, (6) information management, (7) measurement, and (8) quality assurance.
- *Organizational project-enabling process group*: The organizational project-enabling process group compasses activities involving resources to support project completion to meet stakeholder expectations. Organizational project-enabling processes consist of six processes: (1) life cycle model management, (2) infrastructure management, (3) portfolio management, (4) human resource management, (5) quality management, and (6) knowledge management [1, 28].

The systems engineering methodology incorporates the processes contained within these system process groups in a hierarchical fashion.

The International Counsel on Systems Engineering (INCOSE) incorporates a functional modeling approach via an input-process-output (IPO) diagram to organize and display pertinent data on a particular system engineering process. The construction IPO diagram contains five elements: (1) inputs, (2) process activity, (3) output, (4) controls or constraints, and (5) enablers or mechanisms. **Figure 1** shows a system engineering IPO diagram [1].

The inputs block includes necessary items for the process such as system requirements, organizational structure, raw materials, data, documentation, and so on. The outputs block includes expected process results, such as stakeholder ready system/product/service, supporting resources, residue, and so on. The enablers block includes items to assist the process such as human

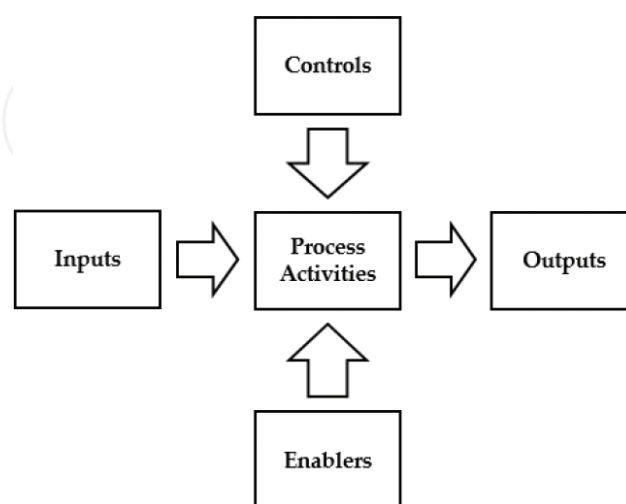


Figure 1. System engineering IPO diagram.

resources, materials, liquids, computers, facilities, maintenance, support, and so on. The controls block includes process boundaries such as technical, political, sociological, economic, environmental, and so on [4, 18, 25].

3.5. Systems engineering process models

There are several system engineering process models to depict the system lifecycle. The first is the waterfall model as shown in **Figure 2**. The original use for the system engineering waterfall model was for software design.

The systems engineering spiral model is an adaptation of the waterfall model. **Figure 3** illustrates the spiral model. Notice the four distinct quadrants equating to the major area of the system engineering process, namely, identify, design, evaluate, and construct.

Returning to the generic system lifecycle, a common model depicting the system engineering process is the “Vee” model, appropriately named due the V-shape formed by the activities of the model. **Figure 4** illustrates a generic system lifecycle in a Vee model.

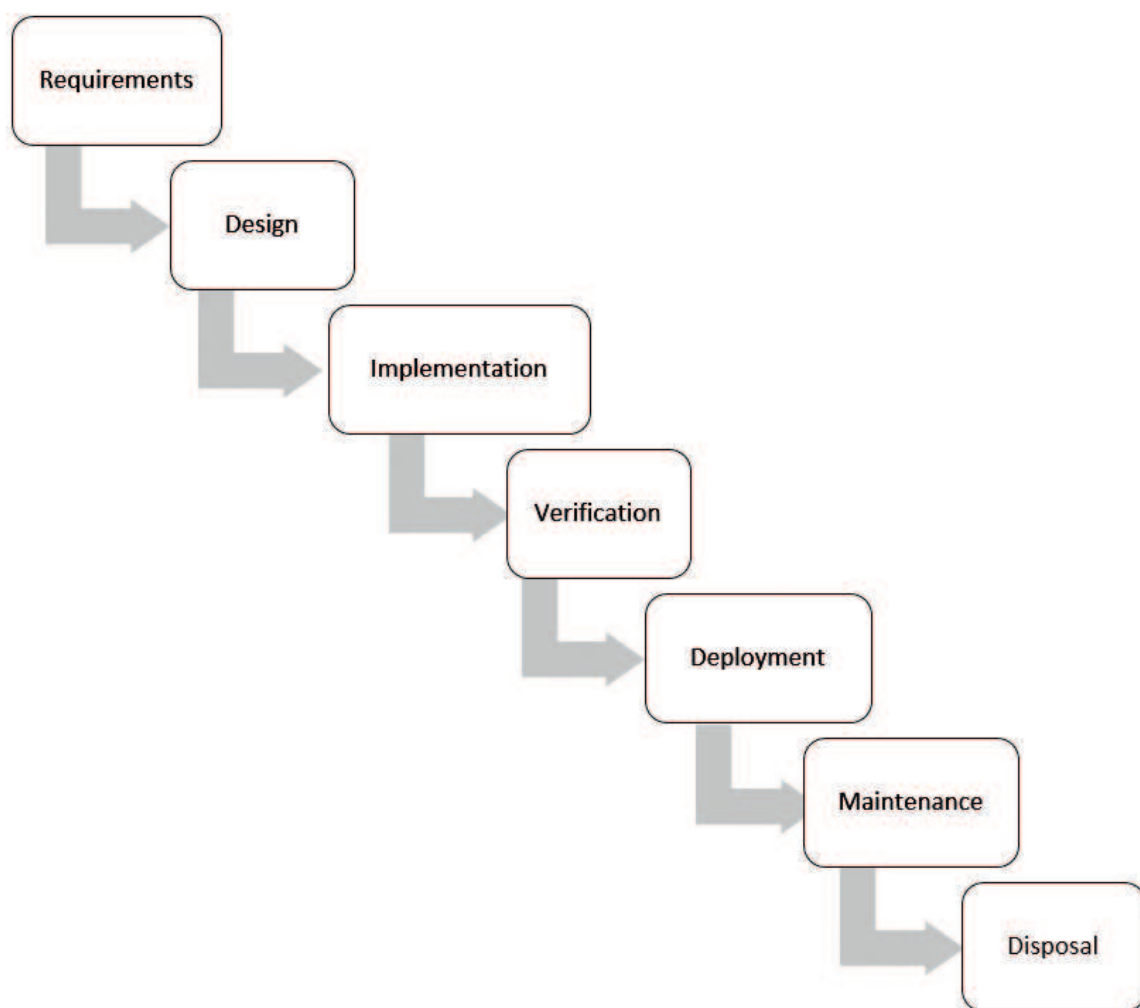


Figure 2. Waterfall system engineering process model.

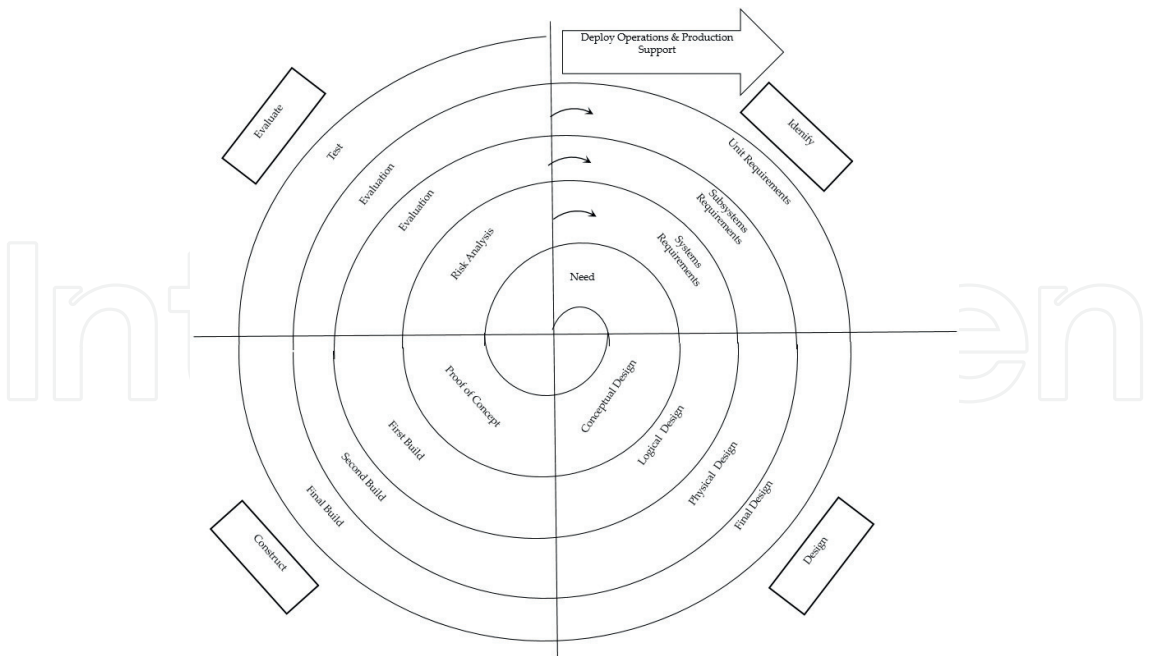


Figure 3. Spiral system engineering process model.

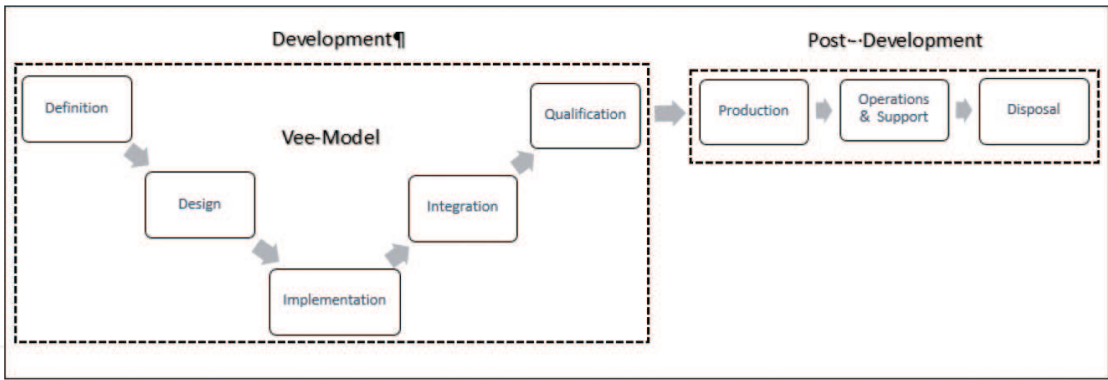


Figure 4. Generic system engineering process Vee-model.

The V-shape occurs during the development of stage of the system lifecycle. The left side of the Vee-model embodies processes for system decomposition, architecture, and design with meeting stakeholder desires and the right side of the Vee-model embodies processes for system integration, verification, and validation culminating in entrance into the post-development production activity. The Vee-model indicates the development of the system from customer needs to production. The post-development indicates the production, operations, and disposal of the system. The Vee methodology considers time and system maturity moving from left to right during system formulation. The process is also incremental and iterative to respond to system tradeoffs [1, 4, 16].

4. System engineering management

4.1. Management plan

The defining document for system creation is the Program Management Plan (PMP), also known as the Project Management Plan (PMP), also known as the Engineering Program Plan (EPP). The PMP distinguishes ascertains processes, critical milestones, and events. The basis for PMP development is the statement of work (SOW), which includes (1) summary statement of tasks, (2) task input requirements, (3) specification reference identification, and (4) specific results description. Typical PMP events include technical reviews, engineering releases, trial and tests releases, production releases, acceptance testing, logistics support, audits, and progress reviews [16, 18].

The PMP leads to the establishment of the Systems Engineering Management Plan (SEMP). The SEMP dictates the implementation of the system engineering procedures. Initiation of the SEMP occurs early in the process during the definition phase of the system lifecycle. The basis for the SEMP is the SOW from the PMP. Three of the primary activities incorporated in SEMP are (1) development program management, (2) systems engineering process, and (3) engineering specialty integration. Development program management includes organization, scheduling, risk management, and so on; systems engineering process includes requirements, functional analysis, trade-offs, and so on; and engineering specialty integration includes reliability, maintainability, producibility, and so on [13].

The SEMP is the top-level blueprint for systems engineering, forms the overall strategy for technical project advancement encompassing activities milestones, organization, and resources requirements to accomplish necessary functions and tasks, and requires modification or tailoring to meet the stakeholder requirements [1, 4, 18].

4.2. Tailoring

Tailoring involves altering of SEMP strategy and planning processes to align more closely with stakeholder requirements. There are three general tailoring categories: (1) organization or project, (2) programmatic risk, and (3) product or service. Organization or project tailoring could include adjustments for size, complexity, or type, programmatic risk tailoring could include adjustments for schedule, budget, or performance, and product or service tailoring could include adjustments for criticalness, complexness, innovativeness, precision, improvements, or certification specifications [16]. While there are many approaches to the tailoring process, some critical activities for the tailoring process include identification and documentation of tailoring influences, compliance with applicable standards, stakeholder input on tailoring decisions, lifecycle process selection requiring tailoring, and rendering tailoring decisions [1].

4.3. Product-based systems

Product-based systems encompass development and delivery of commodities or goods. The product-based system consists of the end product and accompanying enabling products. The

enabling products include products to support the end product throughout the product-based system lifecycle. The end product of a product-based system is the commodity or good itself [16]. Some characteristics of product-based system include tangible end product, production in advance of consumption, intellectual property rights, complimentary products, fixed cost structures, generic product knowledge, and long-term relationship with stakeholders [30].

4.4. Service-based systems

Comparable to product-based systems, service-based systems also include enabling products to support the service-based systems throughout the service-based system lifecycle. However, the end product is service instead of a commodity or good. Services entail activities transforming the state of an entity by jointly contracted terms between service provider and customer. Nine service system entities are to be discussed: (1) customer, (2) goals, (3) inputs, (4) outputs, (5) processes, (6) human enablers, (7) physical enablers, (8) informatics enablers, and (9) environment [1] as shown in **Figure 5**.

Spohrer and Maglio define a service system as a system that “enables a service and/or set of services to be accessible to the customer (individual or enterprise) where stakeholders interact to create a particular service value chain to be developed and delivered with a specific objective” [31]. There are three basic service systems types: (1) flow, (2) human activities, and (3) governing. Flow service systems may include transportation, supply chain, energy, information, and so on; human activities service systems may include construction, retail, healthcare, and so on; and governing service systems may include education, national defense, and so on [1, 31, 32]. Alternatively, Fanrich and Meiren [33] suggested four service system focuses: (1) process-focused, (2) flexibility-focused, (3) customer-focused, and (4) knowledge-focused service systems.

Some important key characteristics distinguishing services systems from product systems include (1) direct face-to-face contact, (2) ill-defined merits of quality and productivity, (3) reusable key assets, (4) utilized equipment often unprotected by intellectual rights, (5) focus on technology understanding, (6) necessitates utilization of technology, and (7) requires incorporation of technology management strategy [30]. The design and operations of service

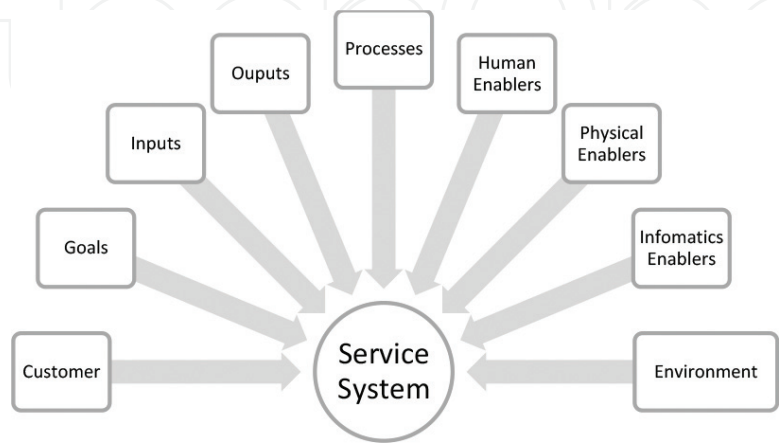


Figure 5. Service system entities.

systems “is all about finding the appropriate balance between the resources devoted to the systems and the demands placed on the system, so that the quality of service to the customer is as good as possible” [1, 34].

4.5. Operation management

Bateman and Snell [35] define management as “the process of working with people and resources to accomplish organizational goals. “Referring to this management spectrum, three fundamental planning domains emerge (1) tactical planning, (1) operational planning, and (3) strategic planning. Tactical planning occurs at the functional level and focuses on the short term, operational planning occurs throughout the organization and focuses on the intermediate term, and strategic planning occurs at the upper level of the organization and focuses on the long term. There are many definitions of operations management; some definitions of operations management are given as follows:

- *Definition 1:* “Operations management is the management of systems or processes that create goods and/or services” [36].
- *Definition 2:* “Operations management refers to the systematic design, direction, and control of processes that transform inputs into services and products for internal, as well as external customers” [37].
- *Definition 3:* “Operations management is the business function that plans, organizes, coordinates, and controls the resources needed to produce a company’s products and services” [38].
- *Definition 4:* “Operations management is the design, operation, and improvement of productive systems” [39].
- *Definition 5:* “Operations management is the set of activities that creates value in the form of goods and services by transforming inputs into outputs” [40].
- *Definition 6:* “Operations management, as a field, deals with the production of goods and services” [41].
- *Definition 7:* Operations management is the “effective planning, organizing, and controlling of the many value-creating activities of the firm” [42].
- *Definition 8:* Operations Management is “the process of managing the system of designing, producing, and delivering goods and services that add value throughout the supply chain and benefit the final customer” [43].
- *Definition 9:* “Operations management is the science and art of ensuring that goods and services are created and delivered successfully to customers” [44].
- *Definition 10:* “Operations management is the activity of managing the resources that create and deliver services and products” [45].
- *Definition 11:* “Operations management is about giving customers what they want while making good use of inputs and resources so that costs are low enough to yield a profit” [46].

- *Definition 12:* “Operations and supply chain management is defined as the design, operations, and improvement of the systems that create and deliver the firm’s primary products and services” [47].
- *Definition 13:* Operations management is “the planning, scheduling, and control of the activities that transform inputs into finished goods and services” [48].
- *Definition 14:* Operations management is the “management of the transformation process that converts labor, capital, materials, information, and other inputs into products and services for customers” [49].
- *Definition 15:* “Operations management is the management of processes used to design, supply, produce, and deliver valuable goods and services to customers” [50].

Based on these definitions, operations management entails performing essential activities for transforming inputs into outputs. This is congruent with the objectives of systems engineering. Essentially, operations management answers questions relating to what activities are relevant to delivery of goods and services. System engineering expands the “what” into how processes to reduce the cost, schedule, permanent risk measure for product-based or service-based system realization.

5. Conclusions

This chapter examined some fundamental methodologies of systems engineering and equates these activities to operations management. Essentially, operations management answers the “what” question and system engineering answer the question of “how” regarding delivery of goods and services to the end user. System philosophy is the holistic nature of thinking which allows a big picture view of the system. This system philosophy is the basis system of engineering process. The driving focus of system engineering is to address the three major drivers of products or services, namely cost, performance, and time in an efficient manner while meeting stakeholder requirements. The processes employed by systems engineering provide an orderly approach of transforming inputs into outputs to deliver these products and services while lessening stakeholder risk. Not only will system engineering provide the means to accomplish this, it will reduce cycle time for new products and services enhancing an organization’s competitiveness in the market.

In the future, incorporation of modern technology will influence the direction of both systems engineering and operations management processes and techniques, such as adaptive manufacturing, robotics, artificial intelligence, virtual warehousing, big data, drones autonomous vehicles, socio-technical networks, and so on. Organizations able to response swiftly to changing spatial-temporal dynamics of stakeholder requirements will survive. Adapting approaches comparable to agile systems engineering will assist organizations with meeting service and product system design parameters for the predictable shortened lifecycles resulting from increased technology utilization. These forecasted approaches will permit effective creation of quality goods and services to deliver to the customer at a reduced risk, which is the ultimate goal of operations management.

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