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Chapter 1

Introductory Chapter: Background and Current Trends in Operations Management

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Additional information is available at the end of the chapter

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1. Introduction

Operations management (OM) may be considered to be a multidisciplinary field that focuses on effectively managing an organization's processes for the production and distribution of specific products and services. It applies both qualitative and quantitative concepts and techniques to increase process efficiency and effectiveness, reduce costs, assure high-quality output, and improve organizational flexibility to changing demands.

While some authors trace the roots of OM to much earlier periods (e.g., [1]), operations management began to truly define itself during the industrial revolution of the late 1800s and particularly the early 1900s. Taylor [2] developed efforts in standardization and specialization, with a focus on workers, their tasks, and how to effectively manage them. This leads to the formalization of such OM sub-disciplines such as product design, production scheduling, inventory control, capacity planning, and quality management. Throughout much of the twentieth century, operations management had such a manufacturing orientation that it was referred to as factory management and later production management.

In 1973, Bell [3] postulated that the economy would soon provide more value and employment from the service industry than from the manufacturing industry. Reflecting this transformation, the service industry in the United States currently accounts for approximately 80% of this country's gross domestic product [4]. As the economy transitioned, the tools and techniques of traditional production management were quickly adapted for service industry applications. In recognition of this shift, within 5 years of Bell's book, the field was already beginning to be referred to as production and operations management (e.g. [5, 6]).

Continued adaptation and expansion of the OM perspective occurred as attention further shifted toward analysis of the supply chain. Originally, the supply chain only referred to the flow of materials from outside sources to the internal company user. This was extended to include the flow of materials, information, and services from raw material suppliers, through factories and warehouses, to the end customers. As factory-centric and service-centric improvements were progressively made, and associated gains in efficiency and effectiveness obtained, greater opportunities for improvement were viewed as existing in this expanded supply chain context. The idea of supply chain management (SCM), that is, the effective planning, organizing, and coordinating of a supply chain's activities, began to emerge. Articles discussing this approach began to appear in the literature during the mid-1990s (e.g., [7]). This trend continues to this day, emphasizing its continued prominence as an area of research and investigation [8, 9]. The assimilation of supply chain management completed the integrated and comprehensive view of business processes in the production of goods and services, thus forming the present concept of operations management [1].

2. Current status and trends

As observed by Gunasekaran and Ngai [4], "the management of operations in both manufacturing and service organizations has evolved tremendously over the years." The authors further note four trends that have emerged and will continue to affect the field of operations management [4]:

- "The market has become global, thereby compelling enterprise operations to keep up."
- "Consciousness toward the environment."
- "The application of information technologies …in managing operations has altered the landscape of operations management."
- "Manufacturing has become more of a service industry, indicating significant service OM, including project management."

These trends are not mutually exclusive but interweave with each other in varying degrees.

3. The global economy

Operations management has had to evolve to address the global economy and its expanding manufacturing and service competitiveness. One early impact of globalism was the response to Japanese competitiveness in productivity and quality during the 1980s, with the subsequent widespread adoption of Japanese production techniques, such as total quality management (TQM) and just-in-time (JIT) scheduling [1].

The importance and influence of emerging economies on the world's economy has been well documented [10]. The era of global capitalism is considered to have begun with the collapse of the Soviet Union and the commitment of China to implement capitalism. As the market became increasingly global, it required companies to transition toward international operations, joint ventures, and further outsourcing. Supply chain management then became critical due to this worldwide sourcing of products. Both smaller and developed economies will continue to face challenges derived from the competition of emerging economies, not only in manufacturing, "but also in the development of innovative products and services" [4].

4. Sustainability

Interest in sustainability and the relevance of operations management to it have increased over the past decade. OM research and practice has begun to respond to demands to address this issue of sustainability. These efforts include product design with consideration of design for the environment (DFE) concepts; process improvement incorporating lean operations; and logistics including recycling and the use of closed-loop systems [11]. Walker et al. [11] further note the initial focus on resource productivity, that is, the need to reduce resource consumption and utilize resources more efficiently. This included an emphasis on green products and processes and reduction of CO_2 emissions and other wastes.

The literature has indicated a recent shift in emphasis from standalone sustainability to more cross-functional considerations, such as sustainable supply chains. This also includes a deeper and broader investigation of social and humanitarian concerns.

5. Information technology and quantitative methods

Over the past 20 years, information technology/information systems (IT/IS) has transformed the operations and functions of companies. The advancement of IT/IS created a vehicle for enterprise-wide integration. As a result, conventional OM functions (e.g., production planning and control, and logistics) have had to adapt and incorporate the internet, enterprise resource planning (ERP), third-party logistics (3PL), knowledge management, radio frequency identification (RFID), and customer relationship management (CRM). ERP has become an integral part of global supply chain management. It would be almost impossible to achieve a well-integrated supply chain without the application of an effective ERP system and the internet [12]. Currently, companies' efforts are focused on developing an RFID-based supply chain to deliver further improvements in business visibility and customer service [4].

Underlying many of these IT applications are the enhanced use of quantitative methods. These quantitative methods may include such analytical approaches as decision theory, heuristics, operations research/management, science-based mathematical models, simulation, and statistical/probabilistic methods. Gunasekaran and Ngai [4] outline a number of quantitative methods that could be used to model and analyze future operation management functions based on these current and emerging trends.

6. Changes in the manufacturing and service industries

The respective profiles of the manufacturing and service industries have changed due to these influences of globalism, IT/IS, and environmental concerns. Companies have been further compelled to compete based on an array of performance criteria, such as price, quality, flexibility, dependability, and responsiveness. Thus, they have had to develop the following operational techniques and strategies: (e.g., [13]):

- Lean manufacturing is a system-based methodology for the reduction and elimination of waste in all its forms [14]. These lean concepts have been extended to service operations and delivery.
- Agile manufacturing as a key component of operational flexibility [12]: This may include the use of reconfigurable manufacturing systems, which are designed for rapid change in structure and components to respond to sudden market changes
- Business process reengineering (BPR) infers a basic restructuring of essential business functions and processes to optimize the workflow and productivity in an organization [15]. This optimization is measured in terms of performance indicators, including cost reduction, and increases in revenue and profitability, which are then mapped with the processes to which they apply.
- Supply chain management is increasingly treated more as a strategic and cross-functional activity in the context of a global operating environment [13]. This includes the development of build-to-order supply chains and other configurations that support a greater level of flexibility and customer responsiveness.
- Systems engineering entails a logical sequence of events which converts a set of requirements into a complete system description that fulfills the objective in an optimum manner [16]. It provides a framework to integrate these progressively more complex techniques.
- Project management has long been considered to be an OM topic [13]. As manufacturing has shifted from mass production to mass customization, the capability of project management to address unique aspects "has regained its importance in global enterprise environments and operations" [4].

7. Summary

Over time, the field of operations management has grown in depth, breadth, and importance. It incorporates both engineering and behavioral concepts, and utilizes quantitative analysis techniques (now often fielded via an IT/IS platform), for systematic management decision-making. Research in OM continues to evolve in terms of topics, themes, motivations, and methodologies. This book examines some of these recent advances.

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Chapter 2

Supplier Management in Service Industry: What can be Learned from Automotive Manufacturing?

Robert G. Batson

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Abstract

The objective of this chapter is to describe how many of the supplier management practices of the U.S. automotive industry can provide learning points for those who manage service organizations. After a review of the four service sectors (distributive, producer, social, and personal services), we define supplier management. The three main functions within supplier management—control, improvement, and planning—are illustrated and discussed. The suppliers for a specific service are even more diverse than those cited for an automotive OEM; many services use suppliers from each of the other service sectors. Consistent with automotive OEMs, service companies outsource all three categories of supplies—goods, services, and software—though the proportions and contribution of each supply category to operational excellence may differ. Service operations experience waste, and we review the accepted list of eight wastes for service operations, noting that each of these wastes could be caused by a supplier. Essential practices of supplier management for a service industry are organized around the concept of customer-supplier partnership, a six-step hierarchy first identified for automotive OEMs. With the addition of two more imperatives, assure service dependability and manage the service supply chain, we explain how these eight practices may be adapted to services.

Keywords: service sectors, supplier quality, supplier management, supplier planning, supplier improvement, supplier control, service supply chain

1. Introduction

Zhou et al. [1] state that in operations management, "the study of services has lagged the study of manufacturing," noting that "service firms also transact with their suppliers and service their downstream customers. This very much resembles the classic manufacturing supply chain structure." The purpose of their 2009 article was "to identify and discuss major findings that contrast service and manufacturing supply chains as well as adding an operations management perspective to existing understandings." Their research can be viewed as a response to earlier articles in the *Journal of Operations Management* concerning the evolution of service operations management. The research presented here addresses supplier management in services and can be viewed as yet another step in that evolution, suggesting what a service industry might learn from world-class supplier management practices used in manufacturing supply chains.

Modern automotive original equipment manufacturers (OEMs) each employ a version of the Toyota Production System [2] and manage all facets of the relationship with their first tier external suppliers using a formal system of supplier management. Rather than focus on the "lean" practices for which these OEMs have become world-famous, the objective of this chapter is to describe how many of the supplier management practices of the U.S. automotive industry can provide learning points for those who manage service organizations. In particular, it will be useful to review the eight sources of waste (muda) in service systems to frame the beneficial role supplier management might play in improved efficiency of the service supply chain.

A simple definition of service is "work performed for someone else." Quinn and Gagnon's [3] definition is "Services are all those economic activities in which the primary output is neither a product nor a construction." Product-oriented sectors of the U.S. economy always produce a tangible product; a service may or may not terminate in a tangible product. Services are rendered on demand—either instant demand or scheduled demand—often with the customer present and involved in the service transaction. Therefore, the reliability characteristic "ready on demand" is critical for high-quality service. Once service begins, uninterrupted service (again, a reliability characteristic) is another customer expectation. As explained by Andres-Lopez et al. [4], there are five inherent characteristics of service found in the literature: Intangibility; Inseparability—the service's generation and consumption often occur simultaneously; Variability in response to specific customer requests may be intentional—information gets transformed into customized action in an attempt to satisfy the request; Perishability—services generally cannot be inventoried, though there are exceptions (consider college courses that are delivered asynchronously to distance education students); and Lack of Ownership. In contrast, a manufactured product is tangible, produced, and consumed at different locations at different times, expected to be of consistent quality, to be inventoried with like items, and to have clear ownership as it changes hands. These authors put forth a more detailed definition of service: "A set of one-time consumable and perishable benefits delivered by a service provider commissioned to the consumer needs, which are consumed and utilized by the triggering service customer."

It has been observed that when the totality of service sectors are considered, such as social, financial, and personal services, service quality depends as much on human reliability as equipment reliability. According to Zimmerman and Enell [5], service quality is "fitness for use as determined by those features of the service that the client recognizes as beneficial." A well-known summary list of service quality determinants was published by Ghobadian et al. [6]: Reliability, Responsiveness, Customization, Credibility, Competence, Access, Courtesy, Security, Communication, Tangibles, and Understanding the Customer. Consider how closely these characteristics parallel the expectations which U.S. consumers hold for the OEM that designs and manufactures their new automobile. Suitable modifications would of course apply, such as broadly interpreting service reliability—providing the pledged service on time, accurately, and dependably. Such parallels are the basis for this chapter.

"Service quality is the extent of alignment between customer expectations and their perceptions of provided service" [4]. Service quality matters a great deal to the economic prosperity of the U.S. In the microeconomic sense, Lewis [7] observed "service quality is considered a critical determinant of competiveness" because it:

- Sets expectations for the future.
- Affects repurchase intentions.
- Affects what customers say to other potential customers.
- Attracts new customers, if perceived to be high.

Drucker [8] convincingly argued that the macroeconomic competitiveness of postindustrial societies (such as the U.S.) depends on improving the productivity of knowledge workers, who for example make up 40% of the U.S. workforce. He notes that many knowledge workers depend on specialized information, facilities, and equipment to render their service, and that "productivity of the knowledge worker is not—at least primarily—a matter of quantity of output. Quality is at least as important." In this well-known article, Drucker clearly viewed the assembly worker at an automotive OEM to be a knowledge worker (using both his brain and hands), in addition to the more obvious engineers, accountants, purchasing agents, and other professional employees. Quality Management at the OEM has become systematized, with functions of quality planning, quality improvement, and quality control. Each automotive OEM has a quality management system (QMS), which may or may not be registered to the international QMS standard ISO 9000. Supplier quality is considered extraordinarily important, given the extensive content of modern vehicles purchased from suppliers and delivered just-in-time or just-in-sequence to the assembly plant. Quality planning addresses model year changes to "design in" quality to next-generation modules or parts and efficiency in the good's production and supply chain processes. Most OEMs practice continuous quality improvement inside their plants and employ supplier quality engineers to extend the QMS into supplier plants and the manufacturing supply chain that connects them to each other and the OEM. Quality control is exercised item-by-item and delivery-by-delivery, in an attempt to pass on the correct items, in the correct quantity, at the correct time, with correct packaging/identification, and to the next customer in the supply chain. Control implies that defects are detected quickly, removed from production flow, and replaced. The focus of the QMS is of course on prevention of defects, not detection and correction. In a real sense, supplier quality management as practiced at the modern automotive OEM is a well-developed practice of supply chain risk management.

The service sector of the economies of developed countries has exhibited steady growth over the past 60 years, in percent of employment and percent of gross national product (GNP). Even in 1950, 55% of U.S. workers were service workers (contrasted with 26% in France).

Today, over 75% of British and U.S. workers, 65% of French workers, and 60% of workers in Germany and Japan are service workers. A total of 70% of GNP is attributed to services in Belgium, France, the U.K., and the U.S.

Prior to 1975, the best-known explanation of national economic development was built into the Fisher-Clark three-sector scheme with 11 industry types, with Service listed last:

- Primary sector: Agriculture, Mining, Fishing, Forestry.
- Secondary sector: Manufacturing, Construction, Utilities.
- Tertiary sector: Transportation, Communication, Commerce, Service.

Over time, the percent of economic activity in a country's primary sector shifted first toward secondary and then toward tertiary due to productivity gains and the rising per capita income that stimulated the demand for a variety of services. As service industries expanded in the developed world, a new sectoral scheme was needed.

In 1975, Browning and Singlemann published a landmark study funded by the U.S. Department of Labor, *The Emergence of a Service Society* [9]. They proposed six sectors, four of which are services, to better capture the economic activity in the U.S.:

- Extractive (identical to primary).
- Transformative (identical to secondary).
- Distributive services (transportation, communication, wholesale and retail trade).
- Producer services (financial, insurance, engineering, law, business services).
- Social services (health, education, welfare, and government).
- Personal services (domestic, lodging, repair, entertainment).

They observed that the big shift over the decades of the 1930s–70s was not into services per se but very predominately a shift into producer and social services. For purposes of this chapter, the two "goods-oriented" service sectors, distributive and producer services, are most important because they include services that would most benefit from supplier management. They are situated between the first two "production" sectors and the last two "consumption" sectors. Although Browning and Singlemann placed utilities in the transformative sector, we are going to make a distinction between electric power generation (clearly transformative) and electric power distribution, which along with pipeline services (natural gas, water, etc.) shall be classified as a distributive service. Note also that distributive services, in turn, support all economic sectors. A failure in distributive service will affect direct customers in *all* economic sectors, including other distributive services. If the failure duration extends into minutes, hours, or even days, customers of the failed distributive services experience indirect or "cascading effects." This vulnerability of interconnected infrastructures has been recognized by Chiles [10], Little [11], and others.

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2. Background on supplier management

The Gartner Group defines supplier management to be "the process that enables organizations to control costs, drive service excellence, and mitigate risks to gain increased value from their vendors throughout the (procurement) deal's life cycle." In fact, it has been said that to limit financial, business, and reputational risk, it is crucial to properly manage suppliers. Supplier Management can be conceptualized as a part of (at the intersection of) purchasing management, quality management, and supply chain management as suggested in **Figure 1**. Supplier management begins with the establishment of performance expectations specific to the supplier's goods and services, with the understanding that each supplier put under contract will have its performance measured and tracked on an appropriate time basis, which could be minute-by-minute, hourly, daily, monthly, quarterly, etc. The three main functions within supplier management are control, improvement, and planning as illustrated in **Figure 2**. These three functions coincide with what Juran called the Quality Management "Trilogy" [12], adapted to Supplier Management. Supplier planning results in the performance expectations mentioned above, which may be written with a current supplier in mind or be put out for bid. If there is more than one candidate supplier (which may be preferable for competition and risk avoidance), another part of supplier planning would be "sourcing" carried out by purchasing professionals. Supplier improvement is another expectation built into any automotive OEM's contract with a supplier, where improvement could be expected in any performance criterion, especially those where chronic under-performance is detected. Supplier control (costs, quality, delivery performance, accuracy of billing, etc.) is a fundamental function of supplier management—repetitive measurement of supplier performance, identification and reaction to upsets and unexpected events, and assuring rapid restoration of the status quo by the supplier.

Consider first the way in which parts suppliers are organized for an automotive OEM. There are tiers, and the first tier is considered most important—delivering subassemblies (modules) or individual items (body molding, paint) that are integrated directly into the vehicles

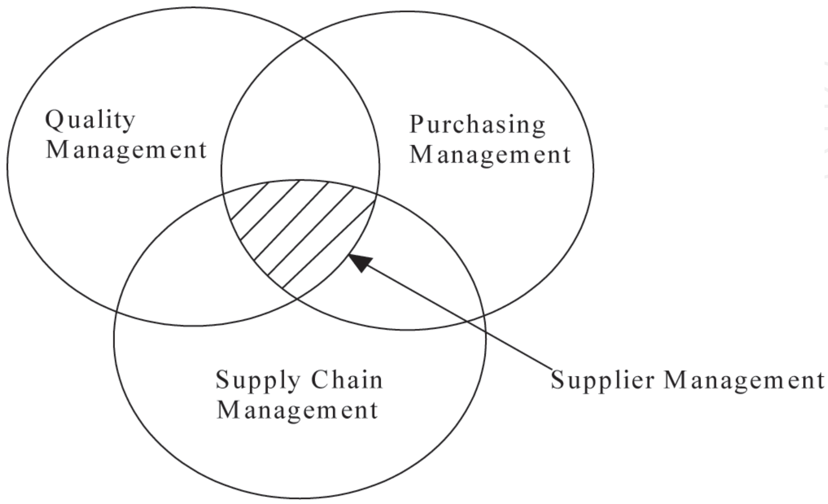

Figure 1. Supplier management in context.

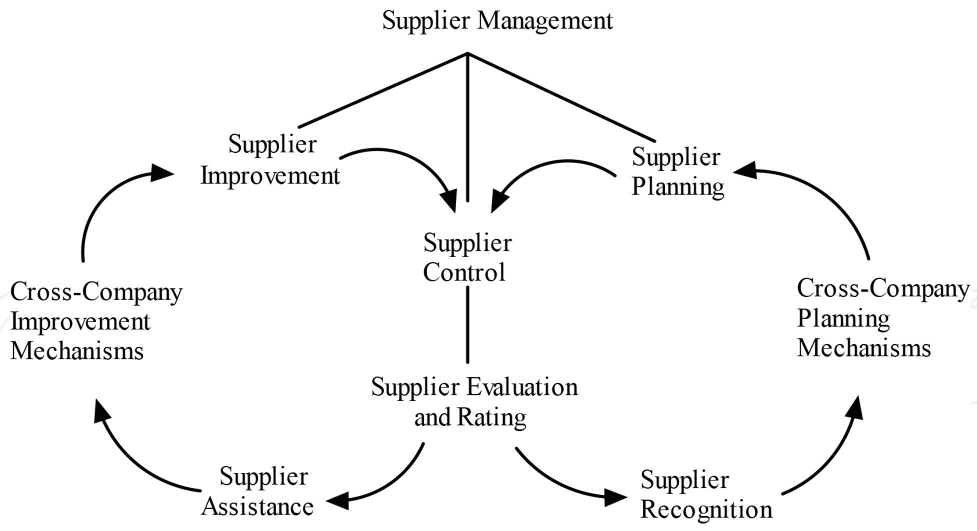

Figure 2. Supplier evaluation and rating originates in supplier control, and in mature applications leads to supplier improvement and planning functions.

under assembly. Second tier suppliers provide parts and services to the first tier, and of course, a failure of one of them can become a failure at the OEM, if the first tier passes it on. The Toyota Production System has a Maxim: Never pass on a known defective to the next work station or process in manufacturing or to the next tier in the automotive supply chain. Transportation suppliers include the companies whose trucks deliver subassemblies and parts to the assembly plant, and perhaps, different companies that load up the finished vehicles and deliver them to dealers. These are third-party logistics suppliers or 3PLs. In addition, OEMs will utilize temporary employee services, whenever there is a shortage of workers in a particular area of the plant. Of course, all the utilities used in the conduct of the OEMs business are key service providers—often taken for granted, until one of them fails. OEMs in the U.S. must of course comply with a large variety of U.S. government regulations concerning vehicles they produce (e.g., fuel efficiency, safety on the road), as well as worker safety and compensation. Some state governments provide the services of selection and training of entry-level hourly personnel; medical and child care on-sight are probably contracted out to qualified suppliers. Besides goods and services, OEMs typically purchase software from an external "business service" rather than write it themselves. All these supplier types—3PLs, utilities, federal and state government agencies, medical care providers, and software developers—would be typical of services as well.

The suppliers for a specific service are even more diverse than those cited for an automotive OEM. Many services use suppliers from each of the other service sectors. Reflecting back on the four service sectors of Browning and Singlemann, it is easy to confirm these potential customer-supplier relationships. For example, a parcel delivery company is considered to be in the transportation industry, but such a company (e.g., UPS) would use external insurance and law services, expect government agencies to provide clear explanation and fair enforcement of regulations, depend on health providers to keep employees well, and use external repair services for operations equipment it does not maintain itself (e.g., HVAC systems, elevators, perhaps even material handling equipment). In turn, each of these UPS service providers may use UPS, or a competitor, for delivery of documents, certain equipment, and repair parts for its equipment. Consistent with automotive OEMs, service companies outsource all three categories of supplies—goods, services, and software—though the proportions and contribution of each supply category to operational excellence may differ.

To distinguish the supply chain in a service industry from the more familiar supply chain supporting a manufacturing industry, consider the following definitions of supply chain management (SCM):

- "SCM involves the management of flows between and among stages in a supply chain to maximize total productivity," from Chopra and Meindl [13].
- "SCM is a process-oriented, integrated approach to procuring, producing, and delivering end-products and services to customers … It covers the management of materials, information, and funds flows," from Metz [14].
- "The supply chain refers to all those activities associated with the transformation and flow of goods and services, including their attendant information flow, from the source of raw materials (and basic services) to the end users. SCM refers to the integration of all these activities, both internal and external to the firm," from Ballou et al. [15].

In a nutshell, the process of locating, obtaining, transforming, and transporting the inputs needed to satisfy the customer is the core function of SCM. By meeting this overriding quality goal, profitability is considered to follow. Taylor [16] noted that "service firms typically have little need for physical inputs other than office supplies," but this statement seems to be too narrow; one must consider that distributive services use fuels for transportation vehicles or electrical energy for communication networks. Social services such as health care and education are critically dependent on physical goods such as over-the-counter or prescription drugs, computer equipment and software, and textbooks. But, we agree with Taylor that:

- Both the service and manufacturing industries require an input of labor to complete the processing necessary to satisfy their promise to the end customer;
- Both industries require capital investment in equipment that allows their employees to do their work efficiently and safely;
- The primary difference is what gets manipulated by labor:
    - In manufacturing, labor costs arise from procuring, transporting, and manipulating physical material;
    - In service industry, the majority of labor is expended on manipulating information and developing relationships;
    - Capital investments in machinery and equipment are typically much higher in the manufacturing industry, though again there are exceptions such as distribution and computer networks associated with each of the four service sectors.

Another difference between manufacturing and service supply chains is logistics. Manufacturing supply chains focus on moving physical materials from one location to another, such as from second tier supplier, to first tier supplier, to the OEM or from OEM, to distributor, to the end customer. OEMs also must have in place an "After-Sale Service Supply Chain," which interestingly engages them in service delivery. Some features of this service that are different than delivery of the original product are: End customers have immediate needs for parts and repair service—response times are much tighter than the original sale; Thousands or even millions of part numbers may be involved in servicing decades of changing models; These products can be quite dispersed geographically—literally, all over the world; Personnel, for instance trained repairmen, are part of the service delivery and must be prepositioned or moved where needed; resources such as repair manuals and parts must be readily available; components or entire products which are returned to depots or the OEM's manufacturing facility engage the supplier in reverse logistics; the relationship with the customer extends far into the future, perhaps 20 years or more; software to support After-Sale Service Supply Chain Management may not be as well developed as enterprise software used to manage the manufacturing supply chain.

In some service organizations, physical materials arrive through a supply chain and are delivered to the customer as part of the service—in support of, rather than integrated into, the intangible service. In other service organizations, no physical product is moving except utility deliverables (electricity, water, gasoline, and natural gas) or perhaps a few sheets of paper in producer services such as law or engineering. In the producer service sector, improvements to speed the flow of communication—such as upgraded servers or new software—is the equivalent of OEMs negotiating faster transport or better shipping rates with their 3PLs. See Zhou et al. [1] for a comprehensive discussion of commonalities and differences between service and manufacturing supply chains.

Finally, service operations experience waste (muda, in the Toyota Production System [2]) just as Taiichi Ohno first described in manufacturing operations. Such waste in manufacturing systems is now referred to as the *original seven* wastes. Much more recently, Bicheno and Holweg [17] have developed an often-referenced listing of *eight wastes for service operations*:

1. *Delay* in the sense of customers waiting—for initial service, a delivery, a repair, a response that does not happen as promised to, or expected by, the customer.

2. *Duplication*—perhaps submitting data or information multiple times, either on forms or in response to queries from different parts of the service organization.

3. *Unnecessary movement* by the customer, such as standing in multiple physical queues, waiting on-line in multiple virtual queues, generally unable to complete a service transaction at one location or in one step.

4. *Unclear communication*, starting with the unclear directions on how to access the service or use service features, and continuing with time wasted seeking clarification.

5. *Incorrect inventory* for a wholesale or retail organization, so that both employees and customers are unsure of what is available now, or when it will be available; also, customer dissatisfaction with substitutes.

6. *Opportunity lost* to retain current customers or win new customers, by failure to establish rapport, ignoring customers or treating them in an unfriendly or rude manner—a failure in relationship building and management.

7. *Errors in the physical part of the service transaction*, such as defective products in the product-service bundle (e.g., poorly cooked or cold main dishes in a restaurant; lost or damaged goods in home delivery from on-line shopping).

8. *Supplier quality errors*, a general lack of quality in service processes such as a supplier of school bus services to a school system that randomly fails to pick up some students in their neighborhood, fails to deliver them to the correct school, or cannot get them to their school before the school day begins.

It is easy to see how each of these wastes could be caused by a supplier, especially wastes numbered 1, 5, 7, and 8. Note that these four service wastes may relate back to a supplier's performance criteria: delivery schedule, delivery accuracy, supplier product quality errors, and supplier process quality errors. Avoiding the eight service wastes, therefore enhancing both quality and efficiency of service, should be part of supplier management in any service industry. For example, Swank [18] cited Jefferson Pilot Financial (JFP, a full-service life insurance and annuities company) for its application of lean principles to resolve waste in two of the categories above:

Delay: JFP "replaced one of its vendors with a company that not only provided faster turnaround times at a lower cost, but also was willing to commit to ongoing performance improvements."

Unnecessary Movement: For a JFP call center, "measure performance and productivity from the customers' perspective—the percentage of customers whose issues are addressed in a single call."

3. Essential practices for supplier management in a service industry

The relationship between buyer and supplier may progress from infancy to full maturity as follows: "one time only purchase," with no obligation from either side that a sale will occur in the future; "transactional," where the buyer and supplier have established an on-going "arms-length" relationship for repeat sales, with order-entry and tracking, subsequent delivery and billing, accepted disposition of product-service bundles that fail to meet quality or delivery expectations, etc.; a multifunctional customer-supplier relationship or "partnership"—also known as an "arms around" relationship"—where the supplier is considered an organizational extension of the buyer, with extensive information exchange (such as sharing of technological and/or customer information) and expectations on both sides that the supplier will be included in future business, perhaps even expected to provide R&D that helps with the buyer's product quality, cost competitiveness, and efficiency of operations. There is an extensive literature on supplier relationship management. For more on partnerships, see Batson [19].

Liker and Choi [20] reviewed how U.S. automotive OEMs build "deep supplier relationships" also known as "customer-supplier partnerships." The result of their review was the supplier-partnering hierarchy, a six-step hierarchy with one step leading to the next. Liker and Choi state "Toyota and Honda have succeeded not because they use one or two of these elements but because they use all six together as a system." We believe that with proper interpretation, and augmented by human and equipment reliability (service dependability), this six-step hierarchy can be used as a guide for supplier management in any service industry, as explained below.

The supplier-partnering hierarchy of Liker and Choi [20] is described next, with steps numbered as suggested in the article, each followed by a few prescribed actions for the buyer.

3.1. Understand how your suppliers work

- Learn about supplier's business
- Go see how suppliers work
- Respect suppliers' capabilities
- Commit to co-prosperity

Under this set of prescriptions, one sees the buyer exhibiting willingness: to learn (perhaps from written, verbal, or audio-visual sources); to go observe actual operations and learn directly from the suppliers' managers, engineers, and workers; to develop and exhibit a respect for the suppliers' capabilities, some of which may exceed the buyer's capability in the same area; and to commit to long-term, shared prosperity on both sides of the partnership. Customer-supplier partnerships flourish when the supplier develops a respect for the OEM's customers and an intense interest in those customers' experience with the product-service bundle. The buyer, while showing humility and trustworthiness, and sharing customer information, is being proactive in building a foundation for the next five steps in the hierarchy. Liker and Choi [20] cite an OEM benchmark survey in which "suppliers said that Toyota and Honda were better communicators and were more trustworthy, and more concerned about suppliers' profitability, than other manufacturers were."

Adapting this practice to Service Industry: It is immediately obvious that if the supply is a good, the same four actions can be applied. If the supply is software, the buyer will depend on surveys and ratings of suppliers of such software, previous experience with this supplier, and/or exploratory visits with the vendor or trial utilizations of their software (limited implementation). References from other firms or agencies within the service industry are also important. If the supply is a service, sometimes there is only one supplier (e.g., water or electrical utility); when two or more suppliers of the service exist, visits to the supplier and unbiased assessment of their respective capabilities can be accomplished by a purchasing agent or a sourcing team. Service suppliers are motivated by potential long-term contracts with buyers who have long-term prospects for success, leading to co-prosperity.

3.2. Turn supplier rivalry into opportunity

- Source each component from two or three vendors.
- Create compatible production philosophies and systems.
- Set up joint ventures with existing suppliers to transfer knowledge and maintain control.

It appears Liker and Choi are prescribing that the buyer creates an environment where the potential suppliers "compete in a context of cooperation," as recommended by Deming [21]. Liker and Choi [20] in their first prescribed action contradict one of Deming's Fourteen Points [21], Point #4, wherein Deming says "move toward a single supplier for any one item, on a long-term relationship of loyalty and trust." Liker and Choi cites the Big Three U.S. OEMs, claiming they "set vendors against each other, and then do business with the last supplier standing…Neither Toyota nor Honda depends on a single source for anything; both develop two or three suppliers for every component or raw material they buy." This appears to be part of their practice of supply chain risk management, protecting against disruptions due to weather, labor strikes, etc. Action to "create compatible production philosophies and systems" suggests that suppliers to lean OEMs should be lean themselves, and that the philosophies and systems that govern production, inventory, and flow up and down the supply chain must be compatible. Joint ventures with existing suppliers might take the form of establishing R&D companies to address joint issues, funding or sharing of production facilities, and consolidation centers that keep complexity away from the OEM's production line; also, encouraging two suppliers—for example one from overseas and the other U.S. based—to form a joint venture to address a specific OEM need for the next model year.

Adapting this practice to Service Industry: Having a single supplier for each supply is actually typical of service industries. For instance, a government agency or a university will typically have a sole source for office supplies, for maintenance of copy machines, and for printing, cafeteria, and security services. However, such contract will periodically be rebid, and generally, there will be at least two qualified bidders for every supply (good, service, and software) the buyer is seeking. The quality of supply will often be identical, so such contracts may go to the lowest bidder. The production philosophies in the service may differ somewhat from the supplier (e.g., a university delivers courses in batches and schedules activities on a semester-by-semester basis; a textbook supplier may operate a pull system, only producing textbooks as orders are received; a supplier of copier paper may "produce to stock," using a push system to have inventory at the ready in the home or regional warehouse). Where such diverse systems must be compatible is in information exchange for inventory management: on the supplier end governed by meeting combined demands from many universities and on the buyer end governed by having the right books, at the right time, in the right quantity for the limited number of students enrolled in a particular course. Concerning student housing and cafeteria service in addition to the bookstore, one can envision how a university might encourage a joint venture between a private developer of student housing, a food service company, and a book seller to serve students where dorm space is unavailable or where a particular class of student (e.g., married) will be served.

3.3. Supervise your suppliers

- Send monthly report cards to core suppliers.
- Provide immediate and constant feedback.
- Get senior managers involved in solving problems.

Liker and Choi emphasize that instead of letting trusted suppliers “do their own thing,” Toyota and Honda “do not take a hands-off approach; they believe suppliers’ roles are far too vital for that.” They use elaborate systems to measure the way their suppliers work, to set targets for them, and to monitor their performance at all times; this is the essence of supplier control in **Figure 2**. Controls are the flip side of the trust Toyota and Honda have in their suppliers. Honda sends reports to its suppliers’ top management every month. A typical report has six sections: quality, delivery, quantity delivered, performance history, incident report, and comments. Honda expects its core suppliers to meet all their targets on metrics like quality and delivery. If a vendor misses a target, the company reacts immediately. Both Toyota and Honda teach suppliers to take every problem seriously and to use problem-solving methodologies that uncover root causes. If suppliers are not able to identify the causes, the manufacturers immediately send teams to help them.” It is well known that when the OEM’s senior managers get involved with a supplier issue and contact the senior managers at the supplier’s plant or corporation, resources get directed to solve the problem to both managers’ satisfaction.

Adapting this practice to service industry: Core suppliers are those whose supply impact customer satisfaction with service performance (timeliness, safety, and other quality indicators) and cost. The maxim “what gets measured, gets managed” applies here. First comes a commitment to measure supplier performance and then comes a commitment to confidentially report results of these measurements to the supplier, with an indication where performance is good-to-excellent and where improvement is needed. This approach could be new to both sides, because “service firms tend to rely on competitive pressure of market forces to drive supplier improvement” (Krause and Scannel [22]). Information exchanges need to result in action at the suppliers, and if feedback is ignored, then definitely senior managers should become involved.

3.4. Develop suppliers’ technical capabilities

- Build suppliers’ problem-solving skills.
- Develop common lexicon.
- Hone core suppliers’ innovation capabilities.

When a supplier evaluation points toward the need for “supplier assistance” as shown in **Figure 2**, such assistance may take the classic form of “supplier development” orchestrated by two departments at the OEM (purchasing and supplier quality)—OEMs maintain staff engineers to fulfill these needs at certain suppliers who appear, for whatever reason, do not have the ability to develop themselves: “Toyota and Honda have invested heavily in improving the ability of their first-tier vendors to develop products” [20]. Or, assistance may take the form of a “cross-company improvement team” focused on a specific item of supply that appears to have a chronic problem (quality, delivery, quantity, labeling, etc.) that cannot be solved by one staff member, or even a kaizen team, at the supplier. What is often the case is that the *symptoms* of the problem show up in the OEM inspection or assembly steps, but the *causes* are back at the supplier or perhaps in the suppliers supply chain. For more on best practices in automotive supplier development, see Batson [23]. Supplier development and supplier relationship management are intimately related. As the relationship progresses

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toward partnership, research has shown that the buying firm is more willing to engage in supplier development and in those forms of direct involvement that require commitment of time and resources.

Adapting this practice to service industry: On the surface, these three actions seems natural between an automotive OEM and each of their module or part suppliers; when the supplier is in a completely different industry than the buyer, which may be the case with service industries, such cooperation is possible so long as problem-solving skills are generic (Kaizen method and tools, reliability and maintainability improvement, safety analysis techniques) and innovation capabilities offered by the OEM actually apply to the supply.

3.5. Share information intensively but selectively

- Set specific times, places, and agendas for meetings.
- Use rigid formats for sharing information.
- Insist on accurate data collection.
- Share information in a structured fashion.

Liker and Choi [20] convincingly contrast the Chrysler information sharing philosophy with that of Toyota and Honda: Chrysler's philosophy seemed to be, "If we inundate vendors with information and keep talking to them intensely, they will feel like partners"… "Toyota and Honda, however, believe in communicating and sharing information with suppliers selectively and in a structured fashion" (as suggested in the prescribed actions above). Furthermore, "meetings have clear agendas and specific times and places…there are rigid formats for information sharing with each supplier." The Japanese OEMs believe that inundating people with data diminishes focus, while targeted information based on accurate data (facts) leads to results.

Adapting this practice to service industry: Should be no more easy or difficult than for manufacturing industry suppliers.

3.6. Conduct joint improvement efforts

- Exchange best practices with suppliers.
- Initiate kaizen projects at suppliers' facilities.
- Set up supplier study groups.

Liker and Choi [20] claim that "Because Toyota and Honda are models of lean management, they bring about all-around improvement in their suppliers…Honda, for example, has stationed a number of engineers in the United States, and they lead kaizen (continuous improvement) events at suppliers' facilities…Honda's engineers believe that the company's goals extend beyond technical consulting; the aim is to open communication channels and create relationships. Honda's Best Practices program has increased supplier's productivity by about

50%, improved quality by 30%, and reduced cost by 7%." Supplier's keep the cost savings and are better suppliers to other product lines for Honda and for other customers in general. Toyota is reported to set up "study group teams," where supplier and OEM personnel learn together how to improve operations. Mercedes-Benz has reported its use of cross-company improvement teams to improve M-class SUV supplier performance in Batson [24].

Adapting this practice to service industry: Should be no more easy or difficult than for manufacturing industry supplier, although one can argue that a service industry buyer may not be cognizant of best practices in the industry of his suppliers. Two approaches might be to require the supplier to identify and report best practices in his industry and to collaborate in a study group to jointly uncover these best practices.

As noted in the introduction, two reliability imperatives in service delivery are "Ready on Demand" and "Uninterrupted Service" once service begins. Neither of these was included in the supplier-partnering hierarchy, so below we add a seventh step to the Liker and Choi model. Finally, continuing this focus on timeliness of service from the customer perspective, we add an eighth step to manage the service supply chain in a manner that values your customers' time (minimizes delay is service waste #1 above). Both of these practices are added to the six-step supplier-partnering hierarchy and are described in the context of service industry, so no adaptation explanation is needed.

3.7. Assure service dependability via equipment and human reliability

Equipment reliability is highly valued in extractive and transformative industries (such as automotive OEMs) because of the direct impact of equipment on manufacturing productivity. Therefore, which services depend on equipment reliability? Almost any service uses the computer in some way. Service organizations often depend on heating, ventilation, and air conditioning (HVAC) to keep the service environment at a comfortable temperature. But these sorts of equipment dependency are not the kind of linkage between reliability and quality we seek to expose here. Computers that fail are often "backed-up" and interchangeable. A computer, or HVAC unit, that fails is often returned to service quickly, and the minor inconveniences to service customers are forgotten. A simple model proposed by Thomas [25] revealed more about "types" of service and their respective dependence on equipment for productivity and quality. Thomas [25] stated that to effectively manage a specific service business, it is necessary to answer two questions: (1) How is the service rendered? and (2) What type of equipment or people tenders the service? To answer Question 1, he posited two types of service: equipment-based service and people-based service. In equipment-based service, three implementation mechanisms were identified: automated; semi-automated (carried out by a relatively unskilled operator); or carried out by a skilled operator. Examples of such implementations for automated are telephone or computer network service; semi-automated might be the subway train or amusement park wheel one rides; and skilled might be the diamond cutter or lathe operator. In people-based service, again three implementation mechanisms were identified: unskilled labor, skilled labor, and professionals. Examples of such implementations for unskilled labor might be house-keepers, ditch-diggers, or stock boys; for skilled labor, examples might be automotive assembly or repair personnel, air-conditioner installers or maintainers; for professionals, consider teachers, lawyers, and medical personnel. These examples answer Question 2, "What type of equipment or people tenders the service?" Obviously under this scheme, the automated equipment-based service would have the strongest dependence on equipment reliability. It also appears that people-based service would have the strongest dependence on human reliability, such as skilled labors using best practices of their trade, and professionals using their career training and norms of their profession in a consistent, timely manner.

McDermott et al. [26] argued that when considering the role of technology in services, a two-dimensional classification scheme worked best. They posited two types of service: substantial product component and pure (or strong) service. On another dimension, they classified services into either knowledge-based service or knowledge-embedded service.

For example, a pure service that is knowledge-embedded could be package delivery company like UPS or FedEx. Yes, physical packages are being delivered, but the timing and programming of the delivery path from sender to receiver are knowledge based, depending on data bases, bar codes, and other "embedded" information technology. The delivery of college course content, in-person, is a pure service that is knowledge based; delivery of that same content via Internet would be a knowledge-embedded pure service. Knowledge-based services are those where most of the customer value is provided by the person providing the service hence depend more on human reliability. Knowledge-embedded services are those which embed the customer value in a system that provides the service, and so human-machine system reliability is the key. This framework focuses on where the "valued added" comes from, rather than what the process "looks like" [26]. Their second dimension depends on classifying services by the extent to which physical product is incorporated within the output. These authors state that "a service which has a significant product component may, in many ways, behave like a production environment… the nature of the environments in each of these quadrants differ significantly with respect to technology management in service."

3.8. Manage the service supply chain to minimize customer delay

From the customer perspective, minimizing delay in the service experience depends on the service provider managing physical and virtual queues in the supply chain in a manner that values customer time. The quality and concern with which this queue management is carried out are observed by the customer, who should be kept informed of service time remaining, and it significantly impacts their perception of the services rendered—essentially the quality, cost, and time expense of the service are weighed to determine the value rating the customer assigns to the service experience. Time delays are just another form of cost.

4. Conclusions

The objective of this chapter was to identify supplier management practices of the US automotive industry and demonstrate how these practices can each be adapted to manage the diverse suppliers found in a service industry. We began by defining services and identifying five inherent characteristics of services that distinguish it from manufacturing and construction: Intangibility; Inseparability; Variability; Perishability; and Lack of Ownership. Next, we defined service quality and its determinants, and how automotive OEMs employ a standardized Quality Management System. To establish the context and diversity of service industry, the Browning-Singlemann [9] six-sector model was reviewed.

In the next section, an extensive background on supplier management was provided, again focused on the world-class practices of automotive OEMs and how they utilize the three functions of supplier control, supplier improvement, and supplier planning. Supply chain management was then defined, and the similarities and differences between a manufacturing supply chain and a service supply chain were identified. Both supply chains require input of labor to complete the process of locating, obtaining, transforming, and transporting the inputs needed to satisfy the customer. Also, both supply chains depend on capital equipment, which must be reliable, maintainable, and safe to operate. The primary difference between the two is what gets manipulated by the labor: physical material (goods) in the manufacturing supply chain; information and relationships in the service supply chain—though in some services, physical items may be delivered simultaneously in a product-service bundle.

We identified the accepted list of eight wastes for service operations: Delay (effects on the customer); Duplication; Unnecessary Movement (by the customer); Unclear Communication; Incorrect Inventory; Opportunities Lost (to retain a customer or to win a new customer—a failure in relationship building and management); Error in the physical part of the service transaction; and Supplier Quality Error. An example of an insurance company whose customers were experiencing undue delay and unnecessary movement, prior to improvement projects, was reported.

Adapting the supplier-partnering hierarchy of Liker and Choi [20]—a hierarchy of six steps identified from extensive research on supplier management at US automotive OEMs—to services was the basis for the final section which identified eight "Essential Practices for Supplier Management in a Service Industry":

- Understand how your suppliers work.
- Turn supplier rivalry into opportunity.
- Supervise your suppliers.
- Develop suppliers' technical capabilities.
- Share information intensively, but selectively.
- Conduct joint improvement efforts.
- Assure service dependability via equipment and human reliability.
- Manage the service supply chain to minimize customer delay.

The last two imperatives (added by the author) are strongly related to the service customer's expectations for "Ready on Demand," "Uninterrupted Service" once it begins, and in general "Respect for (valuation of) Customer's Time" spent engaging with your service. These in turn

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relate back to how the service provider hires and trains those who maintain his equipment, those who interface directly with the customer, and those suppliers who are included in or provide logistics within his supply chain.

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Performance Measurement System Based on Supply Chain Operations Reference Model: Review and Proposal

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Abstract

Current study provides a performance measurement system (PMS) based on Supply Chain Operations Reference (SCOR) adapted for the service sector. A systematic literature review was conducted on 16 performance measurement systems, which included 44 performance indicators and various performance metrics. Performance indicators and metrics were sorted according to conceptual similarities and then related to the five management processes intrinsic to SCOR model (plan, source, make, deliver and return). Indicators researched in a review of the literature were classified into six groups, namely, financial, velocity, sustainability, quality, resource utilization and customer services. The proposed PMS fills a gap in literature by forwarding a tool for the evaluation of the supply chain performance within the service sector.

Keywords: literature review, performance indicators, performance measurement system, supply chain management

1. Introduction

Although the supply chain (SC) is viewed as an extension of a company, several organizations do not evaluate any effective performance to integrate their supply chain members. The evaluation of supply chain performance is quite crucial for the company's operations since the primary aim of the supply chain is to maximize the generated overall value [1].

The evaluation of performance does not merely select but also assesses indicators to provide an appraisal of the company's situation and identify possible improvements [2]. Supply chain performance is mainly related to the functioning of the company under analysis, with special focus on its core processes interconnected to other supply chain members [3].

After the selection of a set of indicators that may be used to manage organizations, a performance measurement system (PMS) is established to assess improvement opportunities for the organization. Conceptually, the performance measurement system is defined as a set of metrics used to quantify the efficiency and effectiveness of actions [4].

Consequently, the design of an effective PMS is basic since its usability is crucial for controlling the company's operation processes [2, 5–7].

Despite the current importance given to performance measurement systems, several shortcomings are still extant, such as those related to non-financial indicators and to the behavior of organization members who fail to make the system function properly [2]. PMS is a widely discussed topic, albeit rarely defined. It may be casually defined as the process of quantifying action in which measurement comprises the process of quantification and action leading toward performance [8].

The study of performance measurement systems is challenging since it is still unclear how they enhance the effectiveness of an organization [9]. Moreover, when it comes to the service sector, there is a major gap in the supply chain field and the literature on this topic is still scarce [7, 10], similar to what happens with the evaluation of performance [11].

Service supply chain is a broad concept that encompasses companies dealing with spare parts supply, outsourcing, finance, insurance, retails and government services. Due to the service sector's several peculiarities and the gaps previously mentioned, there is a need for better understanding what exactly makes service performance measurement problematic [12].

Supply Chain Operations Reference (SCOR) is a model which supports a PMS development, since it is not only able to measure and improve the company's internal and external business processes [13], but also presents a cross-functional framework which integrates business processes re-engineering, benchmarking and performance measurement [14].

Owing to the lack of research publications related to service supply chain management (SCM) and performance measurement, the chapter structures a Performance Measurement System based on the SCOR model to assist the service sector's supply chain management, especially at the operational level. Even though specialized literature presents a framework for measuring the supply chain performance [11], there is only a dearth of studies that associate performance indicators to every process of the SCM model. Consequently, a theoretical framework on supply chain management and performance measurement system is presented foremost. Secondly, we establish the methodological procedures and the results achieved by the proposed PMS, followed by the concluding remarks on the overall topic. The chapter foregrounds the theoretical constructs developed in the dissertation by [15]. Furthermore, the literature presents a practical application of the PMS in a service company, ratifying the feasibility of the proposed PMS [16].

2. Supply chain management

The supply chain is a continuous process—ranging from the purchase of raw material up to the final product—with several functions, such as sales forecasting, purchasing, manufacturing, distribution, sales and marketing [17–19], with three major flows, namely, materials, information and money [20]. Supply chain management has represented a new frontier to obtain competitive advantages [21].

Mentzer et al. [22] define supply chain as the systemic and strategic coordination of traditional business functions and the tactics across the latter within a particular company and across businesses within the supply chain, to improve the long-term performance of individual companies and the supply chain as a whole.

Even though most of the definitions involving supply chain refer to the traditional concept (physical SC), there are some implications which differentiate physical SC from service SC. This is precisely the aim of the chapter. Ellram et al. [23] define service supply chain as the management of capacity, demand, customer relationship, supplier relationship, service delivery, cash flow and information flow. Moreover, the efficiency of a service SC depends on how to handle the items previously presented, whilst traditional SC demands more process standardization [23, 24].

Due to its dynamism, supply chain management requires mandatory decisions to improve its performance [25], framed into three categories or levels: strategic, tactical and operational. At the strategic level, it must be decided how to structure the chain, its configuration and the processes that will accompany each stage. Decisions made during this phase are also known as strategic decisions [26].

At the tactical level, planning includes decisions about which markets and locations must be supplied, the construction of inventories, outsourced manufacturing, policies of refueling and storage and frequency and size of marketing campaigns. Tactical-level measures include time efficiency of purchase order cycle, reserve procedures, quality assurance methodology and flexibility of capacity. Furthermore, the tactical level assures the achievement of specifications made at the strategic level [27].

Periodicity is weekly or daily at the operational level and during this phase firms make decisions on customers' individual orders. The supply chain settings are fixed at this phase and planning policies should be already defined. Operations aim at implementing operational policies in the best suitable way, or rather, with a reduction of uncertainty and the optimization of performance, while constraints set by configuration and by planning policies are taken into account. Measures at the operational level comprise day-to-day capacity, ability to perform failure-free deliveries and the capacity to avoid complaints [26].

Despite advances in SCM and improvement in organizational effectiveness and efficiency, some challenges still need to be coped with, among which functional integration, collaboration with suppliers and, particularly, the alignment of a performance measurement system, may be mentioned. In fact, most organizations will never achieve an effective improvement without such alignment [28].

In the case of the alignment mentioned above, the concept of supply chain integration (SCI) must be introduced. According to Flynn et al. [29], SCI is the degree of collaboration among manufacturers and their partners to achieve effectiveness and efficiency on the flow of materials and information, including money and goods. Silvestro and Lustrato [30] underscore the importance of integrating financial supply chain and physical supply chain, due to the complexity of current supply chain networks. Furthermore, the highly complex supply chain networks tend to improve their performance as long as they are integrated, corroborating the benefits of SCI [31].

Besides the SCI issue, sustainability is also the chapter's main topic. Green supply chain management (GSCM) is increasingly becoming an important strategy for the sustainable development of enterprises, since it is a sort of modern management method on environmental protection [13]. GSCM consists of social responsibility, from purchasing, manufacturing, distribution and marketing to reverse logistics [32, 33], which is an extended concept of SC [34]. Consequently, its aims toward a decrease in negative impacts, such as energy consumption, emissions and solid wastes [35].

In order to cope with such complexity, specific models are extant to assist the three management levels. According to the literature, there are two main models for managing a supply chain, namely, the Supply Chain Operations Reference (SCOR), developed by the Supply Chain Council, and the Global Supply Chain Forum (GSCF), developed by [36].

SCOR is the first reference model which has been built to describe, communicate, evaluate and identify opportunities for the improvement of work and information flow. Since the model uses standard measures for processes and activities, the former may be measured, managed, controlled and redesigned to achieve a certain purpose [37]. In the case of GSCF, it presents a more systemic view, highlighting the importance of balancing, physically aligning and managing technical aspects within the administrative management for a successful SCM [38].

The SCOR model provides a framework that relates performance metrics, processes, best practices and human labor within a single structure that enhances better communication among SC members and increases its efficiency, as well as promoting improved technology. Since the chapter aims at proposing a measurement system for service supply chain, SCOR has been preferred to GSCF due to its focus on performance metrics.

SCOR is actually more suitable for measuring service supply chain because of the relevance of human labor's impact on its performance. Since it is somewhat complicated to control human performance in service operations, the employment of a measurement system for controlling human performance will contribute significantly to service SC.

Consequently, SCOR is a useful tool to ensure, document, communicate, integrate and manage key business processes along the SC, helping companies to conduct a systematic analysis and promoting communication among members at the firms´ internal and external milieu [39].

After foregrounding the supply chain management, that is, service supply chain and models of managing SC, it is important to investigate the concept of the performance measurement systems and their importance for the supply chain management.

3. Performance measurement system

Wong and Wong [40] discuss the importance of evaluating the supply chain's performance to achieve adequate efficiency by providing the best possible usage of combined resources among chain members and by offering products at competitive prices. Performance evaluation is thus an important tool for managing supply chains [41, 42], since organizational performance always exercises a considerable influence on the companies' activities [43].

Discussion on performance evaluation started in the late 1970s due to dissatisfaction with traditional accounting systems. Henceforth, this field of study has been developing in the literature [44], in terms of supporting its implementation and monitoring strategic levels [17], as well as identifying deficiencies and pointing toward pre-established goals [45]. Currently, the issue is widespread in the industrial and service sectors [46].

Regarding the supply chain, performance assessment has become increasingly important, especially in the manner the benefits of integration with suppliers improve performance [47, 48]. Furthermore, Cousins et al. [49] state that close contact with suppliers and customers are increasingly mentioned as a differentiating factor in the performance of supply chains. In fact, Gunasekaran et al. [50] highlight information sharing, communication and trust as being the essential factors to improve the performance of companies and integrated supply chains.

According to Gunasekaran et al. [27], although they have been in the limelight, measurement and performance metrics pertaining to the supply chain management are not receiving adequate attention in the literature due to lack of empirical findings and case studies on measures of performance metrics within the supply chain.

According to Kuo et al. [5], in general, if the measurement system is applied to distribution centers, six categories have to be considered, namely, financial, operational, quality, safety, employee and customer satisfaction. However, these categories may be generalized for several different scenarios. In addition to the criteria of cost and quality, Chan [51] insists that other performance measures may be used, such as resource utilization, flexibility, visibility, reliability and innovation. Moreover, Gunasekaran et al. [26] suggest that the performance measurement system may either be classified according to company levels (strategic, tactical and operational) or classified as financial and non-financial.

Among the researched papers (by Otto and Kotzab [52], Lohman et al. [47], Schmitz and Platts [53], Bremser and Chung [54], Folan and Browne [43], Rao [41], Giannakis [55], Bhagwat and Sharma [56], Gaiardelli et al. [57], Akyuz and Erkan [58], Naini et al. [59]), it has been noted that the Balanced Scorecard (BSC) is a state-of-the-art model, with widespread usage.

Balanced Scorecard combines financial and non-financial metrics. Objectives and metrics hail from the company's strategy and vision, focused on four perspectives, namely, finance, customer, internal business processes and learning/growth [60]. Further, Tezza et al. [61] presented 140 approaches on performance measurement systems for the 1980–2007 period and papers were divided into four classifications: corporate, supply chain, service and individual.

The following section tackles the methodology used, especially with regard to papers' selection and research on performance indicators.

4. Methodology

So that the proposed objective could be accomplished, the following steps were established: (1) definition of the theoretical conceptual framework; (2) indicators survey (compilation) and performance metrics; (3) definition of performance indicators; (4) definition of performance metrics; and (5) proposal of a PMS directed toward the service sector. **Figure 1** details all the methodological steps used in the current study.

4.1. Definition of the theoretical conceptual framework

The steps for defining the theoretical conceptual framework are (1) definition of the topic under analysis, or rather, the supply chain associated with the evaluation of performance; (2) database selection, or rather, choosing a relevant database within the academic environment; (3) selection of keywords for searching articles; (4) selection of articles in scientific journals, excluding articles from conferences and patents; (5) analysis of abstracts to identify research problem and work justification, methodology used and results; and (6) defining texts that will foreground the review of the literature.

The *Web of Science* (ISI) has been adopted for its journals' impact factor, presenting important papers in terms of their topics and being academically relevant for the purpose. In fact, this database indexes the most important literature in the world [62].

So that a systematic review of the literature could be undertaken, keywords were defined and software Endnote® was used to support the entire process. The papers were sorted according to the following keywords: Performance Measurement, Supply Chain, Supply Chain Performance, Service, Performance and Supply Chain Service. Repeated papers, books, book sections and patents were excluded and only articles from scientific journals remained, particularly from the *International Journal of Operations & Production Management*.

4.2. Indicators research and performance metrics

Based on the articles defined in the previous section, indicators and performance metrics that compose a PMS service sector were highlighted. Fourteen approaches related to performance evaluation were found, plus two relevant applications, resulting in 16 approaches, as shown in **Table 1**.

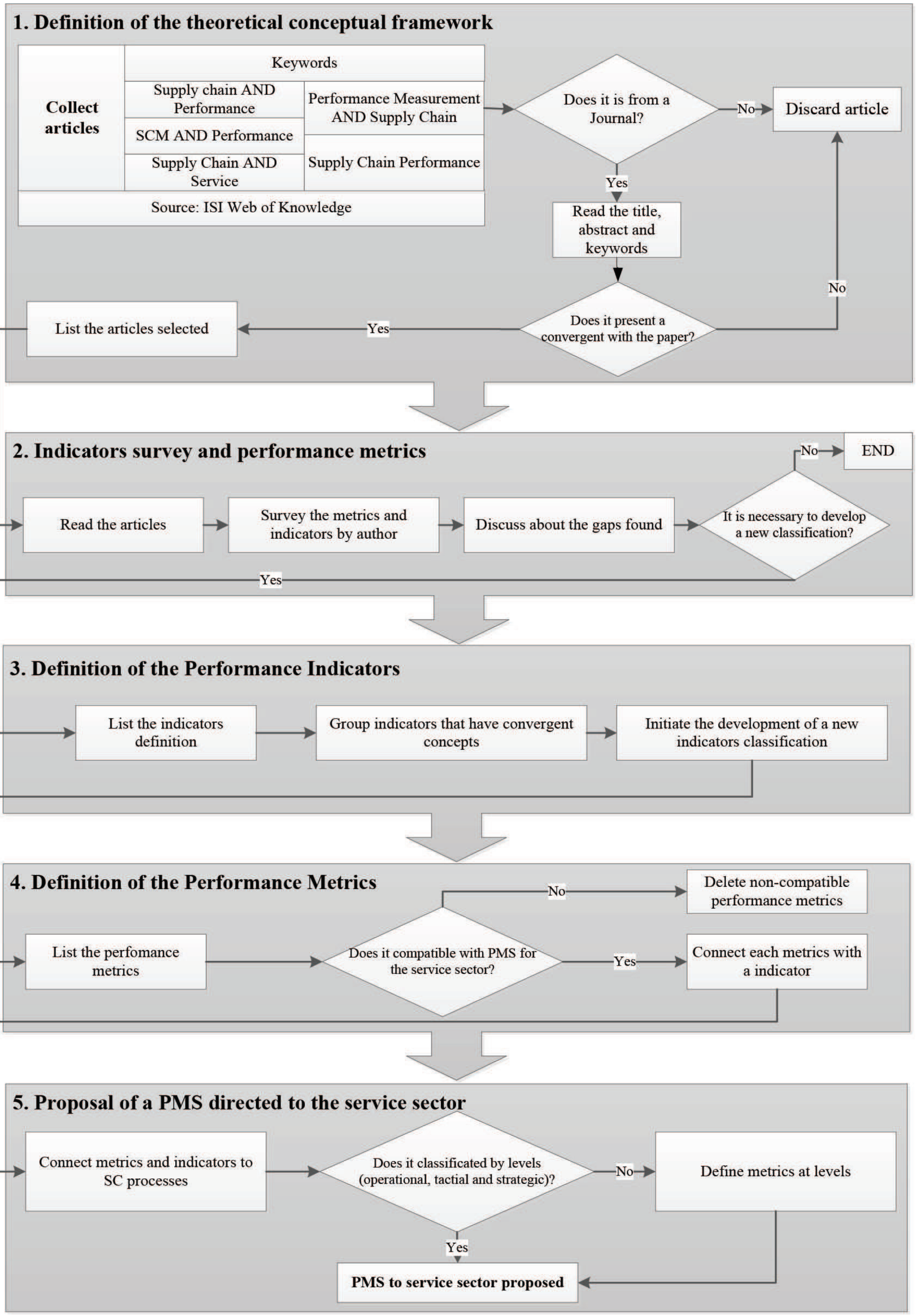

Figure 1. Methodology for a performance measurement system in a service supply chain.

4.3. Definition of the performance indicators

Indicators and metrics were defined for each basic process of the SCOR model (planning, supply, make, deliver and return) so that a PMS could be prepared. All indicators retrieved from the review of the literature were listed and separated by author. Forty-four indicators were provided. A respective concept was tagged to each indicator, according to the authors. Based on their definitions, a group was formed as **Table 1** reveals (Section 5.1).

The above step has been necessary: a PMS requires various approaches from different authors. Although these authors use different tags for the same indicators, their definitions converge and thus a grouping process is required.

A few examples may be required. Since the indicators 'Assets' and 'Sales' are somewhat related to the cash flow of the company or of the supply chain, a group tagged 'Financial' was proposed for indicators with the same relationships (cash flow).

The group 'velocity' was related to the timing of the supply chain for fulfilling market or corporate demands upstream or downstream. 'Sustainability' was related to supply chain environmental issues; 'quality' was related to the fulfillment of norms, meeting customers'

Groups	Associate indicator	Justification	Authors
Financial	Asset/asset management, sales, contribution margin, costs, financial profitability, costs of return, logistics costs	Corporate financial related to performance.	L, H, SCC, Ch, L, L, Ho, L, Bi, SG, SM, Ch, SCC, Ch, BB, C, BS, SM, S
Velocity	Punctuality, Compliance, Delivery Performance, Time, Speed, Lead time, Responsiveness, Flexibility	Measure related to supply chain timing for fulfilling market or corporate demands, upstream or downstream	SM, Pa, S, Bi, SG, H, SM, Ho, P, Bi, SSC, Ch, S, BB, B, Bi, SG, SM, Ch
Sustainability	Environmental ethics, recyclability, return of items	Related to supply chain environmental issues	SM
Quality	Reliability, quality, legal compliance, availability system, outputs, trust, service	Related to fulfillment of norms; related to meeting customers' needs	SCC, CHO, SG, SM, SM, PA, B, P, CH, H
Resources utilization	Resource utilization, inventory, transport measurements, logistics measurements, processes, internal processes, resources	Related to use of physical resources needed to serve customers	Bb, Ch, Ho, V, SM, C, BS, B
Customer services	Empathy, privacy, security, growth and learning, innovation, measurement and customization production, efficiency, tangibility.	Related to customer service itself and to the factors affecting this service	Pa, Ch, P, C, BS, BB, SG, V, Pa, Ch

Caption for 16 authors: P: Parasuraman et al. [63], S: Stewart [64], BB: Brignall and Ballatine [65], B: Beamon [66], C: Cravens et al. [67], Ho: Holmberg [68], L: Lambert and Pohlen [69], V: van Hoek [70], H: Hausman [71], Bi: Bititci et al. [72], Pa: Parasunaran et al. [73], SG: Shepherd and Günter [74], SM: Sellitto and Mendes [75], BS: Bhagwat and Sharma [56], SCC: Supply Chain Council (2010) and Ch: Cho et al. [11].

Table 1. Summary of indicators, their respective definitions and suggested indicator.

needs; 'resource utilization' was related to the actual use of physical resources needed to serve customers; and 'costumer service' was related to the customer service itself and the factors affecting this service.

In other words, the procedure unified the indicators found in the literature. Only six groups were formed, namely: financial, quality, velocity, resource utilization, sustainability and customer service.

4.4. Definition of performance metrics

Metrics for the selected indicators were developed for performance according to the basic processes of the supply chain. The step involves the consolidation of a measurement system suited to the needs of the company's performance. These metrics were focused on the service sector, foregrounded on the review of the literature.

Similarly, all metrics/measures have been surveyed according to the review of the literature. Separated by supply chain processes (plan, source, make, deliver and return), metrics were classified according to the most appropriate indicator (defined in the previous step), based on the definition of each.

For instance, the metric "full time cash flow" was related to the indicator on the Financial Planning process, since all metrics related to the financial indicators are somehow related to costs. In fact, "total time cash flow" represents somewhat the planning of the supply chain. The above scheme was undertaken for each metric discussed.

In addition, all metrics were divided into strategic, tactical and operational levels. Some of the metrics have been classified in the work of Gunasekaran et al. [26]. Metrics with no level definition were classified and justified into each level.

Another example is the 'Inventory Costs' metric related to the Financial indicator and directed to the 'source' process. The item 'Inventory Costs' was classified at the operational level since cost information may be obtained in a shorter period of time and such information reflects what has already been planned, where operating policies have already been defined at strategic or tactical levels.

Since the main goal of the current research is the construction of a PMS at the operational level, the metrics classified at strategic and tactical levels were disregarded, and only metrics were taken into account for the operational level.

4.5. Proposal of a PMS for the service sector

Since indicators were placed in groups (defined in the previous step), the metrics were separated into each process (plan, source, make, deliver and return). Separated into processes, the metrics were classified according to the most appropriate indicator (defined in the previous step), based on the proposed definition of each indicator. Subsequently, the metrics with no definition of levels (strategic, tactical and operational) arranged in the literature were classified and justified for each level. The metrics classified at strategic and tactical levels were disregarded, that is, only metrics for the operational level were taken into account for the consolidation of PMS.

5. Proposal of a PMS directed to the service sector

This proposal includes the following sequential steps.

5.1. Research of performance indicators

Table 1 shows indicators separated by authors, their definition as stated in the literature and the basis or justification for grouping them into one of the six proposed groups (financial, velocity, sustainability, quality, utilization and customer service)

The next section discusses the construction of a system of performance measurement focused on the service sector.

5.2. Definition of a PMS for the service sector

Figure 2 presents the metrics sorted by indicators focusing on the operational level for each SCOR process. Further, five metrics were excluded—percentage of manufacturing of main product costs (F), economic order quantity (F), percentage of erroneous artifacts (Q), percentage of manufacturing orders in US dollars fulfilled within the deadline (V), percentage of manufacturing orders in units (tons, parts, etc.) within deadline (V)—due to their non-applicability to the service sector. In fact, there were mostly related to manufacturing.

Finally, **Figure 3** shows the metrics defined for the PMS according to the proposed model and to the following criteria: (F) financial, (Q) quality, (V) velocity, (U) utilization service, customer service (C) and (St) sustainability.

The article "Performance measurement system in supply chain management: application in the service sector" [16] is an application that presents a practical application of the PMS in a service company, using the Analytic hierarchy process (AHP) that indicates which metrics is more important to the supply chain in service sector.

The PMS proposed has as one of the objectives measuring the importance of processes and metrics established. For this, the Expert Choice software was used. Two research instruments were developed. The first aims at comparing the processes and the second compares performance metrics. To synthesize the processes weights, an arithmetic mean of responses between the focus-firm and suppliers was calculated resulting in the **Table 2**.

Table 2 shows that the most important process between the two firms is source. It is the process in which the focus-firm receives supplies from supplier, to supply the firm focus needs good planning of its inputs. The second most important is the plan process: the focus firm, this process consists of planning to meet the demand in convergence with the supplier; on the other hand, in the supplier it consists of planning the purchase of inputs to meet the clients, including the focus-firm.

PLAN

Finance	All metrics related to the financial indicators are related to costs, investment values and cash flow in the planning stage of the supply chain.
Quality	These metrics are related to the quality indicator, because they scale the ability to meet customer expectations, to perform the promised service in a reliable way (trust) and also measure responsiveness (outputs) and also meet the standards and legal requirements of SC operations.
Velocity	All metrics related to the velocity indicator, refer in one way or another to the estimated time required for planning, and that's why it was framed in this indicator.

SOURCE

Finance	All metrics related to the financial indicators are related to costs, investment values and cash flow in the supply process.
Quality	Metrics related to the quality indicator relate to meeting the specifications, delivery as expected, assistance provided by the supplier and the ability to solve problems of mutual form in SC.
Velocity	All metrics related to the velocity indicator refer to the time of supply in the supply chain.

MAKE

Finance	The financial indicator in the "MAKE" process is mainly related to the production costs involved in the process, and it is also related to inventory levels, where the capital of the company is tied up.
Quality	Metrics relate to Quality, as they are designed to verify the degree of customer satisfaction.
Customer Service	The metrics are related to customer service as it reflects the process of "production" of the service.
Resource Utilization	The use of resources in the process "MAKE" reflects the need for machinery, equipment and capacity utilization
Velocity	Related metrics over time, flexibility and delivery due date are placed on the speedometer.

DELIVER

Finance	The financial indicator in the process "Deliver" is related, in a general way, with logistics costs.
Quality	The metrics are related to the quality indicator since they verify the conformity of "delivering" process.
Customer Service	The metrics are related to the customer service level.
Resource Utilization	The metrics are related to how the available resources are being used and if they are used correctly.
Velocity	The metrics are related to time, flexibility and responsiveness, so were classified into the "velocity" group

RETURN

Finance	Metrics are related to costs which may affect the return process, so they were related to the financial indicator.
Quality	The quality indicator relates to the metrics as they relate to the problems that can occur during return.
Customer Service	This metric reflects the need of service systems to meet customer needs. The metrics are related to the customer service level no ato da entrega do serviço
Sustainability	The metrics are related o environmental issues in the return process, so the most appropriate indicator was "Sustainability".
Velocity	The metric is related to the time and so was classified into the "velocity" group.

Figure 2. Indicators related to SCOR processes.

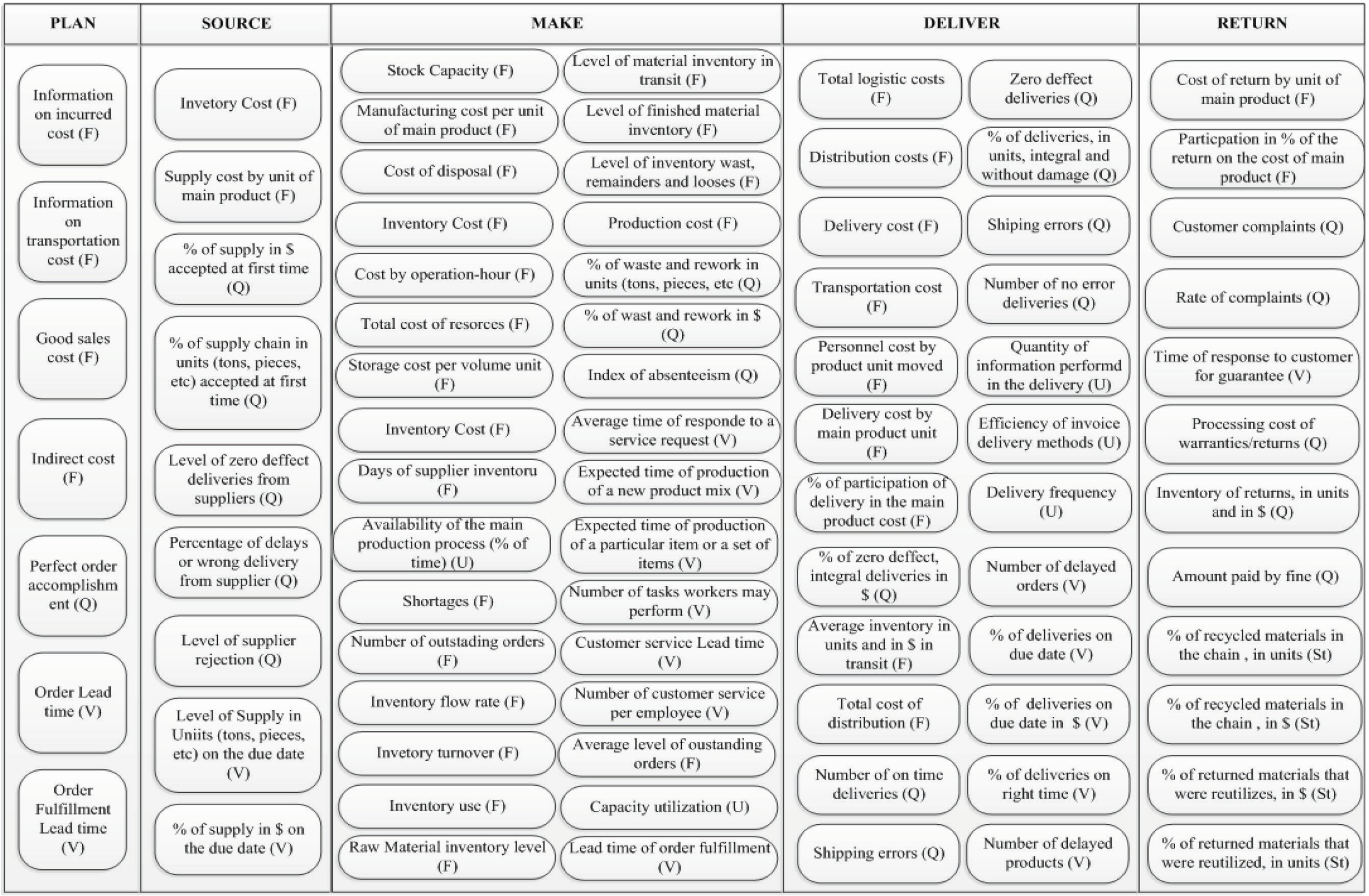

Figure 3. Performance measurement system at operational level in the service sector.

Order	Process	Degree of importance (%)
1	Source	25.29
2	Plan	21.55
3	Deliver	19.50
4	Make	17.20
5	Return	16.47
Total		100

Table 2. Mean for processes importance degree.

The third most important process between companies is delivering. In the focus firm consists of the customer contact to deliver products/services. On the other hand, in the supplier, the "delivery" process is the action of delivering the products required to the supplier firm. The fourth most important process is make, which is associated with tender care to the client in focus firm to understand its needs, while the supplier (for being an importer/distributor) consists of the charge separation step. Finally, there is the return process.

The second part of the ranking is to sort the PMS metrics. Thus, **Table 3** lists the metrics by order of the processes and in descending order by degree of importance.

According to **Table 3**, the most relevant indicator in the planning process is the fulfillment of perfect order, which indicates if what was planned to meet the demand was executed on the purchase orders, that is, if the expected was achieved, being a quality indicator with 38.5%, followed by the metrics on cost information (financial) with 32.08% and lead time order (speed) with 29.40%.

In the source process, metrics were prioritized in this order: stock costs (financial) percentage of supply in dollars on the due date (speed), percentage of deliveries in units on the due date (speed), percentage of deliveries in units accepted on the first time (quality) and percentage of deliveries in dollars accepted on the first time (quality). the stock cost is the amount one incurs to have goods in stock, involves storage costs, opportunity cost, cost of capital employed, cost of obsolescence and others. Despite being focused company and supplier of services, they need equipment to perform such services and also supplies to sell to customers.

The make process has the metrics "Average response time to a request for service" as the most important in this process, related to the speed indicator. It is related to the average time needed to answer a request from a client, after it has already been answered.

In the deliver process, the metric "Detect-free Deliveries" was listed as most important, followed by the "cost of delivery" and finally, "the number of deliveries at the right time." The metrics "Detect-free Deliveries" is related to the quality indicator and means the number of deliveries in which the product or service were delivered as expected by the client.

In the return process, the metric of customer complaint was considered the most important. This metric is an indicator of quality that can express customer satisfaction with the company.

Process	Indicator related	Metrics	Degree of importance (%)
Plan	Quality	Fulfillment of perfect order	38.50
	Financial	Cost information	32.08
	Speed	Lead time of order	29.40
Source	Financial	Stock costs	30.73
	Speed	Percentage of deliveries in dollars on the due date	25.03
	Speed	Percentage of deliveries in units (tons, parts, etc.) on the due date	19.03
	Quality	Percentage of deliveries in units (tons, parts, etc.) accepted on the first time	15.03
	Quality	Percentage of supplies in dollars accepted on the first time	10.18
Make	Speed	Average response time to a service request	31.88
	Financial	Number of pending orders	18.78
	Customer service	Number of services per employee	16.38
	Customer service	Lead time of customer service	17.28
	Financial	Production cost	15.68
Deliver	Quality	Deliveries without defects	45.05
	Financial	Delivery costs	28.15
	Quality	Number of deliveries on time	26.75
Return	Quality	Customer complaints	30.18
	Sustainability	Percentage of recycled materials returned, in units	26.53
	Speed	Response time to customer for warranty	24.08
	Sustainability	Percentage of recycled materials returned in dollars	19.20

Table 3. Summary of the degree of importance of metrics.

According to the results, it is possible to settle the most important metrics between focal company and supplier, expecting the relationship's performance to be improved.

6. Conclusion

Theoretical research on the evaluation of performance reveals that, although the topic has been researched for years, yet there is no consensus in the literature on its application. One approach on the evaluation of performance is related to the performance measurement system. Consequently, a review of the literature based on the supply chain and on the service sector was performed to elucidate this gap. performance measurement systems under analysis demonstrated lack of consensus on the topic, especially with regard to indicators. Among the 16 approaches, 44 indicators were raised, reduced to six groups on account of their definition and application, namely, financial, velocity, sustainability, quality, resource utilization and customer services.

SCOR comprises planning, supplying, making, delivering and returning. Based on a systematic review of the literature, a performance measurement system was proposed, taking into consideration the supply chain management through the basic processes identified in the SCOR model. This model was considered feasible according to [16] in terms of its practical applicability.

The theoretical contribution is related either to the unification of the existing literature based on various authors or to the performance measurement system proposed in supply chain management processes, presenting a framework of relevant indicators associated to the SCOR model. In other words, a better perspective of Supply Chain Management in the service sector through unification is suggested, in which the proposed PMS approaches the state-of-the-art in terms of supply chain performance measurement.

Among service companies, the nomenclature 'make' would not be the most appropriate. Thereby, future studies following current line of research would possibly replace the term 'make' by 'attend' or join it to the 'source' process, depending on the type of company.

As the main practical result, this chapter obtained the prioritization of the most relevant processes and metrics for clipping the SC under study. Another important result found was the separation of activities occurring in the focus firm on basic processes suggested by the SCOR model.

Based on the review of the literature and even with advances in research on performance measurement in supply chains, many companies are still immature on integration and sharing of information. Therefore, lack of collaboration between the focused firm and suppliers or between the focused firm and customers impair such relationship.

6.1. Directions for future researches

It may be suggested that, in future studies, the integration of enterprises should be observed. In fact, their relationship may be improved due to integration. The chain will turn out to be more responsive. While working with integration among members to reach a perfect order, risks involving supply chain management should be explored. Consequently, research works on SCM that measure chain risks and find ways or methodologies to lessen them are strongly suggested.

Since the relationship between suppliers should be collaborative, suppliers must be chosen not only for reasons based on costs or time, but also on their willingness to help the focused company so that both would be able to satisfy their customers in a sustainable manner.

The limitation of current research is due to the emphasis on a specific sector (service) and a validation has not been done yet. Other results for PMS may be acquired depending on companies and parts involved.

Therefore, future research work may be replicated in practical examples of supply chains so that differences, similarities and particularities of each application may be noted and, consequently, the proposed PMS may be adapted to different situations.

In addition, a PMS validation and verification should be made considering the condition of the supply chain, the particularities of the sector (service or industry), observing which processes and metrics are most important for each case.

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Chapter 4

Operations Management and Decision Making in Deployment of an On-Site Biological Analytical Capacity

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Additional information is available at the end of the chapter

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Abstract

Deployment of an on-site laboratory to contain an expanding outbreak and protect public health through rapid diagnosis of infected patients and identification of their contacts is a challenging and complex response, further complicated by time limitation and dramatic consequences of failure. Effective operations management and decision-making are critical for a successful Fieldable Laboratory (FL) mission at each phase of the mission. To analyze the principles and challenges of the operations management and associated decision-making process, the FL mission has been broken down into five successive interlinked phases defined as the "FL mission cycle" (FL-MC). Each phase comprises a set of operational functions (OFs) corresponding to the mission activities. Some decisions are associated with a single OF, whereas others are taken across different OFs and FL-MC phases. All decisions are treated as logical entities inherently linked to each other and to the whole situational context within the FL operational domain. Being part of the laboratory information management system (LIMS), the FL domain ontology is developed as the main knowledge management tool supporting the decision-making process. This is an essential way to promote interoperability and scalability between different FL modules and health care capacities during cross-border biological crises.

Keywords: biological analytical capacity, operational functions, decision support, knowledge management, health crisis response

1. Introduction

Deployment of a biological analytical capacity—a Fieldable Laboratory (FL)—in response to a health crisis caused by a biological agent (B-agent), such as an outbreak of a disease, or a deliberate or accidental release of a B-agent, is a complex strategic enterprise undertaking requiring neat operations management based on efficient decision making. To be ready for a rapid FL deployment as soon as a disaster strikes implies a thorough preparedness complemented by detailed planning phases. The trained FL operators must be available for the mission and confident in the quality and objectivity of the decision-making process; the laboratory equipment and materials for B-agent identification and diseases diagnosis have to be in place and ready to use; the means of transportation, as well as security, safety and funding mechanisms of the mission have to be agreed in advance with the mission customers and secured.

Flexibility is another key component of any public emergency response. FL has a highly flexible configuration, which makes it suitable for a wide range of missions. Given the uncertainty inherent to every crisis response, the FL staff has to be prepared for any unforeseen situation, even though the basis for preparedness remains a strong qualification of the staff and a solid experience in using cutting-edge technologies, FL materials and equipment. The FL performance is largely regulated by the availability and use of laboratory standard operating procedures (SOPs), guidelines and best practices in the field, and the respect of national and international laws and ethics regarding the control and management of biological threats and patients care.

In its current form, the FL structure and specific requirements for a generic deployment of laboratory capacities have been identified taking as a model the B-LiFE (Biological Light Fieldable Laboratory for Emergencies) capacity developed by the Center for Applied Molecular Technologies (CTMA) of the Université catholique de Louvain (UCL) and supported by the Defense Laboratory Department (DLD) of the Belgian Armed Forces. The FL provides a consistent operational structure at the disposal of national, European and international stakeholders when domestic health care capacities are lacking or devastated by the disaster (e.g. shortages or absence of skilled local health care staff combined with a high fatality rate due to the outbreak). This applies especially when the scale, intensity and complexity of the crisis require urgent and drastic countermeasures. The turnaround time for transporting and deploying the FL is very short since the current concept employs a series of compactly packaged, properly labeled and pre-listed equipment placed in dedicated carrying cases, which can easily be moved together, deployed and used by a limited staff of trained personnel. The main advantage of deploying a FL in close vicinity to the patients is its ability to provide quick diagnosis and health monitoring for evidence-based laboratory-guided medical decisions. This aspect was particularly well illustrated during the last Ebola outbreak [52] where the B-LiFE (Biological Light Fieldable Laboratory for Emergencies) team deployed a FL from December 2014 to March 2015 to support the medical staff of the Ebola Treatment Unit of N'Zerekore run by the NGO ALIMA (Alliance for International Medical Action) in the forest area of Guinea [35, 38, 41, 42, 53] see **Figures 1** and **2**.

The FL operations management serves as a bridge between the field operators deployed for the mission, headquarters in the reach-back laboratory and external stakeholders. In the present work, the problems of decision making, information sharing and coordination at FL are

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Figure 1. B-LiFE deployable analytical capacity and inflatable antenna, Ebola mission, Guinea, December 2014 to March 2015.

Figure 2. Inside the FL tent: glovebox and analytical tools.

studied taking into account the needs, procedures and requirements of field operators. The present work summarizes the practical findings on structuring the FL operational domain, the heterogeneous information that the FL staff have to deal with in the crisis response and management situations. This work presents the most recent development in terms of tools, methods and mechanisms of the FL operations management and decision-making support. The result was consolidated by integrating the assessment of certifiers appointed by the European Commission during the certification procedure of B-LIFE/B-FAST as a self-sufficient module of the EU Medical Corps, namely the EU medical and laboratory modules exercise "MODEX" in Sweden in April 2017, and subsequent "ModTTX 4" Table-top exercise in Belgium in May 2017.

2. Structuring the FL domain

To facilitate the FL operations management, it is necessary to structure the FL domain in such a way that all its components and interlinks between them become visible, enabling laboratory operators to track the path of the informed decision-making processes. The basis for structuring the FL domain is FL operational functions (OFs), which need to be carried out by the FL at different phases of the mission cycle in order to identify and actively counter threats, to be prepared for, to respond to and to recover from crises of both incidental nature or deliberate attacks (http://www.practice-fp7-security.eu/).

The lessons learnt from past FL deployments (**Table 1**, Section 4) proved that even if every mission is unique in terms of goals and context, the FL mission cycle (FL-MC) consisting of OFs divided into five chronological phases and transversal functions is valid for any type of mission. The process described here is being used as support of operations management for decision makers regarding FL staff training, contacts and discussions with stakeholders, and preparation for next FL missions.

The generalized FL mission is represented as a cycle with five phases, shown in **Figure 3**.

Each phase of the FL-MC consists of several steps, which are in turn comprised of OFs to be implemented at each step. The whole FL-MC contains 92 OFs, and they are as follows:

Phase 1. **Mission assignment**

STEP 1-1. **Request for mission**. OF 1-1-1. Request for lab mission.

STEP 1-2. **Specifications assessment**. OF 1-2-1. Launch mission cycle. OF 1-2-2. Needs and constraints. OF 1-2-3. Logistics. OF 1-2-4. Adjustment of capacity to requirements. OF 1-2-5. Final feasibility check.

STEP 1-3. **Mission acceptance**. OF 1-3-1.Governmental and employer's approval. OF 1-3-2. Confirmation of mission.

Phase 2. **Mission specification**

STEP 2-1. **Planning on-site deployment**. OF 2-1-1. Characteristics of on-site location. OF 2-1-2. Mission clearance. OF 2-1-3. Ensure host nation support. OF 2-1-4. Establish contact with local authorities and services. OF 2-1-5. Finalize convention and contracts with third parties whenever needed. OF 2-1-6. Selection of mission staff and PersPack. OF 2-1-7. Specific staff training. OF 2-1-8. Medical check-up. OF 2-1-9. On-site medical support. OF 2-1-10. Operational ethical and legal requirements. OF 2-1-11. Selection and checklist of tools.

STEP 2-2. **Logistics: procurement and delivery**. OF 2-2-1. Procurement of tools and equipment.

Phase 3. **Mission execution**

STEP 3-1. **On-site transportation**. OF 3-1-1. PHS&T (safe packaging, handling, storage and transportation) and loading tools. OF 3-1-2. Hazardous materials and items specifications for transportation. OF 3-1-3. Transportation of cold products.

STEP 3-2. **On-site deployment**. OF 3-2-1. Accommodation, water and food. OF 3-2-2. Healthcare and MEDEVAC (medical evacuation). OF 3-2-3. Installation of platform/vehicle/existing infrastructure. OF 3-2-4. Cold chain. OF 3-2-5. Ensuring and securing power and water supply. OF 3-2-6. Ensure on-site security. OF 3-2-7. Biosafety aspects. OF 3-2-8. Lab organization.

Location and date	Exercise	Deployment type	Communication tool	Focus on mission cycle: Specific component or comprehensive cycle	Aim of mission (specific mission-related OF)
Kananga, West Kasai, Republic Democratic of Congo, 14 April–4 May, 2009	KAYA KUMPALA	***OPERATION*** (Mil)	Military parabolic antenna	Mission assignment Mission execution	OF related to a first deployment in a military environment threatened by a local outbreak (transportation, logistics of the laboratory, quality of tests, data transmission) [26] Aim: rapid identification of monkeypox virus [17]
Brussels, 29 November 202	First B-LIFE Exercise	***EXERCISE*** (Civ-Mil)	SES—EMERGENCY. Lu GATR antenna	Mission specification	OFs related to: site selection, geolocation and traceability of sample, biological detection, First integration of Civilian SatCom for data transmission
Rienne, Belgium 10–12 May 2012	MAYDAY	***EXERCISE*** (Civ-Mil)	Parabolic antenna ASTRA2CONNECT	Mission execution	OFs related to: rapid biological identification, testing access on-site using road transportation, data transmission using SES Broadband
Pionki, Poland, 22–25 April, 2014	PIONEX	***DEMO*** FP7-PRACTICE (Civ/Mil)	Local WiFi provider AIRBUS DEFENSE	Whole mission cycle	OFs related to each part of the mission cycle. Aim: large-scale CBRN exercise PIONEX; integration of B-LiFE capacity in the first multiuser response system to a CBRN incident.
N'Zerekore, Guinea, Dec 2014–Mar 2015	EBOLA OUTBREAK	***OPERATION*** *B-LiFE/B-FAST*	SES- EMERGENCY. Lu GATR antenna	Whole mission cycle	All previous OFs and additional ones appearing mandatory to deploy in a real life situation: rapid response to an Ebola outbreak—support to an Ebola treatment Center unit in a very remote location in guinea, with no communication.
Munich, Germany, 7–13 Feb, 2016	CLUELESS SNOWMAN	***EXERCISE*** *B-LiFE* (Civ/mil)	SES- EMERGENCY. Lu GATR antenna	Whole mission cycle	All OFs defined in the Ebola mission revised, improved or added after a thorough mission debriefing, and based on lessons learned and return on experience (e.g. a specific assessment of biosafety measures and procedures by a biosafety officer). Aim: training mission—joint exercise with the Bundeswehr Institute of Microbiology

Location and date	Exercise	Deployment type	Communication tool	Focus on mission cycle: Specific component or comprehensive cycle	Aim of mission (specific mission-related OF)
Bologna, Italy, 12–15 Apr 2016	FOOD DEFENSE	***DEMO*** FP7-EDEN B-LiFE (Civ)	Not done	Whole mission cycle	All OFs as defined above, integrating new, specific biosafety procedures. Aim: validation and use of new technologies usable on-site for the new application of "Food Defense" as part of a large-scale CBRN exercise
Revinge, Sweden, 20–24 Apr 2017	MODEX EU AMPs modules	***EXERCISE*** B-LiFE/B-FAST *CERTIFICATION*	SES- EMERGENCY. Lu GATR antenna & Astra Connect parabolic antenna	Whole mission cycle	All OFs as defined above and implemented for the certification of B-LiFE as rapidly deployable, self-sufficient capacity within the framework of the EUCPM and the ERCC (Voluntary Pool) as developed by the EUCPM (DG ECHO) [24, 25, 29]. Aim: testing the interoperability between AMP/AMP-S, deployable analytical laboratories, EUCPT/TAST, and LEMA
Bruges, Belgium, 24–27 May 2017	Mod4TTX Table-top	***EXERCISE*** B-LiFE/B-FAST *CERTIFICATION*	Not done	Mission execution	OFs focusing on laboratory procedures Aim of the table top: testing the procedures used by B-LiFE; the aim was to look at these procedures while considering the need for interoperability with other medical modules (AMP/AMP-S) as well as USAR teams, other deployable analytical laboratories, EUCPT/TAST, and LEMA

Table 1. Contribution to B-LiFE deployment to the identification of mission-related operational functions (OFs).

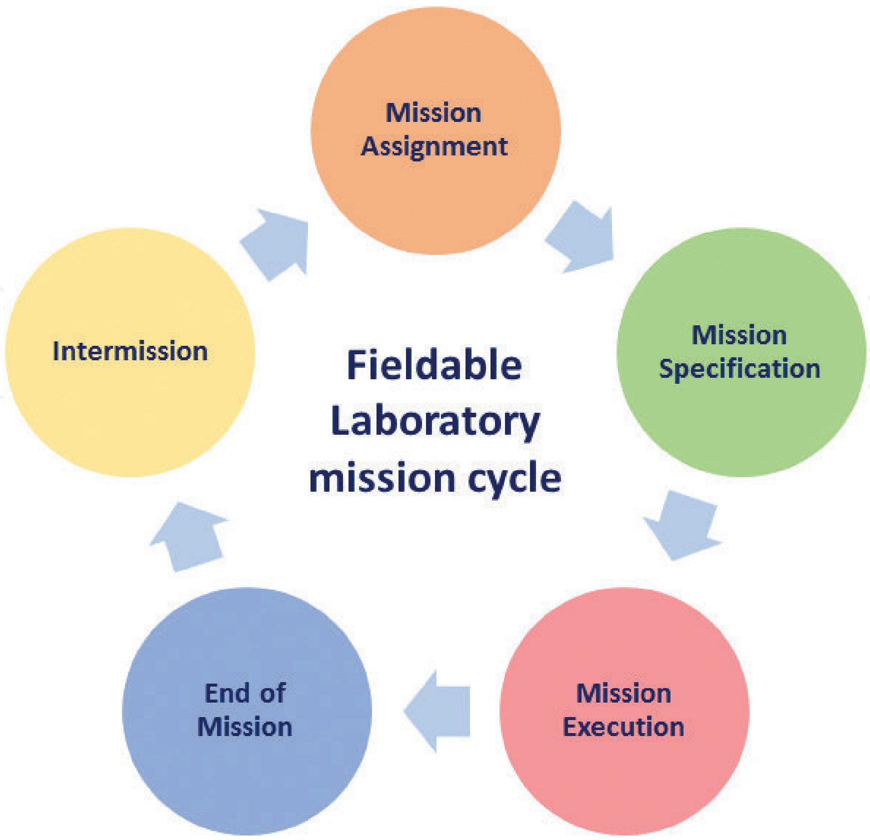

Figure 3. Five chronological phases of the FL mission cycle.

OF 3-2-9. Installation of sanitation area and toilets. OF 3-2-10. Set up of lab procedures and protocols. OF 3-2-11. Deploy tools according to required operational conditions. OF 3-2-12. Final security and safety check.

STEP 3-3. **On-site dry run**. OF 3-3-1. Power supply crash test. OF 3-3-2. Dry run of deployed lab.

STEP 3-4. **Briefing and communication**. OF 3-4-1. Briefing for all participants on the objectives and procedures of the mission. OF 3-4-2. Handover when new staff arrives to mission. OF 3-4-3. Communication with headquarter and recording actions.

STEP 3-5. **Pre-analytical phase**. OF 3-5-1. Decision on sampling. OF 3-5-2. Field security analysis. OF 3-5-3. Sampling strategy. OF 3-5-4. Move inside the site. OF 3-5-5. Sampling by lab team. OF 3-5-6. Sampling by third parties. OF 3-5-7. Tracking of samples. OF 3-5-8. Transmission of sample data to lab/communication. OF 3-5-9. Transportation of samples. OF 3-5-10. Decontamination of samples. OF 3-5-11. Preparing staff and materials. OF 3-5-12. Samples reception and validation of packaging. OF 3-5-13. Updating recorded data. OF 3-5-14. Inactivation of biological samples. OF 3-5-15. Preparation of aliquots for reach-back analysis. OF 3-5-16. Sample preparation.

STEP 3-6. **Analytical phase**. OF 3-6-1. Sample analysis. OF 3-6-2. Maintenance of laboratory. OF 3-6-3. Waste management. OF 3-6-4. Analytical impact of climate conditions.

STEP 3-7. **Post-analytical phase**. OF 3-7-1. Validate analytical results. OF 3-7-2. Interpretation of analytical results. OF 3-7-3. Reporting. OF 3-7-4. Follow up on report. OF 3-7-5. Storage of residual samples after analysis.

Phase 4. **End of mission**

STEP 4-1. **Preparation for FL repatriation or relocation**. OF 4-1-1. Decontamination and cleaning. OF 4-1-2. Condition hazardous samples and reagents for transportation. OF 4-1-3. Pack cold products for transportation. OF 4-1-4. Condition materials for transportation. OF 4-1-5. Dismantle tents, prepare vehicle for transport.

STEP 4-2. **Site restoration**. OF 4-2-1. Decontaminate site. OF 4-2-2. Rehabilitate site.

STEP 4-3. **Repatriation or relocation**. OF 4-3-1. Evacuate non-disposed waste. OF 4-3-2. Transportation practicalities.

STEP 4-4. **Debriefing**. OF 4-4-1. Immediate feedback on the past mission. OF 4-4-2. Final report. OF 4-4-3. Inventory. OF 4-4-4. Lab storage. OF 4-4-5. Medical and psychological follow-up. OF 4-4-6. Final budget.

Phase 5. **Intermission**

STEP 5-1. **Lessons learned**. OF 5-1-1. SWOT analysis and continuous improvement process (CIP). OF 5-1-2. Coordination of preparation.

STEP 5-2. **Preparation for next mission**. OF 5-2-1. Maintaining stocks. OF 5-2-2. Metrology. OF 5-2-3. Training and exercise. OF 5-2-4. Occupational health annual check-up. OF 5-2-5. Ensuring financial and human resources.

Transversal operational functions: OF 0-1. Financing. OF 0-2. Supply chain. OF 0-3. Maintenance and sustainability. OF 0-4. Communication and information management. OF 0-5. Safety/security.

3. Operations management and its support tools

Operations management is defined as the management of systems or processes directly involved with the provision of goods and services to customers [37, 50, 51]. The present work demonstrates consolidation of all the heterogeneous components of the operational system in the FL domain, i.e. planning, coordination, control of the human, financial and material resources, management of FL staff, equipment, including technology and information needed by FL to provide the service as defined by the FL service requesters and according to the specificity of the mission.

FL operations are based on the clear understanding of the needs of the service providers, where these needs have been iteratively collected and analyzed in multiple previous deployments listed in Section 4, **Table 1** and detailed in [59]. The whole FL structure (i.e., its mission-dependent configuration depending on the type of mission, the contents and amount if materials, equipment, staff members, logistics, supply chain) is all defined with the purpose to deliver the most appropriate FL service in relation to the parameters and specificities of the mission.

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In order to develop the FL as an operational system integrating all the materials, technologies, processes, information needs and the decisions associated with every activity, the following components have been developed:

- The mechanism allowing continuous improvement of the FL structure and configuration has been identified. The FL-MC has been described as consisting of five successive phases with 14 steps and 92 operational functions [57, 58]. The OFs required for carrying out the mission have been identified and described in detail; the decisions to be made at each OF have been defined and information needs for taking every decision have been identified.
- The FL technologies and processes (tools, such as lab equipment, materials, reagents, communication tools) required for executing OFs have been listed, described and associated with every OF.
- The ontology has been developed [57] as a component of the Laboratory Information Management System (LIMS), to serve as the knowledge base and the tool for existing FL domain information structuring, modeling, grounding and accommodation of new information. The ontology is applied to prepare the FL mission, to describe the relationships between OFs and tools and to provide the decision support for the FL operators and decision makers.

3.1. LIMS and ontology

Since it is practically impossible for anyone to keep in mind all information and details about FL missions in general and specifications of the currently planned mission in particular, the information management concepts and tools play a major role in the quality and precision of mission preparation. To unify the communication process within the FL and to consolidate the information necessary for optimal operations management and decision making at the document management level, a laboratory information management system (LIMS) targeted for FL is under development [57]. One of the advantages of LIMS is that it is compatible with the information systems of other stakeholders and health care modules, e.g. other laboratories and field hospitals, and can be integrated in such a way that information sharing process is harmonized and transmission of relevant data facilitated. A LIMS is therefore a crucial component of an operational laboratory as it gathers the key information which will be produced by the laboratory operators, used by them internally, and transmitted to the laboratory stakeholders for exploitation after proper formatting. The best illustration is, for instance, the collection of patients' data, which need to be used by the medical team for guiding patients' local care and treatment, and by local, national, regional and international health authorities implicated in the operational management of the crisis.

The FL-targeted LIMS includes integrated databases where each FL tool is linked with specific information among which the class and description, date of acquisition, price per tool (€), dimension (*length x width x height; cm*), volume (m^3) and weight (*kg*), electrical power (*kW, kVA*), SOP, related biosafety procedures, precise location in the storage room and dedicated carrying case. For each mission, information can be immediately retrieved with respect to the number of available items, total volume, weight, electric energy consumption and value of the equipment selected. Within the LIMS, the databases are connected with the FL-specific ontology described in [11, 44, 57]. The *ontology* here is understood as a formal, explicit specification of a shared conceptualization describing the FL as operational domain [30, 31]. The FL ontology serves as a knowledge base for FL missions preparation, planning and execution. The ontology is used to formalize and structure the FL domain operation in the situation of a biological crisis preparedness and response to ensure a continuous improvement of the laboratory service. Being computer-modeled and flexible in its configuration, the ontology aims to provide an easy access to all the information stored in LIMS before and during the mission. Moreover, all the generic information is formatted in such a way that it is reusable for different missions. Ontology enables therefore the laboratory operators to compare easily the FL structure and functionalities to other similar capacities, be they civilian or military, fully autonomous or acting as part of larger organizations, such as NGOs or military authorities. The ontology facilitates the use of a common terminology while providing a shared vocabulary of concepts to comply with recognized standards, best practices and procedures, establishing in this way a common ground between internal FL operators and external decision makers and stakeholders.

Every OF in the FL consists of a set of complex activities requiring acquisition, continuous update and consolidation of heterogeneous information (i.e. multiple sources and formats) regarding the current crisis situation, standard operating procedures (SOPs), best practices in addressing crisis preparation management and in problem-solving, specific operational knowledge about technologies and processes, knowledge of regulations, guidelines, legal and ethical issues to adhere to. Within the single-operational domain of FL functionality, some OFs are seen as decision-making nodes that have impact on other OFs execution, while others are action nodes requiring compliance with the SOPs with no variable decisions inside.

The FL ontology models the information available a priori, provides the links between all the OFs, as well as parameters, attributes and tools used in every OF. Such a comprehensive approach largely facilitates the process of FL mission preparation and informed decision making. The ontology-based approach to the definition of FL domain framework provides the computer-readable domain representation, allows for updating the context and makes the computational support to human sense-making possible.

In fact, both LIMS and ontology cover and control all the aspects vital for the FL operations management, by defining and describing the laboratory OFs, financial and human resources to implement them, technologies, materials, equipment, processes and guidelines used for every OF execution, patterns and a priori background knowledge about FL mission parameters, records of information related to biological sampling, samples tracing and tracking, results of samples analysis, all biosafety and biosecurity aspects and reporting to external stakeholders. In that respect, the LIMS is the heart of an optimal, robust and efficient global operational crisis management.

The FL ontology is developed in the open-source Protégé environment release 5.0.0 beta-17 (http://protege.stanford.edu/) [47]. Protégé employs OWL formal language to express the semantics of constructs, enabling operators and developers to reason over the FL domain constraints and properties, and to infer new facts from existing definitions. All the information in the ontology can be both asserted (i.e. explicitly stated) and entailed by means of automatic reasoning. The logical consistency of the entire model of the FL operation domain is ensured by 3251 logical axioms (rules) and filters delimiting the restrictions for all the relationships between all kinds of ontology entries.

The major ontology classes describe the types of FL missions, the FL OFs that are performed during the different mission phases (**Figure 1**), and the transversal OFs which are present in all phases of FL missions, as well as the tools used in OFs. The current version of the FL ontology comprises 92 OFs (listed above in Section 2) and 117 categories of the following types of tools: lab equipment, lab consumables, polymerase chain reaction (PCR) equipment, personal protective equipment (PPE), storage devices, waste management tools, devices to record data, logistic tools, communication tools and generic tools.

The current version of the ontology is the result of iterative tests and validations during multiple FL missions. It was last validated in the B-LiFE project during the MODEX exercise in April 2017. The details of the validation process are presented below in Section 4.

3.2. Decision making for efficient operations management

When analyzing and modeling the decision-making process in the domain of a FL deployment in response to a biological crisis, we assume that all decisions during the FL-MC [39, 58] (with reference to numerous works in humanitarian and defense operations decision making, such as [1, 2, 4, 9, 10, 14, 18, 19–21, 27, 32, 34, 36, 43, 45, 48, 54–56, 61, 62] are taken considering all the knowledge accumulated by the time of the mission, the background context and the new information received in the course of the mission.

The possibility of a mission and its further implementation is based on the presupposition that a mobile capacity exists, is available and is ready for deployment. This starting point serves as the main prerequisite for the possibility for the mission launch. Then, all the decisions made during the mission assignment, specification, preparation and confirmation are made to specify the details, the mission parameters (such as the mission location, duration, number of tests to be performed daily, materials needed for this particular mission, trained FL staff members needed), conditions and requirements for the guarantee of security, staff safety and costs of the mission. With the said presupposition in mind, and from the point of definition of the mission goal in Phase 1 *Mission Assignment*, the overall behavior of the FL staff and their decision making are goal-oriented. All decisions are made with the view of the goal of the FL mission and the necessity to reach this goal. The FL mission goal is clear, and it is multi-fold. In general terms, the goal of any FL mission consists of the following elements:

- To be deployed in a defined location for a certain period of time, agreed with the mission stakeholders;
- To perform diagnostic tests and biological (biochemical) assessment of patients according to the biological threat agent and known clinical land biological consequences;
- To provide health care support to the population in the affected area and contain a spread of biological threats, hence containing or limiting the health crisis;
- To keep FL staff healthy and safe;

- To test novel technologies for biological threat detection and diagnostics, to follow-up patients included in therapeutic trials (e.g. new drugs, new vaccines) according to the mission scenario and specifications;
- To return to the base safely at the end of the mission and with all equipment and materials properly decontaminated and, if possible, in usable condition.

All these elements of the FL mission goal strongly determine the success of the mission. Thus, every phase, step, and OF performed by the FL as well as every decision taken at each critical moment of the mission, contribute globally to the final success of the mission. As in any real-life situation, every decision brings opportunities to reach the ultimate goal, and at the same time, can be associated with risks that, if neglected or too high, might prevent the team from reaching the goal. Thus, decisions are never binary, never strictly positive or strictly negative; the decision-making process is always about balance, choice, estimating what prevails and trying to anticipate opportunities or risks. Decision-making process is not linear; there can be regrets, comebacks to previous steps, e.g. taking another path that would bring a different outcome. In the domain of FL deployment for biological crisis response, the decision makers often consider several alternatives for every decision, taking into account the current context and looking for continuously updated information. Therefore, they may look back and consider previous decisions as no more appropriate to the evolving context and change them partially or totally to adapt them better to this new, sometimes elusive reality. However, following the methods of contextual inference in computational semantics [5, 46, 60], we consider every next decision in the FL-MC as increment of the context which satisfies all the logical requirements and therefore consistently fits in the whole picture like a puzzle. Every next decision, be it a new one, or an updated previous one, has to be accommodated in the context. The process of accommodation of every next decision is an active dynamic process requiring fusion and interpretation of all the available information, balancing the parameters, and using this information for finding an acceptable solution enabling advancement to the next step of the cycle.

A decision-making process consisting of various interrelated components (i.e. identification of the problem, assessment of the available information, evaluation and selection of alternatives, evaluation of the result) requires a general scheme where logically transparent representations of single decisions are first created, and then these representations are subjected to further semantic operations which relate them to the context where the decision is made. If a decision is a part of a decision belonging to a wider scope, the named semantic operations should integrate the new decision into the obtained interpretation of the previous context including all the decisions, which have been processed up to this moment of time.

Formally, the evolution of the decision-making process is of cumulative character, consisting of a sequence of decisions $<\varphi_1,\ldots,\varphi_n>$. These decisions can be thought of as simple choices from a set of possibilities, or more complex choices that include both a choice of action and various parameters associated with that action. In a simple case where parameters are not involved, the decisions can be defined as sets of possibilities, with possible continuous or discrete values. So for instance, the "go/no-go" decision is binary (and it clearly constrains what can happen in the future). But other decisions, such as how many items from a variety of materials shall be deployed for a particular mission, will be represented both by a choice and associated parameters, such as deciding whether to bring a certain type of reagents, and then how much of these to bring. In these cases a decision φ_i can be expressed as a vector $\varphi_i = (\delta_i, \pi_i)$, where δ_i is the categorical decision (which tools shall be brought to the mission, for instance) and π_i is a set of parameters that describe the decision in more details (such as the amount, volume, weight of the tool items) and $\varphi_i = 0$ would mean that this tool shall not be brought at all.

After decision φ_i has been made, we call a representation of the state of the world at that point in time R_i, which encapsulates the aggregate impact of all previous decisions φ_i through φ_i. Thus, there is a representation R_1 of the decision φ_1; we then use this representation as a context to adapt and interpret φ_2, which, when matched with R_1, will give the representation R_2 for $<\varphi_1, \varphi_2>$; and so on.

Thus, we have a series of decisions φ_i, which collectively define the current situation R_i at time *i*. These prior decisions jointly constrain the next decision, φ_{i+1}. That is, the set φ_{i+1} from which the next decision is drawn is itself a function of $<\varphi_1, \varphi_2, \ldots, \varphi_i>$. These decisions are made in a dynamic environment, so the information considered for taking the next decision may be different from the information on hand when taking prior decisions. Assume a sequential nature to the decisions, so that decision $k > 0$ may constrain decisions $k + 1, k + 2, \ldots, k + n$, but not decisions $1, 2, \ldots, k\text{-}2, k\text{-}1$. Then at any time *t*, due to new information, we can go back and change any given decision φ_i, where $i < t$ (i.e. the decision taken before the time *t*), changing the former state of the world from R_i to R'_i. But then we have to make sure that decision φ_{i+1} is in the permissible set given R'_i, φ_{i+2} is in the permissible set given R'_{i+1}, and so on up to time *t*. That is, changing past decisions may have a ripple effect on other past decisions, and could further constrain/reduce the constraints on the current decision.

In the process of a decision accommodation, then, the following main problem has to be resolved: given the fact that the evolution of the FL-MC context includes not only the entire preceding context, but also all the set of contexts corresponding to different alternatives at previous steps—in which context exactly shall the accommodation take place? In other words, which path of incrementing the context with new decisions shall be considered optimal and provide the best result? To answer this question, let us look into the decision accommodation process in more detail. We consider two types of situational contexts. The first type of context is *global* that covers the situation R_i at the given moment of time with all the events evolved, information received and decisions taken up to this moment, i.e. covering times *1* through time *t-1*. The second type of contexts are *local contexts* where individual decisions φ_i, parts or fragments of them are considered. The advantage of the notion of *local contexts* is that it gives maximum flexibility when "playing" with alternative decisions and alternative paths, sometimes considering them only temporarily, to estimate the possibility for the optimal decision path without breaking the logic and consistency of the global situation.

Thus, updating the situational context *C* with a decision of the form $\varphi \rightarrow \psi$, requires consideration of local contexts such as $C + \varphi$ and $C + \varphi + \psi$, and these local contexts will be considered during the process of the situational context update. Let ψ contain a decision that did not fit well enough in the context $C + \varphi$, then *C* does not accommodate this decision and needs its alteration as a whole or change of some its parameters. In this case the accommodated decision should update one of the considered contexts in such a way that ψ can be accommodated locally. It can take the form of direct update of the local situational context where the situation ψ must be computed, with some variable parameter α, so that the resulting update of the context will not be just $C\backslash(C + \varphi\backslash(C + \varphi + \psi)$, but $C\backslash(C + \varphi\backslash(C + \varphi + \alpha + \psi))$: this leads to *local accommodation*. Another variant of situational context update with a new decision is possible: the decision maker can come back not to the initial context, but to where the parameter(s) of the intermediate decisions can be changed, i.e. φ_j, where $j < t$ and then to add some information or new parameters, say, γ, to the context where the decision is computed. The result will be the following: $C\backslash(C + \gamma + \varphi)\backslash(C + \gamma + \varphi + \psi))$.

On the other hand, the decision maker might go back to the initial context, add a variable parameter β in the global situational context and start the update of the situational context again. This leads to the global accommodation of the decision, and the resulting update will take the form: $(C+ \beta)\backslash(C + \beta + \varphi)\backslash(C + \beta + \varphi + \psi))$.

This process of accommodation of new decisions in the global situational context reflects the dynamic procedural approach to the decision-making process with its iterations and possibilities of changing previous decisions or parts of them. Such flexibility allows handling the complexity of the domain, heterogeneity of the information, parameters and factors of the decisions to be taken.

The developed ontology models the FL domain, and provides all the background context for further operations. Containing all the necessary entries—the OFs, tools, actors involved in the mission, and all links between them—the ontology thus contains the antecedents, i.e. reference points. New information received by FL during the mission preparation or mission execution can be either bound to the existing referents in the ontology, or new ontology entities (objects, tools, or events) can otherwise be created to accommodate new information if it did not exist before. In this way, new information is smoothly fused in the mission context, inheriting some of the existing links and creating new ones. That is why the ontology is the core tool for the context increment, update, data and information fusion for further use.

The knowledge-based operations management process, the list of OFs modeled in the ontology and interlinks between all the pieces of knowledge in the FL domain make it possible to track the decision-making process and identify its inner logic. OFs are interconnected with one another in such a way that OFs actually serve as the basis for tracking the path of decision-making process across the different phases of the FL-MC. In the FL domain all the information coming to the decision makers is considered relevant for decision making. Redundancy might complicate the computational modeling, but it appears practically that all the information are handy and can be used at some point, sometimes not immediately, but later at another phase. Redundancy sometimes helps to confirm hypotheses in case of uncertainty.

Information processing in operating complex systems such as FL can be seen as alternating between data-driven (bottom-up) and goal-driven (top-down) processing. In goal-driven processing, attention is directed across the environment in accordance with active goals [6, 7]. The decision makers actively seek information needed for achieving the mission goals, which, in turn, simultaneously act as a filter in interpreting the new information that is perceived. In data-driven (or stimulus-driven) reactive processing, perceived environmental cues are processed to create or enhance situational awareness with, as a consequence, the identification of new goals that need to be set [22]. The term *situation awareness* has emerged as an important concept in dynamic human decision making. According to Endsley [22], situation awareness is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future". Situation awareness is described as the decision maker's internal model of the state of the environment. Based on that representation, the decision maker can decide what to do about the situation and carry out any necessary actions.

The most critical component of the effective decision-making process is the correspondence of the real situation in the real environment and the situation model obtained in the decision maker's mind based on the situational awareness and analysis [49]. Human factors such as cognitive bias, stress, emotions [12], relationships within the team and with external stakeholders, and personal features of the decision maker naturally influence the decision-making process. While the existence of these factors is presumed, the practical lessons learnt and objective success of the FL multiple deployments have proven that the responsible FL manager and all FL staff members are excellent professionals. Their behavior during the mission and decisions they make are, in the first mission, goal-oriented. Driven by the motivation for the mission success, they are able to cope with human factors and make decisions objectively and impartially. That is why we do not consider any decisions in terms of "right" or "wrong". Presuming that the decisions are taken by experienced competent staff, based on multiple mission parameters and factors, we rather speak about decisions in terms of their impact on other decisions and on the mission as a whole.

The decision-making analysis is made with the help of structural-functional approach to studying the mechanism of balancing the compliance with the fixed procedures and decisions taken in a dynamically changing context. Prevailing of opportunities increases the chance for success. Prevailing of risks is not necessarily a mission-stopper. Actual or potential risks are present in every situation and arise from almost every decision. However, the presence of risks does not necessarily put the mission at stake. What matters here is the significance of the risks, their impact on the FL OFs, possibility or absence of possibility to minimize or neutralize the risks. Only if the risks are too high, presenting a threat that the FL mission goal will not be achieved, and if any subsequent measures and decisions aimed at decreasing the risk do not lead to opportunities, then the decision to stop the mission might be taken.

FL missions at their every step and as a whole are associated with three major types of risks:

- Risks related to security of the FL mission staff and materials;
- Risks related to health—here the staff safety, biosafety and medical issues such as then need for medical evacuation in case of a disease or an accident requiring urgent repatriation are included in health risks;
- Risks related to costs—costs of materials, reagents, transportation of FL staff and equipment, maintenance costs during the mission—all are included in this category.

The objective of every decision made during the FL mission is to ensure opportunities for the mission success, or find opportunities, or create them, and in parallel to minimize risks. Efficient decision-making process, prospective and retrospective risk analysis at every point of the FL mission and timely risk management are the integer part of FL operations management [16] and concurrently secure the FL service to the best needs of stakeholders.

The FL-MC has been defined as the result of multiple iterations and lessons learnt from previous FL deployments. The composition of the FL-MC presented in Section 2 and the list of OFs to be implemented at every phase and step of the mission have been iteratively developed and agreed between all the actors involved in the missions. This FL-MC and the associated set of OFs are common for any type of FL mission. Thus, it is highly unlikely that any new information received by the FL staff could disturb the MC and OFs. New information will be unavoidably bound to one or more existing OFs and will be processed accordingly. New information can impact only parameters of the mission, e.g. exact location of deployment, mission duration, the number of trained FL staff needed for the mission, the number of samples that need to be processed by FL per day, the 24/7 type of service or not, the equipment and other materials that can be used to fulfill certain tasks.

As mentioned above, the decision-making process is never linear, it is not always sequential, and it is based not only on internal FL operations but also on numerous external factors. New information or new data that influence the FL operations can occur at any time, at any phase, during any OF implementation. Every time the FL staff receives new information, its following properties are of most interest for decision-making process:

1. Timing—at what phase of the FL-MC the information is received, to which OF it is related;
2. If this new information can be bound to the existing ontology entities (processes, tools, actors), or new entities shall be created;
3. When the new information is embedded/integrated/fused to the current context, then the impact can be estimated in terms of what opportunities this new information brings and to what risks it is associated. This point is relevant for information bound to "decision nodes" in OFs. Information related to "action nodes" is neutral, just actionable.

The categories of new information that the FL staff usually needs to receive and interpret according to the current situation and integrate in the current context, are as follows:

- Epidemiological information about the current disease spread, the number and location of cases and their positioning on a local map.

Epidemiological data significantly influence the FL operations requiring the following decisions:

- The dynamics of the outbreak, e.g. the number of new cases and contacts per day or per week and the speed of spreading.
- Depending on the number and distribution of cases, it is important to decide the perimeter of the area considered for samples collection, i.e. the accessibility of the patients, or the

accessibility of patients to existing treatment centers or deployed health care facilities which function as sample collection points.

- If the currently deployed FL capacity can handle all the cases, or if extra mobile capacity must be envisaged in the area to investigate very remote patients and collect their samples. For instance, this can be done by using the Extra-Light Fieldable Laboratory (ELFL) that is a part of FL. ELFL is a vehicle-based capacity which can be deployed for 2 days as far as at 50 km distance from the FL. Deployment of ELFL in itself would require careful assessment of the available trained staff, division of effort, costs, safety and security risks, as well as the possibility of a permanent stable communication between the ELFL and FL.
- If and how many of additional FL staff members, how much of resources, assets, equipment, materials will be required for handling the new cases and if the work can be done within normal working hours or daily work, or if the workload requires a 24/7 work schedule and, in the latter case, for how many days.
- If the costs for additional assets, materials, and equipment are acceptable for the FL manager.
- Daily updated health status of every patient: close follow up of biological and clinical data knowing that critically ill patients and long hospitalizations require more laboratory human and material resources.
- Should the FL deployment be extended beyond what was initially planned? This type of decision will be taken according to the answers provided to some of the questions cited here above, hence to the sufficiency/insufficiency of resources, materials, supply chain possibility to provide more materials if needed and volunteers availability if the mission is prolonged;
- New information can appear internally in the FL and can be related to the condition of equipment in case such equipment, e.g. a glovebox necessary for samples analysis, breaks down and needs urgent repair or replacement. The problem can be solved by replacing the broken parts with spare parts, which presumes careful mission preparation, planning, and spare parts logistics of critical equipment deployed. Alternatively, a rapid supply chain solution must be in place in case spare parts or whole piece of equipment must be outsourced.
- Similarly, internal problems related to the physical health and mental condition of the FL staff members. Sometimes medical evacuation (MEDEVAC) of one or more persons can be necessary, and/or team member replacement. Here decisions about the necessity of MEDEVAC are made according to availability of transportation, availability of trained personnel to replace the evacuated staff member, associated costs, timing—all these factors would influence the decision-making process.
- Potential security issues, such as an attack on the FL in case of deployment in a politically unstable area and civil or military unrests with possible harm for the staff members and/or equipment, might force decisions to definitively stop or transiently interrupt the mission.
- Potential safety issues, such as other contemporary natural disaster, e.g. an out-of-control fire with toxic fumes, or an extensive environmental contamination with dangerous chemical products, might also require to stop or interrupt the mission, evacuate and/or repatriate the FL.

- An external stakeholder might request the FL deployment for the purpose of a new therapeutic trial (new vaccine, new drug therapy) for which standards of ethical and legal conduct impose a regular follow up of patients condition, i.e. a thorough evaluation of the therapeutic response and early identification of potentially related side effects. Likewise, testing a new diagnostic method (point-of-care testing [POCT] or Rapid Diagnostic Test [RDT]) by first responders may also be part of the request for deployment. Such a request can cause decisions on the feasibility of the tests, costs, availability of materials, reagents and trained staff to perform the tests, estimation of the workload for these additional tests and their compatibility with the main mission goals.
- Depending on the evolution of the epidemiological situation, or on the request for additional tests, the decisions might be taken to increase the work capacity in terms of staff or working hours, as discussed above.

It is important to underline that we do not associate risks to information itself. Any information, any fact is neutral. It can be interpreted in a positive or negative way, bringing opportunities or risks only when it is consistently integrated in the existing picture of the FL realm, when it becomes part of the context. Only then, it can be interpreted, analyzed, and actionable decisions can be taken accordingly. To illustrate the neutral character of new information, irrespective of its contextual interpretation, let us consider the following example: suppose that the FL manager receives information about new cases of the disease outbreak in a certain area. Globally, it is very negative news for health authorities and the population of the affected area. On the one hand, this information can fully justify the launch of the FL mission, and provides a real opportunity to start the mission. On the other hand, further feedback that no new cases are detected is a very good news for public health authorities while, for the FL deployment perspective, it may interrupt the preparation of the mission and even lead to the decision to cancel it. However, if this information about the absence of new cases is received when the FL is already deployed on-site, which means during the "mission execution", it can imply that the FL mission has a positive impact of the containment of the outbreak, according to the primary objectives of the mission.

4. Validation

The present work is the result of the practical experience accumulated by the FL staff through the multiple missions detailed in **Table 1**. The military mission in 2009 deployed the first fieldable laboratory prototype. This mission was a pioneer deployment without yet any specific supporting tools such as LIMS or ontology. The FL was not yet shaped into an autonomous capacity and a single structured information space but benefited from the military logistics and facilities at the military camp at Kananga where it was deployed. Following each new deployment, a careful planning and thorough preparedness appeared crucial to anticipate on all possible human resources and materials needed on-site to ensure a successful mission. Consequently, the work carried out to systematize the experience of laboratory operators, to structure the FL domain and to develop tools supporting the mission preparation and execution, started already before the second mission. Every new mission brought a new operational context with new parameters and new conditions of deployment for which the LIMS and ontology were iteratively developed and tested during the deployment. Lessons learned and return on experience from participants were systematically collected at the end of each mission in order to improve all the aspects related to the mission cycle and its OFs and to be prepared to implement them in the following deployment. This recently led to the MODEX exercise in Sweden and a final validation by the European Space Agency of all aspects related to terrestrial and SatCom integrated in B-LiFE, and to a European certification as autonomous module in the voluntary pool of assets set for activation by DG ECHO in the framework of the EUCPM.

Naturally, the process of ontology development faced many challenges, due to the intrinsic nature of the ontology concept. The ontology, as discussed and applied in the current work, is a model of a niche of interest, i.e. the FL domain of a deployable laboratory, and its design and configuration largely depend on the representation of the domain by the developers specifically addressing this niche [28]. In order to make the resulting ontology usable on the most possible generic way, and therefore not restricted to the FL staff, but also acceptable for external stakeholders, frequent consultations using formulation and clarification of competency questions were organized with experts inside and outside the laboratory, individually and in groups, to reach an agreement on the most appropriate organization of information in the ontology. A few variants of data representation were implemented in parallel, challenged by various case studies, and the variant performing best was chosen for the new version. Every new version of the ontology was iteratively tested by developers and assessed by B-LiFE users during the new mission planning and preparation phase, and the resulting version was further improved after each mission execution. With a substantial number of approaches, methodologies and metrics elaborated in previous research [3, 8], [13, 33, 40], the evaluation and validation technique appearing as the most relevant for the FL application ontology was chosen in order to cover both the domain conceptual and technical scope. The main functionalities of the ontology subject to the conformity assessment by users were:

- The ontology completeness, i.e. if it appropriately covers all the concepts (lexicon/vocabulary, hierarchy, taxonomy) of the FL domains without any gaps in knowledge;
- The overall usability and acceptability both by the users and the developers, e.g. consistent use of the terminology, precise description of concepts and correct definition of their properties and links between them;
- The ontology explanatory power, i.e. ability to support users in the decision-making process. An example of test case could include the questions: “Given the known mission location and duration, how many gloveboxes will be necessary to take along? Are they already available or do they need to be purchased additionally? Is there available personnel trained to use the necessary equipment? Do they need a specific maintenance during the mission?”
- The ontology logical consistency, i.e. the absence of contradictions in the definition of classes, subclasses, semantic relations, axioms and other entries;
- The ontology computational efficiency, i.e. the size and the speed with which the LIMS can work with the ontology;

- The ontology expandability to account for new missions, i.e. in the technical terms this criterion refers to the ontology structure/architecture design allowing further development.

Such in-depth analysis and iterative improvement process helped to achieve a result that was globally helpful for all the B-LiFE users, and was therefore considered final. It is noteworthy that the terms "final result" should be understood as an appropriate way of information representation of the ontology as validated by users. However, this does not exclude further development in case of a new mission characterized by new, not yet encountered or experienced requirements. In such case, it is possible to add a new module or new tools to the ontology without modifying or altering the global structure.

5. Conclusions

The current work presents key results of the research on operations management and decision-making process regarding the deployment and on-site use of a FL. This work is particularly applicable to the context of a health crisis caused by either a natural infectious outbreak, an accidental biological incident, or a deliberate release of life-threatening biological agents. Considering the lack of standards concerning the structure and use of deployable analytical capacities, the current research is a contribution to harmonization of the procedures, where harmonization is key in case of a cross-border crisis response requiring the use of deployable capacities from different countries and different actors, and where interoperability and scalability of the response is a must. With the aim of making the FL operations transparent and comparable to similar capacities, a unique effort of structuring the FL domain has been made. The phases, steps and OFs characterizing the FL-MC are described.

The tools and mechanisms supporting the FL decision-making process are discussed. It is of note that all the decisions made by the FL manager and staff during the mission are subject to the actual goals of the mission, being defined at the Mission Assignment phase. While there are no "right" or "wrong" decisions, each of them pushes the mission forward by bringing opportunities to reach the goals and make the mission successful, even though this path is often non-linear. Every decision is indeed associated with risks, subject to alternations [15], comebacks, regrets and updates depending on a dynamically changing context. The approach to modeling of the decision-making process, as presented here, is based on the method of contextual inference in computational semantics. The contextual inference supports the decision-making process, itself linked to the FL domain information space, which is modeled in the ontology. Every time new information is received from the internal FL operations or from external sources, it can be linked (bound) to the existing entity (process, tool, person, and event) in the ontology. In this way, it will be integrated in the FL domain mission context by means of the ontology reasoner ensuring logical consistency between the existing and new entries. Otherwise, if no entity in the ontology can bind the new information, the latter can be embedded in the context by creating a new one. In case the new information is confirmed, it must be integrated in the global context of the mission for further use. In case the new information is not confirmed, remains uncertain, or whose validity has not been firmly established, it can be accommodated only locally, temporarily, without changing the global context.

This work focuses on fully autonomous deployment when the mobile capacity operators themselves have to make decisions and implement the OFs, ranging from basic (e.g. provision of equipment, power supply, food and accommodation for the staff) to complicated procedures (e.g. logistics of transportation and supply chain), that are needed to fulfill the operational requirements. It is their responsibility to choose OFs and requirements to implement and to communicate and negotiate with the stakeholders requesting the mission and the downstream users. This work does not take into account military mobile laboratories or field hospitals [23] that both benefit, in principle, from a dedicated planning and preparedness coupled with efficient military or humanitarian logistics capacity. Neither do we consider deployments by major international non-governmental organizations like Doctors Without Borders (MSF, Médecins Sans Frontières) or United Nations humanitarian organizations like World Food Program, since their centralized organization and financial power provide them a total autonomy in decision making regarding the modalities of deployment and support to missions. In many ways, their working processes and internal organization appear, however, quite similar to those used by militaries, which enable them to deploy their capacities at any time and any location in the world.

A thorough analysis and systematization of the decisions related to each OF bound to a FL capacity should have a positive impact on decision makers and end-users when they consider a field deployment of this type of capacity during a major health crisis or biological incident. A field deployment of a FL capacity should no more be a mysterious black box where no one else than laboratory operators understand the needs, procedures and requirements. A proper characterization of each fieldable capacity with a clear definition of all related OFs should make the requirements and conditions of deployment more transparent and easier to carry out. Such transparency should lead to better preparedness, leading to a more timely and efficient response as well as a better harmonization of procedures. The latter requirement is essential if we want to promote interoperability and scalability between different FL modules and health care capacities during cross-border biological crises, as is the goal of the EUCPM.

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Abbreviations

AMP	advanced medical post
AMP-S	advanced medical post with surgery
ARTES	advanced research in telecommunications systems
B-FAST	Belgian first aid and support team
B-LiFE	biological light fieldable laboratory for emergencies
BoO	base of operations
CBRNE	chemical, biological, radiological, nuclear, and explosive materials
CTMA	Center for Applied Molecular Technologies
DG ECHO	Directorate General for European Civil Protection and Humanitarian Aid Operations
EDEN	end-user driven demo for CBRNE
EMC	European medical corps
ERCC	Emergency Response Coordination Centre
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
ETU	Ebola treatment unit

EU	European Union
EUCPM	European Union civil protection mechanism
EUCPT	European Union civil protection team
FL	Fieldable laboratory
FL-MC	Fieldable laboratory mission cycle
IAP	integrated applications promotion
LEMA	local emergency management authority
LIMS	laboratory information management system
MIRACLE	mobile laboratory capacity for the rapid assessment of CBRN threats located within and outside the EU
ModTTX	Modex table top exercise
OF	operational function
OSOCC	On Site Operations Coordination Centre
PRACTICE	preparedness and resilience against CBRN terrorism using integrated concepts and equipment
RDC	Reception and Departure Centre
TAST	technical assistance support team
UCL	Université catholique de Louvain

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Chapter 5

Balancing Operational Services in Healthcare: An Indonesian Perspective

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Additional information is available at the end of the chapter

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Abstract

The purpose of this chapter is to discuss the concept and application of business management services, especially healthcare services. This chapter also features an important issue in healthcare management, balancing conceptual and applied operational services and marketing in healthcare management. The text is organized in four parts. The emphasis is essential uniqueness of healthcare service management. The first part contains an introduction to healthcare covering a wide range of healthcare settings, such as clinics, hospitals, beauty treatments, fitness centers and so on. The second part contains the design of the quality of primary and secondary level healthcare services, measurement, strategies and impacts. The third part contains a healthcare customer satisfaction guarantee, experience, expectations and performance, including dissatisfaction, switching healthcare provider, trust, commitment and patient loyalty. The fourth part contains changes in healthcare business, government policies, information technology, access to health care, and state and private health insurances in Indonesia.

Keywords: operation services, service management, healthcare management, Indonesia

1. Introduction

Operation management is the activity of managing the resources which are devoted to the production and delivery of products and services or in other words about how organizations produce goods and services. Every organization has an operation function because every organization produces some type of products and/or services [1]. Roth and Larry [2] define the concept of service operationally as the core portfolio and the device service element. There are five elements of the core services, namely:

1. supporting facilities, such as physical and structural sources that must be in place for services to be delivered,
2. the facilitating goods that comprise the materials, supplies and merchandise that are used or consumed in the service delivery process,
3. the facilitating information that supports or enhances the execution of the explicit services,
4. the explicit services that represent the customer's experiential or sensual benefits; and
5. the implicit services, which are characterized by psychological benefits or more.

The customer always has to interact with the service provider, while producing the services, in the service company. Contact may also be indirect, the service process continues for a long period of time, resulting in a large number of contacts and interactions, in a certain way. This interaction can take a long time. If the customer feels that they are getting a lower quality, the exchange value of money stops and why should they stay? [3]. Satisfaction with a core service is important for overall customer satisfaction and, in turn, for customer loyalty [4]. This also applies to healthcare services, such as clinics, hospital, beauty care, fitness center and so on.

Consumers in healthcare are patients. They have less choice of type and quality of treatment provided—both personal and therapeutic—unless the patient is a medical/paramedical officer. He has no choice in terms of diagnosis, various tests, and scans to do. There is also no choice about prescribed medications. Salgaonkar describes that such a patient is in the hands and control of the doctor, like a child in hands of the mother [4]. Healthcare is a unique field and therefore cannot be held to the same customer service standards of other industries [5].

2. Healthcare services

2.1. Measuring the quality of health services

Use of a widely accepted quality assurance tool in healthcare and social services is an essential procedure of effective and result-oriented quality management [6]. Service quality (servqual) measurement techniques are increasingly being studied and have been a key area in the marketing literature over the last few decades, including quality dimensions [7]. A multiple-item scale of servqual developed by Parasuraman, Zeithaml and Berry in a series of studies of six service firms (1985 [8], 1988 [9], 1991 [10], 1994 [11]) by refining and replicating in some samples shows that the difference between consumer expectations about the performance of service firms and actual performance provides a consumer perception of service quality. Servqual is also developed by Cronin and Taylor. The authors investigate the conceptualization and measurement service quality and relationships between service quality, consumer satisfaction and purchase intentions [12]. Cronin and Taylor also measured service quality by reducing expectations in the perceptual model [13].

Nowadays, Internet, in addition to facilitating human interaction, also has become an important channel for service delivery; however, many aspects of both the content and the process of how to measure online service quality are still much discussed by many scientists. Rolland and Freeman have designed, developed and evaluated a reliable and valid scale for the measurement of electronic service quality, specifically in the retail business in French context. The authors have extracted the dimensions matched five of the nine factors identified in the literature review, namely: ease of use, information content, security/privacy, fulfillment reliability and post-purchase customer service [14]. Piercy uses 3399 samples from 4 companies (2 pure plays and 2 multi-channels) to develop 9 dimensional online service quality models, namely: the website, trust, customer service, information, ease of contact, no advertisements, personalization, company image and product range. The author found the trust in the company and the online pure-play companies to be the most important dimensions of online service quality, with customer service also highly rated [15].

According to Baird, healthcare is a highly personal service. Patients are usually under emotional and physical stress. If all healthcare employees can act with compassion and care as they come into contact with patients, visitors and other family members, they will feel safe for receiving needed services for disease treatments, diagnosis and prevention [16]. Lee measures service quality in healthcare organization with namely HEALTHQUAL. HEALTHQUAL is an integrated model to measure the health care satisfaction questionnaire (HCSQ) based on the patient's view, the hospital view and the perspective of accreditation institutions.

HEALTHQUAL is divided into two aspects: process and result. Process is divided into four aspects, namely, empathy, tangible, safety and efficiency. While the result consists of degree of improvements of care service [17], the determinants of hospital service quality according to Zaim et al. were broken down into two main categories, namely tangible factors, which refer to technology, physical facilities, personnel, communication materials and so on, and the intangible factors, consisting of five sub-factors, namely reliability, responsiveness, assurance, courtesy and empathy [18].

2.2. Strategies and impacts

Service providers must be able to provide the services of quality in accordance with the expected customers, because the role of service quality is still recognized as an important factor in the survival of a service company. Each time a customer comes in contact with every aspect of the service system (service meeting), they are presented with an opportunity to evaluate the service provider and form an opinion of service quality. In healthcare, the patient is the consumer, who is a customer of healthcare, and is a different kind of customer from other customer types of services. It may be that other consumers may postpone the decision to use the service, but the patient has to take action immediately. The patient's behavior is determined by various unavoidable factors such as the patient's physical condition, the illness involved, the seriousness of the case and so on. [4].

According to Kotler, satisfaction is a function of performance and perceived expectations. It forms three impacts: that if performance equals expectations of customers, it will cause satisfaction, if performance is less than expectations of customers, it will cause dissatisfaction and if performance exceeds the expectations of customers, it will cause increased satisfaction and happiness [19]. While Baker said that there are differences in managing expectations between patient's expectations and actual experience [20]. Patients who are vulnerable and often ill, physically and/or emotionally, have great expectations in each visit. Each patient has a set of variables that affect their level of satisfaction, involvement and, ultimately, loyalty [16].

3. A healthcare customer satisfaction guarantee

3.1. Experience, expectations and performance

When a patient arrives to get in touch with a healthcare provider until completion, the patient assesses his experience. The patient's direct experience of the treatment process through a clinical meeting or as an observer (e.g., as a patient on a hospital ward) can provide valuable insights both physically and non-physically through vision [21].

Parasuraman, Berry and Zeithaml conducted a study of customer expectation. Their findings indicate that customer service expectations have two levels: desired and adequate. The desired level of service is the service that customers expect to receive. The adequate level of service is the service that the customers find acceptable. Customers believe the desired service as a "can be" and "should be" service, adequate service as a "will be" service, both separated by a zone of tolerance. The researchers also explained that the three levels tend to be different for the reliability result dimension and the tangible, responsive, assurance and empathy process dimensions. According to them, the consumers view reliability as the core of service and tend to have higher expectations for it [22].

Patient's expectations of the process and outcome of treatment develop from three main sources [23]:

1. previous experiences and memories in the specific and related settings;
2. comes from word of mouth, experiences shared by family members and friends and media and advertising, including both television and print media;
3. develop through a number of different processes which may depend on the nature of the expectations.

3.2. Patient satisfaction, dissatisfaction and switching healthcare provider

As Kotler explains earlier, satisfaction occurs because consumer expectations are in line with performance. Customer satisfaction and patient satisfaction cannot be equal, because health is typically a complex blend of emotions, the real and the unreal, and the consumption of health cannot be seen [24]. Patients do not readily express their feelings regarding the quality of healthcare they received [4]. A patient said that they are satisfied sometimes using assumptions that patient satisfaction can be useful as an indicator of health [25]. When patients are disappointed with the care they receive, they switch healthcare providers [26, 27].

3.3. Trust and commitment

According to Berry, companies can build consumer trust in three ways [28]:

1. open lines of communication,
2. guarantee their services, and
3. provide higher standards of behavior.

Everything a patient sees, hears, feels and experiences in a healthcare setting should instill trust [16]. Morgan and Hunt propose a model in which commitment and trust are the keys to the success of a marketing relationship, with the impact [29]:

1. encouraging exchange partners to preserve investment in relationships,
2. hindering the search for short-term alternatives, and
3. keeping the belief that the couple will not act opportunistically.

Morgan and Hunt also say that trust is the key to commitment in relationship marketing. However, the relationship between patients with service providers can affect patient satisfaction in primary and secondary healthcare [30].

3.4. Patient loyalty

Brand loyalty and customer loyalty have almost the same meaning. Dick and Basu designed the concept of customer loyalty as the relationship between a person's attitude toward an entity (one of which is service) and one's patronage behavior [31]. Meanwhile, Gremler and Brown say that there are three separate dimensions of customer loyalty: behavioral loyalty, attitudinal loyalty and cognitive loyalty [32].

Astuti and Nagase explain patient loyalty into three groups, namely reinforcement of loyalty, weakened loyalty and potential destruction of loyalty [27]. Relationship marketing, patient satisfaction and retention programs are variables to build reinforced loyalty. Based on their hypothesis that loyalty will increase when there is an interactive relationship that adds value to patients with healthcare providers, appreciation, happiness and happiness reactions to treatment services that meet expectations and retention programs are designed to encourage patients to return. However, some variables have different effects to patient loyalty on hospital than clinical. For instance, the retention program did not meet the criteria for status as a predictor of loyalty to the hospital.

Loyalty will be reduced when the patient decides to try treatment elsewhere, experience dissatisfaction or receive negative information about service performance. The analysis results show that switching service providers has a significant negative impact on loyalty for the clinic but is not the case for hospitals although the direction of the relationship is negative. In other words, hospitals can benefit from spurious loyal customers. Based on Bloemer and

Kasper, spurious brand loyalty, the repeat buying of the brand, is not based on any real commitment but on inertia [33].

The variable that has the potential for destruction of loyalty is relationship marketing, which has a significant negative effect on the switching provider. Hospitals and clinics provide services through good relationships between patients and providers. If the service provider does not build a good relationship, the patient moves, the relationship ends and potential loyalty is destroyed, which will ultimately increase the patient's desire to change healthcare providers.

4. Health business in Indonesia

4.1. Changes of healthcare business in government policies

Based on the results of the Organizational for Economic Co-operation and Development (OECD) survey, Indonesians believe that the government's actions and policies should work to realizing the progress and prosperity of the people, including health issues. Excitingly, Indonesia is ranked first where the level of public confidence to the government is in the top position. Based on these data, 80% of people believe in the government's move [34].

The government has changed various arrangements on healthcare business, such as the organization of clinics. Clinics as providers of health services at the beginning of the community should be appropriate in development and protection to the community, the land of establishment and adequate facilities and infrastructure. Even clinics can open inpatient services [35]. In order to improve the quality and range of advanced services, the Government of the Republic of Indonesia regulates the hospital. This is to regulate the rights and obligations of the community in obtaining health services. The rules are regulated in the Act, that the hospital is a health service institution that organizes health services, individuals who provide inpatient, outpatient and emergency care services [36]. To improve accessibility, affordability, patient and community protection and the quality of pharmaceutical services, it is necessary to arrange pharmaceutical services in pharmacies. This pharmacy is also regulated in the Regulation of the Minister of Health of the Republic of Indonesia Number 9 Year 2017 [37].

4.2. Access to health services and information systems

The development of health services has succeeded in improving the health status of Indonesian society, although not yet felt even in remote or isolated areas, including coastal areas and small islands. The government therefore undertakes the fundamental efforts of improving access to health services to these areas. People in urban or rural areas can easily get access to the health services they want, both government and private health services.

Limitations or unavailability of data and information accurate, precise, and fast are the factors that hinder people from accessing health services. Therefore, the government also made reform through Act Number 36 Year 2009, which stated that to organize effective and efficient health efforts, health information is required health information [38].

4.3. State and private health insurances

Health insurance in Indonesia is experiencing significant growth. History records that health insurance began in 1960. Over time, the government improved the insurance system in Indonesia. In 1992, the government mandated the Public Health Maintenance Guarantee Program, and then in 1996 the government developed the Social Safety Net program. In 2003, the government implemented Poor Family Health Care Security in 3 provinces and 13 districts [39]. In 2005, a health insurance program was introduced for the poor (under the name of Askeskin), a subsidized social health insurance intended for the informal sector and the poor [40]. Askeskin has been shown to lower out-of-pocket spending by 34% of the poor [41]. Then on January 1, 2014, the government incorporated several insurance companies to serve the National Health Insurance, which established the Social Security Administering Body [39]. This institution is a public legal entity which is directly responsible to the president and has the duty to organize national health assurance for all Indonesian people, especially for civil servants, civil servant pensioners and army/police, veterans, pioneers of independence and their families and business entities and others or ordinary people. Article 14 states that every Indonesian citizen and a foreigner who has worked in Indonesia for at least 6 months shall be a member of the Social Security Administering Body. In addition, each company must register its employees as a member of this health insurance institution. The person or family who is not working at the company must register themselves and their family members at this institution. Each participant of this institution will be drawn of a fee whose amount is determined later. For the citizens unable to pay, the contribution is borne by the government through an aid program for the poor [42].

The government has obliged the public to use insurance under government-appointed institutions; is private insurance still needed? The Social Security Administering Body Health becomes the standard protection received by the community that has become a participant. However, due to its standard service, not all match this health insurance service. There are services that may not be covered, or a standard service, so that people who need more personalized or more convenient services also add private commercial insurance. Insurance in Indonesia is governed by the government; it is intended to provide assurance to both insurer and insured parties in order to be responsible for all their respective obligations.

5. Future research

The potential for the development of healthcare business in Indonesia is still very good. It is proven many clinics, private hospitals, provide a satisfactory service. Clinic provides a variety of services, such as beauty treatments. So does the hospital, providing a variety of services for certain diseases.

Unfortunately the completeness of the service for treatment is only available in big cities. But different for remote areas, even patients have to travel that is not easy, as must through the river, forest or barren areas. Medics or paramedics are also still few who serve such a society. Therefore, it is better for the government to build a place for treatment in an area that is easily accessible by the patient. The government should also offer research projects for researchers aimed at solving access problems. Or it can be done by independent researchers to overcome the problem of accessing difficulties by creating a community that understands health problems especially for elderly patients. So in case of emergency the community can cope faster before being taken to the nearest clinic or hospital.

6. Conclusions

The concept and application of business management services, especially health services, is part of a more specific operational management. Balancing concepts and practices are discussed in the area of marketing management, particularly service issues. Basic and advanced healthcare services may differ in service from ownership, such as government and private property, or from financing for medical treatment, such as government financing through national insurance or self-financed through insurance.

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Chapter 6

A New Model to Improve Project Time-Cost Trade-Off in Uncertain Environments

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Additional information is available at the end of the chapter

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Abstract

The time–cost trade-off problem (TCTP) is fundamental to project scheduling. Risks in estimation of project cost and duration are significant due to uncertainty. This uncertainty cannot be eliminated by any scheduling or estimation techniques. Therefore, a model that can represent uncertainty in the real world to solve time–cost trade-off problems is needed. In this chapter, fuzzy logic is utilized to consider affecting uncertainties in project duration and cost. An optimization algorithm based on time-driven activity-based costing (TDABC) is applied to provide a trade-off between project time and cost. The presented model could solve the time–cost trade-off problem while accounting for uncertainty in project cost and duration. This could help generate a more reliable schedule and mitigate the risk of projects running overbudget or behind schedule.

Keywords: scheduling, fuzzy logic, time–cost trade-off, cost estimating, risk management

1. Introduction

Operation management (OM) is vital to achieve success in many disciplines, particularly in a field which requires dealing with large amounts of information such as the construction industry. Most construction projects are a collection of different activities, processes and requirements, involving different factors and aspects to consider. In this way, making decisions in such environments can be a hard task. For these reasons, the need for OM to assist the characterization of such complex scenarios arises. OM could help project managers to improve their decision regarding project time–cost trade-offs (TCTP) [1]. To expedite the execution of a project, project managers need to reduce the scheduled execution time by hiring

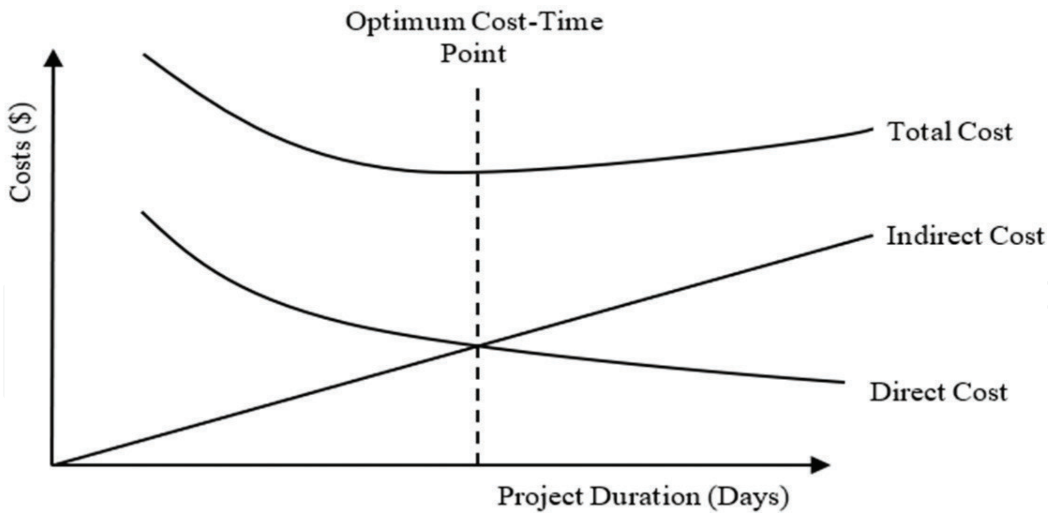

Figure 1. Project cost and time relationship.

extra labor or using productive equipment. But this idea will incur additional cost; hence, shortening the completion time of jobs on critical path network is needed. According to several researchers, time–cost trade-off problem (TCTP) is considered as one of the vital decisions in project accomplishment [2]. Usually, there is a trade-off between the duration and the direct cost to do an activity; the cheaper the resources, the larger the time needed to complete an activity. Reducing the time on an activity will usually increase its direct cost. Direct costs for the project contain materials cost, labor cost and equipment cost. Conversely, indirect costs are the necessary costs of doing work which cannot be related to a specific activity and in some cases, cannot be related to a specific project. The total project construction cost can be found by adding direct cost to indirect cost. When the trade-off of all the activities is considered in the project then the relationship between project duration and the total cost is developed as shown in **Figure 1**. **Figure 1** shows that when the duration for the project is reduced, the total cost becomes quite high and as the duration increases, the total cost increases [3]. The literature review of current practices reveals a shortage of existing tools and techniques specifically tailored to solve the time–cost trade-off problem while accounting for uncertainty in project time and cost. The objective of this research is to develop a model to find time–cost trade-off alternatives using TDABC and fuzzy logic. The next sections discuss these analytical methods.

2. Time-driven activity-based costing

The activity-based costing (ABC) concept was first defined in the late 1980s by Robert Kaplan and William Burns [4]. At first, ABC was utilized by the manufacturing industry where technological expansions and productivity developments had reduced the proportion of direct costs but increased the proportion of indirect costs [5].

ABC was developed as a method to address problems associated with traditional cost management systems, which tend to be usable to accurately determine actual production and service costs or provide useful information for operating decisions. ABC is defined as "a method for tracing costs within a process back to individual activities" [6].

ABC has been used in the construction industry for cost estimating [7]. Further, ABC has been used to forecast the optimum duration of a project as well as the optimum resources required to complete a defined quantity of work in a timely and cost-effective manner [8]. Although traditional ABC systems provide construction managers with valuable information, many have been abandoned or never were implemented fully [3]. The traditional ABC system is costly to build, requires time to process, is difficult to maintain and is inflexible when needing modification [3]. These problems are particularly acute for small companies that are not likely to have a sophisticated information processing system. Further, ABC is very expensive for medium-sized-to-large companies.

To overcome the difficulties inherent in traditional ABC, Kaplan and Steven presented a new method called "time-driven activity-based costing (TDABC)." The new TDABC has overcome traditional ABC difficulties, offering a clear, accessible methodology that is easy to implement and update [4]. TDABC relies only on simple time estimates that, for example, can be established based on direct observation of processes [9].

TDABC utilizes time equations that directly allocate resource costs to the activities performed and transactions processed. Only two values need to be estimated: the capacity cost rate for the project (Eq. (1)) and the capacity usage by each activity in the project (Eq. (2)). Both values can be estimated easily and accurately [4]. Kaplan and Steven (2007) further define the capacity cost rate and the capacity usage as follows:

$$\text{Capacity cost rate} = \text{Total estimated cost} \div (\text{Working hours} \times \text{Efficiency rate}) \tag{1}$$

$$\text{Capacity usage rate} = \text{Capacity cost rate} \times \text{Activity duration} \times \text{Quantity} \tag{2}$$

Although TDABC has many advantages over ABC, TDABC is not flawless. There are many difficulties associated with this deterministic TDABC approach. TDABC is unable of accounting for any variation or uncertainty in the project cost and duration (Hoozée and Hansen, 2015). Research carried out in TDABC, so far, has applied deterministic approaches. But, because of uncertainty present in the estimation of project cost and duration, a fuzzy TDABC would lead to more accurate results [10].

3. Fuzzy logic

Fuzzy logic is a technique that provides a definite conclusion from vague and inaccurate information. Fuzzy set theory was first introduced by Zadeh in 1965. He was motivated after witnessing that human reasoning can utilize concepts and knowledge that do not have well-defined boundaries [11].

A useful method for investigating many everyday problems is fuzzy approximate reasoning or fuzzy logic. This technique is founded on the fuzzy set theory that allows the elements of a set to have variable degrees of membership, from a non-membership grade of 0 to a full membership of 1.0 [12]. This smooth gradation of values is what makes fuzzy logic tie well with the ambiguity and uncertainty of many everyday problems.

Fuzzy logic has become an important tool for many different applications ranging from the control of engineering systems to artificial intelligence. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and false [13]. Fuzzy logic and fuzzy hybrid techniques have been used to capture and model uncertainty in construction, thereby improving workforce and project management. Fuzzy logic can effectively capture expert knowledge and engineering judgment and combine these subjective elements with project data to improve construction decision-making, performance and productivity [14].

Among the various shapes of fuzzy numbers, the triangular fuzzy numbers (TFNs) are the most popular [15]. A triangular fuzzy number μA(x) can be defined as a triplet (a_1, a_M, a_2). Its membership function is defined as follows [16]:

$$\mu A(x) = \begin{cases} \frac{x - a_1}{a_M - a_1} & \text{for } a_1 \leq x \leq a_M \\ \frac{x - a_2}{a_M - a_2} & \text{for } a_M \leq x \leq a_2 \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

where $[a_1, a_2]$ is the interval of possible fuzzy numbers and the point $(a_M, 1)$ is the peak. This parameter (a_1, a_M, a_2) signifies the smallest possible value, the most promising value and the largest possible value, respectively [17]. **Figure 2** illustrates a TFN.

4. Fuzzy time-driven activity-based costing model

This model utilizes TDABC as a tool for tracing costs and time within a project back to individual activities. TFNs are proposed as a logical approach to manage uncertainty in the deterministic TDABC system. TFNs were used to signify vagueness of TDABC because of their simplification to formulate in a fuzzy environment. Further, they are potentially more intuitive than other complicated types of fuzzy numbers such as trapezoidal or bell-shaped fuzzy numbers [16]. This model has the ability to fuzzify the project cost and duration by

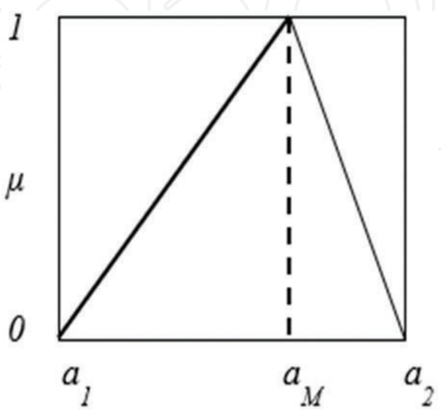

Figure 2. Triangular fuzzy number.

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transferring these values from crisp numbers to fuzzy sets. A crisp number has a specific value while a fuzzy set has a possible range of values [15]. Then after applying a fuzzy rule, the model will defuzzify the cost and duration of the project to transfer these values back to crisp numbers. **Figure 3** shows the fuzzy logic process that has been used in this model, as suggested by [14]. The fuzzy TDABC model consists of three stages as follows:

4.1. Model stage one

The first step in stage one is to transfer the three-point estimate of project duration from crisp values to the fuzzy set. This can be done by calculating the estimated project duration using one of the traditional scheduling techniques (i.e., CPM) [18]. This value will be called the moderate duration and will use the notation D_M. Then the pessimistic duration (the maximum project duration) should be calculated using expert opinion. The pessimistic duration notation is D_P. Finally, the optimistic duration (the minimum project duration) should be calculated also using expert opinion. The optimistic duration notation is D_O.

The second step is to transfer the three-points estimate of project cost from crisp values to the fuzzy set. This can be done by calculating the estimated project cost using one of the traditional cost estimation techniques (i.e., unit area cost estimate, unit volume cost estimate or parameter cost estimate) [18]. This value will be called the moderate cost and will use the notation C_M. Then, the pessimistic cost (the maximum project cost) should be calculated using expert opinion. The pessimistic cost notation is C_P. Finally, the optimistic cost (the minimum project cost) should be calculated also using expert opinion. The optimistic cost notation is C_O.

During this step, each activity's moderate duration, optimistic duration and pessimistic duration should be determined. The notations for an activity moderate duration, optimistic duration and pessimistic duration are d_m, d_o and d_p, respectively. The third step is to calculate the fuzzy capacity cost rate (CCR) using Eq. (4):

$$CCR = \left(\frac{C_P}{D_O}, \frac{C_M}{D_M}, \frac{C_O}{D_P}\right) \tag{4}$$

Then, the fuzzy capacity usage rate (CUR) should be calculated as a triangular membership function (TMF) using the following equations:

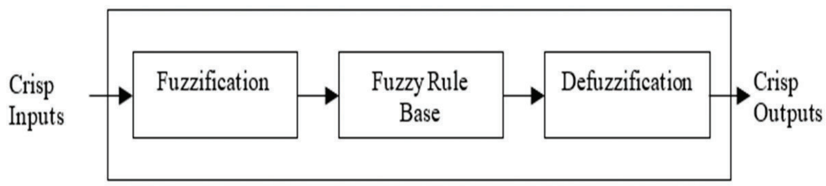

Figure 3. Fuzzy logic controller.

$$\text{CUR} = \begin{pmatrix} \frac{C_P}{D_O} \\ \frac{C_M}{D_M} \\ \frac{C_O}{D_P} \end{pmatrix} * \begin{pmatrix} d_o \\ d_m \\ d_p \end{pmatrix} * \begin{pmatrix} Q \\ Q \\ Q \end{pmatrix} \tag{5}$$

$$\text{CUR} = \left\{ \left(\frac{C_P}{D_O} * d_o * Q \right), \left(\frac{C_M}{D_M} * d_m * Q \right), \left(\frac{C_O}{D_P} * d_p * Q \right) \right\} \tag{6}$$

where Q = Number of Each Activity (quantity).

The fourth step is to defuzzify the triangular membership function (TMF) to get crisp CUR values. Available defuzzification techniques include a max-membership principle, a centroid method, a weighted average method, a mean-max membership method, a center of sums, a center of largest area, the first of maxima or last of maxima [19]. Among these, a centroid method (also called Center of Gravity [COG]) is the most prevalent and physically appealing method [20]. The α-cut method is a standard method for performing arithmetic operations on a Triangular Membership Function [21]. The α-cut signifies the degree of risk that the decision-makers are prepared to take (i.e., no risk to full risk). Since the value of α could severely influence the solution, its choice should be carefully considered by decision-makers. **Figure 4** shows a TFN with α-cut. The higher the value of α, the greater the confidence ($\alpha = 1$ means no risk) [21].

By using the center of gravity (COG) defuzzification technique and $\propto = 0.1$, crisp CUR values (cost values) can be calculated for each activity using the following formula:

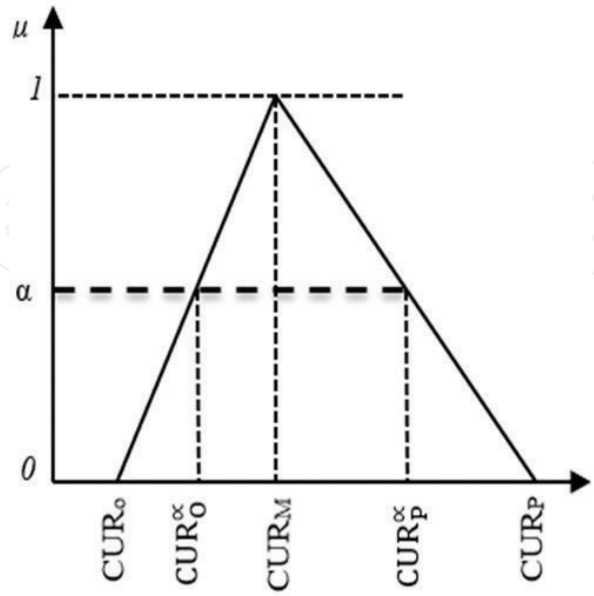

Figure 4. Triangular fuzzy number with α-cut.

$$CUR_{COST}^{\propto} = \frac{\int_{CUR_O^{\propto}}^{CUR_M} \mu A(\mathbf{x})xdx + \int_{CUR_M}^{CUR_P^{\propto}} \mu A(\mathbf{x})xdx}{\int_{CUR_O^{\propto}}^{CUR_M} \mu A(\mathbf{x})dx + \int_{CUR_M}^{CUR_P^{\propto}} \mu A(\mathbf{x})dx} \quad (7)$$

where:

$$CUR_{COST}^{\propto} = \text{Improved cost estimate of an activity at } \propto = 0.1$$

$$CUR_O^{\propto} = \left(\frac{C_P}{D_o} * d_O * Q\right) = \text{Optimistic cost at } \propto = 0.1$$

$$CUR_P^{\propto} = \left(\frac{C_O}{D_P} * d_P * Q\right) = \text{Pessimistic cost at } \propto = 0.1$$

$$CUR_M = \left(\frac{C_M}{D_M} * d_m * Q\right) = \text{Moderate cost}$$

The crisp $CUR_{COST}^{\propto}$ value that is calculated in this step is the improved cost estimate for an activity at $\propto = 0.1$ and its notation is $(iac_{0.1})$.

The fifth step is to repeat the same process to get the improved cost estimate for all project activities. Finally, add the improved cost estimate for all the activities to get an improved cost estimate for the project at $\propto = 0.1$. The project improved cost estimate will be abbreviated as $IPC_{0.1}$

$$IPC_{0.1} = \sum_{i}^{\text{Project}} \text{improved activities cost at } \propto = 0.1 \quad (8)$$

4.2. Model stage two

The first step in stage two is to calculate the fuzzy capacity cost rate (CCR) using the new $IPC_{0.1}$ cost and the following equation:

$$CCR = \left(\frac{\mathbf{D_O}}{\mathbf{IPC_{0.1}}}, \frac{\mathbf{D_M}}{\mathbf{IPC_{0.1}}}, \frac{\mathbf{D_P}}{\mathbf{IPC_{0.1}}}\right) \quad (9)$$

The second step is to calculate the fuzzy capacity usage rate (CUR) as a triangular fuzzy function using the following equation:

$$CUR = \begin{pmatrix} \frac{\mathbf{D_O}}{\mathbf{IPC_{0.1}}} \\ \frac{\mathbf{D_M}}{\mathbf{IPC_{0.1}}} \\ \frac{\mathbf{D_P}}{\mathbf{IPC_{0.1}}} \end{pmatrix} * \begin{pmatrix} iac_{0.1} \\ iac_{0.1} \\ iac_{0.1} \end{pmatrix} * \begin{pmatrix} \mathbf{Q} \\ \mathbf{Q} \\ \mathbf{Q} \end{pmatrix} \quad (10)$$

$$\text{CUR} = \left\{ \left(\frac{\mathbf{D_O}}{\text{IPC}_{\mathbf{0.1}}} * \text{iac}_{\mathbf{0.1}} * \mathbf{Q} \right), \left(\frac{\mathbf{D_M}}{\text{IPC}_{\mathbf{0.1}}} * \text{iac}_{\mathbf{0.1}} * \mathbf{Q} \right), \left(\frac{\mathbf{D_P}}{\text{IPC}_{\mathbf{0.1}}} * \text{iac}_{\mathbf{0.1}} * \mathbf{Q} \right) \right\} \tag{11}$$

where $\text{iac}_{0.1}$ = The improved activity cost at $\propto = 0.1$ (it is already calculated in stage one).

The third step is to defuzzify the triangular membership function (TMF) using the center of gravity (COG) defuzzification technique. Using COG and $\propto = 0.1$, a crisp CUR value (time value) can be calculated for each activity using the following formula:

$$\text{CUR}^{\propto}_{\text{TIME}} = \frac{\int_{\text{CUR}^{\propto}_{O}}^{\text{CUR}_M} \boldsymbol{\mu}\text{A}(\mathbf{x})\text{xdx} + \int_{\text{CUR}_M}^{\text{CUR}^{\propto}_{P}} \boldsymbol{\mu}\text{A}(\mathbf{x})\text{xdx}}{\int_{\text{CUR}^{\propto}_{O}}^{\text{CUR}_M} \boldsymbol{\mu}\text{A}(\mathbf{x})\text{dx} + \int_{\text{CUR}_M}^{\text{CUR}^{\propto}_{P}} \boldsymbol{\mu}\text{A}(\mathbf{x})\text{dx}} \tag{12}$$

where:

$$\text{CUR}^{\propto}_{\text{TIME}} = \text{Improved time estimate of an activity at } \propto = 0.1$$

$$\text{CUR}^{\propto}_{O} = \left(\frac{\text{D}_O}{\text{IPC}_{0.1}} * \text{iac}_{0.1} * \text{Q} \right) = \text{Optimistic time at } \propto = 0.1$$

$$\text{CUR}^{\propto}_{P} = \left(\frac{\text{D}_P}{\text{IPC}_{0.1}} * \text{iac}_{0.1} * \text{Q} \right) = \text{Pessimistic time at } \propto = 0.1$$

$$\text{CUR}_{M} = \left(\frac{\text{D}_M}{\text{IPC}_{0.1}} * \text{iac}_{0.1} * \text{Q} \right) = \text{Moderate time}$$

The crisp $\text{CUR}^{\propto}_{\text{TIME}}$ value that is calculated in this step is the improves duration for an activity at $\propto = 0.1$ and its notation is $(\text{iad}_{0.1})$.

The fourth step is to repeat the same process to get the improved duration for all project activities. Finally, add the improved duration for all the activities to get an improved duration for the project. The project improved duration will be abbreviated as $\text{IPD}_{0.1}$

$$\text{IPD}_{0.1} = \sum_{i}^{\text{Project}} \text{improved activities duration at } \propto = 0.1 \tag{13}$$

4.3. Model stage three

In stage three, a sensitivity analysis should be performed to investigate the variability of the results obtained with respect to the choice of the α-cut value. Sensitivity analysis is "the study of how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model input" [22]. One of the simplest and most common approaches to sensitivity analysis is changing the α-cut value, to see what effect this produces on the project cost and duration. To achieve that, stage one and two should be repeated using α-cut values equal to 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0. The results obtained from the different α-cut values will be saved as shown in **Table 1**. The sensitivity analysis will help investigate various levels of confidence associated with each time–cost alternative.

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α-cut	Improved project cost	Improved project duration
0.1	$IPC_{0.1}$	$IPD_{0.1}$
0.2	$IPC_{0.2}$	$IPD_{0.2}$
0.3	$IPC_{0.3}$	$IPD_{0.3}$
0.4	$IPC_{0.4}$	$IPD_{0.4}$
0.5	$IPC_{0.5}$	$IPD_{0.5}$
0.6	$IPC_{0.6}$	$IPD_{0.6}$
0.7	$IPC_{0.7}$	$IPD_{0.7}$
0.8	$IPC_{0.8}$	$IPD_{0.8}$
0.9	$IPC_{0.9}$	$IPD_{0.9}$
1.0	$IPC_{1.0}$	$IPD_{1.0}$

Table 1. Project time and cost at each α-cut.

5. Fuzzy time-driven model verification and validation

To illustrate an application of the fuzzy TDABC model, a case study of seven activities proposed initially by Zheng et al. (2004) was used [23]. The case study illustrates a construction project that has seven activities as shown in **Table 2**. The letters O, M and P in **Table 2** signify optimistic, moderate and pessimistic time and direct cost. The assumed value for indirect cost per day is \$1000, \$1150 and \$2000 for optimistic, moderate and pessimistic values, respectively. The calculated project duration is (60, 81 and 92) days for optimistic, moderate and pessimistic, respectively.

The first step is to calculate the total cost of the project by adding the indirect cost to the direct cost. **Table 3** shows the optimistic, moderate and pessimistic total cost.

Applying stage one of the fuzzy TDABC model begins by using Eq. (4) to calculate the fuzzy CCR as shown in **Table 4**.

Activity	Predecessor	Time (Days)			Direct cost (\$)		
		O	M	P	O	M	P
A	—	14	20	24	23,000	18,000	12,000
B	A	15	18	20	3000	2400	1800
C	A	15	22	33	4500	4000	3200
D	A	12	16	20	45,000	35,000	30,000
E	B, C	22	24	28	20,000	17,500	15,000
F	D	14	18	24	40,000	32,000	18,000
G	E, F	9	15	18	30,000	24,000	22,000

Table 2. Activities duration and cost.

Total cost ($)		
P	M	O
296,772	238,169	205,192

Table 3. Project total cost.

CCR ($): Phase I		
O	M	P
2938	1791	1229

Table 4. Fuzzy capacity cost rate (CCR).

Then, the fuzzy capacity usage rate (CUR) is calculated as a cost function using Eq. (5). **Table 5** shows the CUR values.

Next, α-cut values of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 are applied to the CUR values in **Table 5**. This will generate new CUR values associated with each α-cut. **Table 6** shows the CUR values that are associated with each α-cut for each activity in the project.

Using Eq. (7), crisp CUR values associated with each α-cut are determined for each activity. These CUR values are the improved cost estimate for each activity at the associated α-cut. By adding the improved activities' costs, the project improved cost estimates are determined as shown in **Table 7**.

At this point, stage one of the model is done and stage two begins. By using the improved project costs that have been calculated in **Table 7**, the fuzzy capacity cost rates (CCR) are calculated using Eq. (9). **Table 8** shows the CCR value associated with each α-cut.

Then, the fuzzy capacity usage rate (CUR) is calculated as a time function using Eq. (10). **Table 9** shows the CUR values.

Activity	CUR ($): Phase I		
	O	M	P
A	41,137	35,815	29,489
B	44,075	32,233	24,574
C	44,075	39,396	40,547
D	35,260	28,652	24,574
E	64,643	42,978	34,403
F	41,137	32,233	29,489
G	26,445	26,861	22,117

Table 5. Fuzzy capacity usage rate (CUR).

α	Fuzzy CUR ($)	Activities						
		A	B	C	D	E	F	G
0.1	CUR_o	40,604	42,891	43,607	34,599	62,477	40,246	26,487
	CUR_M	35,815	32,233	39,396	28,652	42,978	32,233	26,861
	CUR_P	30,121	25,340	40,432	24,982	35,261	29,763	22,591
0.2	CUR_o	40,072	41,707	43,139	33,938	60,310	39,356	26,528
	CUR_M	35,815	32,233	39,396	28,652	42,978	32,233	26,861
	CUR_P	30,754	26,106	40,317	25,390	36,118	30,038	23,065
0.3	CUR_o	39,540	40,523	42,671	33,278	58,144	38,466	26,570
	CUR_M	35,815	32,233	39,396	28,652	42,978	32,233	26,861
	CUR_P	31,387	26,872	40,202	25,797	36,976	30,312	23,540
0.4	CUR_o	39,008	39,338	42,204	32,617	55,977	37,575	26,611
	CUR_M	35,815	32,233	39,396	28,652	42,978	32,233	26,861
	CUR_P	32,019	27,638	40,087	26,205	37,833	30,587	24,014
0.5	CUR_o	38,476	38,154	41,736	31,956	53,811	36,685	26,653
	CUR_M	35,815	32,233	39,396	28,652	42,978	32,233	26,861
	CUR_P	32,652	28,404	39,972	26,613	38,691	30,861	24,489
0.6	CUR_o	37,944	36,970	41,268	31,295	51,644	35,795	26,695
	CUR_M	35,815	32,233	39,396	28,652	42,978	32,233	26,861
	CUR_P	33,284	29,170	39,857	27,021	39,548	31,135	24,963
0.7	CUR_o	37,411	35,786	40,800	30,634	49,477	34,904	26,736
	CUR_M	35,815	32,233	39,396	28,652	42,978	32,233	26,861
	CUR_P	33,917	29,936	39,741	27,428	40,405	31,410	25,438
0.8	CUR_o	36,879	34,602	40,332	29,973	47,311	34,014	26,778
	CUR_M	35,815	32,233	39,396	28,652	42,978	32,233	26,861
	CUR_P	34,550	30,701	39,626	27,836	41,263	31,684	25,912
0.9	CUR_o	36,347	33,418	39,864	29,313	45,144	33,124	26,820
	CUR_M	35,815	32,233	39,396	28,652	42,978	32,233	26,861
	CUR_P	35,182	31,467	39,511	28,244	42,120	31,959	26,387
1.0	CUR_o	35,815	32,233	39,396	28,652	42,978	32,233	26,861
	CUR_M	35,815	32,233	39,396	28,652	42,978	32,233	26,861
	CUR_P	35,815	32,233	39,396	28,652	42,978	32,233	26,861

Table 6. CUR value at each α-cut ($): Phase I.

Using Eq. (12), new crisp CUR values associated with each α-cut are determined for each activity. These CUR values are the improved duration for each activity at the associated α-cut. By adding the improved activities' durations, the project improved durations are determined as shown in **Table 10**.

Crisp CUR Values ($) - Phase I								
α-cut	Activities							Improved project cost ($)
	A	B	C	D	E	F	G	
0.1	35,622	34,868	42,040	30,049	50,132	35,266	24,590	252,567
0.2	35,617	34,504	41,744	29,869	49,226	34,905	24,837	250,703
0.3	35,620	34,158	41,449	29,695	48,345	34,550	25,085	248,902
0.4	35,628	33,829	41,154	29,527	47,490	34,200	25,335	247,164
0.5	35,643	33,517	40,860	29,366	46,663	33,857	25,586	245,491
0.6	35,665	33,223	40,566	29,210	45,863	33,519	25,839	243,885
0.7	35,693	32,947	40,273	29,061	45,094	33,188	26,092	242,348
0.8	35,727	32,690	39,980	28,918	44,356	32,863	26,347	240,882
0.9	35,768	32,452	39,688	28,782	43,650	32,545	26,604	239,488
1.0	35,815	32,233	39,396	28,652	42,978	32,233	26,861	238,169

Table 7. Project improved cost estimates.

Using the results in **Tables 7** and **10**, the improved project cost and the improved project duration associated with each α-cut are summarized in **Table 11**.

Using **Table 11**, a plot of the improved project costs versus the improved project durations is created as shown in **Figure 5**. The robustness of the new proposed TDABC model is compared with two previous models:

1. Gen and Cheng (2000) model.
2. Zheng et al. (2004) model.

Activity	CCR - Phase II		
	O	M	P
0.1	0.000238	0.000321	0.000364
0.2	0.000239	0.000323	0.000367
0.3	0.000241	0.000325	0.000370
0.4	0.000243	0.000328	0.000372
0.5	0.000244	0.000330	0.000375
0.6	0.000246	0.000332	0.000377
0.7	0.000248	0.000334	0.000380
0.8	0.000249	0.000336	0.000382
0.9	0.000251	0.000338	0.000384
1.0	0.000252	0.000340	0.000386

Table 8. The CCR value associated with each α-cut.

α	Fuzzy CUR (Days)	Activities						
		A	B	C	D	E	F	G
0.1	CUR_o	9	9	10	7	12	9	6
	CUR_M	11	11	13	10	16	11	8
	CUR_P	13	13	15	11	18	13	9
0.2	CUR_o	9	9	11	8	13	9	6
	CUR_M	12	11	13	10	16	11	8
	CUR_P	13	12	15	11	18	13	9
0.3	CUR_o	9	9	11	8	13	9	6
	CUR_M	12	11	13	10	16	11	8
	CUR_P	13	12	15	11	18	12	9
0.4	CUR_o	10	9	11	8	14	10	7
	CUR_M	12	11	13	10	16	11	8
	CUR_P	12	12	15	10	17	12	9
0.5	CUR_o	10	10	12	8	14	10	7
	CUR_M	12	11	13	10	15	11	8
	CUR_P	12	12	14	10	17	12	8
0.6	CUR_o	10	10	12	9	14	10	7
	CUR_M	12	11	13	10	15	11	9
	CUR_P	12	12	14	10	17	12	8
0.7	CUR_o	11	10	12	9	15	10	7
	CUR_M	12	11	13	10	15	11	9
	CUR_P	12	12	14	10	17	12	8
0.8	CUR_o	11	11	13	9	15	11	7
	CUR_M	12	11	13	10	15	11	9
	CUR_P	12	11	14	10	17	12	8
0.9	CUR_o	11	11	13	9	16	11	8
	CUR_M	12	11	13	10	15	11	9
	CUR_P	12	11	14	10	16	11	8
1.0	CUR_o	11	11	13	10	16	11	8
	CUR_M	12	11	13	10	15	11	9
	CUR_P	11	11	13	10	16	11	8

Table 9. CUR value at each α-cut (days): Phase II.

Gen and Cheng (2004) used a genetic algorithm (GA) approach to find the best Time–Cost Trade-Offs. GA is a search method used for finding optimized solutions to problems based on the natural selection theory and biological evolution [24]. The Zheng et al. model used the modified adaptive weight approach with GA to solve the time–cost trade-off problem. The

Crisp CUR (Days): Phase II								
α-cut	**Activities**							**Improved project duration (Days)**
	A	**B**	**C**	**D**	**E**	**F**	**G**	
0.1	10.9	10.7	12.9	9.2	15.4	10.8	7.5	77.4
0.2	11.0	10.7	12.9	9.2	15.4	10.9	7.6	77.7
0.3	11.0	10.8	13.0	9.3	15.5	10.9	7.6	78.0
0.4	11.1	10.8	13.0	9.3	15.6	10.9	7.6	78.4
0.5	11.1	10.9	13.1	9.4	15.6	11.0	7.7	78.8
0.6	11.2	10.9	13.2	9.4	15.7	11.1	7.7	79.2
0.7	11.2	11.0	13.2	9.5	15.8	11.1	7.7	79.6
0.8	10.9	10.7	12.9	9.2	15.4	10.8	7.5	77.4
0.9	11.0	10.7	12.9	9.2	15.4	10.9	7.6	77.7
1.0	11.0	10.8	13.0	9.3	15.5	10.9	7.6	78.0

Table 10. Project improved duration.

modified adaptive weight approach is a method to represent the importance of each function by assigning different weights to different functions [23].

The results of these two models are compared with the fuzzy TDABC model in **Table 12**.

Figure 6 compares between the fuzzy TDABC result and the results obtained by Gen and Cheng (2004) and Zheng et al. (2004).

Table 12 and **Figure 6** show that the fuzzy TDABC obtains better values of time and cost compared to the result obtained by Gen and Cheng (2000). However, the result obtained by Zheng (2004) is better than the fuzzy TDABC result.

α-cut	Improved project cost ($)	Improved project duration (Days)
0.1	252,567	77.4
0.2	250,703	77.7
0.3	248,902	78.0
0.4	247,164	78.4
0.5	245,491	78.8
0.6	243,885	79.2
0.7	242,348	79.6
0.8	240,882	80.0
0.9	239,488	80.5
1.0	238,169	81.0

Table 11. Improved project cost and duration associated with each α-cut.

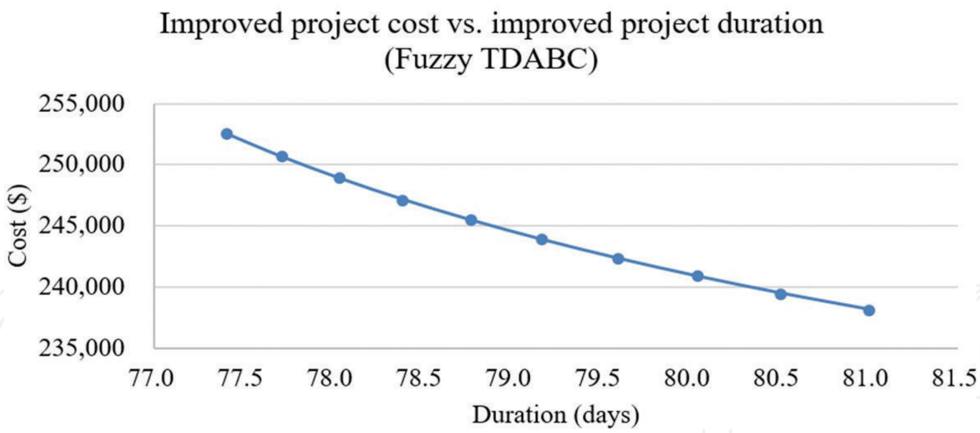

Figure 5. Improved project cost versus project durations.

To further compare the results of the fuzzy TDABC model with the past published results, a test called Wilcoxon signed-ranks test is performed. The Wilcoxon Signed-Ranks test is a non-parametric analysis that statistically compared the average of two dependent samples and assessed for significant differences. Wilcoxon signed-ranks test does not assume normality of the differences of the compered groups [25]. The Wilcoxon test has been selected because the datasets in this case do not follow normal distribution. The method to perform Wilcoxon test starts with two hypotheses. A null hypothesis (H_0) assumes that the results obtained from the three approaches are the same. An alternative hypothesis (H_1) assumes that the results obtained from the three approaches are not the same. **Table 13** shows the Wilcoxon signed-ranks test result.

Table 13 shows that the p-value is 0.036. The p-value, or calculated probability, assesses if the sample data support the argument that the null hypothesis (H_0) is true. A small p-value (less or equal to 0.05) indicates solid evidence against the null hypothesis, so the null hypothesis should be rejected. A large p-value (larger than 0.05) indicates weak evidence against the null hypothesis, so the null hypothesis should not be rejected [25]. The p-value is 0.036, in this case, which is less than the significance level of 0.05. As a result, there is enough evidence to reject the null hypothesis and to conclude that the difference between the results obtained from the three approaches is significant.

Approaches	Criteria		Target
	Time (days)	Cost ($)	
Gen and Cheng (2000)	83	243,500	Least cost
	79	256,400	Least time
Zheng et al. (2004)	73	236,500	Least cost
	66	251,500	Least time
Fuzzy TDABC	81	238,169	Least cost
(This research)	77	252,567	Least time

Table 12. Fuzzy TDABC result vs. previous research results.

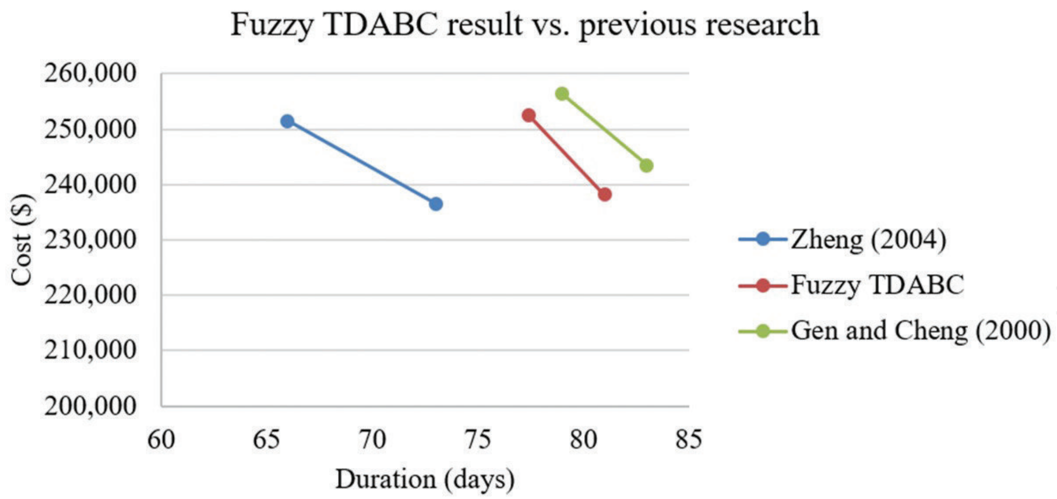

Figure 6. Fuzzy TDABC result versus previous research results.

Source	N	Wilcoxon Statistic	P-Value	Estimated median
Time	6	21.0	0.036	77 Day
Cost	6	21.0	0.036	$246,450

Table 13. Wilcoxon signed-ranks test result.

6. Conclusion

The objective of this research is to develop a model to find time–cost trade-off alternatives while accounting for uncertainty in project time and cost. The presented fuzzy TDABC model provides an attractive alternative for the traditional solutions of the time–cost trade-offs optimization problem. The presented model is simple and easy to apply compared with other approaches. Further, this model obtained a better solution when compared to the GA model that is presented by Gen and Cheng (2000). The fuzzy TDABC model could improve the reliability of the time–cost trade-off decisions. This could help construction companies mitigate the risk of projects running over budget or behind schedule.

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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, con d 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, lifecycle 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. If 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 Stated 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	Production and Deployment	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

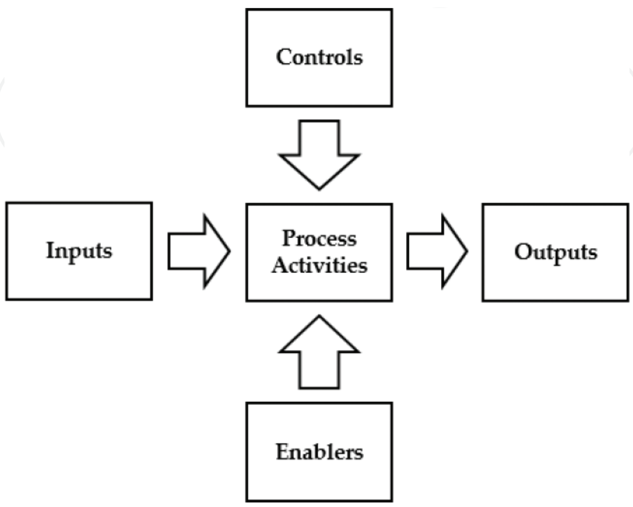

Figure 1. System engineering IPO diagram.

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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.

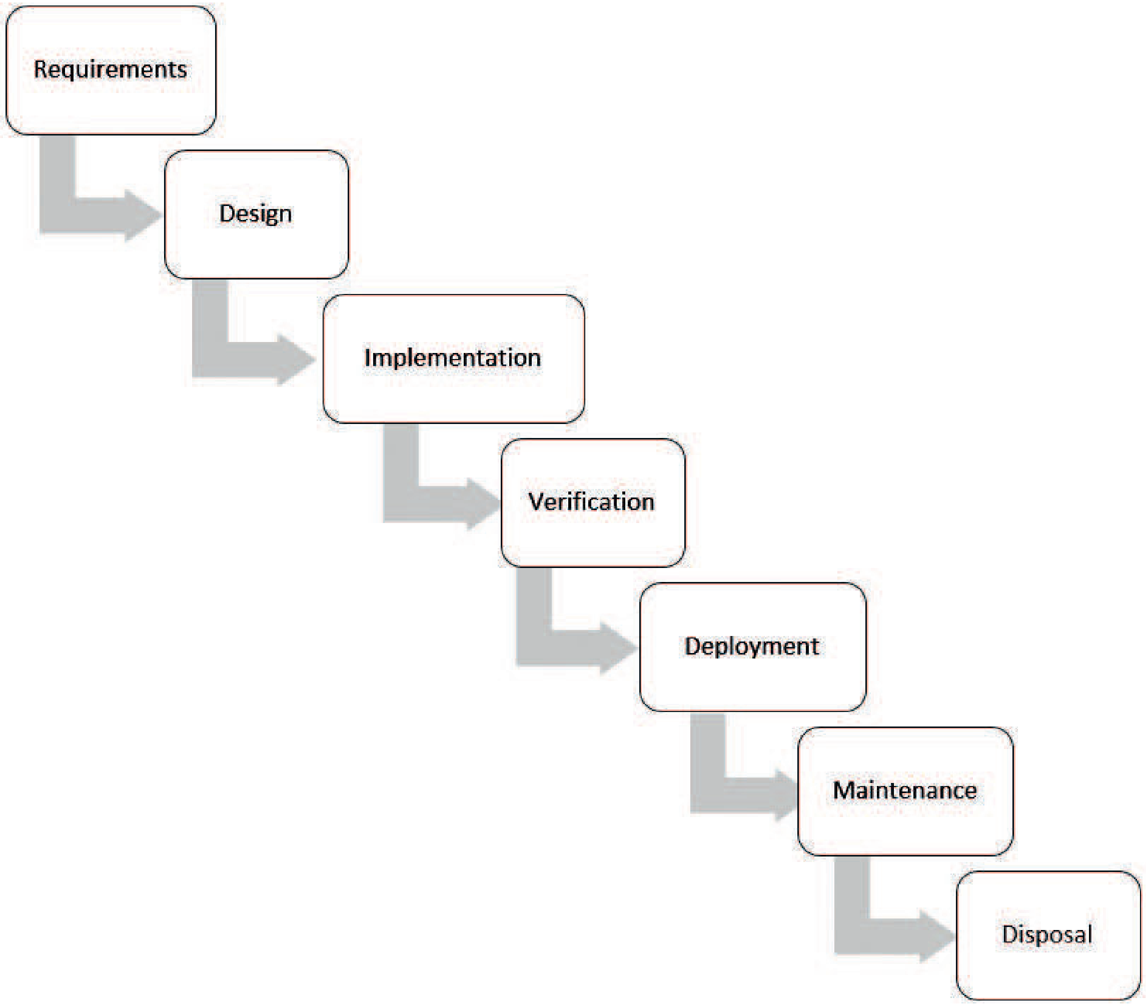

Figure 2. Waterfall system engineering process model.

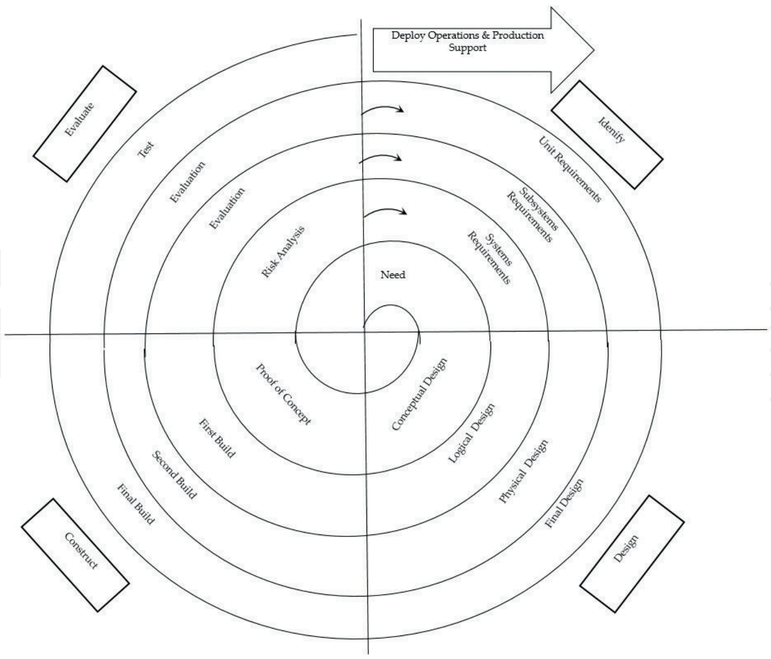

Figure 3. Spiral system engineering process model.

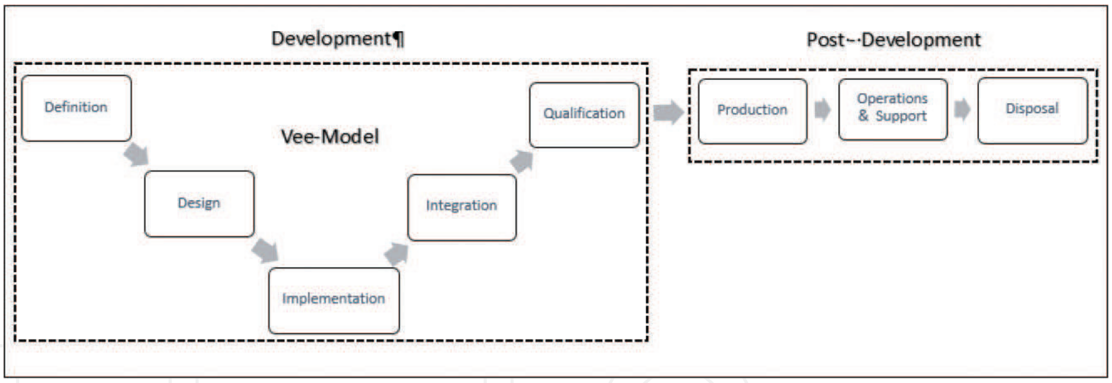

Figure 4. Generic system engineering process Vee-model.

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

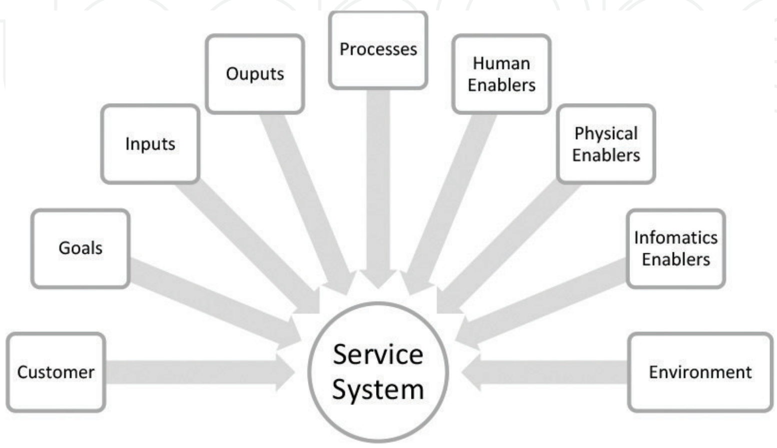

Figure 5. Service system entities.

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 or 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 preforming 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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