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Service Systems Engineering Applications

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Abstract

The rapid growth in the global service economy has greatly increased research in Service Science and Service Systems Engineering (SSE). In Service Systems practice, the service value chain in terms of links among system entities is defined to co-create value and deliver high quality of service. A Service System is thus defined by its value co-creation chain in which all relevant stakeholders collaborate dynamically in real time or near-real time to deliver high quality service according to the business, service, and customer goals. This paper illustrates how SSE can help define, and discover relationships among Service System entities and addresses the service-oriented, customer-centric, holistic systems view in order to plan, design, adapt or self-adapt to co-create value. Modern service systems, which may be classified as system of systems (SoS), mandate well-defined integration and governance to link service system entities for the real-time dynamic analysis of ever-changing requirements within a Service System. In this paper, SSE concepts and methodologies are applied across various SSE stages to describe an intelligent emergency transportation system and a near real-time dynamic Smart Grid service system. Additionally, issues which need to be addressed within SSE methodologies for global deployment of efficient world-wide service systems are discussed. Finally, future work required for improving current SSE methodologies and help steer research towards achieving global service effectiveness is discussed.

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Keywords: service science, service systems engineering, service systems

1. Introduction

The 21st century technology-intensive global services economy, characterized as "information-driven, customer centric, e-oriented, and productivity-focused", requires trans-disciplinary collaborations among society, science, enterprises, and engineering [1]. The top sub-sectors in the global service economy include real estate, financial, healthcare, energy, education, legal, banking, insurance, and investment. Several researchers are utilizing a socio-economic and technological perspective to investigate end-user (customer) interactions with enterprises by developing formal methodologies for value co-creation and productivity improvements. These methodologies have evolved into Service Systems Engineering (SSE) which mandates a disciplined and systemic approach (service

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oriented customer-centric) among different stakeholders and resources in the design and delivery of the service to help customize and personalize service transactions to meet particular customer needs [2, 3, 4, 5]. To achieve customization of individual customer-centric services and assure quality and timely delivery, significant back-stage support (e.g., business processes, governance processes, IT, knowledge management, forecasting, logistics, distribution, etc.) is required. Thus service value co-creation is realized by creating links among the system entities, where all relevant stakeholders collaborate to deliver consistently high quality service in real time or near-real time according to the business, service, and customer goals, using advances in IT and decision support systems [6].

Service system can be viewed as a system of systems (SoS), where individual, heterogeneous, functional systems are linked together to realize new features/functionalities of a meta-system and to improve robustness, lower cost, and increase reliability. The evolution toward SoS thinking is driven by the need to analyze, design, implement modern large complex systems which, in most cases, are composed of independently developed, operated and managed systems according to predefined stakeholder’s needs. Nanayakkara et al. (2010) provide a good overview on the theoretical (open systems approach, SoS architecture, knowledge and behavior emergence, etc.) and implementation issues in SoS and present current research carried out to address these issues [7]. Pineda (2010) demonstrated the inadequacy of current methods, processes and tools (MPTs) in Systems Engineering and presented the need to expand on a Multi-attribute design approach which when applied optimally may lead to the understanding and embodiment of a Complex Engineered SoS framework to realize intended SoS [8]. Sheard and Mostashari classified the different complexities in SoSs (structural, dynamic, socio-political) to help align different levels of complexities in engineered systems to appropriate development management processes [9]. Dagli and Ergin (2009) presented a list of attributes (evolutionary, unexpected changes, patterns etc.) required by a system to transition from a SoS to a complex SoS [10]. For service systems, understanding the integration needs among different systems and system entities and defining the information flows required for the governance, operations, administration, management and provisioning (OAM&P) of the service present major challenges in the definition, design, implementation and lifecycle management (including the disposal and evolution of constituent service system entities) of services [11]. Cloutier *et al.* (2009) presented the importance of Network Centric Systems (NCS) for dynamically binding different system entities in engineered systems rapidly to realize a more adaptive SoS which, in the case of service systems, is capable of knowledge emergence and real-time service discovery [12].

As most modern systems transition towards a SoS architecture, several businesses are incorporating the SoS concepts and methodologies described above, for developing and co-creating applications, comprised of tangibles and intangibles (activities), by flexibly linking loosely-coupled system entities, typically over NCS, to fulfill specific customer requirements [13]. This concept has been made possible by the integrated access to people, media, services, and things, which have enabled new styles of societal and economic interactions, at unprecedented scales, flexibility, and quality. Consequently, modern service systems can now exploit the wisdom of crowds and allow for mass collaboration and value co-creation [14]. Using this concept several researchers have concluded that even manufacturing firms are more willing to produce "results," rather than solely products as specific artifacts by collaborating with end users that can potentially help define such results [15, 16]. As a result, future end-to-end digital manufacturing systems need to integrate fabrication technologies such as 3D printing with advanced design software and image processing tools that will empower customers to utilize technological enhancement (virtual simulators, network based manufacturing) to create their own products in real time or near-real time [17]. Tseng *et al.* [17] proposed an Internet Based Enterprise (IBE) wide end-to-end digital manufacturing laboratory in a virtual platform that integrates all technologies within additive manufacturing to create unique end-products in real time capable of offering Manufacturing as a Service.

Additionally, Apple, Amazon, Facebook, Twitter, eBay, Google and other application service providers are continually performing trade-offs between the business challenges enabled by network centric applications convergence and customers (enterprise or consumer) demanding or co-creating new and more value-adding services. This has mandated the inclusion of human-computer interactions (HCI) and behavioural science in modern service systems to utilize social networking used to share unverified information via audio, messaging, video for designing entirely new services tailored to customer preferences [18]. Although, IT is at the heart of any service business, to fully realize future service systems, such as online manufacturing of goods with production/delivery right at the customer premises, requires the development of run-time platforms that allow real time or near real time customer service discovery and delivery [19]. As part of this effort, the service-centric systems engineering (ScSE) consortium is applying well-defined service design process to Service Based Applications where design time and run-time sub-processes interact in near-real time for the composition, provisioning, orchestration, and testing of personalized services [20]. SSE utilizes these processes to help identify linkages among service entities that create the value chain among new service opportunities, constraints, new technologies, interoperability standards, interface agreements, and process development requirements required to realize potential future services [19]. This paper discusses the effectiveness of applying SSE concepts and methodologies across various SSE stages to describe an intelligent emergency transportation system and a near real-time dynamic Smart Grid service system.

2. Service System Engineering Core Concepts

2.1 Service Meta-Model

Spath and Fahnrich (2007) defined a service meta-model comprised of nine types of system entities, as shown in Table 1, to help understand the business challenges mentioned above and create the service value chain among relevant stakeholders to co-create value [21]:

Table 1. Service meta-model [21]

Entity Type	Attributes
Customer	Features, attitudes, preferences, requirements
Goals	Business, service, customer
Inputs	Physical, information, knowledge, constraints
Outputs	Physical, information, knowledge, waste, customer satisfaction
Processes	Service provision, service delivery, service operations, service support, customer relationships, planning and control
Human Enablers	service providers, support providers, management, owner organization, customer
Physical Enablers	Enterprise, buildings, equipment, enabling technologies at Customer premises (desktop 3D printers), furnishings, location, etc.
Informatics Enablers	information, knowledge, methods, processes and tools (MPTs), decision support, skill acquisition
Environment	Political, economic, social, technological, environmental factors

Utilizing the various methodologies and models SSE helps describe the needs of the intended service including customer requirements and the service value chain among service system entities to align business processes into strategic capabilities that consistently provide superior value to the customer across a number of applications. Spohrer (2011) proposed to categorize different service sectors into three types of Service Systems [22]:

- **Systems that focus on flow of things**: transportation and supply chain, water and waste recycling, food and products, energy and electric Grid, information/ICT & cloud
- **Systems that focus on Human Activities and Development**: buildings and construction, retail and hospitality / media and entertainment, banking and finance / business consulting, healthcare and family life, education and work life / jobs and entrepreneurship
- **Systems that focus on Governing**: city, state, nation

To illustrate these concepts examples of Smart Grid Energy Service System and Intelligent Emergency Transportation System (IETS) are presented in section 3 with specific system entity types identified.

2.2. Service Systems Development Process (SSDP)

The Service Systems Development Process (SSDP) consists of several iterative life-cycle stages with required inputs and expected outputs for each stage to help understand the activities required for realizing service systems. The system engineering stages are expanded to adapt and improve systems engineering methodologies to address the SOS nature of Service Systems. The stages of the SSDP listed in Figure 1 take an iterative approach to fully understand the impact on enterprise capabilities, enterprise process, information Systems, technology, and customer expectations [6]. The SSDP must take into consideration the alignment of several service system entities in all of its stages to realize the overall end-to-end service system. A more extensive review of new service development is presented by Lin and Hsieh [23]. The SSDP stages can help analyze the service systems from an end-to-end perspective and identify the required activities that need to be carried out for discovering and designing the potential service system. During the service strategy phase new services are identified based on end user needs, mass collaboration trends, technology trends, and/or enterprise strategies. The enterprise decides to pursue the development of the selected service systems based on an extensive socio-techno-economic feasibility study. In the service design and development phase the requirements are analyzed and the service system entities' functions, interfaces, interoperability among service system entities, and the service level agreements are identified. The different service functions and service level requirements will be allocated to different service system entities by modelling the service system under all possible operating conditions. Service integration, verification & validation (IV&V) activities will ensure proper information exchange and interactions among service system entities to provide the service continuously in a dynamic operating environment. During the service transition/deployment phase, the service readiness level(s) is (are) analyzed using proper service testing methodologies to ensure proper insertion and operation. Once the service is deployed it enters into the operations stage where the service is continuously monitored to ensure customer satisfaction and service delivery according to contracted SLAs. Service Lifecycle Management (LCM) methodologies such as continuous service improvement are utilized to analyze and set service improvements, potential service enhancements and to identify new service concepts across all entity types. Service LCM also includes strategies for replacement or disposal of the service/service entities, if applicable.

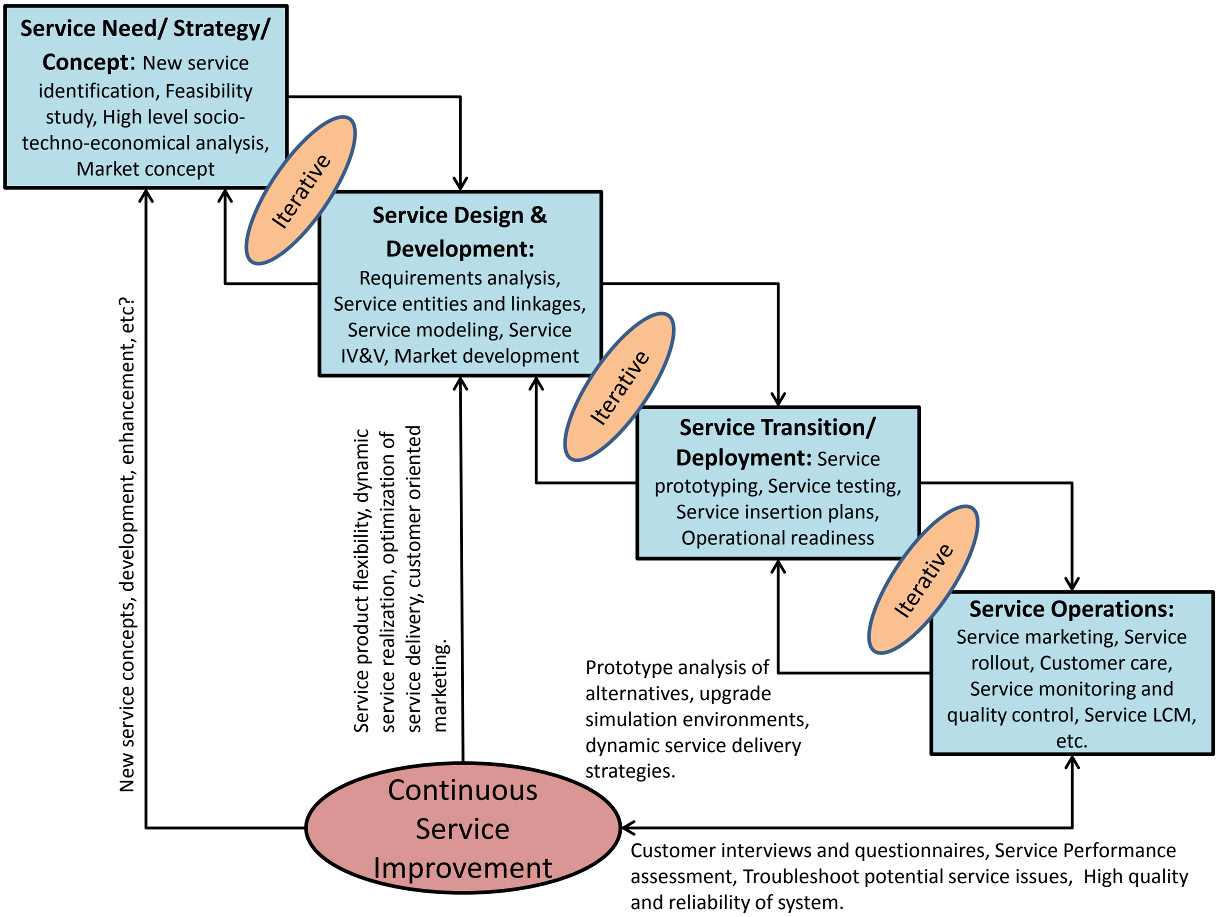

Figure 1. Service Systems Development Process [6]

3. Service Systems Examples

Using the service meta-model and the SSDP it is possible to analyze service needs, service interactions among relevant entity types (e.g., people and enterprises) in different types of Service systems as described above. These service systems resulting from the real-time interaction of service system entities are made possible by emerging technologies and enterprise processes that assist dynamic decision making, on-demand exchange of information, data analytics, risk & conflict analysis, demand response, social networking, etc. allowing for better communications and interactions at the operational, tactical and strategic level. In addition, governance (rules & regulations), emerging process developments, and emerging social behavior might have a direct impact on human interactions, organizational structures, and technology developments for future services. [6].

The service delivery may be contractual or mandatory and key contracted details of the service are specified through SLAs. In addition to SLAs, the real time or near-real time service delivery depends on the comprehensive and reliable monitoring of the service during operations, enabled by the network centricity to ensure end-to-end service delivery. The service operations environment consists of dynamic selection of available resources based on customer needs/preferences, on tracking pre/post service activities, on service continuity plans in case of service contingency such as service resource failure and in many cases dictated by the environment (entity type) conditions e.g., time, weather, regulations, etc. The following sections illustrate how the SSDP and the service meta-model can be utilized along with advances in design & modeling, data analytics, control systems, conflict analysis, and decision support systems to establish linkages among the service system entities.

Strategic directions, policies, and regulations of a nation, region, municipality, etc. drive the needs for new services and associated service systems. Federal Emergency Management Agency (FEMA) and Renewable Energy systems are prime examples of service system driven by government strategies.

3.1 Intelligent Emergency Transportation System (IETS)

An Intelligent Emergency Transportation System (IETS) can be realized by modeling the real-time interactions of the various heterogeneous systems by understanding socio-economic states, utilizing technological advances, and tailoring policy-making to better customer service quality [7]. The service goal in an IETS, shown in Figure 2, is to provide safe evacuation and prompt medical care to the emergency victim(s).

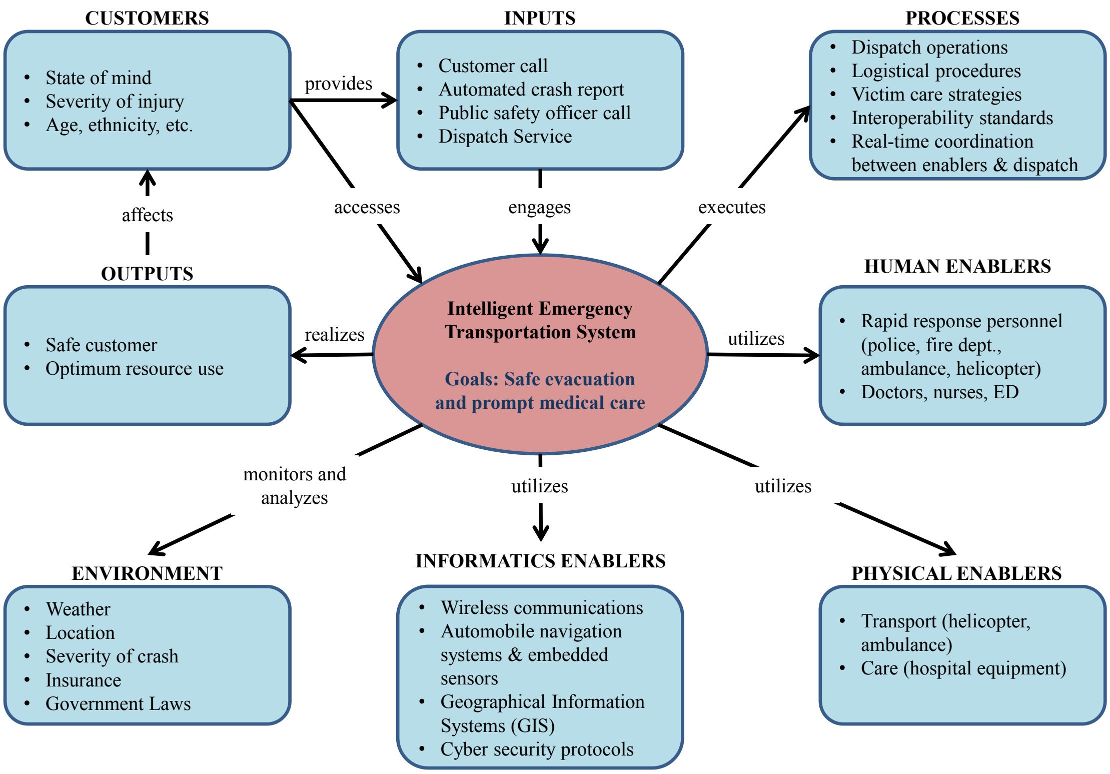

Figure 2. Intelligent Emergency Transportation System (IETS)

Typically, a traveler involved in an accident (customer) has certain attributes (mental state, age, severity of injury). The IETS service can be requested through inputs provided via an emergency call placed to the dispatch service by the customer, via an automated crash report feature, or via a public safety officer on location (on demand exchange of information) [6]. The IETS then creates the service value chain, via linkages among the customer, processes, and various human, physical, and informatics enablers, needed to provide desired service. After effectively assessing the patient's condition based on inputs provided the IETS uses dispatch operations to coordinate operational and logistical procedures in cooperation with all service system entities (demand response) to execute proper victim care strategies. The IETS utilizes advances in communication and information systems as well as advanced automotive navigation systems and sensors (informatics enablers), to access and analyze essential, real-time data about the victim and their surrounding conditions. Spatial Decision Support Systems (SDSS) which utilize Geographical Information Systems (GIS) technology to obtain and process spatial information such as locations of landmarks, satellite images, and socio-economic information with spatial attributes etc. can help provide real-time feedback on the service environment (weather, location, hazardous materials, multi-vehicle crashes, etc.) and is critical when coordinating evacuations [24]. This information can be provided by efficient and reliable voice, data, and video transmissions using wireless communications technology (informatics enabler). These live status updates help the various human enablers (doctors, emergency department (ED)) and physical enablers (ambulance, hospital) share critical information related to the nature of the emergency, the operational conditions of the transportation facilities, and the location of emergency response resources to help communicate, adapt, and coordinate operations and resources. The real-time coordination between enablers and dispatchers to implement adaptive service strategies is enabled by advances in logistical and decision-making tools. Hence, in creating the service value chain among system entities, the availability of real-time data about transportation conditions, coupled with advanced decision-making tools, enables more effective responses and coordination of resources during emergencies. In the case of an emergency situation, when the victim is in a continuously changing critical condition, IETS identifies the appropriate response (risk & conflict analysis) and get the correct equipment (physical enabler) such as a helicopter and emergency personnel (human enabler) to and from the scene quickly and safely, thus co-creating service value in near-real time by aligning customer attributes to organizational processes through various enablers (dynamic decision making).

In summary, proper utilization of the service meta-model and execution of SSDP steps can help create the optimum service value chain among the service system entities with increased data accuracy and analysis, optimum use of resources, and effective use of technology, resulting in a timely and quality service delivery process in addition to cost savings. Additionally, the IETS highlights how humans, technology, and process can be integrated to create greater situational awareness and more enhanced response to identify and utilize the appropriate equipment due to pre-planned management resulting in a more efficient response to the victim at the right time and ensuring patient safety and well-being (output) [25]. The above example demonstrates that service systems can be viewed as knowledge-intensive SoS that have well defined linkages (including access rights) and relationships among different system entities resulting in real-time or near real-time service systems interactions (value chain) for timely and quality service delivery. In a globally interconnected world with educated and technology savvy consumers the services networks created by the interaction of the service systems will be accessible from anywhere, anytime, by anyone with the proper access rights [26]. Although much criticized in recent years, FEMA is an example of an Enterprise that integrates internal and external resources (including partnerships) to provide real-time services to achieve rescue mission requirements. FEMA resources include personnel and organizations, Regional Offices and Disaster Field Offices (DFOs), IT resources and services, corporations, other Federal agencies and their resources, and state and local governments. FEMA facilitates and utilizes partnerships and associations with voluntary organizations, security and Critical Infrastructure Protection (CIP) resources and measures, telecommunications and networking resources, and other resources that can be impressed into service in the event of a national emergency [27].

3.2 Smart Grid as a Service (SGaaS)

According to the National Institute of Standard and Technology (NIST) Framework and Roadmap for Smart Grid Interoperability Standards, the Energy Independence and Security Act (EISA) designated the development of a Smart Grid as a national policy goal, and specified a flexible, uniform and technology neutral interoperability framework that can accommodate "traditional, centralized generation and distribution resources" while facilitating incorporation of new, innovative Smart Grid technologies, such as distributed renewable energy resources and energy storage [28]. Modern power systems are large-scale, complex dynamical systems comprising of many diverse systems spread across large geographical areas. Today's power-grids which supply reliable electrical energy for a variety of customers require extensive real-time and dynamic monitoring and control of energy resources to match energy generation to consumption [7]. The integration of renewable energy sources in legacy power grids to dynamically manage changes in electricity demand patterns depends on the service provider and consumers ability to adapt to real-time grid requirements without losing functionality or efficiency [29]. Livengood and Larson (2009) presented the concept of 'The Energy Box' that provided a platform to achieve this grid transformation by utilizing enabling technologies such as embedded sensors, automated metering and control, etc. to respond automatically to utility-requested demand response signals based on SLAs between the utility and the consumer [29]. Thus a smart energy service system (the Smart Grid) is a NCS heavily dependent on IP enabled layer for the exchange of information among different domains (customer, service provider, operations, markets, generation, transmission and distribution). Thus, the energy service delivery can be dynamically managed and remotely operated using different support systems (e.g., stochastic dynamic programming frameworks that depict weather patterns and electricity usage) to respond to ever-changing energy requirements [29].

In a SGaaS system, shown in Figure 3, the service goal is to provide energy on demand year-round while utilizing renewable energy sources such as wind, solar etc. to reduce environmental impact of energy usage across the globe.

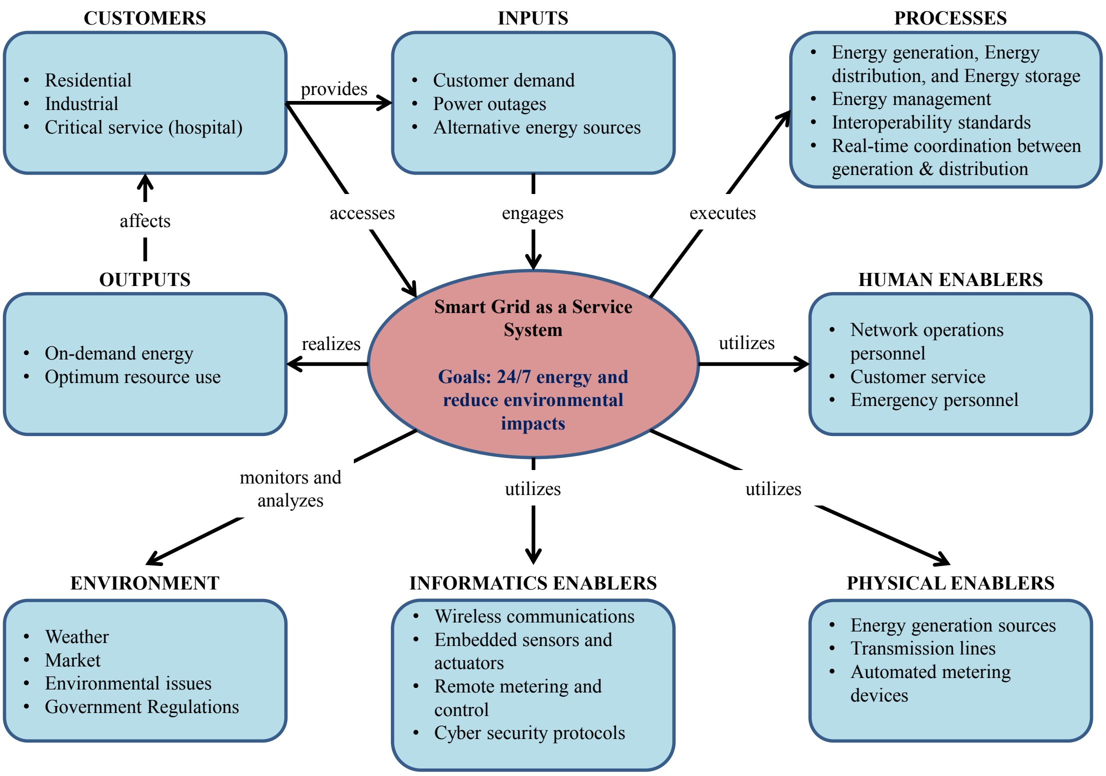

Figure 3. Smart Grid as a Service (SGaaS) System

The SGaaS system consists of customers that could be residential, industry, or service providers which need redundant energy sources in case of unexpected power outages. The SGaaS system receives various inputs (dynamic demand changes, unexpected outages, renewable energy available for use) from these customers with varying access rights (on-demand exchange of information). Based on these inputs and customer attributes, the SGaaS system creates the service value chain that creates the linkages among the customers, energy management processes, and various service enablers (human, physical, and informatics). The SGaaS system then coordinates energy generation and distribution strategies in cooperation within all service system entities in a dynamic environment (weather, peak demand etc.). To achieve such demand-response strategies, the SGaaS system utilizes advances in wireless communications (informatics enabler) to access and assess essential, real-time energy consumption (data analytics) through embedded sensors and automated metering devices (physical enabler). The access to real-time system performance can help the various human enablers (network operations personnel, customer service personnel) and physical enablers (energy generation sources, transmission lines) share critical information to help communicate, adapt, and coordinate service operations and energy resources to ensure prompt demand-response. Additionally, in the case of an emergency power outage detected remotely or through customer calls, the SGaaS system can perform real-time risk & conflict analysis to help identify the appropriate service response. In such cases, an emergency energy management strategy (process), guides emergency service personnel (human enabler) to revise energy generation and distribution strategies or activate energy backup and storage systems to address the energy need resulting from the outage (dynamic decision making). The emergency personnel utilize wireless communications, sensors and actuators, and remote metering and control systems to provide required energy with minimal loss of functionalities thus co-creating service value in near-real time. The NIST reference model [28] for identifying the interoperability standards and cyber security protocols can be utilized to develop architectures for the SGaaS system. The NIST reference model aligns the strategic (organizational), informational (business operations, data structures, information exchanges required among system entities) and technical needs (data structures, system entities' specifications, interoperability requirements, etc.) of the system. Thus the SGaaS system in conjunction with an adaptive architecture framework based on the NIST reference model can help achieve the required interoperability among interconnected service system entities. The SGaaS system utilizes technology and process innovations that align customer inputs to service enablers using well defined and adaptive service procedures to deliver quality and timely service delivery. This concept can provide a platform for an emerging and innovative energy service development and delivery process using a well-managed, secure, and scalable network to enable a dynamic market driven energy ecosystem [28]. For instance, Model Based Systems Engineering (MBSE) methodologies have been utilized by the authors to model the Service ordering process to identify linkages among system entities [30]. Cisco recently presented a white paper that presents the implementation of energy as a service. Cisco demonstrated the utilization of innovative network-based tool to reduce energy costs by up to 33% and illustrated how IP-enables energy management can optimize any organization's energy management strategies. [31]

4. Discussion

In summary, SSE methodologies can be utilized to discover, design, and develop service systems by identifying linkages among system entities as illustrated by two service systems examples presented in this paper. The service systems were analyzed as SoS and decomposed into clearly defined service system entities according to their respective attributes. The SSDP can then help in identifying the list of activities that need to be carried out across various lifecycle stages to potentially realize the service systems. The interactions among the various service system entities are presented to highlight the interoperability agreements required among them for ensuring efficient service delivery. This paper demonstrates the usefulness of SSE for defining required relationships among different service system entities to address the service-oriented, customer-centric, holistic systems view to plan, design, adapt or self-adapt to co-create value. Implementation of SSE methodologies requires a good understanding of cross disciplinary issues to manage, communicate, plan, and organize service systems development and delivery of service taking into account the customer focus and feedback to facilitate service innovation and quality service delivery.

In today's global service economy, new standards and procedures are needed to align policy, customs regulations, export permits, local business practices, logistics, distribution, environmental conditions, etc. in a dynamic service value chain. Service systems require near real-time system modifications/adaptations to create dynamic frameworks aware of constantly changing operating environments and solicit customer feedback and input for value co-creation. To achieve this, service systems need to transition from static design and development of fragmented SoS networks and frameworks to more dynamic frameworks that unify the SoS networks for service discovery and service composition in real time or near real time and allow service operations to optimize service delivery in near real time. Such dynamic frameworks enable near real-time analysis of impacts of newly discovered service on business processes, organizations and revenue for service composition/adaptation in run-time environment [6]. Future research is needed to define such dynamic service configuration frameworks and understand the implications of human behavior (Human-in the-loop), social aspects, governance processes, business processes and Service Level Agreement (SLA) for the enterprise service system. The scalability of service systems in atypical or drastic scenarios (hurricanes, tornadoes, etc.) needs to be understood prior to large scale deployment of such service systems. Novel methodologies are also required to enable adaptation of requirements for new technologies (robots, sensors, renewable energy, nanotechnologies, three dimensional printers, and implantable medical devices) that will exchange information with the service system entities to enable dynamic creation of near-real time service value chains.

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