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Modeling Design Services for Improving Service Delivery Effectiveness

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Abstract

Recent attention has focused on productivity and value creation in the service sector through the advent of service science, management and engineering. Quantitative methods increasingly are being applied to the study of service systems to improve the design, planning and control of service delivery. Designing electronic products can be viewed as a service system, in which a design team or teams provide services that lead eventually to a product specification and/or design. This paper discusses how discrete-event simulation and social network analysis can be used to study and improve design processes and service delivery, and it presents a case study involving design of computer servers.

Author Biographies

Dr. Douglas A. Bodner is a senior research engineer in the Tennenbaum Institute at Georgia Tech. His research focuses on computational analysis and decision support for design, operation and transformation of organizational systems. His work has spanned a number of industries, including automotive, electronics, energy, health care, paper and pulp, semiconductors and telecommunications. He is a member of the Institute of Electrical and Electronics Engineers (IEEE), the Institute of Industrial Engineers (IIE) and the Institute for Operations Research and Management Science (INFORMS), and he is a registered professional engineer.

Moises Cases has thirty-eight years of progressive experience in very-large scale integration chip and package designs, in system level electrical and package designs, and in complex project and people management. Presently, he is a Distinguished Engineer at IBM System and Technology Group and the team leader for system electrical design and integration of modular and blade servers, where he is responsible for signal and power distribution integrity, and system level timing for complex multiple board system designs. He is an IEEE Fellow and a member of Tau Beta Pi and Eta Kappa Nu honor societies. Mr. Cases has received the Hispanic in Technology Corporate Award from the Society of Hispanic Professional Engineers in 2006, the Corporate Business/ Community Representative of the Year Award from Austin Independent School District in 2007, the Albert V. Baez Award from HENAAC in 2007, and the IEEE Engineer/ Teacher Partnership Award in 2008. Mr. Cases has received 47 U.S. Patents and has published 88 refereed technical papers in numerous proceedings, journals and transactions.

Dr. Bhyrav Mutnury is an electrical interconnects and package design engineer at IBM in Austin, TX. He received his M.S. and PhD degrees from the Georgia Institute of Technology in 2002 and 2005, respectively. Dr. Mutnury joined System x server group in IBM, Austin, in 2005 as electrical design engineer for Intel and AMD based high speed server packages and boards. Dr. Mutnury has authored or co-authored more than 25 journal and conference papers and filed more than 12 patents.

Dr. William B. Rouse is the executive director of the Tennenbaum Institute at the Georgia Institute of Technology. He is also a professor in the College of Computing and School of Industrial and Systems Engineering. Rouse has written hundreds of articles and book chapters, and has authored many books, including most recently *People and*

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Among many advisory roles, he has served as chair of the Committee on Human Factors of the National Research Council, a member of the U.S. Air Force Scientific Advisory Board, and a member of the DoD Senior Advisory Group on Modeling and Simulation. Rouse is a member of the National Academy of Engineering, as well as a fellow of four professional societies – Institute of Electrical and Electronics Engineers (IEEE), the International Council on Systems Engineering (INCOSE), the Institute for Operations Research and Management Science, and the Human Factors and Ergonomics Society. He has received the Joseph Wohl Outstanding Career Award and the Norbert Wiener Award from the IEEE Systems, Man, and Cybernetics Society; a Centennial Medal and a Third Millennium Medal from IEEE; the Best Article Award from INCOSE, and the O. Hugo Schuck Award from the American Automation Control Council. He is listed in *Who's Who in America*, *Who's Who in Engineering*, and other biographical literature, and has been featured in publications such as *Manager's Edge*, *Vision*, *Book-Talk*, *The Futurist*, *Competitive Edge*, *Design News*, *Quality & Excellence*, *IIE Solutions*, *Industrial Engineer*, and *Engineering Enterprise*.

Introduction

Service Science, Management and Engineering (SSME) is a new multi-disciplinary field of research that integrates aspects of numerous established fields such as computer science, engineering, operations research, management science, business strategy, social science, and legal science in the study of service industries [1, 2]. Of course, services increasingly underpin the U.S. and global economics. SSME is intended to bring scientific methods to the study of service systems, analogous to methods used for scientific study of previously dominant economic sectors such as agriculture and manufacturing.

Broadly defined, though, services include not only customer-facing industries such as banking and retail, but also business-to-business and intra-firm activities that support delivery of goods and services to end customers. Services can be defined as the application of specialized competencies by one entity for the benefit of another, with both participating in co-production of value [3, 4]. Thus, agriculture and manufacturing embody services in the process of delivering goods to the end consumer. In the case of agriculture, these services can include veterinary services and crop-picking services. In manufacturing, these services can include product design services, installation services and maintenance services. Both sectors require transport services to move goods to market. Indeed, most manufacturers are in the business of providing services without fully understanding the service nature of their business [5].

This paper studies product design and engineering as a service system, using constructs from the field of SSME, to enable this service function to be more efficient and scalable. In particular, the focus is on a knowledge-based service organization that provides electrical design and integration services (EDIS) for computer servers. The rest of this paper is organized as follows. First, product design and engineering is described as a service system. Then, a modeling method is developed to allow analysis of design and engineering services. A case study is presented addressing the EDIS organization, with analysis and results. Finally, conclusions and future research are detailed.

Engineering Design as a Service

Services involve the cooperation of two or more entities to co-create value, often through an entity's taking advantage of superior capabilities offered by the other entities [6]. Without loss of generality, assume that this discussion involves only two entities. One of the two entities generally is viewed as the service provider, and the other as the service consumer (or customer). The provider uses its competencies for service provision and creates value for the customer. The customer adds value to the process by interacting with the provider to determine requirements for the service(s). The customer typically provides value to the provider in the form of revenue, or perhaps in the form experiential learning. Expanding this concept, the provider-customer relationship can exist in a network of entities, whereby each entity serves a set of its customers and is in turn served by its providers. In such a service value network, each entity can be both a provider and a customer.

To illustrate the concept of service value networks, consider design of a future product by a firm. The end customer eventually receives this future product and potentially services associated with it, such as transportation, installation and maintenance (provided either by the firm or by third-party providers). Toward the downstream of the network, the firm's marketing function determines the customer requirements for the future product (functionality and cost) using some form of price positioning to account for competition [7]. The marketing function then works with a product development group to specify technical requirements for the product, based on customer requirements and also on technical feasibilities. The product development group calls on the services of a design team(s) to perform the design work associated with the product. For complex products, there may be multiple design teams organized along functional lines, providing design work according to specific functional areas of the product (e.g., mechanics or electronics). In turn, these design teams may receive services from vendors, for example in the form of modeling services for components that comprise the product being designed. Figure 1 shows a network of service providers and customers that co-create value that results in a completed product design.

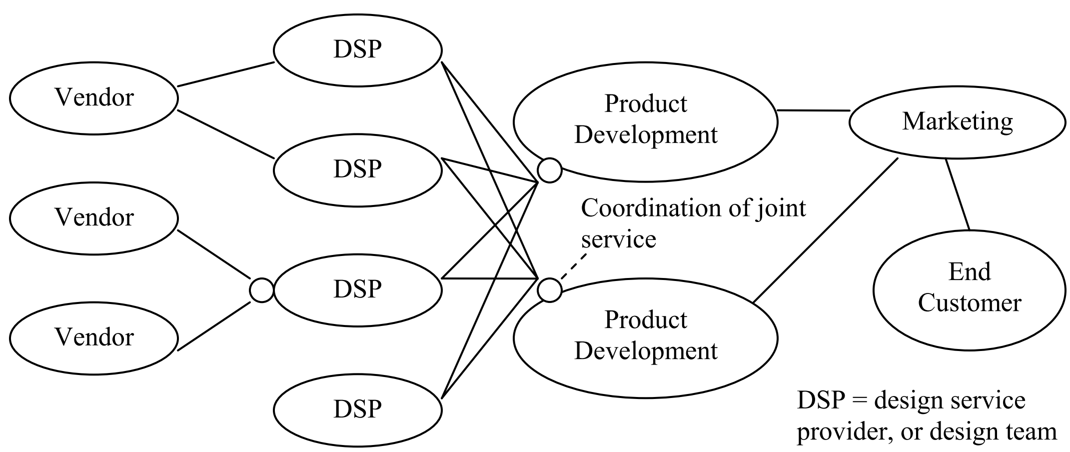

Figure 1. Engineering design service value network of organizations

Each node in the network can function either as a service provider or a customer, or both. Each arc represents value co-creation, such as the interaction between the product development group (service provider) and marketing (customer) to create the value of technical requirements, eventually realized as a finished product design. There are instances where multiple arcs join to a node via a coordination junction. This represents the phenomenon of coordinating multiple service providers in a joint service. In product design, this type of coordination is critical, as the various components and functional aspects of a product design must mesh together without conflicts to form the fully specified design. Note that value in the form of revenue typically is received directly from the end customer, but contributions to the creation of revenue value are made by the various organizations in the network. Sometimes, though, agreements for revenue exchange can be made between these organizations upstream from the end customer.

The concept of service value networks applies at the individual level within a design team, as well. Most complex products cannot be designed by a single individual. The same holds for designs focusing on functional areas within a product. Consider an electronic product with complex circuitry or an aircraft structure. Designing the electronic circuits involves a high level of expertise across the interfaces associated with various components (e.g., processors, memory, etc.). This design work requires deep skills involving each interface. Similarly, structural analysis to support design of the aircraft structure involves a variety of deep skills. Thus, it typically improves efficiency, quality and scalability to have multiple people, each bringing unique skills, to design of a particular product. This concept is illustrated in Figure 2.

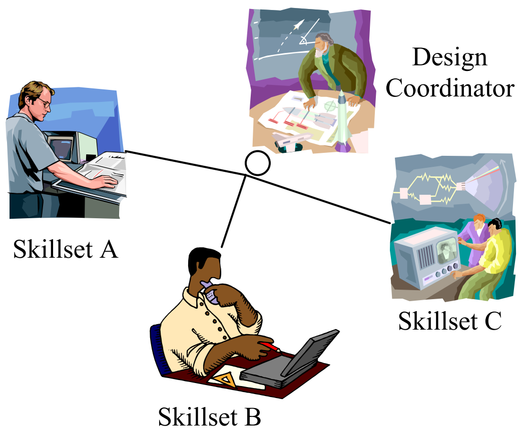

Figure 2. Engineering design service value network of individuals in a design team

For each service provided by the design team, there are individual services provided by each team member. These may be quite specialized and may vary for each individual across different types of services provided by the team, due to the differences in the types of services, plus the availability of team members if the team engages in providing multiple services simultaneously.

The interaction between various entities in a service network produces many different forms of value. In a product design services network, value is received by the firm in the form of revenue from products sold to end-customers. Clearly, this type of value depends on the quality of the design services that result in a manufactured product perceived to have quality by the customer, the implicit assumption being a relationship between the quality of design services and quality of resulting product. For consumer products with short lifecycles, though, service efficiency is important, as well, since being to market first means increased likelihood of receiving larger revenues. This phenomenon is due to the commoditization curve that restricts most revenue to the beginning of the product lifecycle. Value also derives from the firm's reputation for quality products that are introduced before the competition can field similar offerings.

Yet, maintaining service quality is difficult given that uncertain demand can combine with existing capacity limitations and resource allocation rules to cause service level erosion [8]. This points to the importance of modeling and analysis in determining effective resource allocation rules and ways to maintain effective capacity, especially in a growing and changing environment. One method used for such analysis is simulation, which uses models that characterize a system's behavior over time for purposes of experimentation and what-if analysis with the models to support system design and on-going operation. Simulation increasingly is being used for service system applications such as lending service centers [8], mortgage approval services [9], information technology project management [10], human resource planning and service delivery [11] and telecommunications [12]. Two primary types of simulation used to study service systems are system dynamics simulation [13], which is based on a continuous state-change representation involving differential equations, and discrete-event simulation, which is based on discrete, transactional state changes [14]. In this paper, a discrete-event approach is used to model service systems due to the transactional nature of design services.

Modeling Engineering Design Services

Here, the focus is on services provided by design teams within the overall process of product design, development and realization within a firm. In modeling engineering design services, the following generic service system elements are important:

- Service offerings: A service offering is a defined service provided to customers. Examples include financial services (e.g., checking account), maintenance services (e.g., periodic maintenance and upkeep of purchased equipment) or delivery services (e.g., delivery of packages). Generally, services require some level of customization for each specific customer (or category of customers), since they operate in terms of value co-creation between provider and customer. Therefore, a particular offering typically has a generic component that defines the core service, plus customizable elements that relate to scope or specialized functionality. A similar concept has been occurring with products through the phenomenon of mass customization [15]. In design services, an offering consists of a design for a product, design of an aspect of a product, or an analysis supporting design (e.g., whether design requirements are feasible).
- Customers: Customers, of course, provide value co-creation for services. The level to which they participate in such co-creation depends heavily on the degree of service customization. In design services, customers (e.g., a product development group) often represent both the firm and the end customers, in an effort to deploy a successful product to market. Thus, there can be a significant degree of customer input from the product development group into value co-creation for complex products.
- Resources: The service provider has personnel and potentially has assets to provide service offerings. Associated with the personnel is a set of skills that are used in service provision. Skills are critical to service quality and efficiency. A skill can be considered as an area of competency (e.g., customer relations or a technical skill) and a level of competency (e.g., novice or expert). In design services, technical skills are typically critical. An asset is used to aid in service

delivery and can consist of a tool or method, e.g., software that aids the design process. The number of personnel, their skills and skill levels, and the organization's assets determine the capacity and capabilities of the service system.

- Work processes: Work processes comprise the set of tasks needed to perform service offerings. Usually, work processes are organized according to a precedence relationship, whereby certain tasks must be finished before others can start. In addition, tasks may require certain skills and perhaps skill levels to execute properly. Design processes increasingly include a significant number of highly technical tasks related to modeling and analysis.
- Resource assignment rules: For each service engagement, resources must be assigned. This assignment affects the service quality and efficiency. The assignment should be based on skills, but it must also factor in the availability of personnel with required skills given current workload of resources, plus deadlines associated with service delivery. Resource assignment is a difficult problem that can involve trade-offs between service quality and efficiency, and limitations in an organization's set of skills can compound this difficulty.
- Social and organizational networks: In addition to the value networks between organizations and between individuals, there are informal social and organizational networks. This phenomenon has emerged as a field of study in its own right, social network analysis, in recent years [16]. From a design services perspective, social and organizational networks come into play in resource assignment and information-sharing (e.g., problem-solving in design service delivery).
- Value: Finally, value in design services can be characterized as quality (i.e., conformance to technical specifications) or efficiency (i.e., time taken to perform services). Here, the focus is on modeling efficiency. Hence, the duration of service is the measure of value considered.

These elements are modeled using ARENA, which is a widely-used, commercially-available discrete-event simulation package used to model a variety of applications, including manufacturing, business processes and services [17].

Service Offerings and Customers

At a basic level, service offerings can be modeled as a list of items that have attributes describing the core service plus any customizations. Attributes may include duration, number of service personnel required, the percentage time required of each, the skills required (both skill category and minimum skill level required), and the assets available to assist the offering. The service offerings list and its attributes are modeled as tables in ARENA.

Each of these attributes may be part of the core service offering. On the other hand, a service offering can be customized by its scope (e.g., duration and number of personnel required) or by functionality (e.g., specific mix of skills needed). In addition to customization, service delivery typically experiences variations in, for example, duration. This randomness may be modeled as the probabilistic outcome of a random variable. ARENA has constructs for random number generation, enabling sampling from a number of probability distributions, to support modeling randomness. The parameters of the chosen distribution must be specified, though. This should be based on statistical analysis using historical data. Distribution fitting methods are detailed by Law and Kelton [14].

There may be relationships between attributes, as well. For instance, duration may be a function of skill level and asset use. Such functions can be implemented using existing ARENA modeling constructs.

Customers have demand for offerings that can be expressed as a rate with an associated probability distribution to model randomness. For example, a particular product development group may request a new server design every two years on average, but not every two years exactly. This can be modeled as a Poisson arrival process having a rate of two years. Customer demand for service becomes instantiated as a service engagement, which is modeled as an entity in ARENA. An entity is a modeling construct that advances through a set of ARENA modeling blocks that are used to represent the processes of a service system (e.g., queueing, allocation of resources, delays, etc.). This movement through the blocks is used to represent the behavior of the service system over time. A service engagement entity has specific values for the attributes of its associated offering, based on the core offering plus customization. For instance, one attribute is the type of design work being performed. Engagement entities are created at various intervals, representing time between service requests.

Resources

The design services organization has a set of personnel available for its work and a collection of skills necessary to its work. Each personnel resource is represented via an ARENA resource, which can have a capacity limit specified. Each personnel resource has a rating in each skill category to represent skill level. This rating could be "unskilled." Each personnel resource also has a capacity that governs how many service engagements can be performed simultaneously. This information is captured in tables within ARENA. Assets (e.g., design software) may not modeled explicitly, if they are considered to be an integral part of the work processes. If their use is optional and has an impact on service delivery different over their non-use, they should be modeled.

Work Processes

Work processes are analogous to business processes and can be modeled by tools available for business process modeling. Business process modeling has received increased attention in recent years, as businesses have sought to understand their processes more formally to improve performance [18, 19]. One widely used formalism for business process modeling is event-driven process chains (EPCs) [20]. EPCs underpin such enterprise resource planning systems as SAP and are useful for modeling business processes because they have constructs to model tasks, dependencies, resources and control flows. EPCs have the following elements.

- A function is an active element that models a task or activity. A function has an initial state and a resulting state(s). For each execution of the function, the resulting state depends on decision logic embedded within the function.

Functions can be hierarchical in that an EPC can comprise a function within another EPC.

- An event is a passive element that triggers a function. An event can also be created by the result of a function.
- A control flow is the temporal/logical relationship between events and functions.
- An operator is a point where process flow may split or be joined. Operators may be "or," "exclusive or," or "and."
- A process is an ordered collection of functions and events, connected by control flows and operators. A process flow follows a path outlined by the process. A process marker is a link between different processes.
- An organization unit represents which person or organization within the enterprise is responsible for a particular function.
- A material, information or resource object is used by a function as input data, or can be created/ altered by a function and returned as output data.

A mapping can be specified between the EPC representation and process blocks in ARENA that model processes in a service system. In design services, the EPC and ARENA process block representations are well-suited to modeling design tasks, which are characterized by precedence relationships, resource requirements, and process flow splits and joins. Design tasks are represented, for instance, by blocks that use resources (personnel) and also blocks to simulate time delays for the task to be completed. The time delays that are experienced are a function of the task and the skill level of the person performing the task.

Resource Assignment Rules

Resource assignment rules are implemented within the ARENA blocks representing the use of resources. The rules implemented take into account the type of task, plus information on the personnel from which a selection is to be made. This information includes their skills and skill levels, their current workload and social network relationships.

Social and Organizational Networks

These types of networks are characterized by nodes representing people or organizations and arcs representing relationships between them. An arc has a weight denoting the strength of the relationship. Traditional social network analysis uses static methods to identify organizational characteristics and risks, such as gatekeepers (i.e., someone who provides a connection between separate sub-groups in an organization). In studying design services, social networks are considered for their effect on the dynamic behavior of service provision. Social networks are modeled by using a table in ARENA to represent a matrix of person-to-person relationship strengths. A different matrix is used for each type of relationship.

Value

Finally, value is considered as efficiency in providing design services. This is measured by the amount of time taken to produce a design that is requested by a product development group. This time duration is determined by the time taken for the various design tasks and delays in producing the overall design.

Case Study in Electrical Design of Computer Servers

Computer servers are complex products requiring deep technical skills for design. Typically, multiple design teams work on different functional aspects of the server design, such as mechanical, electrical, thermal and test. This case study focuses on an electrical design team that provides design services for a particular brand of mid-level servers intended for small-to-medium enterprises [21]. Its work focuses in several categories of servers:

- High-volume: Servers with less than four processors.
- High-end: Servers with up to 32 processors that require unique chipset designs.
- Blades: Modular servers in blade configuration.
- Storage: Servers that function primarily as storage systems.
- Telecommunication: Specialty servers for telecommunications applications.

Thus, the design team's service offerings consist of design specifications for these categories of servers. Its customers are the firm's product development groups that handle these server types within the particular server brand.

For each server product to be designed, the EDIS team assigns a project lead, or focal point, from the team. This person interacts with the customer (from the product development group) and manages the electrical design tasks within the team. The focal point handles tasks related to the overall electrical design. However, the design involves a number of interface tasks. These are tasks that relate to the standard electrical interfaces found in digital devices (e.g., memory, ethernet, universal serial bus). Most of the interface tasks are delegated by the focal point to interface experts, i.e., members of the design team that have expertise with design tasks associated with a specific interface. There is a specified set of work processes associated with the design of a server. Two of the major sets of work processes, formalized as event-driven process chains, are shown in Figure 3.

There are eight EDIS team members. Team skills are divided into two categories – focal point skills and interface skills. The focal point skills include a skill category for each server type. The interface skills include a skill category for each interface type, of which there are fifteen. Each team member has a particular skill level for each skill category, represented as an integer between zero and three inclusive (zero representing unskilled, three representing expert). The time taken for each design task is dependent on the skill level of the person performing the task. An expert takes significantly less time than a novice or someone with intermediate skills, for example. Based on historical data gathered from the team's operation, an average time to complete each task by a person at each skill level for that task was specified. In addition, a range for the time was specified, thus enabling the modeling of random variation in actual task times.

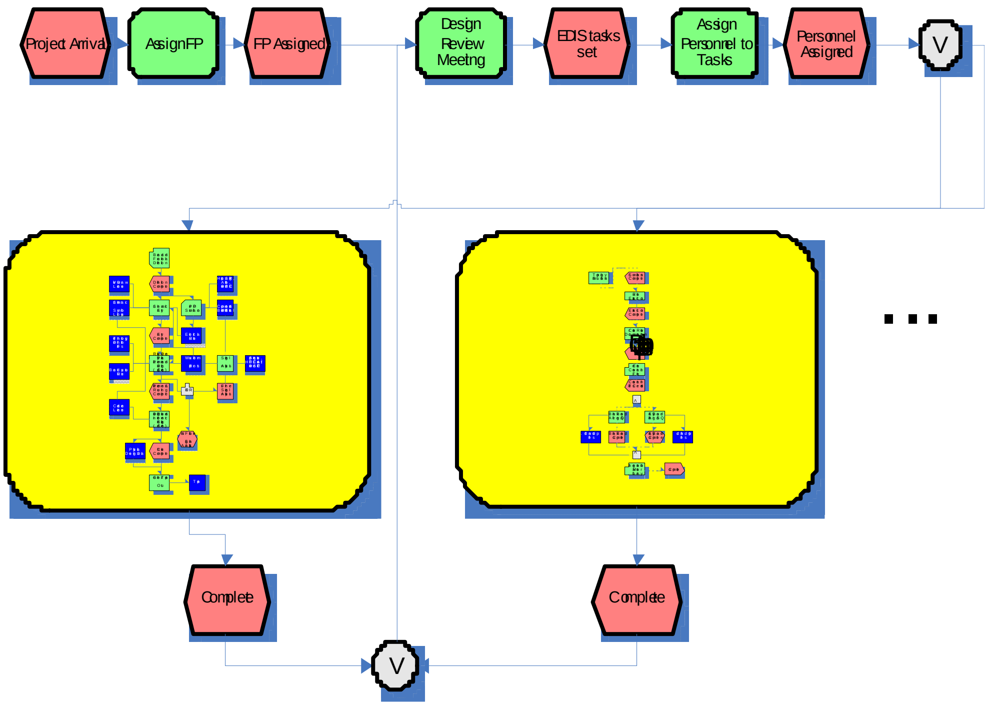

Figure 3. Work processes EPC for design services

There are three types of social network relationships modeled: location affinity, department affinity and skillset affinity. Location affinity is high if offices of two individuals are adjacent, while it is low if they are located in different cities. Department affinity is high if two individuals are in the same department. Skillset affinity is high if two individuals share substantially overlapping skillsets. Figure 4 shows a screen capture of the ARENA model with the work processes detailed. Many of the processes are hierarchical in nature, in that one task node represents a set of lower level tasks.

To demonstrate the model of how the team currently operates, the model was executed for ten replications to give statistical significance for the results (since the model includes effects of random variation). Each replication was set for two years, and there was a one year warm-up period to achieve steady state operation. The baseline performance is shown in Table 1. These results allowed validation of the model by comparison to experts familiar with the electrical design team's operation.

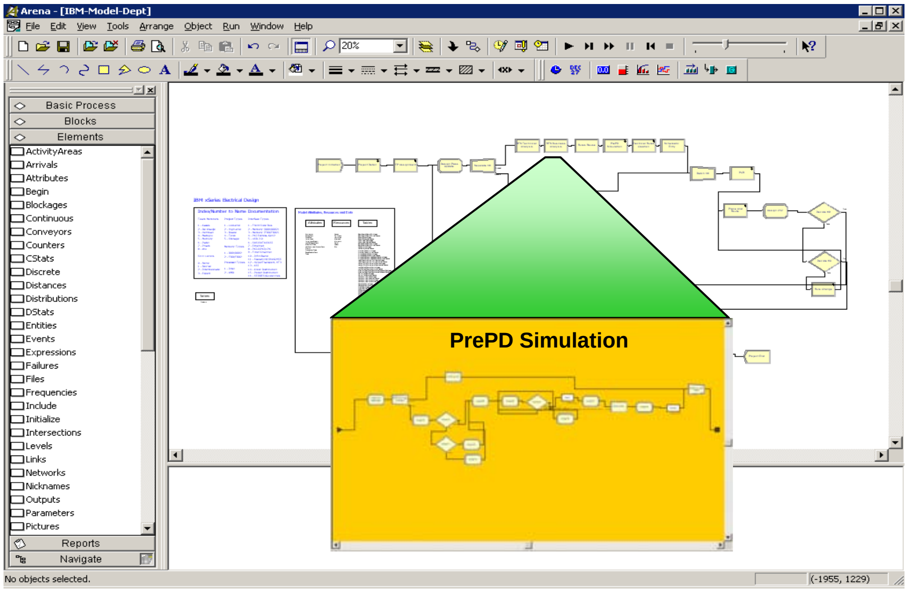

Figure 4. ARENA simulation model of design services team

Table 1. Baseline results from model

Replication	Projects Completed	Average Duration (days)
1	16	532.4
2	29	473.4
3	22	501.1
4	14	590.8
5	24	491.9
6	14	510.0
7	22	506.0
8	26	538.0
9	17	491.6
10	15	482.4
Average	19.9	511.7

Analysis and Results

To study service efficiency, two sets of analysis are described here. The first relates to the organizational architecture of the service team. The team currently uses a shared services model in which each team member serving as a focal point can delegate interface tasks to any other team member. Other teams use a departmentalized model in which team members are organized into departments, each of which works on specific server types. The model of the electrical design team was changed so that it was departmentalized, and an experiment was conducted to compare the performance of the team using the shared services approach versus the departmentalized approach. In the departmentalized approach, two departments were specified, with four team members assigned to each. One department handled high-end and high-volume servers, while the other handled blades, storage and telecommunications servers. The experiment utilized ten replications of the model for the departmentalized alternative under the same conditions as the baseline case (two year period with one year warm-up) and compared the outcome to the baseline statistics. Results are as follows (further information about statistical tests is available in Law and Kelton [14]).

- The departmentalized alternative had an average project duration that was 21% higher than the shared services alternative. This was statistically significant using a t-test, with a p-value of 0.051.
- The department for high-end and high-volume servers had an average project duration that was 59% higher than the shared services alternative's average duration, while the other department had a project duration that was 7% higher than the shared services alternative's duration.

The role of skill levels was studied, as well. In each analysis, the model was run for ten replications, under the same conditions as the baseline case, with each team member set to different skill level across the set of focal point and interface skills for each analysis. For instance, one analysis had each team member set at skill level one for all skills (novice), while the other two had skill levels set at two (intermediate) and three (expert). These were compared with the baseline case, with the following results.

- At skill level one, the average project duration is 39% greater than the baseline case.
- At skill level two, it is 7% less than the baseline case.
- At skill level three, it is 41% less.
- These are statistically different with p-value < 0.011 for each case.

Of course, it is perhaps obvious that skill levels have an impact on efficiency. Having each team member at an expert level of skill across all skill categories is most likely unrealistic and expensive. Thus, the model was adjusted to provide a robust mixture of skills. Each team member's skill level was set to be level one in 50% of skill categories and level three for the other 50%. This was balanced such that each skill category had 50% of team members with skill level one and the remaining 50% with skill level three. Results were as follows.

- The robust skill mixture had 25% reduction in project duration as compared to the baseline case. This was a statistically significant different at p-value ≈ 0.00.

While not as effective as having each team member be an expert across all skill categories, this alternative does demonstrate the benefits of designing skillset mixtures for team members, and the model provides a quantitative method to test different designs prior to implementation.

Conclusion and Future Research

A service science management and engineering case study has been developed for engineering services where an analytical business model has been defined and implemented. The model includes statistical analysis capability and optimization techniques. The benefits of a model-based business transformation methodology have been shown through analytical examples using a real organization. Benefits include better understanding of service processes and value provided through structured data collection, understanding impact of social networks on business outcomes, and the creation of an experimental platform to evaluate as-is and what-if processes quantitatively. In addition, it provides a design aid for robust service provider performance. Some additional future work includes optimizing complex tasks within a project and adding dynamic evolution scenarios to the model among others.

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