Data-Driven Simulation-Enhanced Optimization of People-Based Print Production Service

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Abstract This paper describes a systematic six-step data-driven simulation-based methodology for optimizing people-based service systems on a large distributed scale that exhibit high variety and variability. The methodology is exemplified through its application within the printing services industry where it has been successfully deployed by Xerox Corporation across small, mid-sized and large print shops generating over $250 million in profits across the customer value chain. Each step of the methodology consisting of innovative concepts co-development and testing in partnership with customers, development of software and hardware tools to implement the innovative concepts, establishment of work-process and practices for customer-engagement and service implementation, creation of training and infrastructure for large scale deployment, integration of the innovative offering within the framework of existing corporate offerings and lastly the monitoring and deployment of the financial and operational metrics for estimating the return-on-investment and the continual renewal of the offering are described in detail.

Keywords Service science, service systems, process optimization, people-based services, simulation, analytics

1 Introduction

Many industries are transitioning from being manufacturing-focused to becoming more service-oriented. The nature of service operations can be “equipment-based” or “people-based” (Thomas 1978). People-based service businesses rely on unskilled labor, skilled labor or professionals for their service production. Equipment-based businesses are further classified as being automated, monitored by relatively unskilled operators, or operated by skilled operators. The focus of this paper is on people-based service.

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It has been observed that while the service business can lead to growth in revenue, the gross margins are lower than the equipment business. At IBM the service business units accounted for roughly 55% of the total revenues in 2005, while hardware and software products accounted for the rest. In comparison, however, service business units contributed only about one-third of the company's total profit (Wladaswky-Berger 2006). Services are more labor-intensive, less amenable to economies of scale, exhibit higher quality variations and are generally less productive and profitable compared to the hardware/software business. Improvement of the productivity of the service business is therefore a key imperative for these industries to make the transition successful.

The general idea of improving the productivity of service business is not new. Leffingwell (1917) was one of the early researchers who applied Taylor's Principles of Scientific Management (1911) to the activities of service industries such as banks, insurance companies, accounting firms and mail-order firms. The goal of this effort was to set up routines that once learned and remembered could govern every aspect of office life. Healthcare was another sector where ideas of industrial engineering were applied early on. For example, Barnes' Motion and Time Study (1937) describes "Operating-room setup showing tables for instruments and supplies designed to facilitate the work of the surgeon, his assistant and the nurses". Walt Disney Corporation has utilized industrial engineering techniques and principles of service operations at their theme parks. Chase and Apte (2007) discuss McDonald Corporation as one of the best-known examples where successful application of scientific management to every aspect of restaurant operation was the key factor underlying McDonald's success. The main principles embodied in McDonald's operation include: (1) standardizing and reducing variety of products; (2) simplification, standardization and automation of processes so that workers with limited skills and training can reliably produce quality products and deliver high quality service offerings; (3) monitoring and control of process performance. Levitt (1972, 1976) describes how companies could apply the production-line approach to service business and further suggests that companies can substitute "technology for people and serendipity", and apply three types of technologies – hard, soft, and hybrid – to industrialize service offerings. Most attempts at industrializing a service on a large geographically distributed scale remains focused on achieving standardization and developing cookie-cutter approaches (e.g. McDonald's) or the notion of applying industrial engineering and operations research techniques on a large industrial scale to improve service operations (e.g. Disney).

Unlike the McDonald's model, there are service operations that are geographically distributed within an enterprise but exhibit significant output variety across each operations center. An example comes from document outsourcing business. A service provider such as Xerox Corporation can manage thousands of print production facilities worldwide on customer premises where the output of one print service center can be significantly different from another. The corresponding service processes that deliver this output are also different. The standardization that McDonald's has achieved is not possible because every customer's document production needs are unique and the service provider has to offer variety in order to be competitive. At the same time, the scale of operations at each service center is not large enough to justify a business case for local "Disneyfication".

The challenge is to develop a methodology that can improve the productivity and profitability of distributed people-based service operations on an ongoing basis while maintaining or improving the variety of the service offering to the customer. The improvement methodology should be sufficiently standardized and supported by automated (or semi-automated) software tools, platforms and processes so that it can be deployed profitably across a distributed enterprise. The work should provide insights for innovations across a broader array of service offerings (Jong and Vermeulen 2003) as well as new service-oriented technology and management frameworks of the future (Demirkan et al. 2008).

2 Optimizing Service Operations and Delivering Business Results for Locally Variable Operations

In this paper I describe a methodology for optimizing service operations on a large distributed scale. By applying this methodology to the printing industry, I demonstrate how high business value can be generated. The printing industry reveals that the methodology can address a high level of the local operational variety (i.e. the optimized solution is tailored to meet the needs of the specific customer), can be deployed profitably across hundreds or possibly thousands of service operations using a cost-effective and standardized process and can be adapted over time to changing customer requirements.

The focus of this improvement methodology is on improving the actual dynamic actions associated with providing the service offering i.e. the provisioning of the offering such that the customer has a better service experience in terms of faster cycle times, lower cost and improved quality. The marketing messages to customers have been reinforced with the improvements resulting from the application of the methodology. This has resulted in several existing service contracts getting renewed and new business being secured. It is worthwhile to note that in most cases, the service contracts are renewed or acquired not because new printing technology (i.e. goods) is introduced but because the design and execution of the existing service operation is significantly improved. This also supports the dominate logic view for marketing proposed by Vargo and Lusch (2004), one in which service provision rather than goods is fundamental to economic exchange.

This methodology is presented as a six-step process, each step of which is described in a section of the paper. Section 3 describes high-level characteristics of a specific service domain, the market size and a categorization of the service business. Section 4 motivates the data-driven simulation-based methodology and describes the key innovations embedded in the service optimization solution. Section 5 highlights the key human factors that have to be considered in order to ensure that the optimization solutions can be successfully deployed. Section 6 describes the tools, training and support infrastructure required for a large scale rollout. In particular this section will discuss a seamless, integrated and automated simulation-based toolkit and a scalable process for deployment of the service on a large distributed scale. Section 7 discusses the integration of process optimization solution within existing corporate processes to enable their institutionalization. Section 8 describes how business results have been delivered on a large scale. The paper concludes with some remarks on a service innovation process where researchers and customers work together to develop the innovation.

3 Step I: Identify a Service Operations Domain and Scope the Opportunity

Enterprises and businesses deliver multiple service offerings and it is not clear at the outset which service operations business has significant opportunity. Before too much effort is put into developing a solution, it is important to develop an understanding of the workflows associated with the service operations, scope out the market size and develop a segmentation of the service operations to understand the types of solutions that will be required to address the entire opportunity.

In the printing industry example, I led a team to optimize the productivity of print shops operated by Xerox via a four step procedure: Firstly we modeled individual print shops to convince ourselves that restructuring the work flow from the traditional departmental organization to cellular configurations offered the possibility of substantial productivity improvement. Secondly, working in partnership with the Xerox service delivery organization, we tested and refined these models in a variety of different print shops to demonstrate that the expected improvements were achievable in practice. We further used this opportunity to perfect techniques for marketing these transformational engagements to the various key audiences required to implement them. These efforts led us to market segmentation and to productivity results that enabled us to establish the business value to Xerox of a corporate-wide roll out of the methodology. Thirdly, in partnerships with the appropriate Xerox service and engineering organizations we developed a roll out plan that included the development of the training, tools, support-infrastructure and marketing collaterals necessary for Xerox service personnel to deliver the transformational engagements to Xerox customers. Fourthly, we marketed this plan to appropriate management in the involved organizations in order to obtain the commitment and funding and authorization to implement it. By conceiving and implementing these four steps over a period of 3–4 years, we identified and scoped a highly profitable service offering for Xerox, and secured authorization for its implementation.

Our point here is to emphasize that identifying the service opportunity in some detail, performing enough exploratory applications to establish its implementation and profit parameters, and preparing an actionable implementation plan for corporate management are indispensable initial steps in creating a new profitable service business based on work process optimization. In the remaining Section 3.1

I describe the work flow characterization, market size, and market segmentation used in the original implementation proposal to management.

3.1 Characterization of Workflow in Print-Service Center Environments

Print service center can be classified into three categories based on the activity that they perform – transaction printing, on-demand publishing, or a combination of both. A transaction-printing environment produces documents such as checks, invoices, etc. Each document set is different. Mail metering and delivery are part of the workflow. On-demand publishing environments focus on producing several copies of identical documents with more finishing options such as cutting, punching and binding. Examples of such products include books, sales brochures and manuals. Other environments perform both types of document production simultaneously with varying emphasis on each one.

The document production steps associated with print jobs are indicated in Fig. 1. Typically print service centers have departments that support individual steps of this workflow. Each department supports many different types of internal workflows resulting from the use of different types of software tools, printing machines types (e.g. offset, digital) and a variety of finishing equipment (such as cutting, binding, laminating, shrink-wrapping).

Each of the six generic steps in the print production workflow is associated with a department:

Customer service and production planning department works with the print service center customers to handle incoming requests, negotiate price and due dates, provide tracking and notification, and work with production department to plan and schedule delivery.

Graphics design department designs the content of the document.

Pre-press department performs tasks such as inspection of incoming print jobs, editing jobs for color quality and accuracy, creating proofs and working with the customer service and printing department to coordinate production.

Printing department prints the document. For offset printing, these activities include performing setups on the offset (lithographic) presses, loading

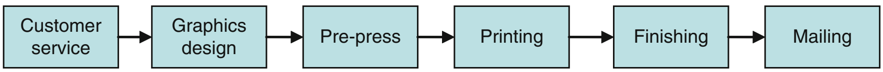

Fig. 1. A print production workflow showing the various production operations

paper and ink, performing runtime color corrections, offloading printed material and transporting it to the finishing department. For digital printing, the input to printers is an electronic print stream and the output consists of printed documents. Digital printing is used for short-run-length jobs and when the variable content is high. Digital printing technology is differentiated by low setup, simpler interfaces and smaller equipment size. The job input is a digital data stream (“digital masters”) rather than hard-copy masters (“mechanicals”). The generation of these data streams creates major changes in the work content of the departments that precede the printing step in the overall workflow.

Finishing department takes as input printed material and performs a variety of finishing operations such as folding, cutting, saddle-stitching, binding and packaging.

Mailing department packs and labels the finished goods and ships them to customers.

Offset printing is the dominant printing technology used today (US Census Bureau 2008). More than 98% of print production revenue is associated with offset and offset-like technology. Nevertheless, customer demand for more personalized documents, quicker turnaround time, lower overhead and set-up costs, and geographically distributed printing has led to the migration of offset workflows to on-demand digital printing workflows for monochrome printing. As color digital systems that produce print quality equivalent to or better than offset print quality at competitive costs are developed, the same migration is expected to occur for color documents. For the foreseeable future both of these workflows are expected to co-exist within the printing industry.

3.2 Market Size

The printing industry is large and fragmented. The North American Industrial Classification System (NAICS) code for “printing and related support activities” is 323. In 2005, the total value of print shipments corresponding to code 323 was $97.095 billion with an annual payroll of $24.893 billion (U.S. Census Bureau 2008). The industry employed 642,300 employees with the payroll per employee of $38,753. An estimate of $100,000 in annual sales per employee is remarkably accurate in determining a commercial printer’s annual sales (The Industry Measure 2007). Changes over time in the numbers of small (1–9 employees), medium (10–49 employees), and large (50+ employees) establishments provide a measure of industry dynamics. Figure 2 shows the number of print service center grouped by the number of employees. The increase in the number of larger establishments and decline in the number of small and medium service center reveals that business is moving from small and medium sized service center to large service center.

Fig. 2. Commercial, quick printers by employee size, 2002 vs 2004 vs 2006 (The Industry Measure 2007)

3.3 Print Production Service Categorization

There have been various taxonomies proposed for classifying service systems. Hayes and Wheelwright (1979) proposed taxonomy based on two dimensions, product or market variety (ranging from high to low) and type of production system (ranging from job shop through batch production, flow line to continuous process). Chase (1978) proposed a classification based on the extent of customer contact in service creation. Shostak (1987) proposes a taxonomy that uses two dimensions: degree of complexity of the service delivery structure and degree of divergence allowed at each process step. Wemmerlov (1990) proposes a similar taxonomy using two dimensions namely, degree of divergence and degree of customer contact. Schmenner (1986) also proposes a taxonomy using two dimensions: degree of labor intensity and degree of customization or interaction. Buzacott (2000) developed a categorization of service system structures based on an analysis of their relative performance and how this performance is affected by the nature of the tasks that have to be performed.

Because of the great diversities in print service centers, a categorization scheme has been developed that allows the development of optimization tools and techniques for various segments of the print service center market. Based on the experience from early engagements, the print service center market segmentation matrix

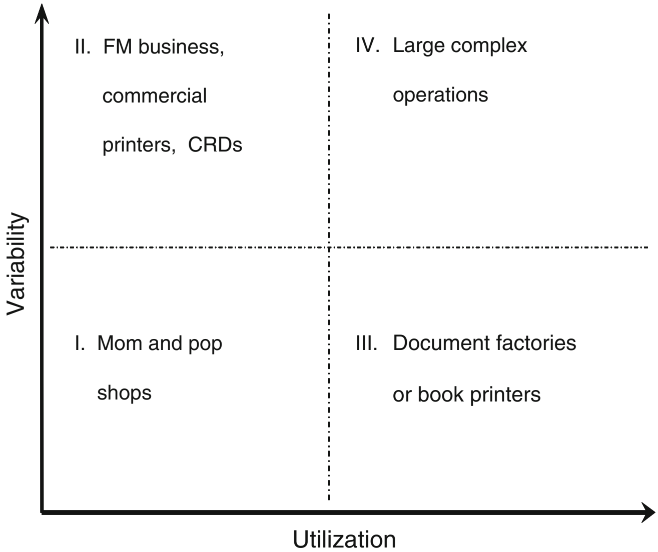

Fig. 3. A segmentation of print service centers within the printing industry (FM designates facilities management. CRD designates corporate reprographics department)

shown in Fig. 3 was developed. Print service centers are characterized based on the job variability (characterized by job mix, job size distribution and job inter-arrival time distribution) and resource (equipment and manpower) utilization levels.

Segment I encompasses service centers that operate individually to produce a few types of products on as-needed basis (e.g., store-front print service centers for convenience document production). Segment II encompasses service centers that are moderately sized (e.g., corporate reprographics departments), produce several different types of job types (typically less than 40), and are challenged with delivering high quality of service such as turnaround time and print quality at competitive costs. Segment III encompasses service centers that typically specialize in a few different types of workflows to create products that are manufactured in high-volumes (e.g., large book manufacturers). Typically these service centers are found to operate at higher levels of resource utilization than print service centers found in segments I and II. Segment IV contains service centers that manufacture a wide array of documents often within a specific industry segment such as financial or healthcare, are large in size (e.g., over $50 million of annual revenue), and exhibit leveraged economies of scale in production processes to achieve better utilization of resources than the service centers in segments I and II. This classification enabled the development of customized solutions that address print shops in each of these segments.

4 Step II: Characterize, Model and Optimize the Service Environment

This section discusses the specific characteristics of a service environment that exhibits high variety and multiple sources of variability and motivates the need for a simulation-based methodology. It further motivates the structure of the solution and the operating policies.

4.1 *Characterization of the Service Environment*

Print service centers experience many sources of variability. Segment II and IV especially exhibit high levels of task size and routing complexity that makes them hard to optimize (Fig. 3). These service centers are primarily make-to-order service systems that cater to specific requests of each incoming customer. The incoming service requests have random arrival and due-date requirements that vary from job to job and often exhibits variability within the same job-type. The size of the jobs is often characterized by highly non-normal distributions as shown in Fig. 4 and sometimes fat-tail distributions (Rai 2008).

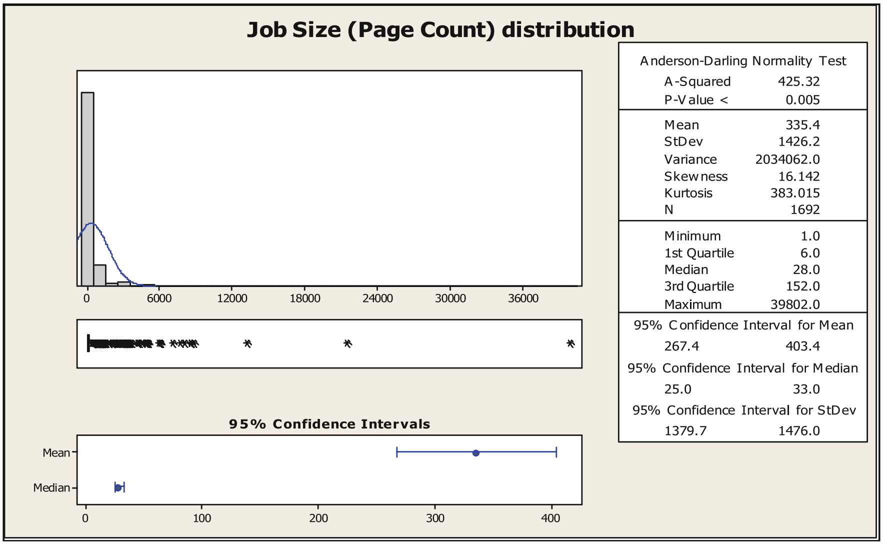

Fig. 4. A histogram of the job size distribution in print production service center can exhibit highly non-normal and long-tail characteristics

Job variety is also high as shown in Fig. 5 and many different product types (i.e. multiple routings) may simultaneously be in the service center at any given time.

Depending on the day of the week or month of the year, the demand is different leading to high demand variability as shown in Fig. 6.

The simultaneous existence of these multiple sources of variability makes it difficult to model, predict and optimize the performance and cost structure of these

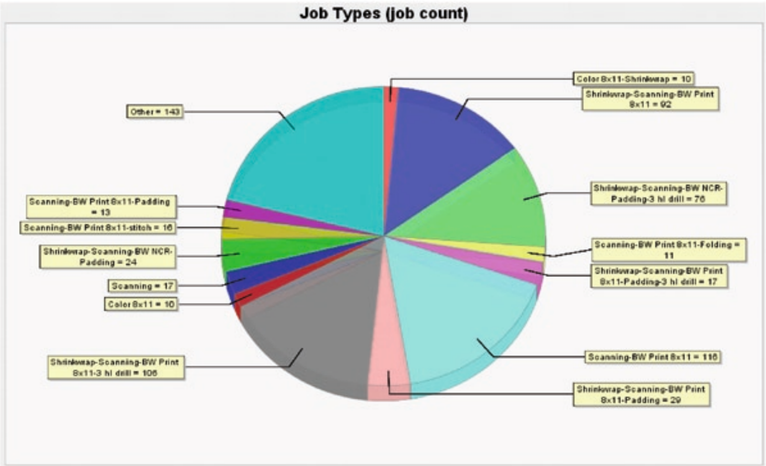

Fig. 5. Print production service centers can have several requests that require multiple routings for fulfillment at any given time

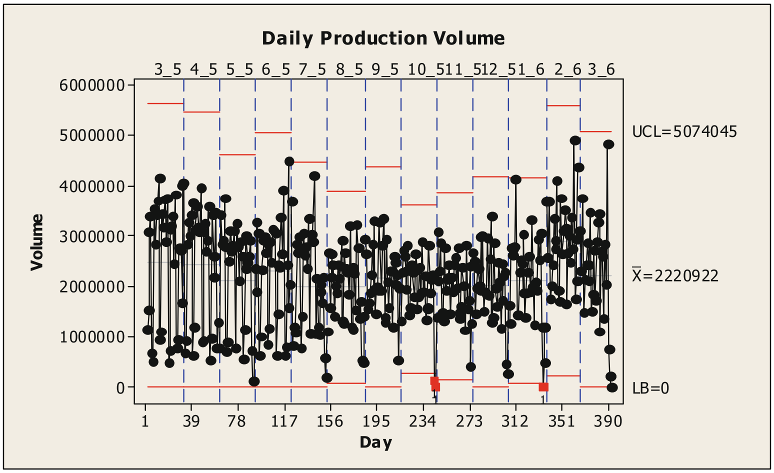

Fig. 6. Print service centers can exhibit very high fluctuation in the volume of incoming print requests

service centers. Discrete-event simulation models can be constructed but they require time and expensive resources and require data collection and validation. Since the conditions of the service center change with time (non-stationary processes), the models need to be updated with time adding additional complexity and cost. Compared with a standardized McDonald's type model, the modeling complexity can be quite high.

An enterprise can take the McDonalds approach and limit the type of document service offerings it provides and create a cookie-cutter operation. While this approach may be applicable to some service centers, the document service variety is determined by the requirements of the document production needs of the enterprise which varies widely across industries and even within industries. The capability to effectively offer document production service offerings requested by the enterprise is one of the key requirements for gaining market-share within the outsourcing business. The ability to handle variety cost-effectively is a key differentiator. Suppliers and vendors that are seen as incapable of offering this variety get excluded from outsourcing consideration.

4.2 Data-Driven Modeling of Service Operations

There are three approaches to model and analyze service processes namely, analytical modeling, direct experiments and simulations.

4.2.1 Analytical Models

These are the best class of models if they can be developed to describe the process at hand. They are usually computationally fast and give good insight into the process. They can also be used to understand how the model variables affect the outcome(s) being studied and perform fast sensitivity and optimization analyses. Analytical models are built on abstractions of the real world process and often make assumptions to get analytical solutions. If the process being modeled is sufficiently complex (which often is the case for real-world service operations), the assumptions that are made to develop the analytical models often make them less useful as predictors of actual system behavior.

4.2.2 Direct Experiments

A second approach is to deploy data collection tools within the service process and then develop analytical tools to analyze and optimize the process. While this is a useful approach, it is limited by the ability to collect data from the processes in an unobtrusive manner without affecting system behavior. Data collection can also be expensive and is often viewed as a non-value added activity unless the data analytics can demonstrate additional value. However, if data can be collected inexpensively on an ongoing-basis, this approach can be effective in assessing and optimizing the performance of service operations. The use of this approach in automated service offerings (ones that require minimal or no people involvement) is well-known. Companies such as Amazon, Google, Yahoo, E-Bay and many others regularly collect service data and use analytics to improve their service offerings.

4.2.3 Simulations

Simulations are used when the process being modeled is complex and not easily amenable to analytical modeling or direct experimentation. It enables the study of the interactions within large systems to get insights into the critical factors that affect desired performance. It can be used to improve and optimize these systems through analysis of numerous what-if scenarios. It can also be used to train personnel without disrupting the actual operations. In many instances simulations are used to establish the validity of analytical models. Simulations are also used with direct experiments and data collection to make them significantly more powerful and useful (Banks et al. 2004).

Advancements in simulation methodologies and increase in available computational power has increased its usage in performing large systems and process analysis. Even though simulation appears to be the most general methodology to model and optimize complex service operations it has two drawbacks namely:

- Simulation models can take a long time to build especially as the process complexity increases.
- The skill level, time and cost required to build simulation models for complex and varying service processes is sufficiently high to inhibit wide-scale deployments of this methodology.

There are many classes of service offerings whose overall operating framework can be represented within a generalized framework but whose specific instantiations have sufficient variability that a single parameterized model is not sufficient to capture the overall complexity. For example, a corporate reprographics department providing print production service can all be described at a high level by a general workflow as shown in Fig. 1. Jobs arrive at the customer service department, are moved to the print area, then to the finishing area and finally to the delivery area. However, when one looks more deeply at the specific instances of these print service centers, one can experience a wide variety. For example, one service center may accept jobs electronically, another may received hard-copy paper documents; the printing area can use digital equipment and/or offset equipment; the finishing area can have automated and/or manual finishers with differing labor requirement. Labor may have different characteristics such as those characterized by skill variations or by their employment category (e.g. permanent or temporary with corresponding wage differences). When one looks at the permutations of these differences, many different process instantiations are possible. While each one can be modeled using any one of the discrete-event simulation packages available in the market, the cost and time associated with building these models can be prohibitive to enable their wide-scale and ongoing use to analyze and optimize these service operations.

Many industries deliver service offerings where people are an intrinsic part of the delivery process. Well known examples include grocery stores, departmental stores, print service outlets, retail banking outlets, restaurants, hospitals, government offices, repair shops and many others. It is not hard to convince ourselves that we live in a primarily service economy if we look at the numerous service industries that surround us and are an integral part of daily life. Owners of these service businesses have long tried to differentiate themselves based on content and quality of the output. However, very few but extremely large franchise owners have applied simulation and modeling tools to optimize the way they deliver these service offerings. Some large franchises (e.g. McDonald's) have tried to achieve process efficiencies by standardization of processes and creating an optimized instantiation of these standardized models. But that also limits their ability to offer wider variety to their customers. On the other hand, specialized restaurants may offer a wide variety of options but cannot typically match the price points of the franchise owners.

Within the print production service space, enterprise clients often demand wide variety in print production that is typical to the document needs of the enterprise. Thus to be a preferred on-site service provider, the print service center has to deliver the required document variety but has to do so at a cost that makes it profitable for them as well. The trade-off between output variety and profitability is a difficult one to manage and if not done effectively can lead to unhappy customers or unprofitable operations.

Since a simulation model is built using abstractions of real-world processes, a key issue to resolve is to determine how much effort is spent in capturing the process details within the model and the accuracy of the prediction that is required. Focusing too much on non-essential details can add unnecessary complexity to the simulation without improving the value it provides while ignoring critical elements can adversely affect its utility and insights it gives. The purpose of the simulation models discussed in this paper is twofold; the first is to provide guidance to make changes to the structure of current state of service operations to improve several productivity metrics and second is to validate that the model-based predictions of the improvements are observed in the re-structured service operations. The emphasis is on capturing the essential elements of the service processes (related to both structural and control aspects) that provide good directional and quantitative guidance on what needs to be changed and how.

The simulations models discussed in this paper are directly driven by data collected from the service operations. The current state metrics are assessed and then changes are made to the structure and control policies within the simulation model to evaluate how productivity metrics can be improved. The improvements are further validated through data collected from the actual re-structured service operations and compared to original state metrics to validate that the model-based changes actually delivered real-life improvements. The combination of data-driven simulation-based modeling and empirical validation of tangible productivity improvements through real-life data collection reinforces the power of this methodology for optimizing service operations. The approach presented in this paper consists of two distinct components. The first is the development of an optimization toolkit based on the rapid modeling and simulation of a service operations center. These models can then be utilized through a series of what-if analysis scenarios (using automated and semi-automated approaches) by relatively low-skilled personnel to optimize the specific operation. The second is the development of a process to deploy this solution cost-effectively on a large distributed scale to multiple service centers within the industry.

This paper presents the solution within the context of the print production service domain. While the domain of application is specific to the printing industry, the solution proposed and learning from this endeavor can be generalized to a wide range of people-based service offerings.

4.3 Service Structure and Process Optimization

The cost and performance of print production service is a function of both the process structure (labor, equipment, facilities layout) and operating policies. To optimize the productivity of the systems it is always necessary to make tradeoffs in system design between the effectiveness in coping with internal and external variability and the efficiency, speed and cost of providing the service.

Most traditional print service centers are functionally organized. All equipment that performs one type of function is located in one area. For example, all printers are located in a print room. Finishing devices such as inserters are located in a separate room. These centers are more akin to job shops that have high levels of flexibility in terms of using equipment for different jobs. Incoming work flows from one department to another until the service request if fulfilled in its entirety.

In the next section, a structure for redesigning the traditional service centers into more efficient and cost-effective operations is proposed.

4.4 Structure Design of Print Service Centers Using Autonomous Cells and Hierarchical Scheduling

Business process innovation or reengineering received much attention in early 1990s. Two books written for business audience (Hammer and Champy 1993; Davenport 1993) attracted wide interest. Hammer and Champy proposed a set of “Commonalities in Reengineered Business Processes” shown in Table 1.

Table 1. Commonalities in reengineered business processes (Based on Hammer and Champy 1993, Chapter 3)

1.	Several tasks are combined into one
2.	Workers make decisions
3.	The steps in the process are performed in a natural order
4.	Processes have multiple versions
5.	Work is performed where it makes the most sense
6.	Checks and controls are reduced
7.	Reconciliation is minimized
8.	A case manager provides a single point of contact
9.	Hybrid centralized/decentralized operations are present

Buzacott (1996) has evaluated the structure of reengineered (and primarily transaction-processing) systems using formal system models from queuing theory to develop insights about the conditions under which such radical changes of system structure are likely to be appropriate. The basis of comparison are performance measures that can only be evaluated using stochastic models, such as the level of work-in-process or the time a transaction spends in the system (where Little's Law $L = \lambda W$ means that it is only necessary to explicitly consider the level of work-in-process). Two systems are compared namely,

> *Series systems*: Here the total work content is subdivided among m facilities arranged in series with each facility dedicated to a single task.
>
> *Parallel systems*: The parallel system has n identical facilities at any of which all required tasks can be performed on a job one after the other without interruption and with little changeover or setups between task.

Using queuing models developed by Harrrison and Nguyen (1990) and Buzacott and Shantikumar (1993), he concludes that moving from a series (flow-line) type structure with division of labor to parallel systems, depends critically on the processing time variability. If the tasks are such that they are the same for all customers and have relatively low complexity, the series service structure can be quite effective. However, high task processing time variability (resulting from task size or task complexity variation) makes it attractive to move to parallel systems. In addition, different types of allocation strategies such as random allocation, cyclic allocation and single queue are explored.

To address the complexity of operations associated with the print production processes, the service center resources are organized in autonomous cells (Rai et al. 2000). As a result, the most common jobs can be finished autonomously inside (at least) one of these cells. Figure 7 shows how traditional print service centers are organized based on a departmental structure operated by specialized workers and

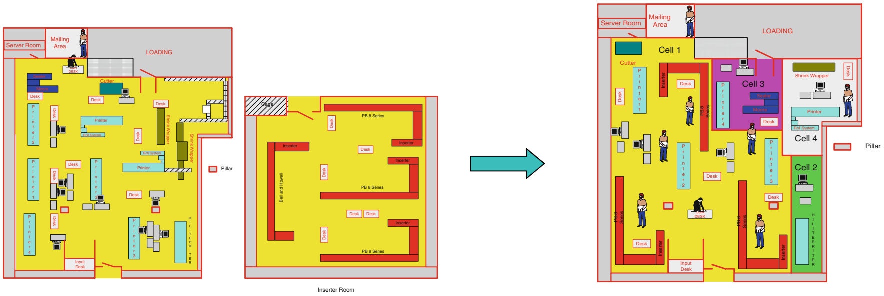

Fig. 7. Figure showing how a departmental configuration of a print service center is transformed into a structure utilizing autonomous cells

compares it to the redesigned operational framework based on autonomous cells where diverse pieces of equipment are collocated and operated by cross-trained workers. This organization into autonomous cells is a key concept of the proposed solution to optimize these print centers, offering the advantages of lowering product transportation times, reducing complexity associated with interaction of large number of job types, easing quality and production control while managing resources more effectively and avoiding congestion. Inspired by the goal of lean production (Womack and Jones 2003) to achieve a waste-free highly efficient document production service center, Xerox coined and trademarked the solution as LDP Lean Document Production®.

To orchestrate the flow and control of jobs through the parallel hierarchical cell structure, the Lean Document Production Controller (LDPC) uses a 2-level architecture (Rai and Viassolo 2001) shown in Fig. 8 for production management. The LDPC has:

- A service center controller module (*Service centerCM*) – high-level controller, in charge of global service center management
- Several cell controller modules (*CellCMs*) – low-level controllers, in charge of local management inside cells

Detailed descriptions of these controllers and the algorithms can be found in the Rai et al. (2009).

The solution requires structural design of efficient autonomous cells (right type, number and configuration of equipment, people and layout) as well as determination of efficient routing and scheduling policies that achieve significantly improved performance over the current state. This is accomplished via the use of discrete-event simulation methodology for evaluating the design and operational efficiency of the restructured process.

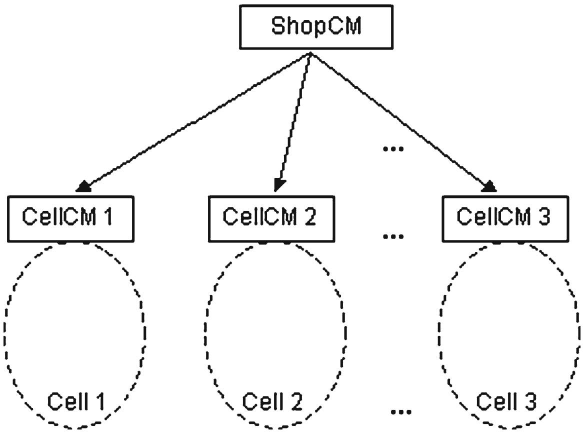

Fig. 8. Two-level architecture for the Lean Document Production Controller

5 Step III: Develop Effective Human Factors Practices

One of the most important and often-ignored aspects of people-based service operations are people who operate and manage them. While data analysis and simulations can provide useful insights into redesigning efficient service operations, ignoring the human factors can prove costly and in some instances nullify the effect of the optimization effort.

From this standpoint, it is necessary to consider both management whose primary focus is to make sure the financial viability and profitability of the operations and the operational staff who are involved in executing and delivering the service on a day-to-day basis. Management needs to be convinced that the simulation-based restructuring will improve profitability and grow revenue and the operational staff needs to believe that this effort will help them deliver better service and improve their future professional prospects.

Conducting experiments on the service operations by restructuring sample jobs based on simulation models and showing before-and-after metrics can be utilized to instill confidence that the simulation predictions can drive tangible benefits to the operations. This can be done prior to performing full-scale simulation and optimization of the entire operations. Testimonials should be gathered from successful engagements and then utilized to build confidence during the course of future engagements.

Since the re-structuring of the operations often requires changes to the facility (such as layout and electrical) that implies cost, management has to be convinced that it is worthwhile to make these investments. A return-on-investment analysis associated with the cost of performing these re-design and the benefits achieved is also critical to getting buy-in. Instituting reward policies that recognizes improvements in operator productivity as a result of re-structuring is also important for the success of the overall optimization effort. It also needs to be emphasized that the re-design effort is not treated as a one-time effort but that the operations needs to continually (or the very least, periodically) assess and improve the structure and control processes.

6 Step IV: Develop Tools, Training and Support Infrastructure for a Large Scale Rollout

This section discusses how the simulation tools were automated and a process developed for large scale rollout of the optimization service.

6.1 Automation of the Simulation Software Toolkit

The benefits of simulation automation are twofold – both technological and economical. Automation enables faster, less error-prone simulations and exploration of a larger design space leading to better solutions. It also allows deployment of this service by less skilled and less expensive personnel improving the economics of the deployment process.

Discrete-event simulation is an established methodology for studying the behavior of a system as it evolves over time. It is frequently used for process modeling in a wide variety of service offerings and industries when direct experimentation or analytical modeling is impractical. Many discrete event simulation software tools (Arena® Simulation Software 2010; ProModel 2010) are available in the market. These tools provide a (graphical) programming interface and basic primitive constructs for model building. The traditional approach to construct a discrete event simulation model is to employ a highly skilled modeler who would typically take significant amount of time (days, weeks or months depending on the size and complexity of the operations) to gather process information data, construct the model and iterate through the design.

However, scaling this methodology to a large scale using available discrete event simulation tools requires major cost investment, infrastructure development, training and periodic refresh to account for changing conditions. There is often sufficient variability in the models that depends on the modeler thereby creating challenges in standardization. This issue can be addressed if a solution can be developed that has a generalized modeling framework that captures essential characteristics of the class of service operations being modeled but has enough flexibility to capture the variation inherent in the specific instantiations within the particular industry. If this problem can be solved, then a modeling solution can be developed that can be scaled and replicated at multiple service center operations. Further, if the process of model building can be automated, it can reduce the time required to build the model and also reduce the errors and associated variations inherent in constructing these models.

To automate a process, it is necessary to understand it in sufficient detail and develop abstractions which are complete enough so that specific instances of the print service operations can be modeled using it. The automated modeling solution should also integrate various aspects of the model building process (e.g. data collection, definition of various elements, process design, planning, scheduling and simulation) to produce a seamless experience for the user. Further, the software toolkit should be embedded in a process improvement framework so that the user can systematically execute the tool effectively and in a replicable manner for optimizing the service centers.

A document production service enterprise may consist of thousands of small on-site operations. Each operation may have few pieces of equipment (e.g. less than 30 machines including computers and printing and finishing equipment) operated by less than 10 service center personnel. The annual revenue being generated from one of these sites may range from $250,000/year to $5 million/year. A service that assesses and optimizes these operations has to be cost-effective to be widely deployable so that it does not negatively impact the profit margins of the operations. Yet the optimization service should be capable of modeling variety and variability discussed earlier.

The approach proposed in this paper to make the simulation capability easier to use is to develop a structure for building the simulation model and automate the time-consuming steps. Instead of working with general purpose primitives available in the simulation model, the service environment is abstracted. Objects and processes that were unique to the document production service industry are modeled as constructs that are recognizable by the industry personnel. An easy-to-use software interface is created to allow the properties and capabilities of the service center to be defined within the simulation tool using these high-level constructs. A range of operating policies, patented process algorithms (e.g. split large jobs into small optimized batches) can be selected and applied to the model. Once the model is defined using a declarative interface using high-level constructs, it is checked for accuracy. Subsequent to that a simulation model is constructed automatically which is then used to optimize the center.

The high-level constructs pertinent to a document production service center consists of equipment, operators, shop schedule, autonomous cell, operating and sequencing policies and service requests. These objects have to be parameterized in a sufficiently generic manner so that specific unique instances can be realized. For example equipment can be described through the specification of its capabilities, setup characteristics, speed, failure and repair time distributions and operator requirements to operate it. While this is a general specification of printing equipment, different values and data sets associated with the individual parameters can readily capture the specific equipments in the shop. Table 2 shows the various objects that are used to characterize the print production service center.

Table 2. A list of objects and their attributes that are required to define a print production service center operation

Objects	Components and attributes
Service center	Autonomous cells, equipment, operators, schedule, operating policies
Autonomous cell	Operators, equipment, schedules, cell operating policies
Operator	Skills, schedule
Equipment	Function capabilities, schedule
Function capability	Speed, setup requirements, variability, operator requirements, status (up or down)
Job	Job structure, quantities at each node, arrival, due, completion and intermediate events (e.g. start, stop at individual steps)

It is useful to remark here that the development of a complete set of these abstractions is a pre-cursor to automation of the modeling process. The specific objects described in Table 2 are specific to the print production service business and will require adaptation for extensions to other industries.

Once a complete set of abstractions to model the service operations has been developed, the next step is to develop the algorithms that will be used to optimize the center. Depending on the approach, these algorithms could be focused on optimizing the structure of the operation and/or the operational controls used to improve the efficiency. For optimizing the print production service centers, three classes of algorithms were developed, namely – methods to design autonomous cells, scheduling policies for routing incoming requests to the cells and operating policies for splitting large jobs and processing them within the cells. There may be many algorithms that can be effective for each of these classes. The automation goal is to allow the user to select them and automatically build simulation models with those algorithms imposed on the models (Jackson and Rai 2000). This automation vastly improves the speed of modeling and reduces the number of errors in the model.

Other aspects of simulation automation require streamlining the various steps of the optimizing process such as data collection, data analysis and reporting, simulation and modeling, scheduling and monitoring so that the user can easily exchange data from one phase of the analysis to another.

Analysis and optimization of such operations involves a large number of choices that manifest themselves as discrete categorical, continuous variables and constraints that are quite complex and requires many trade-offs to be made. The automation of the simulation process of modeling the autonomous cell architecture with hierarchical scheduling enables an exhaustive search of the design space and allows the user to iterate through multiple scenarios. The generalized framework also allows the tool to capture the variety and variability inherent in these service processes and suggest ways to optimize the operations without necessarily reducing the service capability. For more details on the algorithms and modules of the software tool, the reader is referred to Rai et al. (2009).

6.2 Process for Solution Deployment

The process of optimizing the print service center using the solution and tools developed above is broken down into multiple steps as shown in Fig. 9. These are pre-engagement process, assessment, recommendations, implementation and monitoring.

> *Pre-Engagement*: The service center management team is engaged and through the use of demonstrations and presentations, the solution methodology is explained to the service center personnel. The goal of this step is get concurrence from management to initiate the optimization engagement.
>
> *Assessment*: The assessment phase begins with a survey whereby information relating to operational issues is collected using standardized templates. An approach that has proven useful is to demonstrate some of the key aspects of the optimized solution (such as small batch cellular processing and scheduling) on some sample service requests and measure

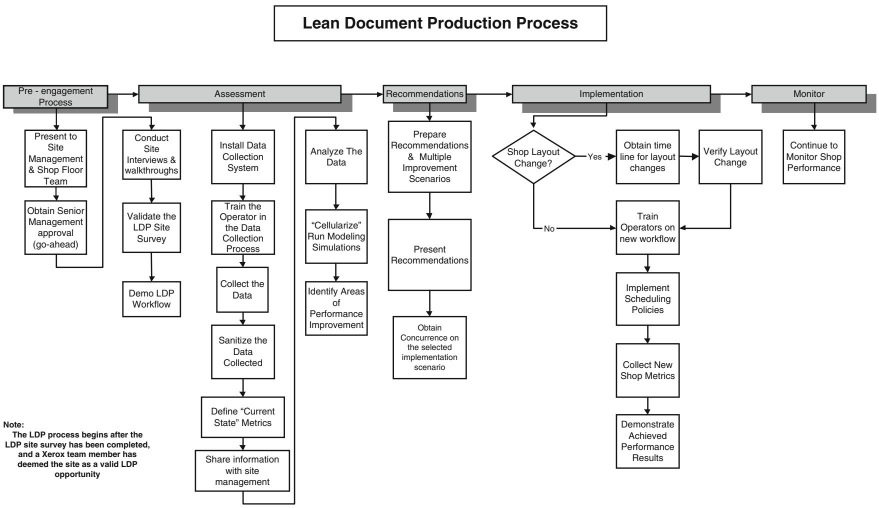

Fig. 9. A multi-step view of how the simulation-based optimization solution is deployed in print service centers

improvements. It is important to address the skepticism of employees at this stage of the engagement and the demonstration exercise is intended to dispel these concerns and prepare them for the step of data collection. Special purpose data collection systems (as discussed in Rai et al. 2009) are installed to collect information. The service center personnel are trained in the use of the data collection tools. The data that is acquired in this phase is periodically checked for quality and consistency and appropriate feedback is provided to the personnel as needed. The data is analyzed to generate current state metrics of the operations and establish a baseline. These include service request lateness, operator and equipment utilization, types of service requests, work-in-process, demand rate profiles and financial metrics (e.g. cost and margins).

Subsequent to developing an understanding of the current baseline metrics, the service center is redesigned into autonomous cells. The software toolkit is used to develop the structure of the cell (equipment, people and their respective skills, layout) by iterating through multiple configurations and scheduling policies. The automation embedded in the modeling and simulation toolkit enables a quick search and iteration over a large number of scenarios as shown in Fig. 10 to develop solutions that demonstrate significant quantitative productivity improvements over the current state. The iterations are performed over both discrete categorical as well as continuous

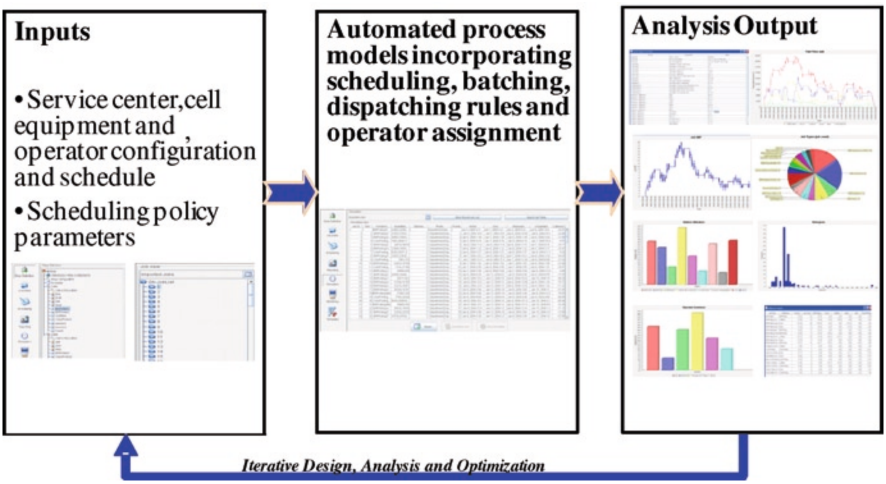

Fig. 10. The figure shows the three steps of optimizing the service center by iterating through defining the service center, automated process modeling and simulations and output analysis

variables such as multiple cell configurations, machine speeds, scheduling policies, skill mix and operations schedule (e.g. one-shift or two-shift operations), variations in request mix and quantity and the like. The innovation and automation embedded in the software enables a much richer and data-driven quantitative analysis and optimization of the process than more qualitative or focused process improvement approaches that are successful in operations with lower variety, variability and uncertainty.

Presentation of Recommendations: The results of the simulation and optimization studies are presented to service center management. A key element is a return-on-investment (ROI) analysis to insure that the approach has business justification. If management accepts the solution, a transition plan for implementing the solution to the new cellular configuration is developed.

Implementation: In this phase, the service center migrates to the new cellular layout. The operators are trained in the new workflows including new scheduling policies. New operational data is collected to fine-tune the operations and demonstrate improvement with respect to the baseline state.

Monitoring: The service center productivity metrics are tracked on an ongoing basis to ensure that the gains continue to be realized from the reengineered process.

7 Step V: Integrate with Related Corporate Processes

7.1 DMAIC and Simulation-Based Optimization

Several companies are utilizing the DMAIC framework (George 2002) for service process improvement. While the DMAIC process is a powerful framework for process improvement, it lacks the use of rigorous discrete-event simulation and optimization tools. Thus if the service operations have significant variety and complexity associated with job mix, non-normal distributions, random failures and repairs, the current set of Lean Six Sigma tools cannot adequately model and analyze the consequences of these interactions.

However, institutionalization of the DMAIC process within an organization leads to a large number of green belt and black belt personnel focused on process improvement initiatives. By training these personnel in the use of the modeling and simulation toolkit and process described earlier, their capabilities are significantly enhanced. These black belts can utilize these tools to optimize the service centers. Within Xerox Corporation, a significant number of black belt personnel were trained in this methodology. This led to a wide-scale deployment of the process optimization methodology (Fig. 11) and toolkit within the printing business.

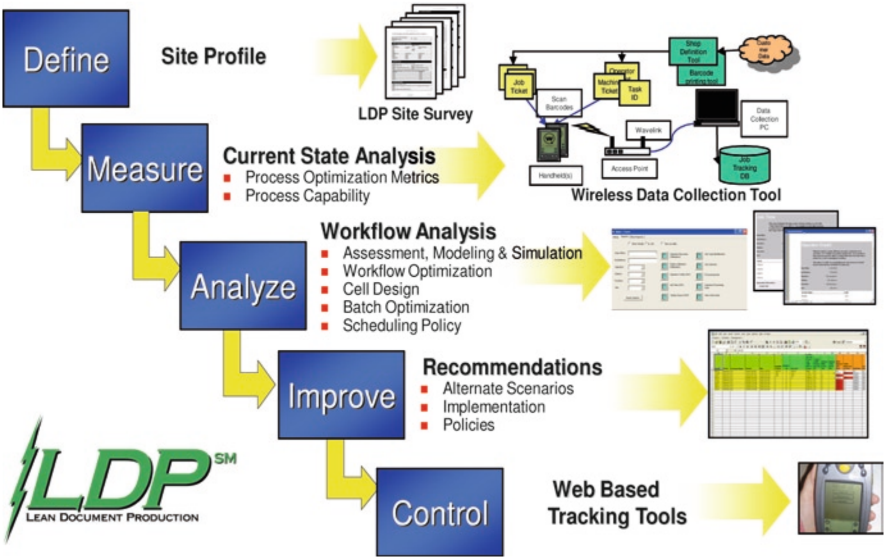

Fig. 11. A mapping of the various tools and analysis steps of the LDP Lean Document Production® solution to the DMAIC process

8 Step VI: Deliver Business Results on a Large Scale

Quantitative measures of improvements resulting from the utilization of the productivity optimization solution averaged over 17 sampled service centers, include labor savings of 20%, productivity (measured as revenue/cost) improvement by 40%, cycle time reduction of 80%, revenue increase of 17%, and annual profit increase of 20% of the revenue of the shop prior to the LDP implementation. Since 2003 it has been widely implemented in the field via the Xerox Corporate Lean Six Sigma (LSS) Black Belt program utilizing the DMAIC process outlined above. A sample of over 80 service centers yields average cycle time improvement of 50% and on-time-performance improvement of 11%. Over 80 consultants have undergone training in the use of these tools and over 100 print production service centers have been optimized using this methodology.

The cumulative value delivered by these engagements is over $250 million across the Xerox customer value chain. In addition, the higher quality and faster delivery enabled by the LDP solution provide strategic competitive advantages to print service centers. Xerox also has filed 64 patents applications related to this solution and 15 have been granted so far.

The LDP innovation was a runner-up at the 2008 Franz Edelman competition (Edelman 2008) sponsored by INFORMS.

9 Remarks on the Service Innovation Process

The service innovation discussed in this paper followed a process that is different from the traditional product innovation. The value chain for delivering a new offering typically involves the conception of the offering by a product team, which then acquires new technology from research and development, develops and tests the offering, and delivers it to the sales and service forces via a structured, phase-gate product development process. In contrast, this invention as described in this paper was developed at customer sites by a team of researchers working in partnership with the sales and service personnel who serviced the sites. This team, in collaboration with an engineering team, created the tools and training that were used to roll out the offerings to sales and service. It drove the planning and implementation of the rollout process, establishing new linkages between the engineering and service organizations. The team established the entire value chain for delivery of the offering in real time, concurrently with the creation of the offering itself, the underlying technology, the toolkit, and the infrastructure needed to deliver the offering to the field.

As emphasized above, our method of service innovation described in this paper can be described as a six-phase process.

I. The innovative concept is co-developed and tested in partnership with customers. At this stage, algorithms and intellectual property are developed and proof-of-concept prototypes are conducted. The scope of the market is established and a market segmentation is constructed.

II. Once the domain and scope of the concept are established the (hardware and software) tools used to implement the innovation concept are developed.

III. Subsequently, the work processes and practices in which the tools are utilized are established. This involves proposing, testing and refining the work process used to engage the customer to implement the service.

IV. Having developed the service and its implementation plan, the next step is to roll out the service to customers more broadly than the initial test prototypes. This involves creating the personnel, training, and infrastructure needed to deliver the service to customers.

V. Typically, the new service offering does not stand alone but must be integrated with other corporate offerings, especially in a large firm like Xerox. This in turn involves the development of more training and infrastructure materials and possible minor adaptation of the original deployment processes.

VI. Finally, the pay off from the large scale implementation must be monitored and financial metrics for its return on investment implemented and tracked. Continually improving the offering is also essential in this step both to improve continually the productivity of the delivery process and to renew the offering so that it is addresses emerging customer needs.

This approach for service innovation has similarities to that proposed by Selden and MacMillan (2006) where they argue a disciplined process of customer R&D at the front lines will turn wishes into an enduring competitive edge and growing market cap. When a service offering gets commoditized, this approach to innovation helps companies generate increasingly tempting value proposition avoiding the trap of having to compete on price. This process also enables one to avoid the pitfalls of innovation (Selden and MacMillan 2006).

10 Conclusions

In this paper, a discrete-event simulation based solution utilizing autonomous cells and hierarchical scheduling is proposed for optimizing a service offering that exhibit significant variability and complexity. Trade-offs exists in the optimization of these processes that can effectively be made by creating simulation models and using them to analyze the interactions. The solution proposed in this paper demonstrates that the abstraction, generalization and automation of the simulation technology to model many service center operations using a common framework and software toolkit is an enabler to wide-scale deployment of this methodology by a wide range of analysts and consultants. The process for deploying the solution was also discussed in the context of the DMAIC process used in industries. The impact of utilizing this approach by Xerox Corporation was briefly summarized.

While this methodology has been demonstrated within the context of the print production service business it motivates thinking relative to the applicability of this methodology for other people-based service businesses that exhibit high variability and variety across multiple instances. A realization of this approach across a broad set of services execution and delivery instances has the potential of significantly improving the productivity of several people-based service businesses while keeping profit margins high without compromising on the variety of service offerings. The methodology presented in this paper provides a structured and replicable approach towards service innovation focused on improving people-based services. It supports the emerging view that services systems innovation can be studied and developed as a science (Spohrer et al. 2007). This should further motivate both researchers and practitioners alike to broadly think on how new innovations leveraging process improvement methodologies, simulation and optimization techniques and emerging computational and IT infrastructures can deliver the next generation of highly efficient, responsive and adaptive people-based service systems.

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