A METHODOLOGY FOR THE DESIGN AND EFFICIENT OPERATION OF PRINT SHOPS

Sudhendu Rai
Xerox Corporation
Phone : 585 422 2417
email : srai@crt.xerox.com

Abstract:
The document production industry is quite large with over $100B of annual revenue within the US alone. Print shops that provide document production services often run on very thin margins. This paper presents a methodology for improving the productivity of print shops. The work discussed in this paper has been applied to real print shops and demonstrated to significantly improve their productivity. Salient features of the methodology and the results of improvements are described. The paper concludes with a discussion of future opportunities and challenges in extending this methodology to other related domains.

Keywords:
Print shops, offset and digital printing, lean manufacturing, print shop design methodology

Introduction

World output for printing and writing paper was 94.8 million tons (that translates to approximately 21 trillion sheets) in 2001 (Lyman et al. [14]). Based on 1997 census reports, there were 42,863 establishments in the US with annual revenue of $97.4B. A bulk of printing related activities are mapped under a group labeled “Printing and Related Support Activities” (code 323) within the manufacturing sector by the The North American Industrial Classification System (NAICS [16]).

Despite the size of the industry, printing in general is practiced more as a craft rather than a state-of-the art manufacturing activity. Around mid-1998, Xerox Corporation initiated an activity led by the author to study printing as a manufacturing activity. The goal was to understand the diverse print production workflows and to improve the productivity of print production environments (i.e. print shops).

Print production environments generally exhibit five characteristics that make them difficult to optimize and operate efficiently.

- *Long bid times*: Customers often want to see physical proofs before committing to the entire print job. Depending on the number of proofing cycles, transportation delays and variability in customer response times, considerable time may be lost in receiving bids. This uncertainty makes it hard to plan for maximal capacity utilization.
- *Diversity in individual workflows*: The workflow required to process print jobs varies considerably from job to job. One job may require proofing, another may not; one may require lamination another may require binding; one may require shipping another may be picked up in person. Even when the processing steps do not vary, the processing times of individual steps may vary considerably as job characteristics change. This variability poses a challenge for effective scheduling of equipment and labor resources

- *Fluctuating demand*: Print shops experience significant fluctuation in demand. As a result, it is difficult to achieve optimal utilization of resources. This adversely affects the cost structure.
- *Variability associated with labor and equipment*: Print shops are often very labor intensive with several tasks that involve manual processing. Skill sets of different personnel vary across tasks and therefore lead to variation in throughput of different production operations. Variability in equipment throughput is also quite frequent resulting from operator skill variability as well as variability in job characteristics. For e.g., a printer may significantly slow down as the size and type of paper is changed. This poses challenges in effective planning, estimation and utilization of capacity.
- *Departmental production and scheduling*: Print shops typically organize their equipment and labor by specific functions to improve utilization of resources and maintain labor force skilled in specific tasks. Jobs are queued at the interface of departments and scheduled for production within departments. Due to the types of production variability listed above, this often leads to high WIP (work-in-progress) and high turnaround time.

Print shops are designed to manufacture highly customized documents that are often embedded in other workflows. This gives a different look and feel to every print shop both in terms of their equipment and job mix, layout, specific operating procedures, service levels, pricing structure and labor policies. This apparent diversity poses a challenge in developing a standardized methodology for improving productivity that is scaleable and adaptable across multiple environments. To better understand the specific characteristics of print production environments and the constraints within which they operate, print shops from various segments (banking, retail, telecommunications, insurance, public sector, transaction and others) were engaged. This study was conducted between 1999 and 2004. The experience gathered from this study was generalized and used to develop best-practices, tools for modeling, analyzing and improving print shop performance and tools for implementing process changes and control policies to improve profitability and performance of these print shops. These tools were developed for use and deployment by existing print industry personnel to reduce deployment costs and get acceptance within the printing industry. This required simplification of the process and tools to enable wide deployment while providing sufficient benefits to make it an economically feasible enterprise.

Based on the experience from these engagements, a segmentation of the print shops within the printing industry has been developed as shown in Figure 1. In this approach, print shops are characterized based on the complexity (characterized by job mix and size) and resource (equipment and manpower) utilization levels.

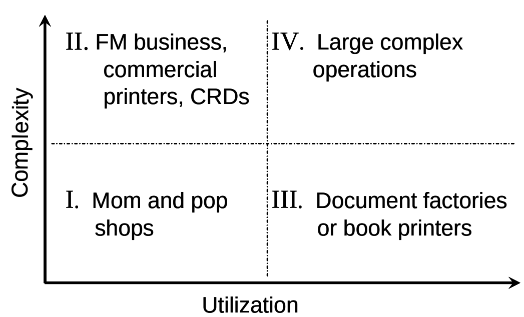

Figure 1: A segmentation of print shops within the printing industry

Segment I encompasses shops that operate individually, produce a few types of products on as-needed basis (e.g store-front print shops for convenience document production). Segment II encompasses shops that are moderately sized (e.g. corporate reprographics departments) and produce several different types of job types (typically less than forty) and are challenged with delivering high quality of service such as turnaround time and print quality at competitive costs. Segment III encompasses shops that typically and specialize in a few different types of workflows (e.g. large book manufacturers) that are manufactured in high-volumes. Typically these shops are found to operate at higher levels of resource utilization than print shops found in segments I & II. Segment IV has shops 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 $50M of annual revenue) and have leveraged economies of scale in production processes to achieve better utilization of resources than the shops in segments I and II. During the course of this study print shops from each of the four segments were engaged. However, a large fraction of this study was focused on print shops in segments I, II and III. Segment IV is still the subject of ongoing and future research and development activity.

A vast literature exists that models the impact of each of these sources of variability independently under the assumption of simple mathematical probability distributions (e.g. exponential). However, it was found that print shops exhibit many sources of variability simultaneously with general statistical distributions describing the variability that make them difficult to model and optimize. These commercial situations are beyond the scope of analytical models available in literature. Therefore an empirical approach was taken that relied on heuristics and multi-level optimization validated by simulations and practical implementations in print shops. Attempts were made wherever possible to leverage insights from analytical results available in literature and generalize them to printing applications. Earlier work that has provided insights into developing the practical approaches discussed in this paper to improve print production workflows include lean manufacturing (Cellular Manufacturing [6], Womack et al. [26]), general principles of factory design and operation (Hopp et al. [12], Buzacott et al. [4], Gershwin [7]), group technology for facility design problems (Heragu [10]), optimal buffer allocation to alleviate productivity shortfalls arising from the impact of random failure and repair time on systems of machines (Buzacott [3],[4], Gershwin [7], Gershwin et al. [8]), queuing network models of manufacturing and service systems (Jackson [13], Baskett et al. [2], Buzacott et al. [4]), labor allocation policies (Bartholdi [1],Buzacott [5]), scheduling methods (Pinedo [17]), real-time feedback based control policies (Gershwin [7], Gershwin[9]) and activity-based and other costing methods (Hilton et al. [11]).

This paper is an exposition of the methodology developed for improving the productivity of print shops and results of applying them to several print shops. In section 1 of this paper, the characteristics of printing environments and the workflows associated with them are described. In section 2 approaches developed to improve the productivity of these environments are indicated. In section 3 case studies and challenges in implementing the improvements are discussed. The paper concludes with a consideration of opportunities for extending this approach to other related services.

1 Print production workflow overview

The production steps associated with print production jobs are indicated in Figure 2. Print shops have departments that support individual steps of this workflow. Each department supports many different types of internal workflows. The various combinations of these diverse workflows lead to a very rich set of print production workflows.

Two types of print jobs are differentiated by the printing technology involved; offset print jobs and digital print jobs. The offset jobs utilize lithographic presses for printing whereas digital jobs utilize digital printing equipment. A brief description of these departments follows:

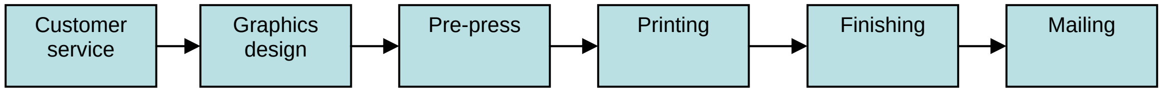

Figure 2: A print production workflow showing the various production operations

Customer service and production planning department works with the print shop 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 refers to tasks performed to design the content of the document

Pre-press functions includes tasks such as inspection of incoming print jobs, editing jobs for color quality and accuracy, creating proofs and working with 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 paper and ink, performing runtime color corrections, offloading printed material and transporting it to the finishing department. Processes used in offset printing include a variety of methods used to transfer an image from a plate, screen, or computer file to some medium, such as paper, plastics, metal, textile articles, or wood. With digital printing, the input to printers is an electronic print stream and the output printed documents. The latter is used for short-run production and when variable content is high. Digital printing technology is differentiated by low setup, simpler interfaces and smaller equipment size.

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 has the responsibility of packing and labeling the finished goods and shipping them to customers.

Offset printing is the dominant printing technology used today (US Census Dept. [27]) with more than 98% of print production revenue associated with offset and offset-like technology. However, the demand for more personalized documents, quicker turnaround time and geographically distributed printing coupled with the prospect of overall lowered setup costs associated with digital workflows has enabled the migration of offset workflows to digital workflows in the monochrome printing segment. As color digital systems with print quality equivalent to or better than offset print quality are developed at competitive costs, the same migration is expected to happen with color workflows. It is reasonable to expect that for the foreseeable future both these workflows will co-exist within the printing industry. Therefore any design and operation methodology for print production has to comprehend both these workflows independently as well as when they co-exist simultaneously.

2 Methodology for improving productivity of print production workflows

Collaborative work with print shops was initiated (Rai et al. [22],[23],[24]) to develop a methodology for analyzing and improving the productivity of print shops. The production methodology utilizes concepts of lean manufacturing combined with novel job-splitting, routing and event-driven scheduling, WIP management approaches and labor cross-training to improve the productivity of print shops. Several tools have been developed for analyzing shop performance and implementing workflow changes within print shops. A brief description of the methodology follows.

Data collection: Data collection tools are installed in the print shop to gather data associated with various production events. Historical job data if available is also gathered to determine the profile of jobs, failure/repair characteristics of equipment and other operational constraints and characteristics. Figure 3 shows a historical job datasheet and a data collection tool (using wireless PDAs) to gather event data from the print shop.

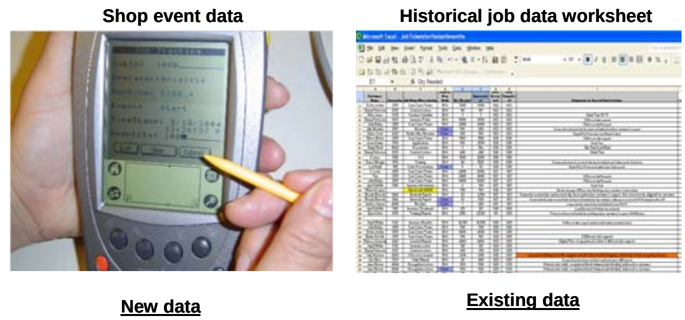

Figure 3: Data collection tools for collecting operational print shop data

Establishing baseline metrics: Print shops are often unaware about the current state of their productivity metrics. Data gathered from the print shop is analyzed to establish the baseline performance metrics such as job lateness, equipment and operator utilization, process capability, equipment processing rates, process cycle efficiency and others (Rai et al. [27]). Various statistical tools (Minitab [15]) are utilized to characterize the production metrics.

Partitioning of job mix into a few primary equivalent classes: Workflow analysis of jobs flowing through print shops often demonstrate that a high percentage of jobs have equivalent workflows such that they can be performed within the same set of processing elements. A tool has been developed for analyzing the various job types and their corresponding contribution to overall flow of work through the shop to partition the job flows into equivalent classes (Rai et al. [18]).

Takt-rate analysis and equipment grouping: The takt-rate (or demand-rate) of jobs that correspond to the primary equivalent classes is analyzed and capacity of each operation is designed to be at least equal to the maximum takt-rate (e.g. Figure 4). Equipment required for production of the primary equivalence classes of jobs is physically collocated in various cellular configurations within the shop (Rai et al. [18]). The purpose of grouping various diverse pieces of equipment in a common area is to create a production cell with required versatility that can completely and autonomously process the primary equivalence job classes. It also enables the implementation of a scheduling methodology discussed next.

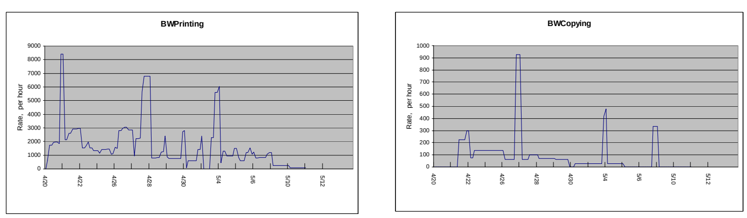

Figure 4: Demand rate for printing operations by daily rates

Scheduling architecture: A two level scheduling architecture (Rai et al. [21]) is proposed for routing and scheduling jobs within the redesigned print shop. For details the user is referred to (Rai et al. [19]). The basic structure of the scheduling policy is shown in Figure 5.

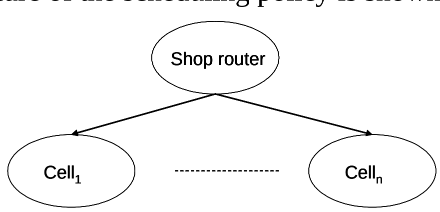

Figure 5: A two level architecture for routing and scheduling jobs in print shops

The shop router receives the jobs and determines which cells can process the job in its entirety. It allocates the job to the feasible cells while balancing the loading of the cells. The cell scheduler sequences the jobs within the queue at the cell based on their due dates and processing time requirements using one or more heuristics. It further splits the jobs into smaller efficient batches (Rai et al. [20]) so that jobs can flow faster within the cell without excessive build-up of WIP. Each cell is allocated operators who are cross-trained to perform all the operations within the cell. WIP control policies are utilized within each cell to control the release of jobs in the cell. Operators are trained to allocate their effort within each individual cell to stations to reduce inter-process buildup of WIP. Buffers are allocated between machines that are prone to failures using empirical heuristics derived from analytical results (Gershwin [7]). Jobs that cannot be processed within the cell are coordinated with other cells for production.

Workflow modeling and simulation: Discrete event simulation is performed to assess the results of improvements resulting from changes in workflow grouping, operator cross-training, grouping diverse equipment into autonomous cells and scheduling policies. Building simulation models is often a time-intensive effort especially when various scenarios have to be investigated to determine improved solutions. To facilitate the model building process, a tool was developed for semi-automatically building the simulation models from a declarative user-interface at which the user specifies the equipment characteristics, elements of the cell, scheduling policies, number of operators and their skill level (see Figure 6). This allows for fast and efficient evaluation of a large number of what-if scenarios and greatly aids in determining an improved solution out of a large search space.

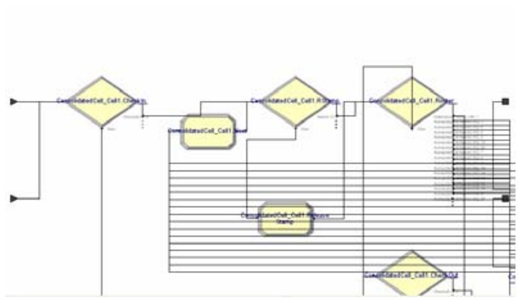

Figure 6: A discrete even-simulation model of a print shop built semi-automatically

Post-implementation tracking and monitoring: The implementation phase involves moving equipment to the new improved layout, implementing the two level scheduling policy using a scheduling tool and collecting new production statistics to determine the scope of improvement and fine tune the process. A scheduling tool provides guidance to operators in the shop for routing and sequencing jobs and performing batch-splitting. Control charts (Minitab [15]) are utilized to perform statistical process control on the new process and data. This is used to compare the new performance statistics with the baseline using techniques such as t-tests, Mann-Whitney and similar tests (Minitab [15]). Data is continually gathered and analyzed periodically (e.g. on a weekly basis) to fine-tune the process and operator training is performed to continually improve performance.

3 Results from case studies

The methodology for improving the productivity of print production environments was developed over several years by working with a wide variety of print shops. Figure 7 summarizes the improvements that resulted from implementing the changes in several different digital printing operations with print-volume ranging from 2 million images/month to over 20 million images/month. Average productivity (revenue/cost) improvements of over 40 percent were realized; labor cost was reduced by 20 percent; capacity utilization increased and average turn around time was cut by more than 50%.

Figure 7: Improvements resulting from implementation of the methodology at several print shops

Implementation of this methodology had its own set of challenges. Print shop operators were usually skeptical about opportunities for significant process improvement and believed that they were doing the best they could. Even after assessments showed potential for improvement, there was significant reluctance on part of print shop personnel to migrate to the new layout and work process. Often implementing changes entailed adding cost to operations and this proved to be a barrier in the early engagements. With considerable coaching and feedback and demonstration of results, however the transition was successfully accomplished at several locations. A key factor that contributed to the success was credibly establishing baseline metrics and then using post-implementation data monitoring to demonstrate quantitative improvements. In some cases, instituting incentives based on production throughput and quality also helped the deployment.

4 Opportunities for extensions to other document production workflows

The methodology discussed in this paper for studying print shops as manufacturing systems and improving their productivity is to our knowledge the first of its kind developed within the printing industry. The methodology is a hybrid approach of analytical and simulation based modeling coupled with practical heuristics and detailed knowledge of printing industry. Early results indicate a significant opportunity to improve the cost structure of printing and related activities and to deliver much higher levels of service than currently found within the printing industry. These techniques have also been extended to other document workflows such as office and production mailroom operations.

A domain that continues to present considerable challenge is one that involves large and complex print operations (Segment IV in Figure 1) that could potentially perform several thousand jobs per day, have several hundred employees, and process several hundred or even thousand different workflow types. The analysis requires dealing with large datasets. This fact raises issues such as scalability of optimization algorithms and impact of interacting influence of multiple sources of variability at higher utilization levels. Similar problems also arise in the analysis of distributed print operations that consists of several print shops that are non-collocated. These and related problems are subjects of ongoing and future work.

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