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Theory of Constraints scheduling:
A printing industry case study

by

Mitchell Andrew Hovland

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Industrial Engineering

Program of Study Committee:
Howard D. Meeks, Major Professor
Howard N. Shaprio
Timothy Van Voorhis

Iowa State University

Ames, Iowa

2002

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Graduate College
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This is to certify that the master's thesis of

Mitchell Andrew Hovland

has met the thesis requirements of Iowa State University

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Howard N. Shaprio
Timothy Van Voorhis

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CHAPTER 1. INTRODUCTION

This thesis seeks to do four things. First, it compares several of the more popular scheduling and mangement methods practiced today. Second, it selects the Theory of Constraints scheduling and mangement methods as being worthy of further review. Third, it applies these methods to the unique setting of the printing industry. Finally, it draws upon experiences from working with a particular printing company and formulates generic scheduling and management algorithms.

The method for studying scheduling and management draws upon material gathered for a case study on Stoyles Graphics, a comercial printer. The Total Assessment Audit project (TAA), for which the case study was commissioned, investigated methods of making operational improvements in small to medium-sized companies. Several improvement opportunities were discovered in this specific company, although; the biggest impact to this company was realized in providing a better means to schedule their jobs. The lessons learned from this project have served as the basis for investigating scheduling methods suitable for the printing industry.

During the initial audit of this company, the TAA team identified several opportunities for improvement including the following: inventory issues, excessive rework, employee training needs, production capacity, staffing, electronic data interchange opportunites, scheduling problems, and prep department resource issues. Solutions were presented to the company for each issue, although; it was discovered that the greatest impact to the company's profitability existed in implementing a better scheduling method in conjunction with the discipline to not revert back to previous practices.

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Proud (1999) generalizes several scheduling problems encountered in a variety of industries. These items can be grouped into three general categories: unplanned external events, unplanned internal events, and scheduling issues. Unplanned external events include late deliveries from suppliers, changes from customers, cancelled orders, and complaints. Unplanned internal events include disruptions on the shop floor, long queues, high work in process, and overtime. Scheduling issues include frequent changes, "hot lists", mismatched inventories, and resources not available when needed.

Using hot lists to set priorities for getting products out the door causes major disruptions and confusion in printing companies like Stoyles. Schedule changes prompted by these hot lists satisfy some short-tem requirements, but often create far more problems for other jobs. Shipment dates are often missed, customers may complain to the sales force, and sales manager tend to vent their anger onto production manager. In addition, a staggering amount of unplanned overtime and quality problems may occur. The hot lists are used because of frequent part shortages, some of which result from late deliveries from suppliers, late ordering by the company, or poor quality of materials. Other part shortages result from inaccurate bills-of-material and inventory record inaccuracies that report materials in stock when they are not.

Schedule change problems often stem from lack of a priority mechanism, or from following the wrong priorities such as keeping machines busy. It is not unusual for a company that has just purchased a new piece of expensive equipment to believe that its first priority is to keep the machine running, even if there are no customer orders that require the machine to be used. The company may assume, possibly incorrectly, that utilizing new equipment will lead to greater output. This may lead to the impression that there is much

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work-in-process, but the reality of this practice is that most of the work coming from the new equipment is stacking up in queues waiting for other operations to start.

Missed shipment dates may result from part shortages or problems with capacity. Some companies are not even sure what their capacity is nor do they have a process in place to measure it. In other companies, measuring processes may be available, but they may not be accurate. Additionally, material can sit in queues on the manufacturing floor because of the capacity issues just described, or because plant priorities and work flows are driven by an overly optimistic sales forecst that is used to communicate priorities to people on the shop floor. Still, other problems on the manufacturing floor have their source in inaccurate forecasts of demand that instruct the plant to build either too much or too little.

These complaints are roughly the same for many companies even though the environments in which they are encountered may be vastly different. The effects of any of these problems can lead to overutilized or underutilized resources, late deliveries to customers, finger-pointing, low morale, fighting over priorities, or end of the month crunch. The leverage to solve most, if not all, of these problems exists in a robust scheduling method. Plenert and Kirchmier (2000) describe an ideal schedule as one having the following traints: maximizes resouce effectiveness, decreases inventory cost, increases inventory turnover, improves customer service, improves communication and coordination, and produces a to-do list that can be followed.

Stoyles was operating with the mentality that no new customer orders were to be refused and that all orders would all be delivered on time. The reality was that they, like many other printers, faced many of the problems just described. Their scheduling system was more directed by the "importance" of each customer and which orders were the most

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delinquint. To solve their problems, nothing short of a simple, systematic scheduling method would work, and become an ongoing practice that the company would continue to use.

In exploring systematic methods for improving this company's scheduling practices, Theory of Constraints (TOC), Just-In-Time (JIT), and versions of Material Requirements Planning (MRP) were considered as potential solutions. The overall management philosophy of TOC was deemed to be of the greatest benefit for a company looking for improvements to its bottom line. In particular, the Theory of Constraints provides two distinct, but similar methods for scheduling projects and production that held the most promise for the printing industry. These in conjunction with simple management descipline provided a powerful tool for operational improvement at Stoyles.

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CHAPTER 2. LITERATURE REVIEW

A review of studies and concepts in the areas of scheduling and management served as the framework for this study. First, a brief history of production and project scheduling is presented. Second, the Theory of Constraints is presented with a focus on two of its main scheduling applications, production and project management. Third, several of the Theory of Constraints techniques are compared to other methods of management and control.

Fleming, Bronn and Humphreys (1987) present a concise history of production scheduling. Prior to World War I, a scheduling methodology wasn't known or at least wasn't widely acknowledged. Henry L. Gantt was one of the first pioneers in the field. While working at the Frankford Arsenal in 1917 he conceived of a project management technique that has survived today under his name, the Gantt chart.

As pressure on time performance was relaxed, the search for and introduction of new and improved scheduling methods had slowed. The concept of Operations Research was being developed near the end of the 1920s; the name itself was apparently coined early in World War II. Operations Researchers felt that the lack of dependency relationships being displayed on Gantt Charts was a severe shortcoming. They started to focus their attention on such dependency, or logic, relationships and began work in the field of networks.

Before World War II, production scheduling was primarily performed using Economic Order Quantity (EOQ) and Linear Programming (LP) techniques. The work of Ford W. Harris on setting manufacturing lot sizes, around 1913, led to the EOQ model (Hopp and Spearman, 1996). The environment pictured for the EOQ model was one of a factory producing various products, in which changing between the products would entail a costly

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setup. The dilemma underlying this method was a trade-off between producing large batches with low setup cost and small batches with low inventory cost. An optimization among these variables would reveal the quantity a factory should produce to achieve the lowest unit cost.

The United States and several European countries began using Material Requirements Planning (MRP) shortly after the World War II when labor was in short supply. This system ensured that the right materials were in the right place at the right time, so as to maximize labor efficiency. Similarly, Just-In-Time (JIT) principles were developed in Japan where labor was abundant but material resources were scarce. JIT focuses on reducing inventory levels close to zero, among other things. The Theory of Constraints (TOC) was formulated in Israel where the scarce resource was capital equipment, around the same time as the other two methods. This movement initially focused on making bottleneck equipment perform as efficiently as possible to maximize output (Plenert and Kirchmier, 2000).

MRP evolved into Manufacturing Resources Planning (MRP II), a system that integrated the manufacturing and financial management elements of an organization. Enterprise Resource Planning (ERP) then became the next stage of the MRP evolution with the integration of engineering, vendor, and distribution information into the planning process. According to Goldratt (1990), scheduling was one of the main reasons for the development of MRP. By 1989, sales of MRP software and implementation support exceeded one billion dollars and today this figure continues to rise (Hopp and Spearman, 1996).

Hutchins (1999) explains that the prime goal of JIT is the achievement of a zero inventory level, not just within the confines of a single organization, but ultimately throughout the entire supply chain. To achieve even partial success, it is necessary to think far beyond the scope of inventory control and look to virtually all aspects of operations

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management. It took Toyota Motor Company over 25 years of constant attention to implement improvements that reduced setups from three hours to three minutes. As such, JIT is not an easily achieved objective, but an ongoing improvement philosophy.

Formal project scheduling began when the Program Evaluation and Review Technique (PERT) was first introduced by the United States Navy in 1958. It was a networking method developed by the consulting firm of Booz, Allen and Hamilton for use on the Fleet ballistic missile program, more commonly known as the Polaris Missile. PERT was intended primarily for use as a statistical tool to help determine whether the missile would become operational within the needed time frame. Due to this success, others felt that PERT could be used as a management tool for controlling projects.

PERT places great emphasis on estimating the probability of completing tasks. Three time estimates are required for each task in a network: "the most likely", "optimistic", and "pessimistic" values. The effort required to determine these estimates is often time consuming. In light of this drawback, PERT primarily became a method used for scheduling and tracking specialized projects, such as shipbuilding.

PERT is better suited to long-term projects rather than in a manufacturing context, where time and resources may be limited. Some manufacturers have attempted to apply PERT techniques, but have met with varied success due to the amount of maintenance and updating required of these systems. The technique never caught on in industry, but the opposite happened among academicians. Many books were devoted to the study of PERT.

The Critical Path Method (CPM) was initiated by the E.I. du Pont de Nemours Company about the same time as PERT, in 1957. CPM is also known as the Arrow Diagram Method (ADM). In this method, a network of arrows represents activities and the circles at

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each end represent events. There were important differences in methodology between PERT and CPM when they were first introduced. These differences quickly disappeared with the almost complete amalgamation of both techniques into a single method containing most of the features of CPM, but nonetheless often referred to today as PERT.

Theory of Constraints consists of many applications that span areas such as production, distribution, marketing and sales, and project management. Several TOC concepts developed into an overall management philosophy applicable from the top to bottom of an organization (Goldratt, 1990). A key TOC development is its structured problem solving method that provides management with the appropriate decision making tools. TOC describes the primary goal of for-profit companies as making money, both in the present and in the future. Progress toward this goal is measured by a new set of TOC defined operational measurements, namely Throughput, Inventory, and Operating Expense.

Dr. Eliyahu Goldratt developed TOC and authored much of its literature. In his book, The Goal (1986), Goldratt created a fictional story that revolves around the life of a plant manager. The book has become widely read in business and management circles. In it, he uses a "business novel" approach to convey his ideas on production and operations management. The concept of Drum-Buffer-Rope, developed in this book, focuses on identifying and exploiting constraint resources.

In the book, Critical Chain (1997), Goldratt introduces his ideas on project management. In it, he describes that uncertainties are the main cause for delays in projects, and that proper management of strategically placed buffers is necessary to avoid these delays. Project progress is assessed by managing tasks on the critical chain. The critical chain is longest path of dependent tasks. Where the critical chain differs from the more traditional

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critical path method is that it assigns buffers in specific locations, rather than within each task, to protect the project schedule. The critical chain method also recognizes that there are a finite number of resources associated with a project, in contrast to PERT which doesn't address resource contention (conflicting task times).

Smith (1994) explains some of the differences and similarities among TOC, JIT and MRP. The selective buffering of TOC contrasts with JIT, which places inventory in Kanbans throughout the plant, and MRP, which places inventory throughout the plant by launching orders in excess of the capacity of the constraint resources. In the Kanban system, each shipment of parts used in making a product comes with a "kanban" or sign. When the stock parts reach a predetermined level, the sign is sent to suppliers, who deliver new ones to the assembly line. JIT seeks setup improvements at every work center, whereas TOC only seeks setup improvement at the capacity constrained resource. TOC is actually less sensitive to changes in the production plan than JIT, which is inherently inflexible and requires an absolutely steady rate and mix of production virtually minute by minute.

MRP is a system designed to push material through the factory. TOC can be viewed as a pull system upstream from the capacity constrained resource and a push system downstream from the constraint. In reality, TOC is never exactly a push system, due to the fact that only necessary work is being performed when available; i.e., no work is performed just to keep resources busy. In a TOC system, if the market becomes the constraint, the whole factory behaves like a pull system, which is exactly how JIT systems operate. MRP requires accurate data globally, whereas TOC requires accuracy only at points feeding the constraint resource. MRP also assumes that setup, move, and processing times are discrete.

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Patterson (1992) compared TOC and labor-based accounting methods when it comes to product mix decisions. The contribution of the Patterson article is that it shows the sub-optimal solution that even Linear Programming would provide when the problem is formulated in terms of traditional labor-based management. Goldratt used a similar example in The Haystack Syndrome (1990). Luebbe and Finch (1992) also compare TOC and Linear Programming. They arrive at the conclusion that TOC is no worse than Linear Programming when it comes to the ability to reach optimal solutions. This is true only as long as the Linear Programming problems are formulated according to TOC concepts, such as Throughput Accounting, in which case they will provide the same answer. Linear Programming is only a mathematical tool and further comparing these two on an equal scale is not appropriate.

Spencer (1994) provided one of the most important articles as to the validity of TOC from a theoretical perspective. This article conducts an analysis of cost accounting and TOC based on fundamental economics. It finds that cost accounting always provides a decision based on the average cost whereas the TOC decision is based on marginal cost. The article goes on to show how marginal cost measurements is a more appropriate measure for decision-making.

One of the recent developments in cost accounting is the concept of Activity Based Costing (ABC). This method is considered by many to be the answer to the problems associated with traditional cost accounting. Low (1992) has a detailed study on traditional cost accounting, ABC, and TOC. He uses specific examples to illustrate how TOC can provide better solutions than ABC and traditional cost accounting. The conclusion of the study was that the traditional methods of cost accounting and ABC concentrate on cost reduction, which has a lower bound, rather than on the throughput maximization focus of

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TOC, which has no upper bound. The ABC method was also identified as very complex and time consuming as compared to the other two methods.

An earlier article by Gardiner and Blackstone (1991) can also be used to illustrate this point. They compare the solutions of a make-or-buy decision by using both traditional cost averaging and TOC approaches. The traditional techniques use the average cost for the part as decision criterion, whereas TOC focuses on the improvement in throughput and the use of constraint resources and also provides a clearly better solution. This is the fundamental reason why TOC helps an organization better improve its performance.

The focus of these studies has revolved around the comparison of Theory of Constraints methods to other common, well accepted scheduling and management philosophies and practices. The difference amongst the various practices were described, and it appears that while any of them may enjoy success in specific cases, the methods of the Theory of Constraints, when followed correctly, hold the most promise for the printing company detailed in this study.

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CHAPTER 3. THEORY

Scheduling and management of production and projects are vitally important to the success of companies in multi-job environments. When done correctly, the company makes effective use of its resources and may then use this scheduling success as a springboard for further improvement. This chapter describes the Theory of Constraints methods for production and project scheduling and management. The similarities between production and project scheduling are discussed. Finally, a synthesis of these methods is presented as a set of generic scheduling and management algorithms. It it believed that these new algorithms will benefit companys in a multi-job, mixed project and production environment.

Schragenheim (1998) presents three basic assumptions that are key to the understanding of the Theory of Constraints philosophy. First, an organization has a goal to achieve. Second, an organization is more that the sum of its parts. Third, the performance of an organization is constrained by very few variables. The primary goal that TOC identifies for any for-profit organization is making more money now as well as in the future.

All companies have some constraint(s) that determines the rate at which work can be completed. A constraint in the production environment is the capacity constrained resource. When dealing with projects the constraint is the longest chain of dependent events, the critical chain. In either case, constraints limit the performance of the company.
Goldratt (1990) describes five focusing steps that can assist companies in ongoing improvement. These five steps serve as the underlying methodology behind both the production and project management TOC applications. The first step is to *identify* the system's constraint. For production, this means finding the bottleneck resource, which is

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running at capacity. In the project environment, the equivalent is to determine the critical chain of tasks. The second step is to *exploit* the system's constraint. This involves scheduling around the constraint (production) or tasks on the critical chain tasks (projects). The third step is to *subordinate* all other non-constraint tasks. To do so, a buffer is used to ensure the constraint or critical chain tasks are neither inactive nor waiting for work from a previous task. The fourth step is to *elevate* the system's constraint. The project or plant can add more resources to increase the production capacity or speed project completion. The final step is to *go back* to the first step if the constraint/critical chain task has changed and to continue to seek improvement for the company.

Measurements

Measurements are indicators of the progress a company is making toward its chosen goal. Theory of Constraints has developed a set of measurements aimed at leading an organization towards globally optimal behavior in its everyday operations. These measurements are Throughput, Inventory, and Operating Expense. To reflect a company's goal of making more money, progress can be shown by any of the following: an increase in throughput, a decrease in inventory, or a decrease in operating expense. The highest amount of leverage, though, exists in increasing the company's throughput.

Throughput (TP) is defined as the rate at which an organization generates revenue. The TOC community generally recognizes throughput as the total sales minus total variable costs associated with each sale over any given period of time. Total variable costs include such items as material cost, commissions, custom duties, and transportation costs. Unlike cost accounting, TOC does not treat labor as a variable cost unless it is based on per unit compensation. Throughput is described mathematically in the following equation

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$$TP = \Sigma \text{ Sales} - \Sigma \text{ Total Variable Costs} \tag{3.1}$$

A company will invest in Inventory and spend on Operating Expense in order to create Throughput. *Inventory* (I) is defined as all the money a company invests in purchasing things that it intends to sell. This includes raw materials, equipment, and building costs. The difference between the TOC and cost accounting definitions of inventory is that TOC assigns finished goods inventory the price of materials and purchased parts that went into the product. There is no value added to the product until it is sold. *Operating Expense* (OE) is defined as the money that the company spends in turning its inventory into throughput. This not only includes direct labor, but also all other expenses like salary paid for engineers, supervisors, secretaries, or salespersons.

None of the above measurements are entirely new. They are familiar to those practicing conventional cost accounting. In combination, they can be used to describe some of the intuitive monetary measurements: Net Profit (NP), Return on Investment (ROI), and Cash Flow. In terms of the TOC measurements, net profit and return on investment are, respectively

$$NP = \Sigma \text{ TP} - \Sigma \text{ OE} \tag{3.2}$$

$$ROI = (\Sigma \text{ TP} - \Sigma \text{ OE})/I \tag{3.3}$$

Product choices based on potential throughput can help a company to determine which option will add the most value to the bottom line. Theoretically, there is no limit to

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throughput, and Throughput can be increased as long as companies can find ways to increase it. Eventually, any company will reach a point where the market becomes their constraint, and then this must be elevated before there can be any further increase in throughput.

Scheduling

The Theory of Constraints has two solutions tailored for common problems that many companies face in scheduling and management of their projects and production systems. Both methods can assist a company to increase its throughput. These methods share the concepts of constraints and buffers. Where they differ is the amount of certainty with which each task's duration can be predicted. Production task times are usually easier to estimate accurately than project tasks times. A production task may be repeated many times and have a well observed process time, while a project task is likely to be an estimate based only on another similar project's task times.

The time to complete each task is represented by a probability distribution regardless of whether it is a production or project step. The generic distribution (Figure 3.1) is characterized as skewed to one direction with a tail that approaches zero probability with increasing time. A typical project task will generally have a long tail to its distribution. A production task will generally have a distribution that is more "pinched", in that the majority of its distribution density will be closer to its average value. Knowing the actual probability distribution of each task is of little importance for the reason that each task has a distribution independent of the others. This means that each task may either be early, on time, or late, but knowing the behavior of one task does not provide any information in regard to the behavior of the other tasks.

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All tasks take some minimum, such as the "Earliest Completion" in Figure 3.1. This is the result of humans and/or machines performing under optimum conditions. Delays, breakdowns, rework, etc. may lengthen the completion time of any task. The probability of completing a task increases as time allocated for that task increases past this minimum amount of time. The task has a median (approximately average) value, of which there is a fifty-percent chance of on time completion. There is also a value at which the task would present an acceptable risk of being completed on time. The "Low Risk Completion" is shown in Figure 3.1. Often this value has a certain measure of "safety" built into it to ensure that the task is not late.

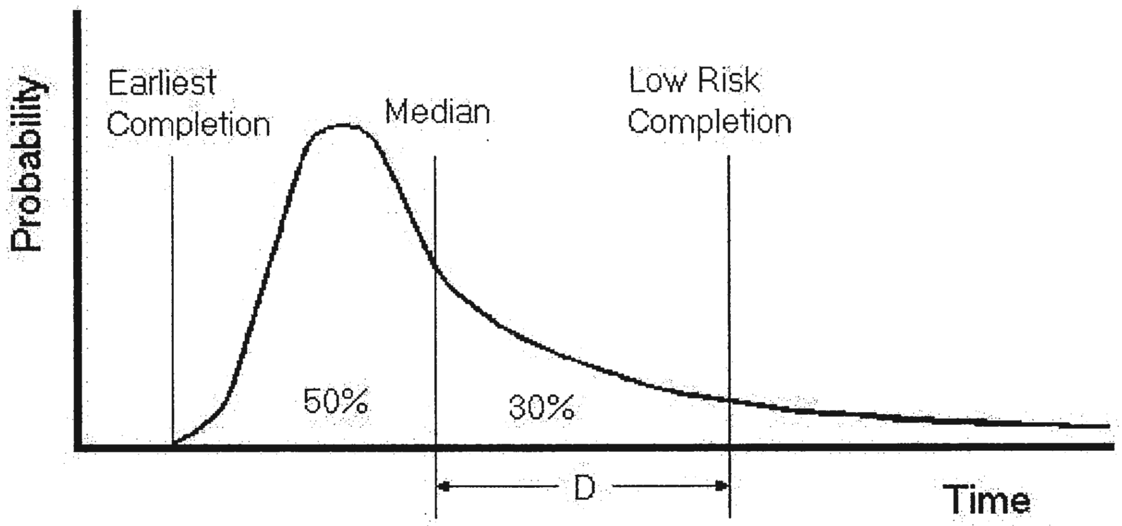

Figure 3.1. A distribution function for a generic task.

Each task has a scheduled start time. If a task is completed early, it is assumed to wait until just before the scheduled start time of the next operation. On the other hand, when a task is late, it will make the start date of the next task late as well. Late completion of each

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task accumulates and the entire project's lateness is compounded. Therefore, the probability of completing the entire job on time is the product of the probabilities of completing each individual task on time; this is shown in Equation (3.4). For a simple job of ten tasks, with each task time estimated at eighty percent probability of on-time completion, the product of the probabilities of all ten tasks yields a probability of ontime completion for the project of approximately eleven percent.

$$P\ [\text{on time}] = P\ [\text{task }1] * P\ [\text{task }2] * \ldots * P\ [\text{task }(n-1)] * P\ [\text{task }n] \qquad (3.4)$$

Instead of estimating each task based on a "Low Risk" of not being completed on time, the TOC Critical Chain Project Management application proposes taking the individual "safety" factors out of each task and aggregating them into a single buffer to protect the entire job. If each task had a known standard deviation, then the standard deviation for the entire job could be calculated as the square root of the sum of the squares of the individual tasks' standard deviations, as follows

$$S[\text{sum}] = \sqrt{S_1^2 + S_2^2 + \ldots + S_{n-1}^2 + S_n^2} \qquad (3.5)$$

In place of the standard deviation for the distribution there is an independent variable *D*, which is the difference between the "Low Risk Completion" value and the median. The value of *D* is a proxy for the amount of "safety" normally added to task duration to ensure its on time completion. TOC proposes that the amount *D* be removed from each task time estimate and aggregated into a collective buffer to protect a group of tasks. The size of the

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job buffer, Equation (3.6), is calculated in a similar manner to the way the standard deviation is calculated.

$$\text{Buffer Size} \cong \sqrt{D_1^2 + D_2^2 + \ldots + D_{n-1}^2 + D_n^2} \qquad (3.6)$$

Given that each task's "Low Risk" value has a probability *P* of on time completion, then a buffer sized according to Equation (3.6) would cause the project to be completed on time with a probability greater than *P*. This can be proven through the Central Limit Theorem (Devore, 1991). Also, when the "safety" *D* from each task is removed and aggregated into a buffer for the entire job, the overall job duration is measurably shorter. Without formal proof, this result is

$$\sqrt{D_1^2 + D_2^2 + \ldots + D_{n-1}^2 + D_n^2} < D_1 + D_2 + \ldots + D_{n-1} + D_n \text{ for all positive D} \qquad (3.7)$$

The implication of these statements is that a job with all the safety placed in a single buffer to protect many tasks will likely be completed in a shorter period of time with a higher probability of on time completion than if each task has its own measure of safety built it.

Project Scheduling

Theory of Constraint scheduling comes closest to the critical path method in approach, but adds several features to produce a more robust scheduling method. The critical path is the longest chain of tasks, such that no task has any slack in its start time. Two assumptions inherent in the critical path method are that there is an unlimited amount of resources that can work on tasks simultaneously, and that any delay on the critical path tasks

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will delay the entire project. As a protection mechanism, a certain amount of safety is normally added to each task. Figure 3.2 is an example of a project network.

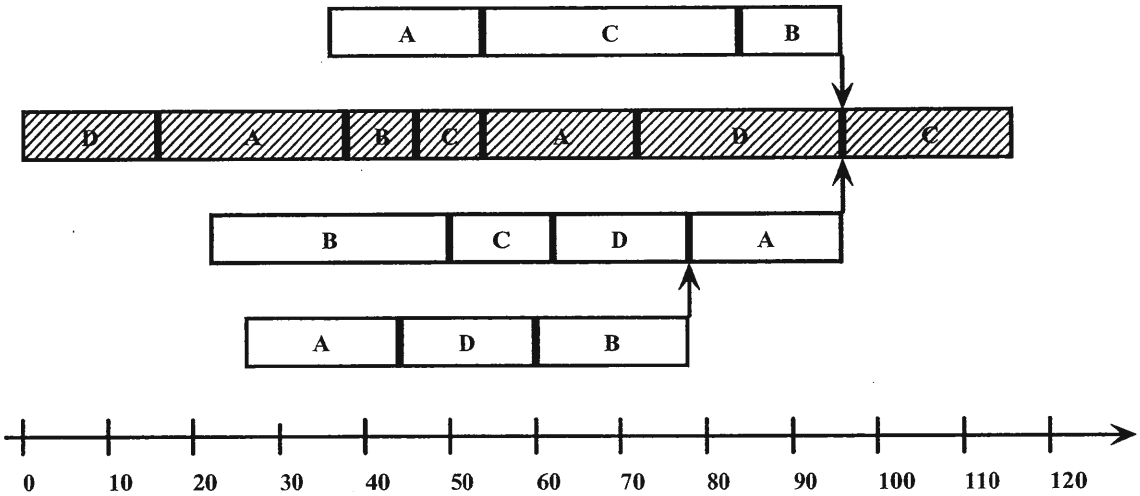

Figure 3.2. The critical path of a project.

The critical path is represented by the shaded tasks in Figure 3.2. Each block represents a task. Within each block is a letter (A through D) representing the resource working on the task at that particular moment. The task duration is measured against a scale at the bottom of the figure, representing units of time. The critical path method assumes that there are multiple resources available to work on different tasks at the same time; for example, resource A is working on two different tasks at time 30. The critical path is the shaded blocks in the figure with a total length of 116 time units.

In the case where there are a strictly limited number of resources available, execution of the critical path method would present a different result. If the available resources were to execute the schedule in Figure 3.2, they would need to switch between tasks in order to work

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on both at the same time. This leads to multi-tasking, which may actually lengthen a project beyond what was initially planned. The effects of multi-tasking are illustrated in Figure 3.3. The top row represents what would happen if one resource worked on three tasks, one after the other, without interruption. The bottom row shows what would occur if the same resource switched back and forth between the three tasks. It would take twice as long to complete each task if the resource multi-tasked. It can also be noted that the total time it takes to complete all three tasks is also longer due to the time it would take that resource to put down one project and take up the next.

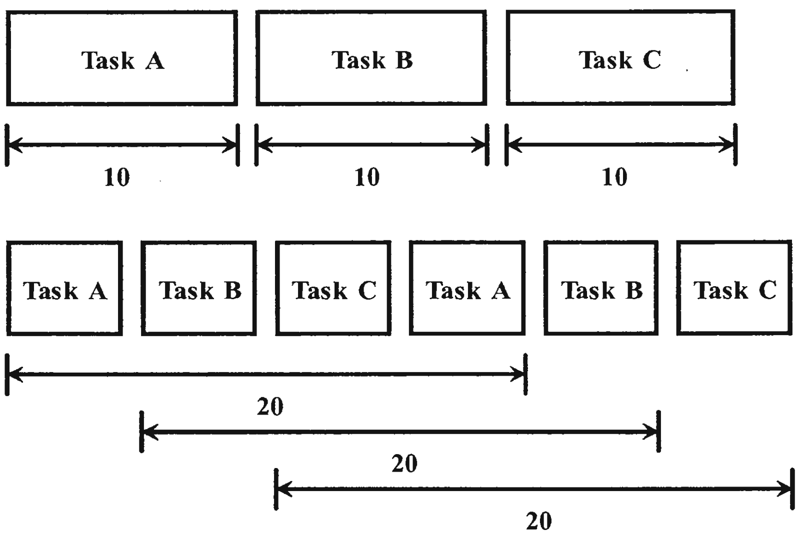

Figure 3.3. Multi-tasking on three different tasks.

The TOC Critical Chain project management application solves many of the problems associated with the critical path method. As a starting point, the critical chain is similar to critical path, but critical chain assumes there are limted resources available, whereas critical path assumes that there may be unlimted resources. The first step in project

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scheduling with the critical chain is to ensure that no resources are working on more than one project at a time. Starting from the critical path in Figure 3.2, each task is adjusted to an earlier start time to avoid resource contention; that is, where multiple tasks require the same resource at the same time. Then all tasks are moved to the latest start date without causing a conflict for a resource's time.

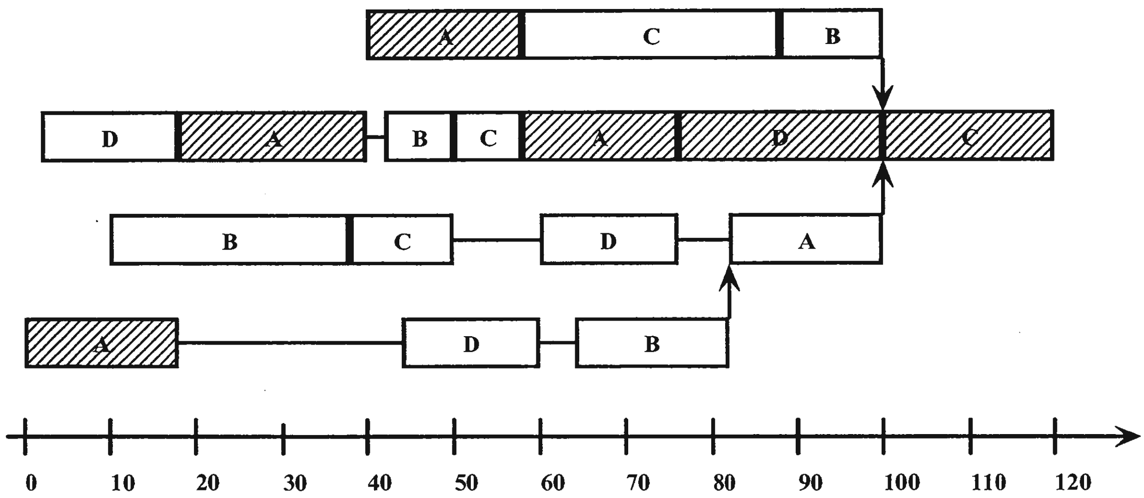

Figure 3.4. Eliminating resource contention.

The same nomenclature is used in Figure 3.4, as in Figures 3.2 and 3.3; boxes represent tasks, and letters A through D represent resources. The critical chain is the sequence of resources A-A-A-A-D-C. Due to the adjustments made to the task start times, the duration of the project in this example is 120 time units; this is longer than the critical path method example of 116 time units. Once contention between tasks for the same resources is eliminated, the next step of the critical chain method is to protect the tasks on the critical chain from a delay in start time by using strategically placed buffers.

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The amount of safety initially placed in each task of the critical chain is stripped and collected into a Project Buffer (PB). Each task now has duration of approximately fifty percent probability of on time completion. The project buffer is inserted between the end of the critical chain and project due date. To further protect the critical chain, another type of buffer, the Feeding Buffer (FB) is inserted where other non-critical chain tasks join into the critical chain. The feeding buffer protects the critical chain from delays occurring in non-critical chain tasks. However, if problems cause a delay bigger than the feeding buffer can accommodate, the project completion date is still protected by the project buffer.

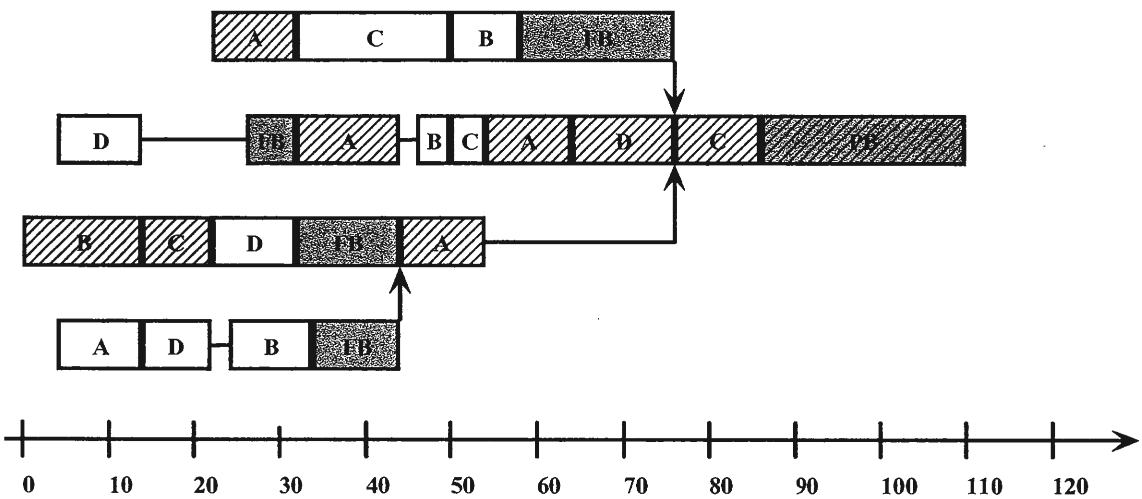

Figure 3.5. The Critical Chain with Safety Removed and Buffers Added.

The total length of the critical chain with the buffers added is often shorter than the length of the critical path method (Figure 3.5). The critical chain in this example follows the sequence B-C-A-A-A-A-D-C. The project has a planned duration of 110 time units. The project may even have a shorter duration if the entire project buffer is not used. To ensure

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that the buffers are used effectively and the project is completed on time or even ahead of schedule, a good buffer management method is needed. This will be described later, but first the TOC production scheduling method is presented.

Production Scheduling

Theory of Constraints production scheduling beings by finding the system's constraint. The constraint may either be internal or external to the plant. An external, or market driven, constraint requires another type of solution and will not be covered here. An example of an internal constraint is presented in Figure 3.6 with five tasks (A through E) and their associated production rates. Here it is obvious that Task C, with an output of eight pieces per hour, is the constraint. All tasks downstream from the constraint can only produce parts at a rate equal to that of the constraint. This means that tasks D and E can only work at a rate of eight pieces per hour even though they can produce more.

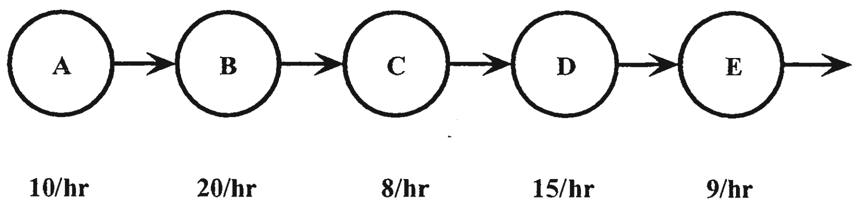

Figure 3.6. Production rates for five tasks.

After identifying the constraint, the system's capacity must be exploited. A decision must be made in advance as to the best way to use the constraint's scarce capacity. The constraint resource must have an uninterrupted supply of materials to work on with

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scheduled maintenance interruptions as the only acceptable pause. A schedule of tasks is arranged so that there will always be work waiting in line to be processed.

Since the constraint is being utilized to its full capacity, all other tasks must now feed it a steady supply of work. All other non-constraint resources simply perform work when it comes to them, as quickly as possible, and then pass the work along to the next operation when finished. Temporary bottlenecks may occur elsewhere in the system. If this occurs at a task before the constraint, then the jobs should be prioritized in order of shortest time until their scheduled time at the constraint. For tasks after the constraint, jobs should be prioritized in order of nearest ship date.

Properly choosing when materials are released can ensure that work arrives at the constraint when it is needed. To accomplish this, there must be a release schedule that is tied to the constraint resource schedule. Figure 3.7 shows the time buffer between material release and processing at the constraint resource. Although this "buffer" is a period of time, an actual physical buffer of material may develop just in front of the constraint resource.

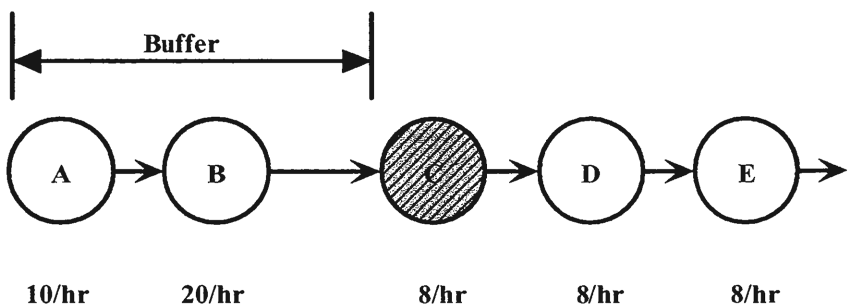

Figure 3.7. Added buffer to protect the constraint resource.

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TOC production scheduling is based on the Drum-Buffer-Rope concept. The Drum is schedule of jobs at the constraint resource. The Buffer is time between the release of materials and the constraint resource's start time. The Rope is the method of releasing work to production exactly when it is needed. All three elements help to effectively schedule production in any plant.

Assembly operations are treated like any other operation with one addition. Figure 3.8 shows the constraint task *C* and a non-constraint task *D* being assembled at task *E*. The constraint controls the rate at which materials leave the assembly task (8 per hour). Materials are released to task *A* in time to support the consumption of the constraint. Materials for task *D*, on the other hand, can be released at any time as long as they are available at assembly at a greater or equal rate than the constraint.

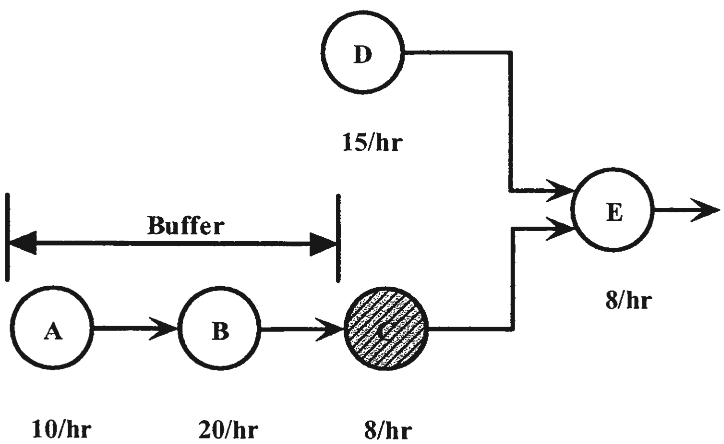

Figure 3.8. Using a buffer to protect assembly operations.

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Buffer Management

To benefit from either of the scheduling methods, a management plan must be enacted to prevent breakdowns or delays from creating chaos in the plant or for the project. The buffers created to compensate for unexpected delays can be used as a management tool by creating a decision point for a specified amount of progress into the buffer. Buffer Management applies to both production and projects. Its major benefit is that it requires the scheduling manager to focus only on the most import aspect of the schedule, the constraint. This focus reduces the stress of becoming bogged down in the details of every job.

For each task the constraint resource performs, there is a buffer in place to ensure all other operations have work available for the constraint when it needs it. The buffer can be divided into three zones. These represent when the manager should: only watch the progress of other tasks (Zone III), formulate a plan to expedite the other tasks if needed (Zone II), and finally take action to expedite the other tasks (Zone I). The buffer manager has the ultimate responsibility for ensuring that the constraint resource is never idled due to other non-constraint tasks. Figure 3.9 shows the three buffer zones. In this example, the constraint is well into Zone II.

The buffer manager watches the position of the buffer zones relative to schedule for each constraint resource. Figure 3.10 illustrates the schedule of work for the constraint (resource C) where the numbers 1,2,3, etc. are the order in which the tasks will be completed. Task C4 and C5 should not draw any of the manger's attention yet. Task C3 is in Zone II where the manager should be planning to take action if look like work will not arrive at the constraint at the right time. Task C2 is in Zone I and requires the manager to find a way to expedite the work if it is not on schedule. Task C1 should be in progress at this time after

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receiving a clean hand-off from the previous task. If Task C1 hadn't started, then all other jobs going through Resource C would be late.

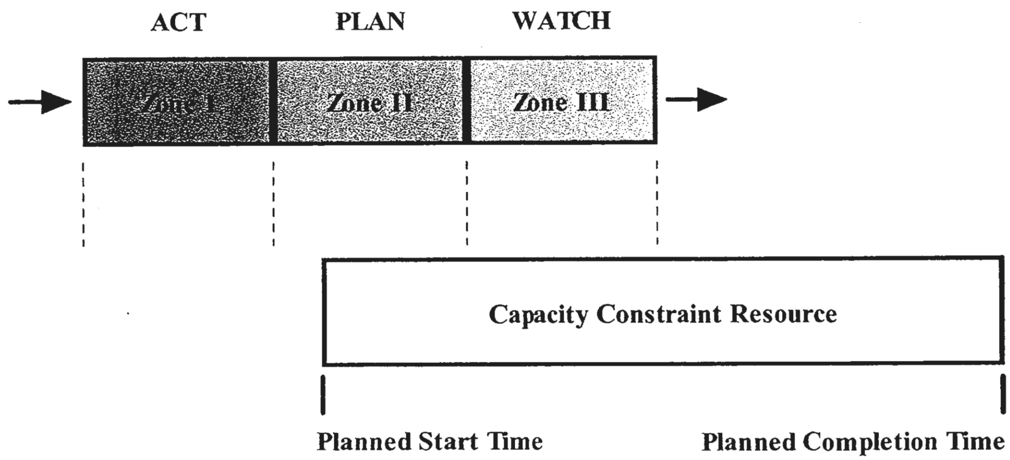

Figure 3.9. Buffer management.

The size for each buffer zone and of the overall buffer is subjective. The buffer manager may start out with three equally sized zones. After some experience, the manager may discover that the size of any of the zones might need to be adjusted, smaller or larger, depending on when they need to receive notification of a possible problem. The overall buffer size might also expand or shrink based on how early or late the jobs are being completed. If the jobs never reach into Zone I, then they have buffers that are too large. On the other hand, if the jobs encounter Zone I frequently (more than 5% to 10% of the jobs), then the buffer may be too small. Experience and common sense will serve as the best guidelines for effective buffer management. The important lesson for the manager is to adjust the buffers dynamically before problems arise.

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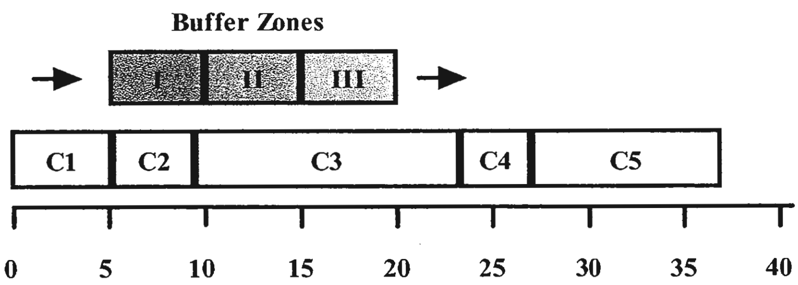

Figure 3.10. Using buffer management.

Generic Scheduling and Mangement Algorithms

The Theory of Constraints scheduling and management methods have been presented up to this point. The following two tables represent a synthesis of the these methods. The Generic Algorithms distill the Theory of Constraints methods in a series of steps that a company could follow to develop their own scheduling system. Table 3.1 presents a series of questions and ideas a company should focus on when they are developing a new scheduling system. Likewise, Table 3.2 presents a series of action the company should take to manage their scheduling system.

Table 3.1. Generic Scheduling Algorithm.

1. IDENTIFY the system's constraint(s)
    a. Is a certain resource utilized more than the others?
    b. Does inventory pile up in front of a certain work center?
    c. Does a certain task get expedited more than the others?
    d. Is there a chain of tasks that determine the project duration?
    e. Does a certain task seem favorable as the system constraint?

2. Decide how to EXPLOIT the system's constraint(s)
    a. Decide the schedule for the capacity constraint resource (Drum)
    b. Create a release schedule that allows for downtime (Buffer)
    c. Tie the release of material to the processing rate of the constraint (Rope)

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3. SUBORDINATE everything else to the above decision
    a. Non-constraint (non-critical chain) tasks
        1. Work on what ever is needed first
        2. Start work as soon as it arrives
        3. Complete work as quickly as possible
        4. Pass work along to the next task
        5. Perform no additional work until it is needed by the constraint
    b. Constraint (critical chain) tasks
        1. Complete work in the order designated on the schedule
        2. Let the next task know the expected completion time

Table 3.2. Generic Management Algorithm.

1. Monitor the progress made into the buffers protecting each constraint.
    a. Zone III - WATCH
    b. Zone II - PLAN
    c. Zone I – ACT

2. Check the status of each task feeding the constraint.
    a. Inform the constraint when work will be available so it is ready
    b. Expedite any breakdowns or delays

3. Assess the buffer sizes
    a. Often in Zone I = Too large
    b. Infrequently in Zone I = Too small
    c. Dynamically change buffer sizes before problems arise

This proceeding algorithms were developed through a combination of research and industrial application. The next chapter persents a specific example from a company in the printing industry. While the company focused on improving its profitability, a large part of their success was based on developing and using a better scheduling method than was previously available to them.

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CHAPTER 4. PRINTING INDUSTRY EXAMPLE

The printing industry exists in a world of stiff competition, demanding customers, and slim profit margins. Small printers, especially, face a variety of challenges in what is considered a low-growth industry. These printers have difficulty finding qualified workers and lately have faced rising costs. Competition due to low-cost, high-speed copiers, laser printers, and color copiers has made in-office printing a viable alternative for low-quality, low-quantity, printing needs.

In order to maintain a competitive edge, many companies instruct their sales representatives to take every order they can get without any consideration of their ability to deliver when promised. Printers who operate without checking into their capabilities often unknowingly create chaos for their entire job schedule, thereby jeopardizing their ability to deliver any lobs as promised. The main reason print buyers leave one printer and seek out another is because of late deliveries (Merit, 1992). The lack of a robust mechanism for scheduling and control of orders ultimately causes companies to lose control of the ability to deliver product on time.

This section details the results of a multi-year effort to create change at a small, family-owned commercial printer, Stoyles Graphics. A Total Assessment Audit (TAA) was used to assess the state of the company and assemble a team of service providers to develop and implement a comprehensive improvement plan to improve profitability, increase efficiency, and reduce waste. The TAA team worked closely with company management to accomplish the company's goals. A key item in the company's plan was to develop a scheduling system capable of delivering better on-time performance.

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A main focus of the TAA process at Stoyles Graphics involved locating constraints in the company's processes and developing methods to increase production. To accomplish this, a team-based approach was used to design and implement a strategy of continuous improvement. A system to actively manage the constraints that limited throughput was also developed. These comprehensive modifications to methods and management practices led to a number of positive changes.

What was the company like?

With a staff of 50 employees, Stoyles operates like many small printers. A sales staff sells directly to customers throughout the Midwest and works with a group of distributors across the nation. Customer service representatives assist the sales staff and act as an interface between clients and the company. A pre-press, or "prep", department creates new electronic artwork and/or amends existing customer files to prepare a job for plating. The plates are used on the one, two, and four-color presses to print jobs. The completed printed materials are collated, folded, stapled, bound, or glued then packaged and shipped.

The company directly serves clients in Iowa and Southern Minnesota and uses a network of distributors to sell printed material nationwide. It has a varied product mix of magazines, books, brochures, newsletters, and custom forms. The company has a long-held interest in customer satisfaction and a reputation for doing high quality work. Providing this level of customer satisfaction has become increasingly difficult for them to maintain as they face shrinking lead times from competitors and lower profit margins.

A preliminary assessment of the company showed that they were maintaining marginal profitability on a yearly basis, with sales and costs fluctuating greatly from month to month. Many jobs were completed late, over 25 percent, and customer service

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representatives regularly asked various departments to expedite jobs for particular customers. The schedule of work in the prep, press, or bindery areas was determined by which jobs were most critical in terms of promised delivery date to the customer. These practices led to a highly stressful environment, where employees were frustrated because they were often pushed to expedite jobs that already arrived late.

Company management was very receptive to the idea of working to find ways to improve their business practices. They were open to allowing consultants look at their operations and provide recommendations that the company could implement. Their enthusiasm for assistance was evident in their desire to understand their market and use this knowledge to increase efficiency, reduce overtime and spoilage, and meet their ultimate goal of increasing sales and improving profitability.

Even with the desire to make improvements to build for the future, the company management was forced to place most of their day-to-day attention on immediate issues. This made it difficult for them to find enough time to devote to future endeavors. They never seemed to have enough hours in the day to focus on improvement. Company management saw the potential for what their company could become and were aware of some of the steps that they would need to take to achieve their goals.

The company faced many obstacles to completing orders in a timely manner. Customers held proofs too long to meet the scheduled press dates, or files arrived in formats that could not be used by the presses, requiring extra iterations on proofs. Due dates approached and sometimes slipped or were changed. Prep employees worked on many projects simultaneously and frequently jumped between different tasks. The pressroom could be swamped on any given day due to unforeseen problems upstream. Bindery personnel

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faced pressure to get things out and overtime was often the rule rather than the exception due to the changing status of jobs and deadlines.

Despite having a production schedule and daily meetings, an unexceptable percentage of their jobs were still being expedited. Customer changes resulted in “hot” jobs taking precedence over others that would be completed late. The plant bottleneck might occur one day in the pre-press department, and a day later it may move to the press department. Temporary workers might be hired to expedite product through the bindery. Stress level among Stoyles employees always seemed to increase as jobs pushed past their due dates. This was particularly evident near the end of the month when jobs needed to be shipped out for billing purposes.

Stoyles needed a new approach to achieve another level of sales and profitability. Company management worked closely with the TAA team to create a plan that outlined the improvement steps the company needed to take. Their roadmap developed in the form of a network diagram that allowed everyone to see how each step related to the next. Solutions to each of the problems were identified and implemented in a logical order. Because of this the company grew confident in what they were doing and developed a process for continuous improvement.

Analysis of the most common problems faced by Stoyles indicated that opportunity existed in the method which the company was scheduling their jobs. By using a robust scheduling method the company could improve delivery rates and minimize late returns from customers, rush jobs, and extra overtime. To simultaneously impact many of the problems and provide the opportunity to later increase throughput and profit, the groundwork had to be laid with a good scheduling system.

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Scheduling A Diverse Mix of Jobs

Maintaining an accurate schedule is particularly difficult for printers because of the large variety of jobs, wide range in quality of incoming electronic files, and fast turn-around times expected of them. Some of their jobs may require three or four iterations with their customers before the jobs are ready for printing. There are always jobs that have to be rushed through the system. Printers need to develop and follow a scheduling method that can handle the diverse range of task times that various job types present. Careful control of the scheduling method is especially important when there are a large mix of products that take varied lengths of time to complete.

Printers must focus on reducing variation of job task times, while also actively managing their interactions with customers. Like most printers, Stoyles' customers are the primary source of variation in the amount of time it takes to complete print jobs. Customers held proofs for unrealistically long times and regularly changed due dates. To account for variation in the customer's proofing step, a buffer was added to the estimated time for each job. This buffer is assigned to each job based on previous experience with the client. The buffer allows a specific job to be late without affecting the due dates of other jobs.

Stoyles new scheduling method focused on assisting the department limiting the company's production. Production could not increase until more orders flowed through the prep department, regardless of the speed of the presses. The presses at Stoyles are efficient and fast; however, they can't produce work until they receive it from the prep department. If there's a constraint in the prep area then presses may sit idle. Therefore, it is imperative to schedule jobs through the prep department in a manner that maximizes their output.

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Stoyles determined that they would develop and use scheduling boards to communicate all of the current incoming jobs to their employees. This information was posted in two main areas. First, the prep area had a schedule board that lists the jobs for the current day and next six days. The board consisted of a series of cards representing each job. The cards listed vital job information, including the date that each job was due to start the next operation. Stoyles found that job information could be accessed quickly and each prep member would know exactly what, and in what order, they were expected to work on jobs.

An important component of this scheduling method was that prep members were given a press due date rather than a ship date. Previously, orders tended to be late because the prep department used the ship date as its deadline, which did not allow enough time for the press and bindery to complete their work. The due date that they now follow virtually guarantees that if the press receives a job on time, the order will be completed on time. If a job can't be completed on time by prep, overtime hours are authorized or a new due date is set so that the prep department is not overloaded.

The press area also has a scheduling board to coordinate its activities. Press workers use their board to know what jobs to expect next. The person in charge of scheduling builds in another buffer between the press and ship dates. This shipping buffer allows for any unexpected delays in the press and bindery departments. Since the press and bindery areas at Stoyles have excess capacity, it is important that they work on the jobs in the order in which they come in. This may mean an extra number of setups and the perception of reduced press efficiency, but they are now supporting prep to make the entire company more effective and profitable.

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At Stoyles, the person in charge of scheduling is the vital link between the prep and press schedules. This person gives each new job an appropriate start date and coordinates changes made to the schedule. Each department now knows what to expect and trusts other departments to deliver their work to the next operation on time. The schedule board is the primary means of communication among all departments in the company. What can and cannot be sold and when products can be delivered depends on maintenance of the schedule. Determining the status of the jobs, the ability to handle rush jobs, and the need for overtime are all decisions that are based on the active upkeep of the schedule.

With the constraint located and the scheduling method in place, management decided where it wanted the constraint to be. Since work flowed through the press and bindery more like a traditional manufacturing operation, Stoyles decided to hold the constraint in its present location, the prep department. This strategic decision had a significant impact on the way they would conduct their business in the future.

A Schedule Trial Run

Stoyles selected ten jobs of various types to serve as a trial run for its new scheduling system. These first jobs were all due in about a month. All other existing and future jobs were flushed from the system, with extra overtime, so that the first ten jobs to be scheduled did not have to compete for resources or management attention. Each of the ten jobs were estimated with realistic task times. Buffers were then added to protect the press and ship dates. Each job was placed into the schedule according to availability of the constraint resource. Stoyles found this to be their design resources. Since they only had two designers available at any given time, each job must find an opening on the schedule in which a design resource could work on it.

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A generic flow for a printing job, with buffers added to it, is used for this example (Figure 4.1). Customer orders are first designed and prepared by the prep department. This department works on the pre-press steps, which include design work, customer approval, plate making, and stripping of negatives needed for the press. The second half of a print job consists of printing, and sometimes collating, stapling, and/or binding. After binding, the order is complete and can be shipped to the customer. A job may also include such additional steps as typesetting, proofreading, and/or folding, which are not depicted below.

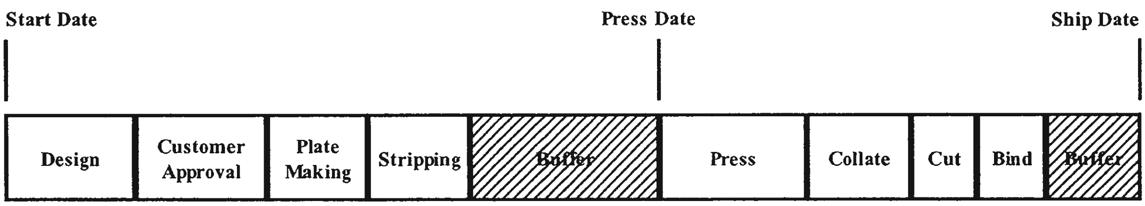

Figure 4.1. A Generic Printing Job with Buffers Added.

Jobs are scheduled according to the availability of the design resources, so that they are always kept busy, but are never overloaded with too much work. In this way, the constraint resource is working efficiently and allowing jobs to proceed to the next task in an orderly manner. All other non-constraint tasks, which have excess capacity, do not need to be scheduled. Stoyles chose to keep a press schedule as a means for communicating upcoming jobs to its operators, to allow them to prepare by setting the presses for specific jobs and to determine if there could be any efficiency in grouping jobs. Practically, these resources performed work as soon as it arrives, on a first-come first-served basis. Based on previous experience, Stoyles estimated times for each task of their first ten jobs (Table 4.1).

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Table 4.1. Estimated Task Times (Days) and Due Dates.

	Job 1	Job 2	Job 3	Job 4	Job 5	Job 6	Job 7	Job 8	Job 9	Job 10
Design	3	4	3	2	2	4	3	2	4	2
Customer	5	7	4	3	4	6	5	3	7	4
Plate	1	2	1	1	1	2	1	1	2	1
Stripping	1	1	1	1	1	1	1	1	1	1
Press	3	5	2	1	1	3	3	2	4	2
Collate	2	2	1	1	1	2	2	1	2	1
Cut	1	1	1	1	1	1	1	1	1	1
Bind	2	2	1	1	1	2	2	1	2	1
Ship Date	Mar 11	Mar 12	Mar 12	Mar 13	Mar 13	Mar 13	Mar 14	Mar 15	Mar 16	Mar 16

With a complete understanding of their first jobs, buffers were established to protect the press and ship dates of each job. The buffers ensure that a late task will not endanger the entire job. If one or more tasks are late, the buffer is in place to protect the due date from slipping under normal circumstances. If something unexpected happened, then steps were taken to expedite the order, such as overtime or hand-delivery to their customers. If a task was completed early, then the job was passed on to the next operation. The next operation will immediately begin working on this job. Adopting such a dispatch method instead of

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scheduling every non-constraint task allows the job to gain the benefit of early task completion, while protecting the job against delays in particular tasks.

Stoyles adopted a rule of thumb for assigning its initial buffer size as equal to one half of the total processing times of the tasks that the buffer protects. This is a general guideline, and they determined that it may be adjusted later on. They developed two buffers; in this case, their "Project Buffer" protects all of the pre-press tasks, and their "Production Buffer" serves to prevent any problems arising from delaying the ship date. Each of the buffers is inserted into each job as if it were a task; the "Project Buffer" came after all the design tasks, and the "Production Buffer" was added on after the final assembly step. The buffer sizes are depicted in Table 4.2.

Table 4.2. Buffer Sizes (Days).

	Job 1	Job 2	Job 3	Job 4	Job 5	Job 6	Job 7	Job 8	Job 9	Job 10
Project Buffer	5	7	4	4	4	7	5	4	7	4
Production Buffer	4	5	3	2	2	4	4	3	4	3

After the constraint has been identified and the buffers assigned, their first ten jobs were scheduled into the plant. Stoyles used the following methodology. The job with the ship date closest to the present time was placed onto the schedule. Its start date was determined by moving the job back in time by the entire length of individual tasks plus the buffers. This continued for each job until all start dates are known.

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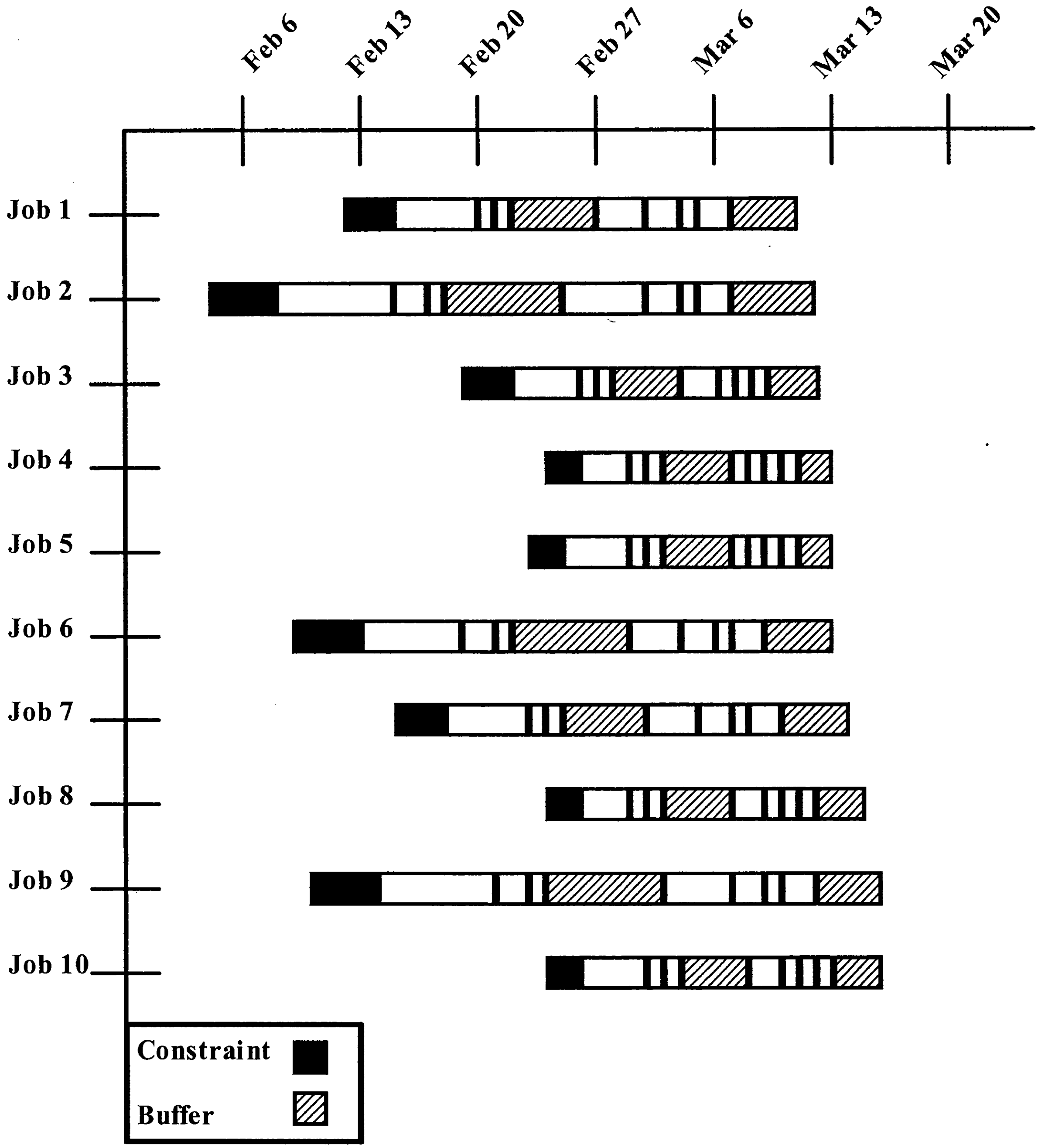

Figure 4.2. Placing jobs on the schedule according to their ship date.

With a schedule in hand, Stoyles noticed that their design resources were overloaded. To resolve these resource utilization problems, they decided to move some of the jobs back to start at an earlier date. It should be noted that these jobs should not be scheduled to start later or else they may not meet their due dates. Of the many possible solutions, they selected to start Job 5 three days earlier, Job 10 two days earlier, and Job 6 one day earlier. This new configuration (Figure 4.2) provided a final schedule with no conflicts. Other solutions are possible and equally valid, but there is nothing to be gained from trying to "optimize" the schedule. All that is needed is a workable schedule.

In the final schedule, the constraint task is never allocated to more than two jobs at once to prevent to prevent overloading. For the other non-constraint tasks, work will be performed as it arrives, and then passed on to the next task as soon as it is completed. Increasing utilization of non-constraint resources pushes more jobs into the system than there are orders to fill. This causes excess WIP and may cause other resources to become temporary constraints. When this occurs, expediting will be significantly increased, resulting in late shipment of orders.

Stoyles successfully scheduled its first ten orders. When new orders are proposed, the scheduling manager will need to integrate them into the existing schedule of jobs. The new orders are now estimated like the initial ten jobs. Each order is placed onto the schedule based on its ship date. Next, the orders are checked to determine if their constraint, the design task, has enough resources available to perform the work. If the design task has the available resources then the job can be accepted and placed in the schedule.

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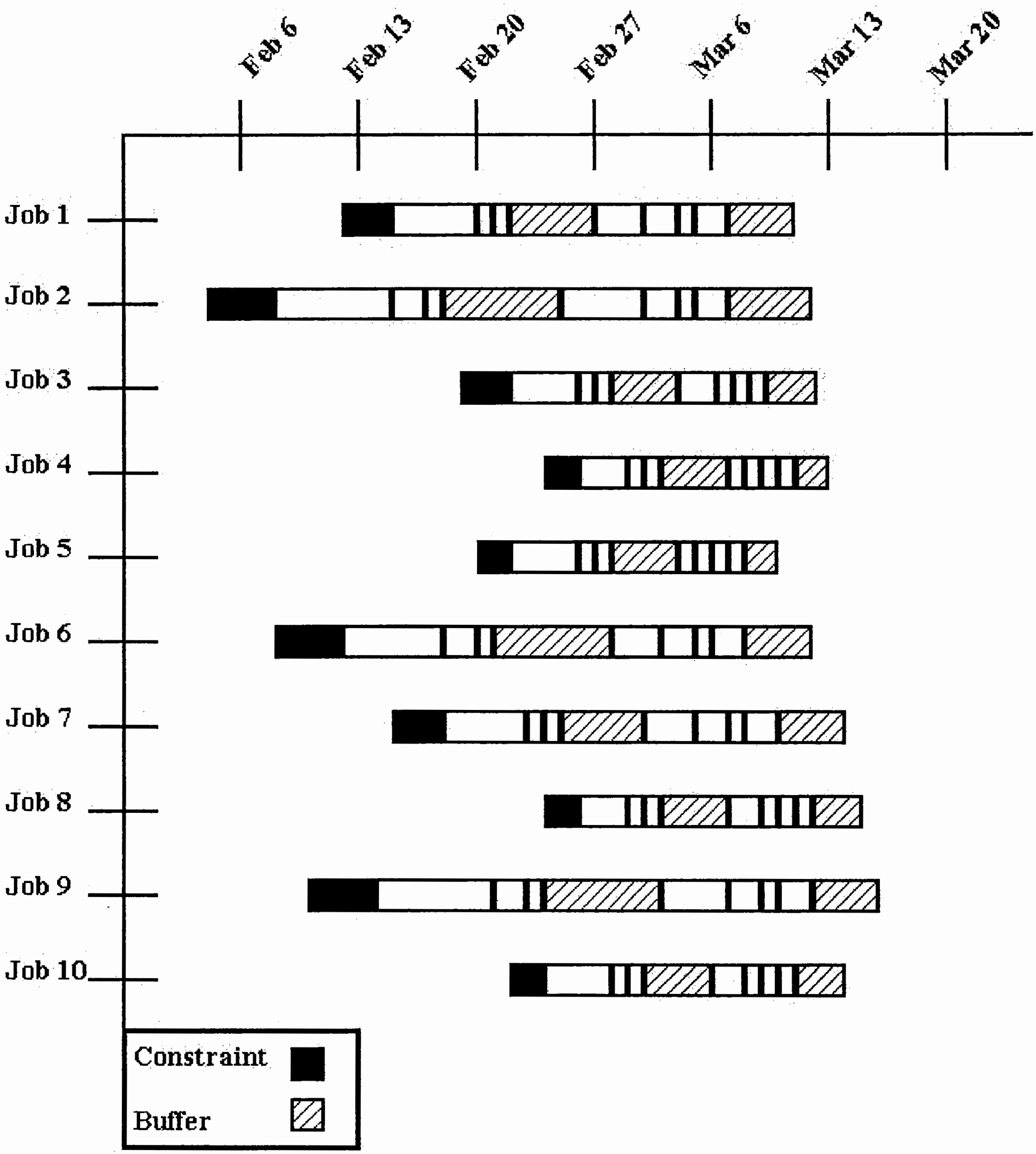

Figure 4.3. The final schedule with no resource contention.

If the design task does not have enough resources, then each particular job needs to be moved to a time slot where there are design resources available. If sufficient constraint resources are not available, so that the order can't be completed by the ship date, then the order should either be turned down or proposed to be delivered to the customer at a later date. It is better, in the long run, for the company to turn down an order instead of dealing with the customer service issues of having multiple late orders. This may be a difficult policy decision for mangers to make, particularly in the face of likely opposition from individual customer service representatives who worry that they would be jeopardizing their relationship with their particular customers.

To demonstrate a robust scheduling system, Stoyles takes two new orders shortly after the initial schedule is implemented (Table 4.3). No changes are made to the jobs already scheduled. The scheduling manager simply follows the rules. New jobs to be added to the schedule must first be checked for available time on the constraint resources. If there are available design resources, then the job would be placed into the schedule such that the job length determines its start date. If there is no available time, either the job would not be accepted, or else it would have to be scheduled to start at another time. Scheduling new orders is not a difficult procedure, since the constraint determines when and where a new job can fit into the schedule.

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Table 4.3. New Customer Orders.

	Job 11	Job 12
Design	4	5
Customer	6	7
Plate	3	3
Stripping	1	1
Press	3	6
Collate	2	2
Cut	1	2
Bind	2	2
Ship Date	Mar 13	Mar 17

With the two new jobs integrated into the schedule (Figure 4.4), Stoyles was on its way to gaining control over its ability to ship to its customers on time. After the successful test run, the company needed to enact policies that would allow the new scheduling system to flourish. The small sample of jobs was only a fraction of what they would face on a daily basis, and the temptation to resort to old, comfortable methods would certainly rise in the face of the first crisis.

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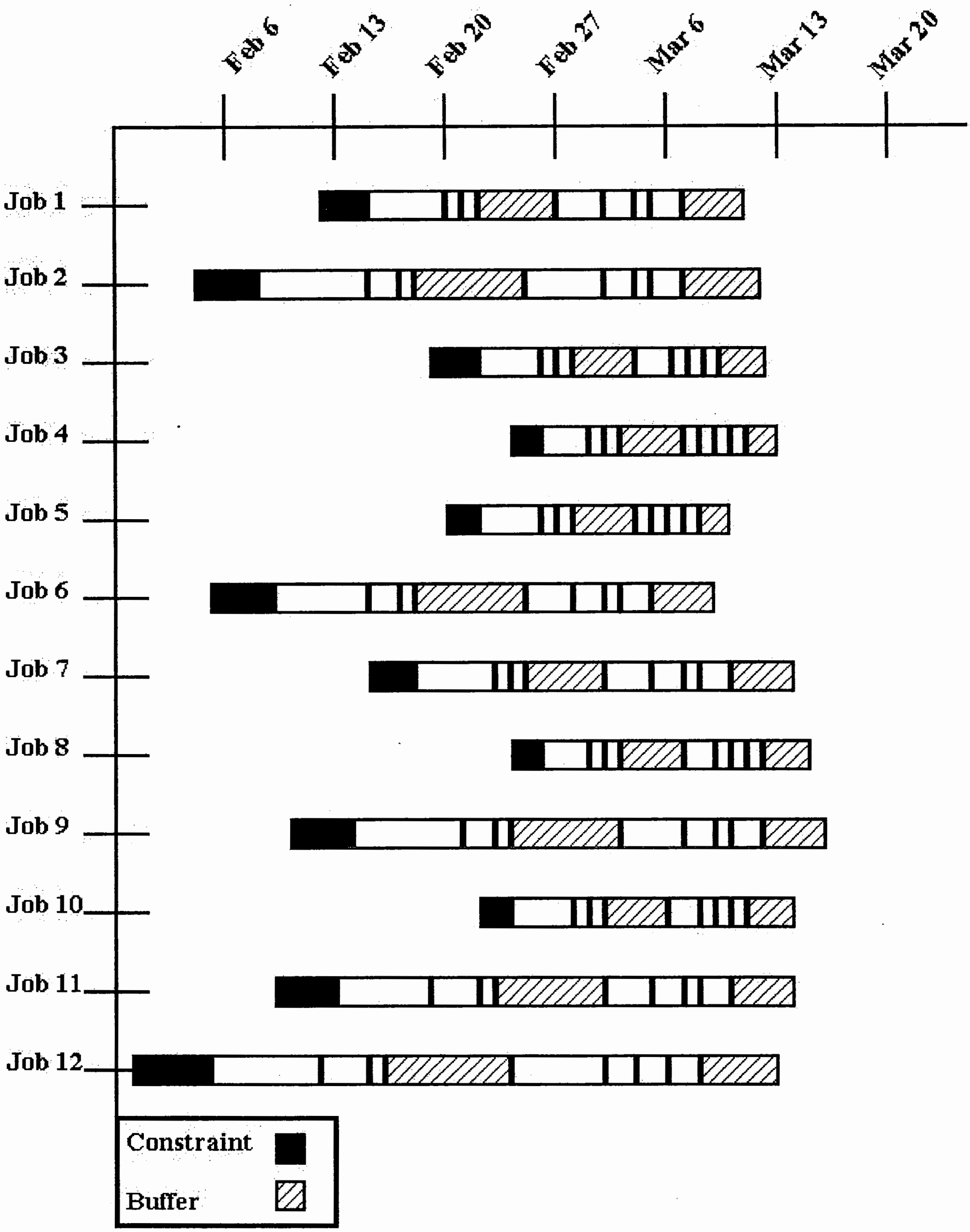

Figure 4.4. Schedule with New Orders Added.

Scheduling is Only The First Step

A good method of scheduling jobs is a solid start, but that alone cannot fully impact a company. There are likely to be some obstacles to implementing this scheduling system. Stoyles needed to make someone responsible for scheduling decisions. Employees also had to learn that the constraint task, in their case the prep work, sets the pace for the rest of the plant and that other areas will not always be busy. Finally, they had to agree that the method would be given a chance to succeed by not allowing anyone to change the way jobs were scheduled and flowed through the plant for a set period of time.

Many issues at Stoyles impacted the success of a new scheduling system. Dealing with them in an appropriate order aided Stoyles in achieving their goal of increased revenue. The company developed a roadmap of steps they would need to take to achieve that goal. This roadmap allowed Stoyles to gain the maximum amount of company-wide improvement by focusing on only the items that would directly benefit their revenue at any given moment.

Rework caused in the prep area limited their throughput for the entire plant. A spoilage team addressed a variety of rework issues to minimize this waste. Changes were also made to proofing procedures, and the job ticket folder was redesigned to improve prep productivity. These improvements helped the prep department get more work out of their area and into press.

Correcting customers' files caused significant delays in the prep department at Stoyles. Errors included missing fonts, color errors, and wrong file format of scans. To address this issue, Stoyles formed a pre-flighting team that provided numerous suggestions to improve operations. Further improvements in prep were made possible by limiting multi-tasking; that is switching between jobs before finishing tasks, which results in a substantial

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amount of lost time. At Stoyles, this occurred when schedules were constantly changed to satisfy internal and client demands. With the new scheduling method, Stoyles' prep employees could concentrate on one job until it was either completed or sent to the customer for proofing before moving on to the next job.

Other functions of the company directly impact the success of the schedule. To prevent confusion, there must be one person in charge of adding jobs and making schedule changes. The person in charge must process every change or addition. In this way, there is never the possibility of overloading the schedule or forcing jobs to be arbitrarily bumped due to a "hot" order. If properly managed, the schedule can greatly minimize the customer service issues.

The customer service representatives have a very important responsibility in maintaining the schedule. It is their job to make sure that customers return their proofs in time for the prep department to meet the press due date. The scheduling system includes a mechanism that reminds customer service representatives to contact the customer two to three days before a job is scheduled to go to press. By managing the customer, better relationships based on performance and trust will develop. The value of winning a customer's confidence is almost immeasurable.

After company-wide change, there is often a tendency to revert to past methods when the system is strained. It is necessary to have a strong manager in place to control the constraint management process. This person must have company-wide perspective and authority, and must track and maintain the amount of expediting that occurs. Too little expediting suggests that the company is overstaffed or the buffer sizes are too large. Too

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much expediting implies that the jobs are not being scheduled correctly, company procedures are inefficient, and/or customers do not understand the critical nature of deadlines.

Each of the items needed to make the scheduling method successful is part of a larger roadmap to company success. The schedule, in turn, is an important step on the road to increasing the sales of the company. As the scheduling method is allowed to work, on-time delivery will improve, confusion in the plant will decrease, and most importantly, a true reading of the plant capacity can be judged.

Increasing the Ability to Sell More Products

One of the most effective means of increasing plant production is to increase the productivity of the constraint task. It was noted at this particular printing company that their most important resources were routinely performing tasks that could easily be completed by others with more free time. Stoyles' pre-press department was thoroughly examined to find methods and procedures within the department to improve productivity. In instances where there was a shortage of equipment, it was suggested that personnel shifts and/or lunches and breaks be staggered to provide extra capacity. Once the constraint has become more efficient and the remainder of the plant has changed procedures to support the constraint, it is necessary to find other ways to increase throughput. Often, this can be achieved by adding machinery or people.

Stoyles was able to increase prep capacity by reducing the amount of time prep personnel spent stripping negatives. By purchasing and using an image setter, prep employees were free to assist in other areas of prep. Stoyles also hired a college student to assist in prep during summer months, a time when many regular employees take vacations.

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Increasing throughput is only beneficial to a company when the increased capacity is followed by an increase in sales. Stoyles recognized that they would have extra printing capacity after an effect scheduling method was in place. A marketing program was their next step to making the company more profitable. Stoyles took this next step by working with a consultant to develop a marketing plan. With the confidence that the scheduling system provides improved throughput and better on-time delivery, they had the opportunity to market these new found abilities to customers. The ability to consistently deliver on time is very desirable to many customers and was used by the company as a strategic advantage over competitors offering longer lead times and lower on-time delivery rates.

Extra press capacity also provides an opportunity to increase sales. Jobs that do not require prep work can be directly begin work at their first step on the presses when one of the presses has time available for the job. Stoyles has a very large web press department that requires very little prep work. Web press and repeat-orders are good examples of jobs that can be used to increase sales without increasing capacity. All such jobs contribute directly to the bottom line profits.

Continuous Improvement

Stoyles found ways to produce and sell more goods in an effort to build upon improvements they have already achieved. To the company, other issues that didn't increase production were secondary but not unimportant. There are many ways to reduce costs that can be pursued in parallel with improvements made to production. Stoyles is working on scheduling and marketing to put them in a position to sell more products. At the same time, they are also looking at several cost-reduction issues to improve their bottom-line profits; among them are lighting, electricity, and waste. When looking for additional capacity in the

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plant, a company should again locate the constraint and find ways to raise its output. This may mean adding resources or equipment, or it may simply mean a change in procedure, such as overlapping shifts or working extended hours.

Once the first-pass of improvement has been completed, it is necessary to begin the process anew to further increase throughput. Significant company-wide change may cause the constraint to move. If the constraint remains fixed, it may be necessary to add additional resources to non-constraint departments as well. Stoyles was able to add capacity to the press department by purchasing a new four-color press. The four-color press also expanded Stoyles' product line, and provided better quality on multi-color jobs. Additional bindery capacity was also created with the purchase of a cutter and folder. For Stoyles, the greater capacity of the press and bindery departments prevented the constraint from shifting from the prep department into these areas.

Where are they going?

The future for printers is likely to remain very competitive. Printing industry outlooks suggest that sales growth rates among printers may slow and paper prices may rise over the next few years. Partnering with customers to reduce turn-around time, cutting costs, and technological advances will continue. There is likely to be growth in several alternatives to printing, most notably through the Internet. Printing habits are likely to change as well. Personalized short-run jobs will impact traditional methods, as flexibility and quick delivery will be important. With low unemployment expected to continue, printers are faced with a variety of challenges.

Stoyles will continue to focus their attention on sales growth and customer retention. Creating strong and lasting relationships with customers is critical to their success. Stoyles

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will proceed with implementing their new scheduling method. They are determined to commit to the changes and see the fruits of their work by reducing expediting and late orders. To fully implement the schedule, they have an employee ready to assume the scheduling duties and continue the training of their employees. These efforts will play into their ongoing marketing activities. Stoyles will continue to monitor their improvements, with sound measures of what is important to their business, and proceed to use these measures for future decision-making. Stoyles will move forward with several changes and continuously seek to improve their business.

Final Comment

This case study demonstrates the value that a holistic approach has on improving manufacturing operations. Stoyles has embarked on an ambitious plan to meet and exceed customer expectations through improved productivity and better management practices. In particular they have built upon their success using Theory of Constraints scheduling methods. It is hoped that this specific industry example can serve as a model for other companies who also seek company-wide improvement.

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CHAPTER 5. CONCLUSION

Total Assessment Audit (TAA) activities occurred over a three-year period at Stoyles Graphics, a medium-sized commercial printer in the Midwest. During this time, a team of public and private sector organizations completed a company-wide assessment audit, assisted the company in developing a roadmap to increase productivity and profitability, and suported the company as it implemented its own plan of improvement. The team initially identified four areas of focus: energy, waste, productivity, and marketing issues. As the project developed, the main focus shifted to their scheduling practices.

Printing companies, like Stoyles, perfom project work in that each order is essentially unique. The types of orders taken by a printing company cover a wide range of items that include books, promotional pieces, magazines, leaflets, etc. Their orders may require original design work, minor changes to existing work, or repeat orders that require no modification. Although each job may have unique design work, it is the printing and assembly tasks of their jobs that share a common process that is almost identical. These aspects behave much like production tasks. Essentially, a print job has elements of both production and projects embedded into it.

From several scheduling methods, the Theory of Constraints was selected as the most appropriate for the needs of this company. TOC concepts for project and then production scheduling were described, then presented along with mangement techniques. Stoyles used these methods as the basis for their new scheduling system. First, ten jobs were scheduled effectively and then two new jobs were added before this new practice was accepted as a

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success. Results seen by this new system include increased on time delivery, shorter job length, and increased capacity. The later of which the company used to increase revenues.

Work with the Theory of Constraints methods via Stoyles Graphics yielded a set of generic scheduling and management algorithms. They comprise a series of steps and questions that need to be completed in order to effectively schedule and manage multiple jobs. To create a schedule, first the system constraint is identified. Second, buffers are placed between the constraint and the non-constraint tasks. Third, only the constraint tasks are scheduled, with all the other non-constraint tasks performing work as it arrives. Finally, new orders are added to the schedule in places where the constraint task has available resources. To mange this schedule, first it is important to watch the progress made into the buffers. Second, non-constraint tasks should never be allowed to impact the schedule of the constraints tasks. Finally, the size of the buffers should continually be monitored and adjusted to ensure that problems do not arise and job length is kept to the minimum.

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