Prioritization and Integration of Lean Initiatives with Theory of Constraints

by

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Bachelor of Science in Mechanical Engineering, Iowa State University, 1998

Submitted to the Department of Mechanical Engineering and the Sloan School of Management in Partial Fulfillment of the Requirements for the Degrees of

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Abstract

The principles of lean manufacturing have taken hold in a number of manufacturing firms as a means of achieving operational excellence through continuous improvement. Womack and Jones have suggested a generalized process for lean transformation in their 1996 book, Lean Thinking. A key element of this process is the creation of value stream maps for each product line. Value stream maps are the basis for planning and tracking a firm's lean transformation. Rother and Shook go further in their 1998 work Learning to See as they describe how these maps are created and then integrated into both the transformation process and the regular business planning cycle. The authors note that difficult questions remain, including: "In what order should we implement?" and "Where do we start?" Advice offered by Rother and Shook is helpful but insufficient given the complexity of many business environments and the scarcity of resources in competitive industries.

This thesis builds upon Rother and Shook's work in proposing a framework for prioritizing lean initiatives. Specifically, Theory of Constraints (TOC) tools are employed as a basis for selecting programs and projects that provide the greatest system-wide productivity improvement for the least cost. In this manner, application of the proposed prioritization framework results in a more effective and efficient lean transformation. Research at the Eastman Kodak Company illustrates how this framework can be applied in a paper finishing production facility. Results highlight the system constraint in the paper slitting operation and the high leverage of machine changeover time in productivity improvement. We conclude that the Theory of Constraints can provide an effective focusing tool for the lean enterprise.

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Table of Contents

Chapter 1: Introduction

1.1 Problem Description

The principles of lean manufacturing have taken hold in a number of manufacturing firms as a means of achieving operational excellence through continuous improvement. Womack and Jones have suggested a generalized process for lean transformation in their 1996 book, Lean Thinking. A key element of this process is the creation of value stream maps for each product line. Value stream maps form the basis for planning and tracking the lean transformation. Rother and Shook go further in their 1998 work Learning to See as they describe how these maps are created and then integrated into both the transformation process and the regular business planning cycle. Their advice can be summarized as follows:

1. Define value from the customer's perspective
2. Document current state value stream
3. Document future state value stream
4. Plan for the transition (create an annual value stream plan)
5. Implement the improvement initiatives

The authors note that difficult questions remain, including: "In what order should we implement?" and "Where do we start?" Advice offered by Rother and Shook is helpful but insufficient given the complexity of many business environments and the scarcity of resources in competitive industries. We wish to select projects and allocate resources so as to achieve the future state value stream at the least cost and in the shortest time. Hence, our primary objective is both to formalize and improve the firm's prioritization process for lean initiatives.

It is worthwhile to note that this problem is not unique to lean circles. Hayes, Wheelwright, and Clark [1998] liken capital allocation without coherent philosophy and process to "a stalagmite: shapeless, inefficient, and of little usefulness." David Garvin notes in the

California Management Review [1993], "Short-term improvement programs sometimes lack clear direction because there are few criteria for choosing among projects." Integration of corporate strategy with these tactical, short-term improvement projects receives attention in literature on productivity improvement (e.g. lean, Six Sigma, and Theory of Constraints), corporate planning and resource allocation.

Rother and Shook propose starting with a value stream loop that is well understood, where success is likely, and where the return is largest. This advice is sensible, but not sufficient for most practitioners. Solutions are rarely obvious, as risk and return can be difficult to quantify in complex and uncertain environments. Likely problems associated with this approach include:

- Prioritization of incremental improvements at the expense of breakthrough change
- Illogical sequencing of projects
- Sub-optimizing the firm objective by focusing on local optima
- Misallocation of resources for projects which don't support the firm's strategy

Our objective is further complicated by the need to incorporate operational improvement projects into the regular budgeting and planning cycle. That is, projects must be funded with capital and people. Because capital and people are limited and have costs associated with their use, not all positive NPV projects can be initiated simultaneously. Any project that requires allocation of capital and people should (and generally does) compete with other projects for resources. Prioritization of lean initiatives and integration into the enterprise planning and control process is necessary for a successful lean transformation. Integrating the proposed prioritization process with the corporate planning process is a secondary objective of this thesis.

1.2 Approach

While the advice of Rother and Shook may prevent companies from "running headlong into massive muda elimination activities – kaizen offensives or continuous improvement blitzes"

[1998], it does not go far enough. Further development is required to ensure resources are deployed effectively and the lean transformation succeeds. Improvement of a complex system requires a system-wide perspective and approach. Other methods and frameworks, particularly the Theory of Constraints (TOC), offer this system perspective and approach. We will explore opportunities for combining TOC and lean principles to create a framework that facilitates the prioritization of productivity enhancing projects. Subsequently, we will investigate the corporate planning process, looking for linkages between these productivity improvement projects and the general corporate planning and budgeting process.

Work performed at Eastman Kodak Company in Rochester, New York during the summer and fall of 2003 provide the foundation for this for this thesis. At Kodak, a production system model was constructed to replicate the performance of a single work center in the photographic paper manufacturing group. We will explore the use of the model within the context of the proposed prioritization process.

1.3 Summary of Findings

This thesis builds upon Rother and Shook's work in proposing a framework for prioritizing lean initiatives. Specifically, Theory of Constraints (TOC) tools are employed as a basis for selecting programs and projects that provide the greatest system-wide productivity improvement for the least cost. Suggestions for inclusion in the corporate planning process have been supplied. We conclude that the Theory of Constraints can provide an effective focusing tool for the lean enterprise.

This framework is further described within the context of a case study of a paper finishing production system at the Eastman Kodak Company. It is observed that applying quantitative models to value stream maps can provide valuable insights in highly complex and dynamic manufacturing environments. However, much of a model's value is realized when a structured approach to planning and problem solving, such as that proposed here, is applied. The location of the constraint in the paper slitting operation was confirmed. A sensitivity analysis of the system revealed the high leverage associated with reductions in changeover time on the productivity of the work center.

1.4 Organization

Opportunities to combine lean principles with TOC systems thinking will be explored toward the goal of formulating a coherent prioritization and integration strategy for the lean enterprise. First, this thesis will illustrate a generic approach. Next, we will provide recommendations for integrating such a process into the strategic and tactical planning processes of the firm. Finally, a case study of a prioritization effort at Eastman Kodak will be described. Implications and thoughts on further research will conclude.

Chapter 2: Prioritization framework

This chapter will describe the proposed prioritization framework. We begin by defining the objectives of the framework. More specifically, we enumerate the results a lean practitioner should experience after working through the framework. We will also explore constraints on the framework. Second, we will review the current literature related to productivity improvement, the Theory of Constraints, and corporate planning and budgeting processes. Next, the proposed framework will be described in detail. Each element of the framework will be explored in depth. Finally, we will describe how the framework can be incorporated into the corporate planning and budgeting process.

2.1 Objectives and Constraints

Our primary objective is both to formalize and improve the firm's prioritization process for lean initiatives. Formalizing the process primarily involves two components. First, a formal process requires structure. A common process structure used in business today is the Plan-Do-Check-Act cycle based upon the work of Walter Shewhart and W. Edwards Demming [Evans, 1999]. This cycle ensures process feedback and continuous learning. We will use this as a foundation for the proposed prioritization process described in section 2.3 of this thesis. Second, the prioritization process must fit in with the firm's strategic and general business planning processes. A suggested framework for this integration is described in Section 2.4.

Improving the prioritization process is more complex, again consisting of several components. First, we wish to identify projects that fit with the long-term strategy of the firm. It is important that each project further a strategic objective. For example, if the firm's strategy calls for improved quality, projects that broaden the product line should be de-emphasized.

Second, consistent with both common sense and economic theory, we wish to maximize firm value by selecting and sequencing projects that provide the greatest return on the resources invested. In a production environment, returns most commonly come in the form of increased throughput, increased quality, and decreased operating costs. This thesis will use productivity improvement as a proxy for all of these operational benefits. The nature of these resources (capital, materials, direct labor, management time and attention, knowledge) can make purely financial return comparisons difficult.

While focusing on these objectives, several constraints must be considered. First, it is assumed that firms are pursuing productivity improvement through lean, and that firms have adopted a basic lean toolkit. Details on such a toolkit are described briefly in the Literature Review in section 2.2.

Second, the final product must be conducive to successful change management. More specifically, John P. Kotter proposes eight steps towards successful change management [1995]:

1. Establish a sense of urgency
2. Form a powerful, guiding coalition
3. Create a vision
4. Communicate the vision
5. Empower others to act
6. Plan for and create short-term wins
7. Consolidate improvements and produce more change
8. Institutionalize new approaches

This thesis, while recognizing the importance of change management, is not set on improving upon or further detailing these success factors. Rather, this list is reproduced and considered so as to ensure these elements will be supported through the introduction of this framework. Organizations seeking to implement the framework described here are well served to observe the guidance of Kotter. Our framework will facilitate these elements of successful change management as much as possible.

2.2 Literature Review

Productivity Improvement

The amount of literature concerning productivity improvement in recent years is evidence of the growth in popularity of these topics in the business community. This section reviews literature of the two most common improvement frameworks: lean and Six Sigma. This review covers the foundational structures and components of lean and Six Sigma as well the specific elements pertinent to this thesis, the prioritization of improvement initiatives.

A lean enterprise is constantly attempting to "do more with less and less – less human effort, less equipment, less time, and less space, while coming closer and closer to providing customers with exactly what they want" [Womack, 1996]. The history of lean manufacturing principles are traced back to Taiichi Ohno and Shigeo Shingo in Post WWII Japan [Ohno, 1998]. These principles were first applied at Toyota Motors and have since become commonplace in manufacturing facilities around the world. The antithesis of lean is muda (Japanese for waste), and much of lean is aimed at elimination of muda. Lean practitioners commonly refer to seven different forms of waste: Overproduction, Transportation, Motion, Waiting, Processing, Inventory, and Defects.

The basic principles of lean can be grouped into three elements: Flow, Takt, and Pull. Flow is achieved by reducing lot sizes (facilitated by reducing setup times) and organizing work and equipment so that material, and hence value, flow quickly throughout the factory. Takt is the amount of time it takes to make one product. Another key element of lean is to match this rate of production to the customer rate of demand. Finally, pull implies that production is initiated at a customer's request (as opposed to pushing material onto the shop floor based upon forecasted demand).

There is a rather consistent set of lean tools and techniques both practiced and described in literature. These include: kaizen, heijunka, gemba, 5S, kanban, SMED, design of standard work, and pokayoke. Kaizen is the Japanese word for improvement and refers to a focused, team-based continuous improvement activity. Heijunka involves the leveling of production rates and product mix. Gemba means "the place where work is done" – generally referring to the shop floor or possibly a lab. For a manager to 'go on gemba' means that he or she will be going to the shop floor, generally to look for improvement opportunities. Organization in a TPS facility is achieved through 5S. In Japanese, these are: seiri, seiton, seiso, seiketsu, and shitsuke. In English the 5S are sort, straighten, sweep or shine, standardize, and sustain or self-discipline. Kanban is the Japanese word for 'sign' and refer to the visual signal used in a TPS facility as a signal to either start production or to move inventory (usually an empty bin or floor space). Set-ups time reduction and quick machine changeovers are performed via the Single Minute Exchange of Dies (SMED) principles established by Shigeo Shingo. Standard work represents a documented version of the preferred process (incorporating man, machine, and material). Pokayoke is the Japanese word for 'mistake-proofing.' Firms mistake-proof by designing processes and products that don't permit flaws either physically or procedurally.

While many companies have reported tremendous successes with lean [Womack 1996], others have reported implementation difficulties [Rinehart 1997]. Some practitioners are seeking to use the tools and techniques initially intended for shop floor improvements to the greater enterprise, including other business processes and industries outside of manufacturing.

In addition to lean, many large industrial companies today have employed Six Sigma tools and techniques with great success [Pande 2000]. Motorola is credited with creation of the Six Sigma quality standard in the late 1980's in their pursuit of more efficient semiconductor manufacturing. Six Sigma is deeply rooted in quality management, sharing many statistical tools and practices. Today, Six Sigma is considered to be applicable to general business process management in both manufacturing and service industries. The words Six Sigma refer to an optimal quality level – 3.4 defects per million opportunities (DPMO) – where five sigma quality disappoints customers and seven sigma quality is too costly. Defects are measured only against the Customer's Critical Criteria, those criteria that must be met so that customers' expectations are met or exceeded. The Cost of Poor Quality (COPQ) refers to the financial loss experienced by the firm failing to meet these expectations. Six Sigma project management involves a five-step process commonly termed: Define-Measure-Analyze-Improve-Control (DMAIC). The DMAIC process is based upon the Plan-Do-Check-Act (PDCA) cycle popularized by W. Edwards Demming and first introduced by Walter Shewhart [Evans, 1999]. Projects are proposed by Sponsors, advised by Master Black Belts, and led by Black Belts or Green Belts.

A manager in a Six Sigma organization faces exactly the same prioritization decision as a manager in a lean organization. Therefore, it is helpful to examine the tools and techniques in Six Sigma literature as well, specifically looking for potential solutions to this prioritization problem. Eckes [2001] describes selection of project criteria and construction of a matrix for evaluating each sub-process based on that selected criteria. Suggested criteria include: fit with strategic business objectives, current performance, and feasibility. Process managers then rank their sub-process in terms of impact on each criterion. The sub-process scoring highest should be targeted for improvement (where score is the sum of the impact scores for each criterion). Adams et. al. [2003] suggest a similar matrix, but with three differences. First, different evaluation criteria are suggested. Second, specific projects (as opposed to business processes) are evaluated. Third, project ratings are collected and then multiplied by a weighting factor for each criterion. Smith et. al. [2002] propose five steps towards project selection:

1. Place a premium on optimal, short-term benefits
2. Evaluate the financial impact of each project
3. Evaluate the business processes in greatest need of improvement
4. Asses the fit of the project with the overall fit wit the firms' strategy and vision
5. Evaluate projects against the impact on key performance indicators.

The authors continue to propose filtering the remaining projects, so as to ensure that each project meets other predefined criteria as well. The guidance provided by these authors with respect to project selection is unremarkable and susceptible to the same shortcomings described above for lean.

Systems Thinking and the Theory of Constraints

The growing complexity and interconnected nature of business has changed the method and tools for analyzing business problems. The rationale for a systems approach is defended in popular works by Peter Senge, Eli Goldratt, and John D. Sterman. Senge describes systems thinking in the following manner:

> "Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static 'snapshots.' It is a set of general principles – distilled over the course of the twentieth century, spanning fields as diverse as the physical and social sciences, engineering, and management." [Senge, 1990]

One tool for systems thinking is the Theory of Constraints (TOC). The Theory of Constraints is the product of Eli Goldratt and is first described in his novel The Goal [1992] and is more fully described in his book Theory of Constraints [1999]. The American Production and Inventory Control Society (APICS), lead by author Thomas McMullen, Jr. published Introduction to the Theory of Constraints (TOC) Management System in 1998.

In broad strokes, TOC aims to find simple solutions to problems presented by complex systems. More specifically, TOC holds that that the goal of a manufacturing system is 'to make money.' A firms makes more money by increasing throughput and reducing both inventory and operating expense. These three elements, throughput, inventory, and operating expense, constitute the three primary metrics of a TOC plant. Throughput is the rate at which a firm makes money via sales. Inventory is defined as the money that the system has invested in purchasing things that it intends to sell. Operational expense is the money that the system spends in order to turn inventory into throughput.

As the TOC name suggests, identification and management of constraints is critical in the improvement of complex systems. A constraint can be anything that prevents the system from reaching its goal. A physical constraint in a manufacturing environment could be the slowest machine on a production line. A policy constraint could be any business rule or indirect process that reduces throughput or increases operating expense or inventory. Buffers are established before the constraints to ensure adequate supply does not starve the constraint. Buffers can consist of inventory, time, or budgeted funds.

Another principle of TOC involves a holistic view of the system and the need to find global, as opposed to local, optimums. A system of locally optimized components will never result in a truly optimized system. Only by considering and analyzing the system as a whole can such a global optimum be found.

More generally, Goldratt proposes a five-step process as shown below in Figure 1.

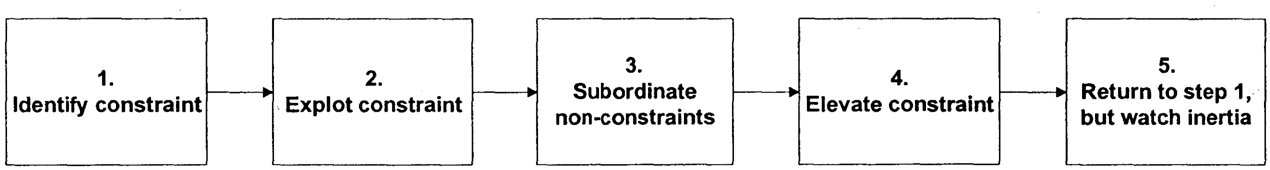

Figure 1: Five Focusing Steps in Goldratt's Theory of Constraints

The first step in the process is to identify the constraint or bottleneck of the system. In a production environment, this is most heavily utilized person or machine. If no resource is utilized 100% of the time, then the system has excess capacity and the limited market for the product is the constraint. The second step is to exploit the constraint, or ensure we are managing the constrained resource to the best of our ability. This might include: minimizing downtime, increasing machine speed, or checking quality prior to entering the constraint. The third step is to subordinate non-constraints. In order to keep WIP from growing, all non-constraints must produce at a rate below that of the constraint. Taken a step further these resources can be scheduled or triggered based upon the production rate of the constraint. The fourth step in the process is to elevate the constraint. This is different than the second step in that the focus is no longer on the constrained resource, but on changing the system to reduce the load on the constraining resource. For example, to off-load the constraint, it may be possible to use a different machine, to outsource production, or shift the product mix so that less constraint time is used per dollar of throughput. Finally, the fifth step is to return to the first step, but to "watch out for inertia," as often it is the less obvious policy constraints that actually prevent system improvement. Advocates of TOC suggest this five-step process can be utilized as a general problem-solving framework, not just process improvement in a manufacturing environment.

Corporate planning and budgeting

Hax and Majluf [1984] describe the formal corporate strategic planning process. This process operates at three different levels within the firm: the corporation, business unit, and individual functions, encompassing the formulation of strategy, supporting programs, and budgeting. A diagram of this process is shown below in Figure 2. Each number in the figure refers to a distinct step in the planning process described below.

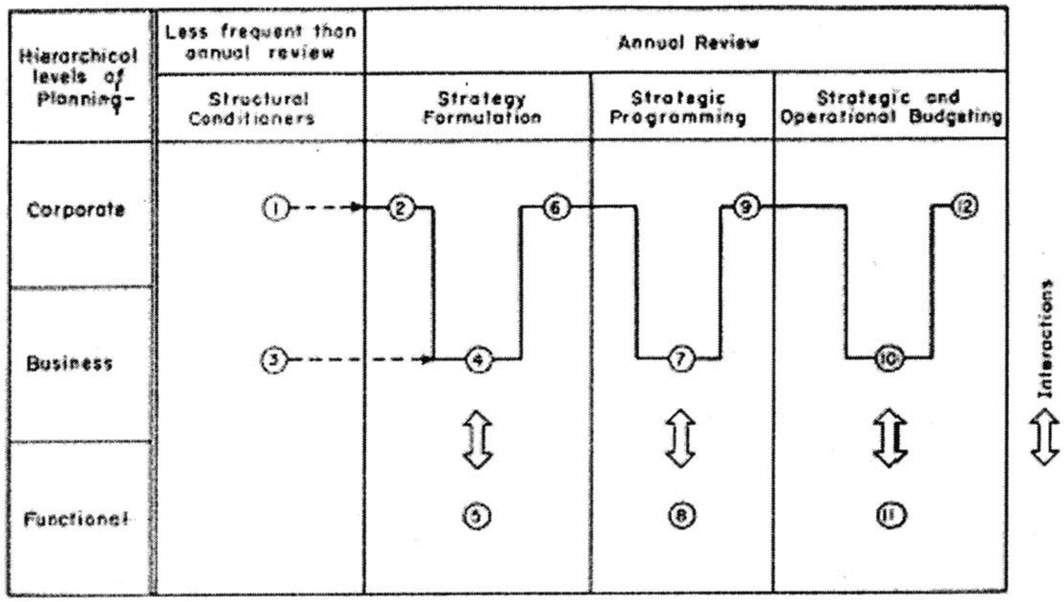

Figure 2: Corporate strategic planning process from Hax and Majluf, 1984

First, Hax and Majluf describe the need to structure and define the corporation. This involves high-level objectives, ranging from initially defining the business units to formulating a corporate mission statement. This normally occurs on a less-than-annual basis. Second, the strategy of the corporation must be formulated, consisting of strategic initiatives, specific performance targets, and expected challenges. Strategy should be revisited annually. Third, the structure of each business unit must be defined. This is more detailed than the corporate structure, detailing the specific products and market targeted by each business. Both corporate strategy and business unit structure lead to the fourth step in the planning process – definition of the business unit strategy. More detailed than corporate strategy, business unit strategy involves planning for specific products and markets. This requires interaction with functional managers, the fifth step in the planning process. This interaction is meant to align objectives and resolve resource conflicts. The fourth and fifth step should be scheduled for annual review, along with an opportunity to consolidate these strategies at the corporate level (the sixth step).

With strategies in place, business units are able to develop programs aimed at achieving a specific business unit strategy (step seven). This logically leads to functional programs that facilitate this business unit program. A program has estimated costs and benefits, project plans, assigned teams and leaders, and a resource budget. Just like strategy formulation, programming requires interaction with functional managers. Business unit strategic programming with functional managers is the eighth step in the planning process. Once completed, these business unit programs must be collected and evaluated at the corporate level (step nine).

Finally, budgets must be appropriated based upon corporate objectives and strategies. The authors recommend separation of 'strategic funds' from 'operational funds' to ensure programs vital to corporate health are funded appropriately. This budgeting process is shown in steps ten, eleven, and twelve. Again, we start and end with a coordinated corporate view, working into the operational layers of the organization to achieve a level of confidence, understanding, and buy-in necessary for an agreeable and realistic budget.

Hayes and Wheelwright [1998] describe a similar, three-tiered model of manufacturing strategy. Garvin [1993] utilized their work in proposing an Integrated Framework for Manufacturing Strategic Planning as shown in Figure 3.

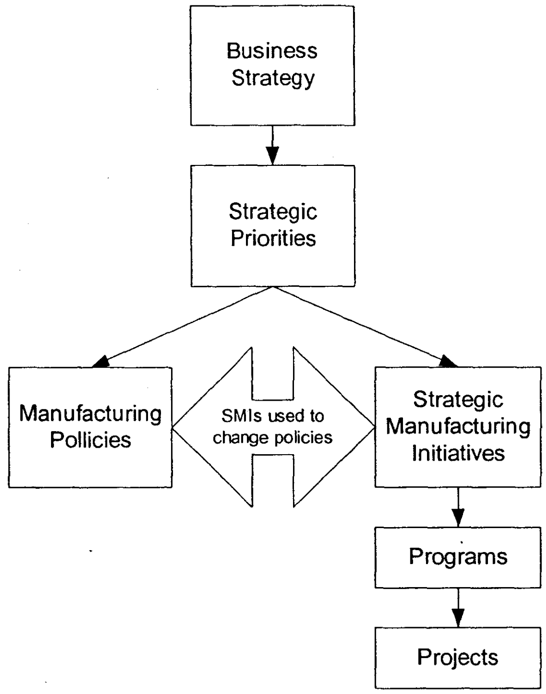

Figure 3: Integrated framework for manufacturing strategic planning from Garvin, 1993

Garvin's process looks quite similar to those discussed above in that the process starts with the corporate view of the organization and works down into business units and then functional groups. While Garvin successfully integrates short-term improvement projects (termed Strategic Manufacturing Initiatives, or SMIs) into the planning process, the model lacks a systems approach and tools for focusing scare resources.

In summary, there are number process models a corporation might follow in establishing corporate and business unit strategy (and subsequently allocate capital). While these models share much in common, one should note that these processes stop short of offering concrete advice on the prioritization of short-term improvement projects. The prioritization process defined below in section 2.3 represents an attempt to overlay a systems approach on this process and introduce a toolset aimed at focusing scare resources towards the most beneficial projects. That it, our goal is not to replace or augment the corporate planning process, but to ensure integration between the prioritization process and the greater strategy and budgeting of the firm. For purposes of describing this integration in section 2.4 of this thesis, we will assume the well-defined Hax-Majluf model to be representative of the process utilized in most firms today.

2.3 Prioritization Framework description

Overview

The prioritization framework proposed here borrows from lean, TOC, and quality management systems. In the introduction to this thesis, a sequence of steps proposed by Rother and Shook outlines how value stream maps should be used to facilitate adoption of lean. The proposed framework borrows heavily from this sequence and is meant to augment the guidance of Rother and Shook in three ways. As mentioned earlier in this chapter, our two primary objectives are to formalize and improve the firm's prioritization process for lean initiatives. Our secondary objective is to integrate this prioritization process within the context of the greater organization (described in section 2.4 of this thesis). In this manner, the proposed framework can serve as a substitute for Rother and Shook's sequence. The four primary steps of the proposed prioritization process are as follows:

1. Define value and establish value metrics
2. Model and analyze the value stream
3. Improve the system
4. Control the system and Learn; Repeat

These four steps are somewhat generic and, in title alone, do not provide a great deal of insight. The remainder of this section will describe each step in detail. Examples are not included in this chapter, as an entire case study using this framework is described in the subsequent chapter.

Step 1: Define value and metrics

Womack and Jones [1996] suggest that the first step must be to define value from the perspective of the customer. That is, value is created only when the customer experience is enhanced. This could take many forms, including: lower prices, higher quality, more reliable availability, etc. It is expected that customer value is a motivating factor in the long-term strategy of the firm, and that choosing between these objectives is an exception to the rule.

This is also an appropriate time to define how value should be measured, and which metrics are suitable to in evaluating the efficiency and effectiveness of the value stream. While often industry and process specific, there are a few characteristics of good metrics. Efficiency metrics are similar to productivity metrics: ratios of some output (production units) per input (labor or raw material). Effectiveness metrics measure how well the process completes the expected task. A common example is to measure customer satisfaction with order fill rates (percent of items shipped on time in complete quantity). Note that these metrics can be customer-focused as well. For example, one could argue that sales order line-item fill rate is superior to SKU or work order fill rate metrics as the sales order line-item most accurately reflects the customer experience.

Step 2: Model and Analyze the Value Stream

After defining our value objective we can begin to diagram the current state value streams. Section two of Rother and Shook's workbook [1998] describes this process in detail. The authors do not recommend sophisticated tools in completing this exercise. As system complexity increases, however, it may be beneficial to create models of the value stream. John. Sterman, Director of the MIT Systems Dynamics Group, makes this point in his text [2000]: "...when experimentation in real systems is infeasible, simulation becomes the main, and perhaps the only, way you can discover for yourself how complex systems work." He describes a number of conditions that limit our ability to make sense of complex system behavior, including multiple interconnections, nonlinearities, and time delays. For example, Sterman cites studies that show humans are successful in identifying direct, linear relationships between variables, but there is great difficulty in the presence of random error, nonlinearity, and negative correlations. Value streams of manufacturing facilities can create such difficult conditions and often warrant the creation of a model.

Modeling is only one component of understanding and managing system behavior. The Theory of Constraints suggests that systems are improved by focusing on the constraining, or bottleneck, resource in the system. Sterman [2000] agrees with this logic, but notes that the TOC process of "attacking bottlenecks as they occur" can be less effective than anticipation of bottlenecks in industries where there is substantial rate of change. With Sterman's warning in mind, the first objective is to identify the constraint of the system. The question we wish to answer is, what process step, if any, limits value delivery? In a manufacturing environment, it can be rather straightforward to calculate the anticipated load on each manufacturing resource (machine, tooling, material, or person). If no resource exceeds 100% utilization, then the market demand is constraining increased throughput. If multiple resources exceed 100%, the most constrained resource is the bottleneck. By definition, improvement in any other area of the business will not improve system throughput. Note that system costs can be reduced in any area of the business, regardless of the bottleneck location. Take, for example, a process step that is non-value added and very expensive, but with much excess capacity. A dollar saved at the process is equivalent to a dollar saved at a bottleneck resource. However, this dollar saved does not have the added benefit of increasing system throughput. One must be very careful in attempting to reduce costs by focusing on non-value added steps exclusively.

To summarize the words of Eli Goldratt [1994, 1999]: Time saved at the bottleneck increases throughput and efficiency while time saved at non-bottleneck resources does not. It is important to know the location of the bottleneck, both now and in future. In cases where the location of the bottleneck is unclear or has the potential to shift to another resource, models can help in outlining the supply and demand features that create bottlenecks both now and in the future.

Second, we wish to evaluate the sensitivity of the system. This analysis will help us answer the question of: which improvement projects will have the largest impact on system performance. Several types of analysis may be appropriate. In a production environment where labor costs have become problematic, it may be useful to measure the labor productivity. A more general analysis may involve simply cost sensitivity.

Step 3: Improve the system

System improvement can take many forms and can follow multiple paradigms. Much has been written extolling the virtues of lean, Six Sigma, and other productivity or quality enhancing frameworks. This thesis is not concerned with comparing and contrasting or evaluating these methodologies. Rather, we will acknowledge that each has demonstrated success, owing much to unique circumstances, including: leadership talents, organization capabilities, business environments, etc. If lean is the chosen framework, this third step will include efforts to implement flow, pull, and takt. Green belt and black belt projects are the implementation technique employed by Six Sigma organizations. If following the TOC five focusing steps, one might work to exploit, subordinate, and elevate the constraint.

Step 4: Control, learn, and repeat

Control of processes, projects, and programs requires a plan, a feedback mechanism, and periodic review with action. In this special case, the plan is our future state value stream map, the feedback mechanism is our value metrics, but review and action is user-supplied.

Whether implicit or explicit, the concept of learning is central to productivity improvement. Learning from results and outcomes and then incorporating these learnings into future efforts is the foundation for continuous improvement. We retain this theme and build upon it. Peter Senge [1990] suggests that the most powerful learning comes from direct experience. He continues with a dilemma – "we learn best from experience but we never directly experience the consequences of many of our most important decisions." Examples provided include R&D investments and executive hiring decisions that, due to the time lag and organizational distance between the decision and the outcome, learning is made difficult.

The primary weapon organizations have used to combat this is the creation of functional silos that subdivide one's world into small enough pieces so as to create sufficient line of sight. Senge also notes that individual learning is different than team or organizational learning. Three dimensions of team learning are noted: the need to think insightfully about complex issues, the need to for innovative, coordinated action, and the process of spreading learnings beyond that of the team. Senge admits that the dynamics of team learning are not well understood; it is difficult to predict teams that produce 'groupthink' from those that a capable of producing group intelligence. Despite this, a reasonable place to start is by creating organizational cultures that facilitate and reward both dialogue and discussion. Better understanding in the area is an opportunity for further research.

2.4 Framework integration

Addressing Kotter's eighth key to successful change management [1995], we wish to institutionalize our proposed framework by integrating our planning process into the annual corporate planning and budgeting cycle. It is worth noting that Kotter highlights two key elements necessary for institutionalization. First, management must 'connect the dots' for the organization, clearly linking the new approach to better performance. Second, the next generation of mangers must be selected and mentored so as to ensure continuity of the change process.

Our literature review reveals that linkage between productivity improvement programming and the corporate planning and budgeting process is both nontrivial and a topic of much discussion. For purposes of this paper, we will assume that the Hax and Majluf model of corporate planning and budgeting [1984] is representative of the status quo in corporations today. We build off of this model and incorporate our proposed prioritization framework, which provides both the systems perspective and resource allocation discipline absent in previous models. A diagram of this revised process flow in show below in Figure 4.

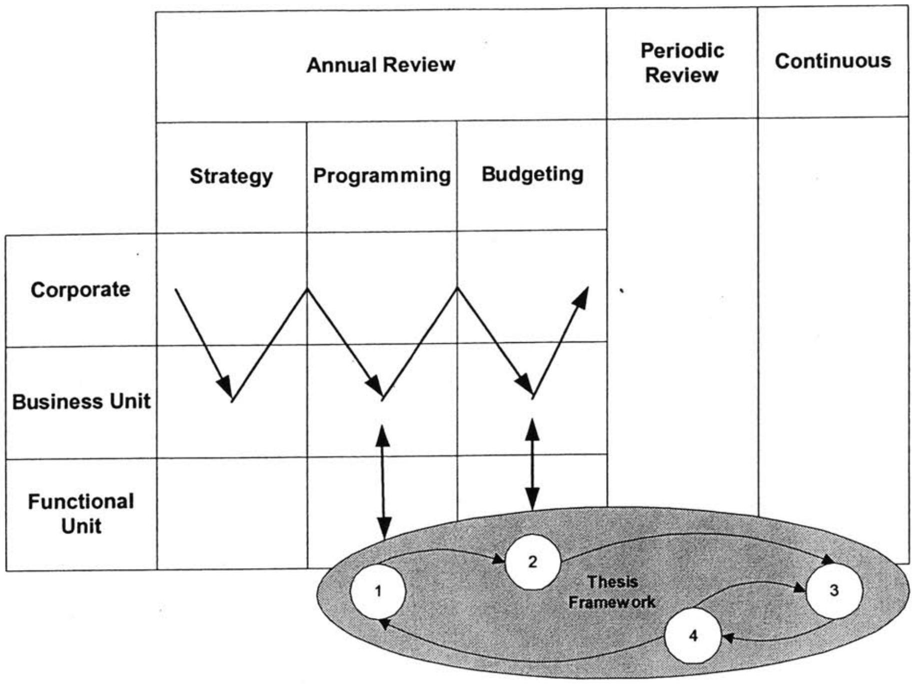

Figure 4: Integration of the proposed prioritization framework with a generic corporate strategic planning and budgeting process

The first and most obvious element of this figure is the commonality shared with Figure 2. The only new element of this figure is the incorporation of the proposed prioritization process. The placement of the proposed process in the bottom right corners is indicative of two main points. First, the timeline for this integration must be on the annual planning cycle of the corporation, but the prioritization process is one that continues year round. Second, the managers of such a prioritization project are most likely to be either functional managers or special project teams assembled to work across functions and business units.

During the annual strategic planning process, business unit and functional managers first discuss strategic programming for the coming year (steps seven and eight) and later, after corporate approval, come back to address budget concerns (steps ten and eleven) [Hax, 1984]. The proposed prioritization process must play a role at each of these junctures. As business unit managers bring strategic thrusts to the table at such a planning meeting, current value stream maps should provide a common language and understanding of the current reality. The future state value stream must accommodate and validate the strategic intent of the business unit. Further, the strategic objectives of the business unit must be reflected in value objective and metrics described in the first step of the proposed prioritization process. With this check complete, the corporate planning process can proceed to step 9 (corporate consolidation and resource allocation) and the prioritization process can proceed to step 2 (model and analyze the value stream). As stated above, the detail of the model will depend on a number of factors, but all information should now be available to evaluate the tactical projects aimed at these strategic program goals. This analysis phase of the process should help prioritize tactical projects based upon the degree to which they will fulfill the strategic program goals and help prepare resource budget estimates for discussion with the business unit manages. This next interaction occurs at steps 11 and 12 of the generic corporate strategic planning process. Budgeting discussion can greatly benefit from the value stream model, as tradeoffs (project A versus project B) become quick and easy to evaluate. Finally, once budgets are agreed upon, tactical improvement projects can be planned and executed (step 3 of the proposed prioritization process). Throughout the year, it is expected that we re-run the value stream model with current data to be sure our previous assumptions still hold. For example, if forecasted demand is much lower than expected, a setup time reduction project may be less important than a fixed cost reduction project. This continuous process is represented by step 4 of the proposed prioritization process.

Chapter 3: Eastman Kodak case study

Research for this thesis was conducted under the support and supervision of the Eastman Kodak Company. While research was performed in the Paper Finishing work centers of the Rochester Photographic Paper Flow, it is expected that this thesis provided insights and applicable learnings for other manufacturing processes in a variety of industries. This chapter demonstrates the utility of the proposed framework in a paper conversion environment.

3.1 Eastman Kodak and Business Environment

Eastman Kodak, as described in their 2002 Annual Report, is engaged primarily in developing, manufacturing and marketing traditional and digital imaging products, services and solutions for consumers, professionals, healthcare providers, the entertainment industry and other commercial customers.

The digitization of imaging, both in image and output, is transforming the photography landscape, and photographic paper is not immune. This transformation partially explains the reduced demand for Kodak's photographic paper. Strong seasonality in end markets introduces additional uncertainty and creates numerous management challenges. Further, the asset intensive nature of photographic paper manufacturing creates barriers to entry and exit for the remaining industry competitors. These factors result is a continual pressure to reduce costs by increasing productivity, by shifting production to low cost facilities, and by rationalizing product offerings.

Eastman Kodak has embraced lean principles in hopes of achieving regular productivity gains. More specifically, management is focused on reducing waste (e.g. excess inventory and floor space) while increasing throughput and quality. Leadership at every level in Kodak speaks the lean vernacular and is committed to implementation of lean concepts. Lean professionals are stationed throughout the manufacturing organization.

3.2 Photographic Paper Finishing

Photographic paper is made from rolls of paper stock by coating, sensitizing, and finishing the raw material. The final process, finishing, involves slitting, spooling, packing, and shipping the photographic paper. These processes and sub-processes are shown in Figure 5 below. The first step in the process, slitting, takes large sensitized rolls and reduces the width to customer specifications using sharp, circular knives. Next, the spooling process cuts the paper to the appropriate length and places the finished material on the appropriate core for customer shipment. One complexity of paper finishing involves making optimal use of the sensitized paper. By carefully organizing how each order fits into a roll of raw material, scrap can be minimized. The rolls are then packaged and shipped to customers. Note that, throughout all of these finishing processes and in storage, the photographic paper material must be protected from exposure to light to ensure product quality.

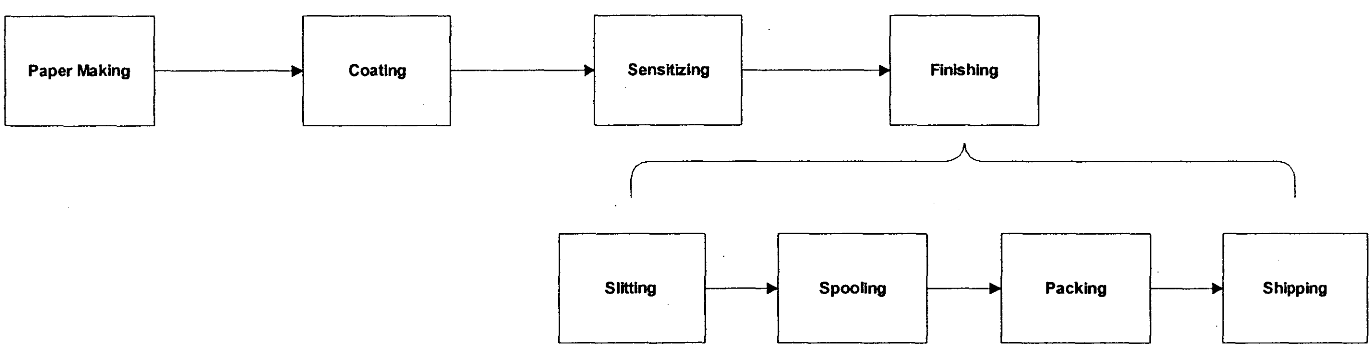

Figure 5: Photographic Paper Manufacturing Processes and Paper Finishing Sub-Processes

3.3 Application of thesis framework

Difficult economic conditions combined with systemic changes in the photographic paper markets reinforce Paper Finishing management's focus on productivity. To better understand the drivers of productivity and the cost and benefits of improvement projects, a model of the paper finishing production system was constructed. The model was used to confirm the location of the manufacturing system constraint and determine leverage points for productivity improvement initiatives.

The model was constructed using Microsoft ® Excel, without the assistance of any add-ins or Visual Basic programming. Primary inputs to the model include projected product demand, inventory positions, machine and process specifications, direct labor employed, and production planning parameters. With this data, the model calculates the input and output for each machine grouping in the work center on a daily basis for the upcoming month or year. These input-output values permit aggregate calculations for productivity, service level, and utilization for the work center as a whole and for individual machine groupings. Examination of plots of inventory position and backlog ensure that the production system is operating at steady state.

Eastman Kodak has adopted a number of the lean principles in their propriety operational excellence program, the Kodak Operating System (KOS). As part of this program, each product line has already created current and future states value stream maps. These maps are not reproduced here, but it is worth noting that these maps follow the instruction of Rother and Shook quite closely.

These existing value stream maps provide the foundation for construction of a model of the paper finishing production system described previously. However, mathematical modeling of the system required further distillation. A simplified material flow is shown in Figure 6.

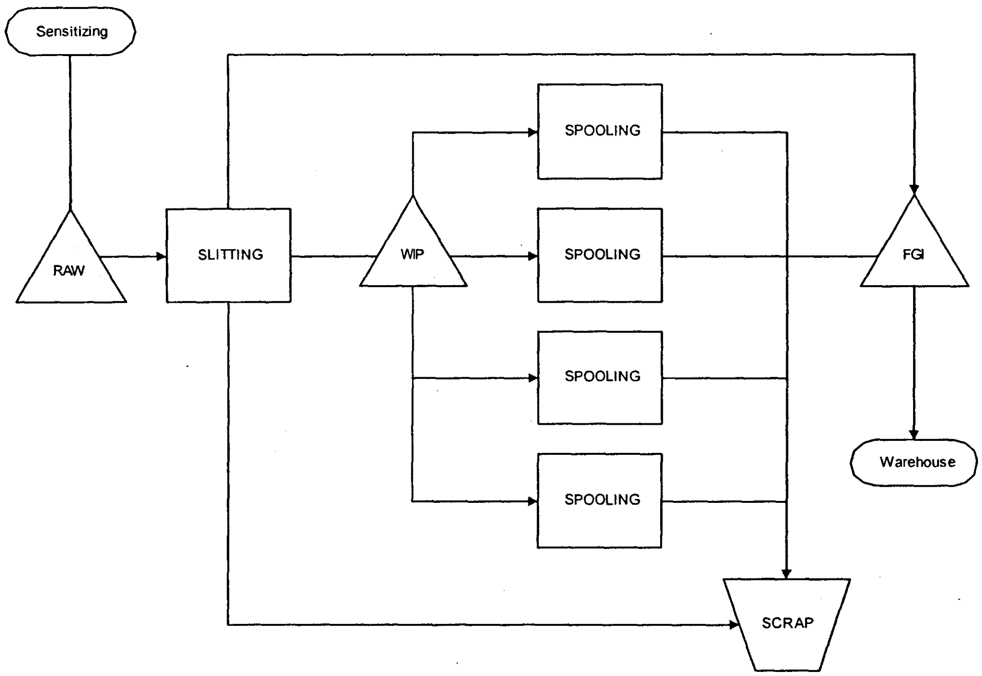

Figure 6: Simplified Paper Finishing material flow diagram used in constructing production system model

When possible, like machines are grouped together. Only where processing specifications deviate substantially are machines modeled separately. The WIP location, shown as a material holding location in this chart, also acts as a machine in some respects, as it is a fully automated system with limited throughput. While inventory and scrap is included in this model, no attempts have been made to verify the accuracy of predicted levels. The model predicts the following processing metrics by machine group and by time period:

- Throughput (good square meters of paper produced per time period)
- Productivity (good square meters produced per direct labor hour)
- Aggregate Service Level (good square meters produced/ square meters demanded)
- Machine Group Utilization (production hours / planned hours)

These calculations require a substantial number of inputs and assumptions. A simplified data map of the model is shown below in Figure 7. The map illustrates which data elements must be supplied, how data elements are utilized and related to one another, and the key calculations on each worksheet.

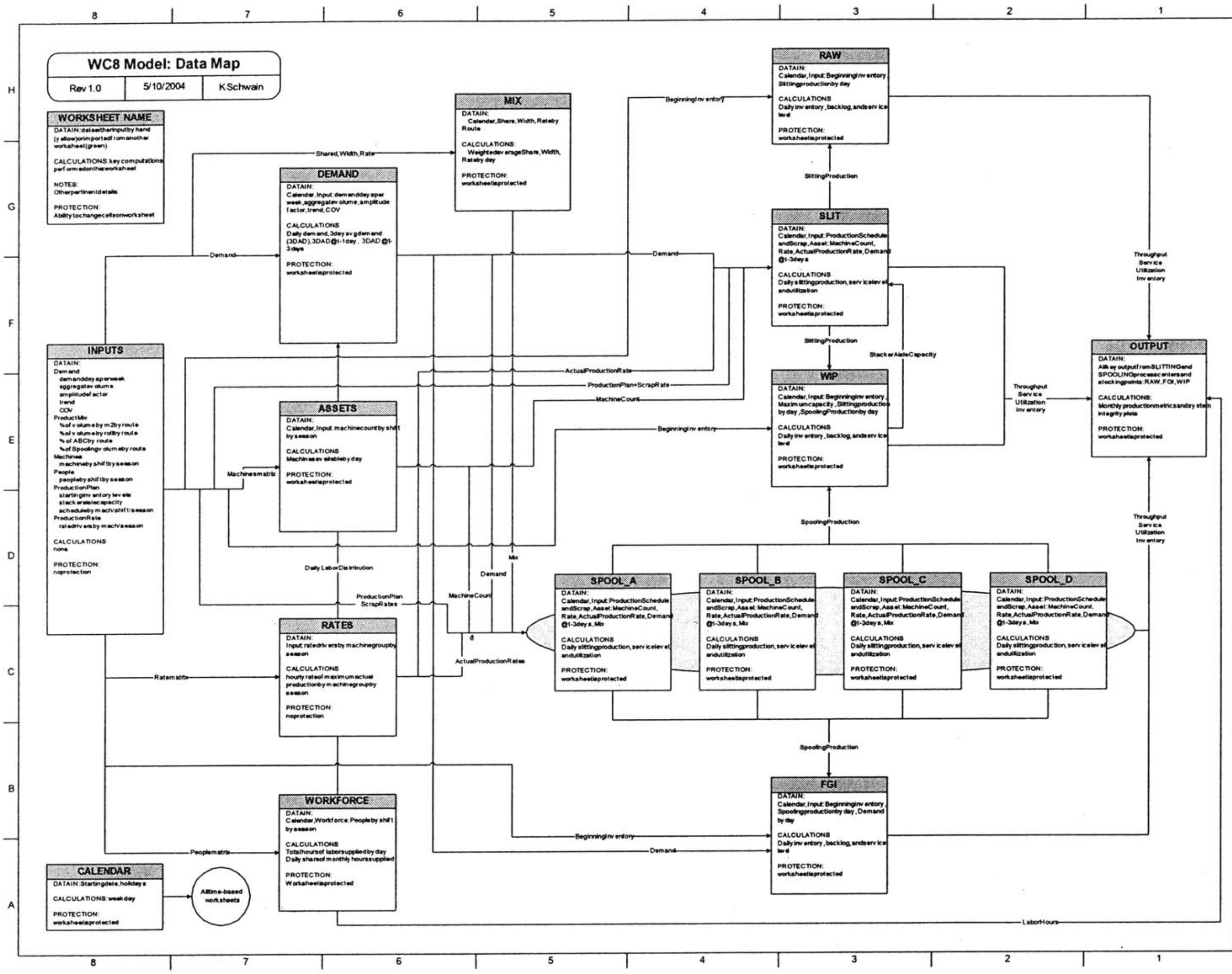

Figure 7: Simplified data map of production system model

The model was created, tested, and verified with the help of production managers, planners, and shop floor personnel. The first step in this process was to recreate the past month of production in the model. All inputs were taken from management reports for the past month so that the results of the model, if different from the actual production results, would reflect upon the model and not the quality of input data. After multiple revision cycles, all stakeholders agreed that the model was accurate 'within an order of magnitude and directionally correct', the standard previously agreed upon. It is worth noting that the difference between model results and actual result for the previous month of production were within a few percentage points. After this verification process, the model was used to evaluate the operating plan for the next year and multiple improvement projects proposed by management. The details of this process are described later in this chapter.

The nature of this assignment rather naturally led to the same questions posed by Rother and Shook: What do we work on next? Where should we focus our time and energy? Even with a robust model, these are not easy questions to answer. In fact, existence of the model makes the need for a process much more apparent; with the capability of answering so many questions at hand, one realizes how important it is to be asking the right questions. The four-step process proposed in Chapter 2 provides an effective framework for answering these questions and utilizing such a model.

Step 1: Define value and metrics

Customers desire a wide variety of high-quality photographic paper products in stock at a competitive price. The paper finishing work centers contribute to this value proposition in a number of ways:

a) maintaining extremely high fill rate of orders from the warehouse (fill rate)
b) maintaining cost advantage and driving further productivity gains
c) achieving operational excellence in the face of declining volumes and introduction of new products and processes.

Management utilizes a number of metrics in efforts to track this value. Categories of metrics include: Health and Safety, Productivity, and Quality. Labor productivity is of particular concern to the paper finishing work centers. Management utilizes a unique metric, dividing the amount of paper produced in a given time period by the direct labor hours charged over the same period. The resulting metric has units of area per time. Implicit in this metric is the importance of labor to these operations. This is explained by the large percentage of up-time spent on machine changeovers. A productive workforce is critical in this type of high-mix, low-volume work center. A time-series examination of this metric reveals that labor productivity has declined in the preceding months. While some of this is explained (and expected) as a result of decreasing manufacturing volume, there was a general consensus among management that efficiency had decreased. This decline in labor productivity was the primary motivation behind construction of the model.

Step 2: Model and analyze the value steam

Operation of the model described above offers a variety of insights. Our first concern, as described in the thesis framework, is to identify and quantify the bottleneck in the paper finishing work center. Specifically, the model calculates machine group utilization by day. High utilization indicates high productivity, but also lends itself to a rapid deterioration in service level. The model was supplied with forecasts for the upcoming year and the model calculated the utilization graphed below in Figure 8.

This figure highlights the relatively high utilization at slitting compared to the spooling process centers. Note that slitting is still not utilized 100%, so it is problematic to call this a constraint. While part of this discrepancy is likely caused by modeling or forecasting inaccuracies, some is because of the loading pattern on the equipment (some months experience higher demand than others). Overall, this points to a) some remaining capacity at slitting and b) if or when we find our maximum, it will be experienced first at slitting. The bottleneck could easily change given a dramatic change in mix, which would warrant another trail run of the model.

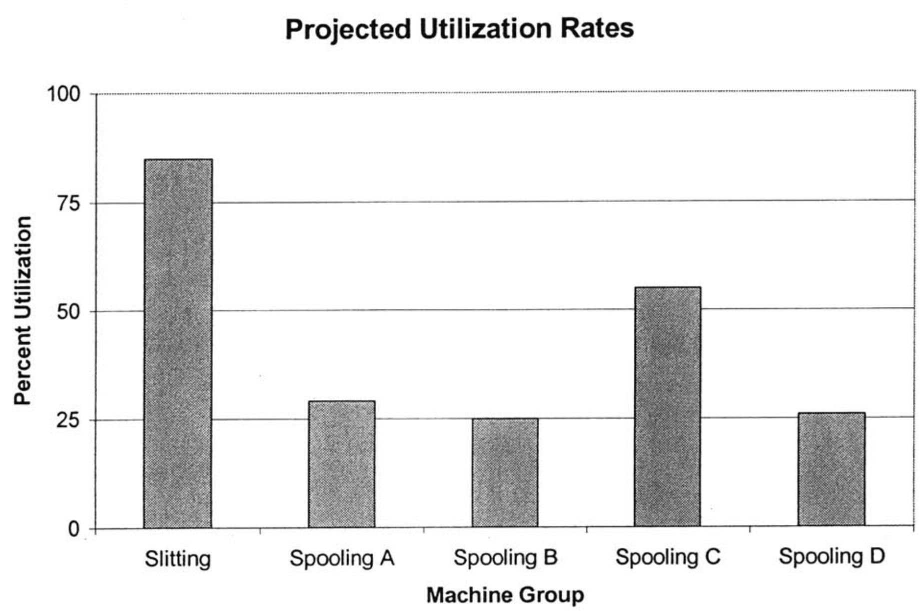

Figure 8: Model Results - projected utilization rates for machine groups in the paper finishing work center

Our second concern, consistent with the thesis framework, is to examine the sensitivity of the system. We want to find determine which management levers provide the most 'bang for the buck' as we attempt to alleviate pressure on the constrained resource. This is a two-part process. First, we will use the model to determine the amount of leverage provided by different improvement projects (changes in an input variable). This analysis will be normalized by calculating the percent improvement in output metrics resulting from a fixed percent change in input. Such analysis requires an initial, baseline model run to be used for comparison. The baseline used for this project was the annual operating plan for the upcoming year. Building from this baseline, potential improvement projects were postulated with alternate model runs. For example, since we know that the constraint of the system is the slitting operation, we modeled several improvements to the slitting operation, including improved uptime due to better maintenance, reducing the frequency of changeovers, and reducing the duration of changeovers. Each scenario requires a new model run. By collecting and then comparing the aggregate results of these model runs, we gain detailed insight into how resources can be deployed so as to maximize operational improvements. Numerical results of this analysis are shown in Figure 11, attached as an appendix. A graphical summary is shown below.

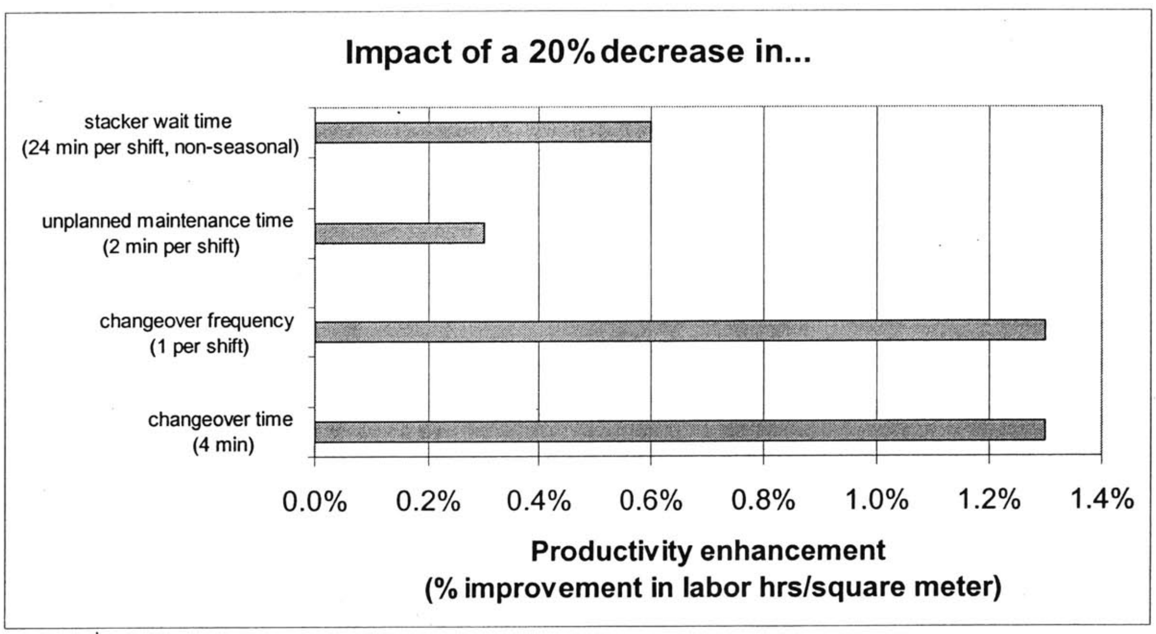

Figure 9: Model results - graphical sensitivity analysis showing productivity gains resulting from different operational levers and improvement projects

This figure establishes the importance of knife changeovers in a high-mix, low-volume paper finishing work center. Projects aimed at reducing changeover time will provide the most return per input reduction. Also, it is evident that as mix grows and changeovers increase, we must place even more emphasis on reducing the time we spend changing knives.

The second step of this process requires management's judgment. While the figure above captures productivity gain opportunities, the costs associated with these gains are not computed. Remaining questions include: how much will it cost to achieve these reductions? What is the probability of success of such a project? These are not simple questions and they do not lend themselves well to this type of model. Said again, what does it take to reduce changeover time by 4 min? Is it equivalent to the cost of removing one changeover per shift? This information can be easily plotted on a 2x2 decision matrix shown in the figure below.

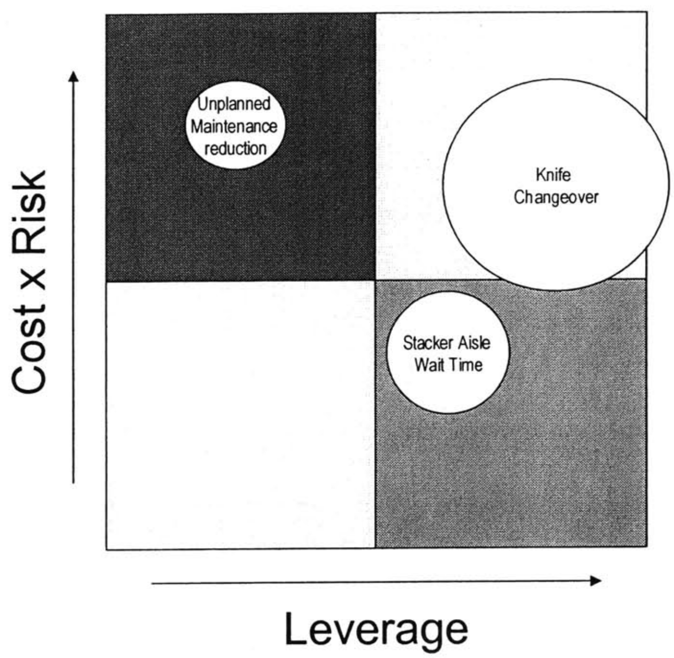

Figure 10: Decision matrix example highlighting relative impact and attractiveness of improvement projects

The four quadrants indicate desirability of a project. For example, the upper left quadrant is painted red, as these projects are costly and risky, while providing little operational leverage. These projects should not be attempted. The bottom right quadrant is the proverbial "low hanging fruit" or "quick-win" area. These projects should be tackled first as they provide high leverage at a low cost and risk of failure. The bottom left quadrant provides less leverage at low cost and low risk – these normal continuous improvement type projects that need to be weighed carefully. Finally, the upper right quadrant identifies the 'breakthrough' projects that provide substantial leverage, providing step-function type gains, but with substantial cost and/or risk. Along with the bottom left quadrant, these projects need to be weighed carefully. A circle has been created for each improvement project, and the size of the circle reinforces the absolute level of performance gained from the project.

Note that all of the 'projects' will produce a number of downstream effects. For example, changeover frequency is influenced by the product mix, but will ultimately impact both inventory investment and service levels as well. Also, some of these factors are interdependent. For example, reducing changeover frequency will likely reduce stacker wait time, as running more homogonous material will result in higher stacker aisle capacity. These interdependencies are incorporated into the model.

Step 3: Improve the system

Specific recommendations were made to the Paper Finishing management team. First and foremost is that the work center is not capacity constrained and no capital investment is warranted at this time. Second, this model confirms management's intuition in observing the leverage of machine changeovers. Set up time reduction is a powerful, though rather difficult opportunity. Third, the 'low hanging fruit' appears to be the resolving the unplanned stacker aisle wait time. This is a seasonal problem, but can be troublesome and, best of all, many on the floor feel this can be reduced or eliminated by optimizing the sequence of the day's production orders. Finally, it is recommended that pursuit of other opportunities, such as reducing unplanned maintenance, not be allocated additional resources as returns on such investment will be very low.

Kodak uses a wide variety of lean tools, including (but not limited to): kaizen, gemba, 5S, kanban/visual controls, SMED/setup reduction, standard work, pokayoke/mistake-proofing, and cross training of operators. For example, the lean champion for paper finishing facilitated a kaizen for setup time reduction. The objective was clearly defined: reduce setup time from the status quo to the best-in-class time for that machine. Calendars were cleared for several full days for operators, supervisors, planners, and production managers. A wide range of potential solutions were proposed and considered by the team. If we couldn't find the data we needed to evaluate an idea, we performed time studies and wrote database queries. Any request for access to people or data was escalated immediately. The resulting solution was the product of collaboration and cooperation.

Step 4: Control, learn, repeat

The Paper Finishing management team has numerous measurement tools in place to help control and monitor the production system. This takes a few primary forms:

- Management Dashboard (monthly tabulation of key results)
- Gembas (weekly walks through the production and office areas)
- Production meetings (daily check-in)

These tools are instrumental in evaluating both the near-term health of the production system and the long-term impact of improvement initiatives. The feedback provided by these sources allows for corrective action and the planning of new initiatives. One opportunity for improvement is to work towards refining tools that provide a more granular picture of key operational metrics. For example, while the monthly dashboard helps gives monthly data on productivity, operating expenses, throughput, etc., but the shop floor control system is not designed such that meaningful setup time data is collected. As described earlier, this setup time provides the most operational leverage for the work center, so both understanding the status quo of this metric and seeing the changes in this metric over time are extremely important. Visibility of a small number of these metrics provide context and explanation for the aggregate numbers already familiar to senior management and, more importantly, allow operators and supervisors to understand their own performance.

Chapter 4: Conclusion

4.1 Findings

Lean and Theory of Constraints (TOC) toolsets have been explored and combined to formulate a prioritization process that ensures a more effective and efficient lean transformation. This process can be summarized in four steps:

1. Define value and establish value metrics
2. Model and analyze the value stream
3. Improve the system
4. Control the system and Learn; Repeat

Suggestions for integrating this prioritization process with the corporate planning process have been supplied and a proscribed process is shown in Figure 4. It is expected that use of this prioritization framework will enable an organization to achieve their future state value stream vision with greater speed and less resources than otherwise possible. We conclude that the Theory of Constraints can provide an effective focusing tool for the lean enterprise.

This framework is further described within the context of a case study of a paper finishing production system at the Eastman Kodak Company. The location of the constraint in the paper slitting operation was confirmed. A sensitivity analysis of the system revealed the high leverage associated with reductions in changeover time on the productivity of the work center.

It is observed that applying quantitative models to value stream maps can provide valuable insights in highly complex and dynamic manufacturing environments. However, much of a model's value is realized when a structured approach to problem solving, as that proposed in this thesis, is applied. For example, this model was useful in answering very specific questions posed by the work center managers (e.g. "what is the impact of reducing lead time?"). With the proposed framework however, management was presented with a larger picture of the supply chain and is asked to focus the analysis (and future questions) on the most critical node in the chain. This targeted analysis pointed to ideas for future kaizens and processes that should be measured in more detail. While much of these results confirmed management's suspicions about where to focus resources, such a tool – when coupled with a formal process – ensures the optimal project portfolio is selected and allocated sufficient resources. In this manner, the work center can continue to reduce the cost and lead-time of photographic paper despite decreasing production volumes.

4.2 Areas for future research

This thesis touches the surface of a number of management topics where further research is warranted. A few of these areas include:

- Team learning: Which teams produce group intelligence and which teams produce groupthink? As team-based work is becoming more common, understanding the success factors associated with team-based work is becoming more important.
- Project valuation: These exercises generally result in management placing numerical values on items which generally aren't measured with numbers or simply throwing darts. Much work has been done on alternative valuation techniques (e.g. real options), but there remains substantial opportunity here.

Finally, we note that proposal of a process and a single case study doesn't constitute success. Application of this framework to other production processes, other industries, potentially non-manufacturing business processes is necessary in determining the usefulness of the thesis framework.

Appendix

INPUTS	Slitting CO Time	Slitting CO Freq	Slitting Availability	Stacker Downtime				
120%	24	6	12	144				
100%	20	5	10	120				
80%	16	4	8	96				
					Percent Change from 100%			
PRODUCTIVITY								
120%	308	308	311	310	-1.3%	-1.3%	-0.3%	-0.6%
100%	312	312	312	312				
80%	316	316	312	313	1.3%	1.3%	0.0%	0.3%
THROUGHPUT								
120%	41.4	41.4	41.9	41.8	-1.2%	-1.2%	0.0%	-0.2%
100%	41.9	41.9	41.9	41.9				
80%	42.4	42.4	41.9	42.1	1.2%	1.2%	0.0%	0.5%
SERVICE								
120%	83%	83%	87%	84%	-5.7%	-5.7%	-1.1%	-4.5%
100%	88%	88%	88%	88%				
80%	92%	92%	88%	89%	4.5%	4.5%	0.0%	1.1%
UTILIZATION								
120%	70%	70%	66%	67%	6.1%	6.1%	0.0%	1.5%
100%	66%	66%	66%	66%				
80%	61%	61%	66%	65%	-7.6%	-7.6%	0.0%	-1.5%

Figure 11: Complete sensitivity analysis results

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