

Manufacturing Responsiveness as a Competitive Advantage and Implementation in a Make-To-Order Environment

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Submitted to the Sloan School of Management and the Department of Electrical Engineering and Computer Science in partial fulfillment of the requirements for the degrees of

Master of Science in Electrical Engineering
and
Master of Business Administration


In Conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology
June 2005

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
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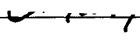
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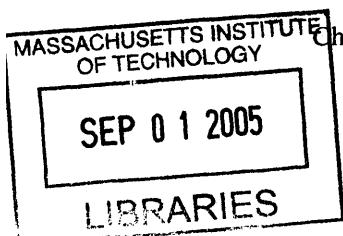
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Abstract

Many companies have been successful differentiating themselves and creating growth opportunities by developing a competitive advantage through their manufacturing operations. During the last century, this operational advantage has generally included economies of scale and the persistent pursuit of lower direct costs. However, this thesis contends that a cost focused manufacturing organization encourages decisions that in the long run make the organization rigid, inflexible and unable to implement innovations the market desires. Not unexpectedly, those companies that fail to recognize and incorporate changing market demands are relegated to reading about their competitor's successes in newspapers and journals.

This thesis further presents an argument to shift the manufacturing organization's operational focus away from cost and towards time. More specifically, this thesis posits that firms should persistently pursue a reduction in the time required to manufacture a customer's order from receipt to shipment.

The ideas here are based largely on literature research as well as insights gained during the author's 6.5 month internship at ABB CNTDS. ABB CNTDS is a joint venture manufacturer of power distribution transformers located in Shanghai, P.R. China. Distribution transformers are produced in a make-to-order environment and include significant engineering and customization for each customer's order. The concepts can, however, be extended to any manufacturing organization looking to gain a competitive advantage through speed, innovation, and customer focus - thereby avoiding the undesirable state of low margin, cost competition.

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Acknowledgements

The Leaders For Manufacturing Program has been an incredible experience. The collaboration of interests from students, faculty, and industry partners allows for a learning experience that is unparalleled and one that I am grateful to have been a part of.

This internship and thesis would not have been possible without the tremendous opportunities provided to me by ABB. Thank you very much to the people at ABB CNTDS for allowing me to become a part of the organization. And special thanks to my project supervisor, Joni Rautavuori, for the support and knowledge sharing. Also, to Sierra Mao and Alice Zhou for the often required interpreter assistance, as well as the Chinese language and culture lessons.

Most importantly, thank you to my family for supporting my frequent relocations and far-off journeys. Without you, none of my accomplishments would have been possible.

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Table of Contents

| | |
|---|----|
| Abstract..... | 3 |
| Acknowledgements..... | 5 |
| Table of Contents..... | 7 |
| Table of Figures..... | 9 |
| 1. Introduction and Thesis Overview..... | 11 |
| 1.1. Project Motivation..... | 11 |
| 1.2. Project Setting and Goals..... | 11 |
| 1.2. Thesis Overview..... | 12 |
| 2. Models of Industrial Dynamics..... | 13 |
| 2.1. Utterback-Abernathy Model of Industrial Dynamics..... | 13 |
| 2.2. Christensen Model of Disruptive Innovation..... | 14 |
| 2.3. The Product Life-Cycle..... | 16 |
| 2.4. A Common Theme – Cost Based Competition..... | 17 |
| 2.4.1. The Alternative – Value Based Competition..... | 18 |
| 3. Value Based Competition..... | 19 |
| 3.1. Time Based Competition..... | 19 |
| 3.2. Mass Customization..... | 20 |
| 3.3. Responsiveness..... | 22 |
| 4. Implementing Responsiveness - Theory..... | 23 |
| 4.1. Moving Away from Cost Competition..... | 23 |
| 4.2. Lead Time as a Metric..... | 24 |
| 4.3. Quick Response Manufacturing..... | 26 |
| 4.3.1. Utilization..... | 26 |
| 4.3.1.1. Variability Amplification..... | 26 |
| 4.3.1.2. Little’s Law..... | 27 |
| 4.3.1.3. From Push to Pull Production..... | 28 |
| 4.3.1.4. Kanban..... | 28 |
| 4.3.1.5. ConWIP..... | 29 |
| 4.3.1.6. Utilization..... | 30 |
| 4.3.2. Efficiency and Unit Cost..... | 31 |
| 4.3.2.1. Financial Metrics and Operational Decisions..... | 31 |
| 4.3.2.2. Aligning Finance and Operations..... | 33 |
| 4.3.3. On Time Delivery..... | 34 |
| 4.3.3.1. The Response Time Spiral..... | 34 |
| 5. Practical Implementation at ABB CNTDS..... | 37 |
| 5.1. Asea Brown Boveri, Ltd. | 37 |
| 5.2. Approach to Lean in Power Technologies Transformers..... | 37 |
| 5.3. ABB CNTDS, Shanghai, P.R. China..... | 38 |
| 5.4. Dry Transformer Process Flow..... | 40 |
| 5.5. Improving Responsiveness at ABB CNTDS..... | 41 |
| 5.5.1. Production Philosophy..... | 41 |
| 5.5.2. Production Planning and Scheduling..... | 42 |
| 5.5.2.1. Cross Department Integration..... | 43 |
| 5.5.2.2. Sequencing Software Tool..... | 44 |
| 5.5.3. Reducing High Value Material Inventory..... | 45 |

| | |
|--|----|
| 5.5.3.1. Copper Wire..... | 45 |
| 5.5.3.2. Core Steel..... | 46 |
| 5.5.3.3. Copper Foil..... | 48 |
| 5.5.4. Metrics Results..... | 50 |
| 6. Analysis of Change..... | 51 |
| 6.1. The Three Lenses..... | 53 |
| 6.2. Strategic Lens Analysis..... | 54 |
| 6.3. Cultural Lens Analysis..... | 55 |
| 6.4. Stakeholder Lens Analysis..... | 57 |
| 6.5. Using the Lenses..... | 59 |
| 7. Conclusion..... | 63 |
| Bibliography..... | 65 |
| Appendix A: ConWIP Parameters..... | 67 |
| Appendix B: Dry Transformer Production Flow..... | 68 |
| Appendix C: Oil Transformer Production Flow..... | 69 |
| Appendix D: ConWIP Card..... | 70 |
| Appendix E: Cross Department Integration Plan..... | 71 |
| Appendix F: Scheduling Tool Sequencing Result..... | 72 |
| Appendix G: Scheduling Tool Chart – Planned Weekly Capacity..... | 73 |
| Appendix H: Steel Inventory Tracking..... | 74 |
| Appendix I: Analysis of Monthly Foil Consumption..... | 75 |

Table of Figures

| | |
|---|----|
| Figure 1. Utterback-Abernathy Model..... | 13 |
| Figure 2. Christensen Model of Disruptive Innovation..... | 15 |
| Figure 3. Product Lifecycle..... | 16 |
| Figure 4. Cost Based Competition..... | 17 |
| Figure 5. Value Based Competition..... | 18 |
| Figure 6. Framework of large scale manufacturing..... | 20 |
| Figure 7: Kanban Control..... | 28 |
| Figure 8: ConWIP Control..... | 29 |
| Figure 9. Effect of Utilization and Variability on Lead Time..... | 30 |
| Figure 10. Response Time Spiral..... | 35 |
| Figure 11. Power Distribution Transformers..... | 39 |
| Figure 12. ConWIP Pull Production Board..... | 41 |
| Figure 13. ConWIP cards in Insulation..... | 42 |
| Figure 14. Core Steel Purchasing..... | 47 |
| Figure 15. Inventory Reduction Results..... | 50 |
| Figure 16. Revenue Growth and Cash Flow..... | 51 |
| Figure 17: Inventory / Revenue..... | 51 |
| Figure 18: Lead Time and Output..... | 52 |
| Figure 19: ABB CNTDS Org Chart, June, 2004..... | 58 |
| Figure 20: CP3 Goals..... | 60 |
| Figure 21: ABB CNTDS Org Chart, September, 2004..... | 61 |

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Chapter 1. Introduction and Thesis Overview

1.1. Project Motivation

Many companies have been successful differentiating themselves and creating growth opportunities by developing a competitive advantage through their manufacturing operations. During the last century, this operational advantage has often included economies of scale and the persistent pursuit of lower direct costs. However, this thesis contends that a cost focused manufacturing organization encourages decisions that in the long run make the organization rigid, inflexible and unable to implement innovations the market desires. Not unexpectedly, those companies that fail to recognize and incorporate changing market demands are relegated to reading about their competitor's successes in newspapers and journals.

This thesis further presents an argument to shift the manufacturing organization's operational focus away from cost and towards time. More specifically, this thesis posits that firms should persistently pursue a reduction in the time required to manufacture a customer's order from receipt to shipment.

1.2. Project Setting and Goals

The ideas here are based largely on literature research as well as insights gained during the author's 6.5 month internship at ABB CNTDS. ABB CNTDS is a joint venture manufacturer of power distribution transformers located in Shanghai, P.R. China. Distribution transformers are produced in a make-to-order environment and include significant engineering and customization for each customer's order. The concepts can, however, be extended to any manufacturing organization looking to gain a competitive advantage through speed, innovation, and customer focus - thereby avoiding the undesirable state of low margin, cost competition.

The deliverables associated with this internship were:

- Operational Process Improvements – ConWIP implementation to move from push based production to pull based production with the end result being reduced manufacturing lead time.
- Material Inventory Reduction – Reduction of high-value material inventory. Includes looking into purchasing procedures and engineering requirements.
- Change Implementation – outsider analysis of practical change at ABB Shanghai with learnings that can potentially be applied to other China subsidiaries of ABB.

1.3. Thesis Overview

This thesis is divided into three main parts. First, I use three well regarded models of industrial dynamics to develop the idea that the traditional view of a competitive advantage in manufacturing is based on economies of scale and efficiencies; the end result of which is an inability to be responsive to changing market demands and further leads to low margin, cost competition. Second, I present an alternative manufacturing philosophy to shift the organization away from concentrating solely on cost and instead become aligned to compete on responsiveness. Lastly, I provide an account of the practical implementation of change towards a more responsive organization as carried out at ABB CNTDS in Shanghai, P.R. China. Along with this account I have included an analysis and general method for implementing change in an organization.

Chapter 2. Models of Industrial Dynamics

In this chapter I use three well regarded models of industrial dynamics to develop the idea that the traditional view of a competitive advantage in manufacturing is based on economies of scale and efficiencies, the end result of which is an inability to be responsive to changing market demands leading to low margin, cost competition.

2.1. Utterback-Abernathy Model

The Utterback-Abernathy model of the Dynamics of Innovation is shown in Figure 1. The rate of product innovation and process innovation are plotted over time. Product innovation includes the underlying technology, market application, features and design. Process innovation refers to the manufacturing capabilities and methods used to fabricate or assemble the product. Utterback describes the three phases of industrial innovation as follows:

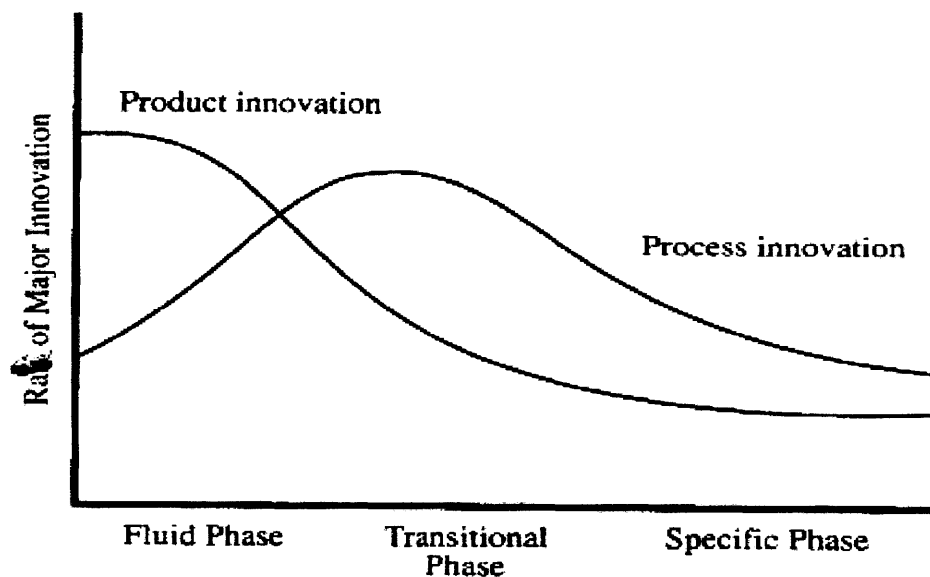


Figure 1: Dynamics of Innovation¹

During the fluid phase, a greater proportion of resources are devoted to product development. There is technical uncertainty and design revisions are frequent. Prototypes are constructed via makeshift manufacturing processes that are flexible and inefficient by

¹ James M. Utterback, Mastering the Dynamics of Innovation, (Harvard Business School Press, 1994).

mass-production measures. The organization's focus is on key product attributes such as market need, performance and aesthetics. A firm can develop a competitive advantage in the fluid phase through rapid prototyping, forecasting market needs, or competency in research and development.

In the transitional phase, a dominant design tends to emerge and therefore the rate of product innovation declines. However, the importance and rate of process innovation increases to accommodate rising demand. Parts and materials become standardized and production volume rises. The manufacturing process, while still somewhat flexible, is heading towards rigidity where changes will be less easily accommodated. An appropriate analogy being that of liquid concrete hardening over time. A competitive advantage in the transitional phase results from providing the customer with value in product performance, attributes and quality; whereby value is perceived relative to other options.

In the specific phase, the product and manufacturing process are tightly coupled such that an innovation in either is difficult and costly. Product features are standard and common, and quality is expected. During this phase, the industry dynamic is cost-based with low cost manufacturing firms having a clear advantage.

The Utterback-Abernathy model is important because it highlights a shift in organizational focus from product innovation to manufacturing process innovation as a means to maximize the revenue gained from a dominant product design. Implied within the model is the subsequent inflexibility to implement changes customers later require. This inability to adapt opens up market space for new competitors, the competitive dynamics of which are best described by the Christensen model of disruptive innovation.

2.2. Christensen Model of Disruptive Innovation

The characteristic Christensen model of industry dynamics is shown in Figure 2. An incumbent firm is focused on the needs of Market 'A' and aligned for incremental improvements in product features or process technology for that market. A smaller niche or lower overall potential profit market (Market 'B') emerges, requiring a similar product

or technology - yet one that is generally of lower performance and higher cost by Market 'A' standards. Given the incumbent firm's entrenchment in Market 'A' and its tightly coupled product and production processes, the incumbent chooses (either through active thought or passive neglect) not to participate in the niche market. This decision creates an opportunity for an entrant firm.

Christensen provides examples of industries where the performance and cost of the entrant product or technology improved over time and eventually satisfied the needs of Market 'A'. This direct competition from below relegated the incumbent to obsolescence or commoditization.

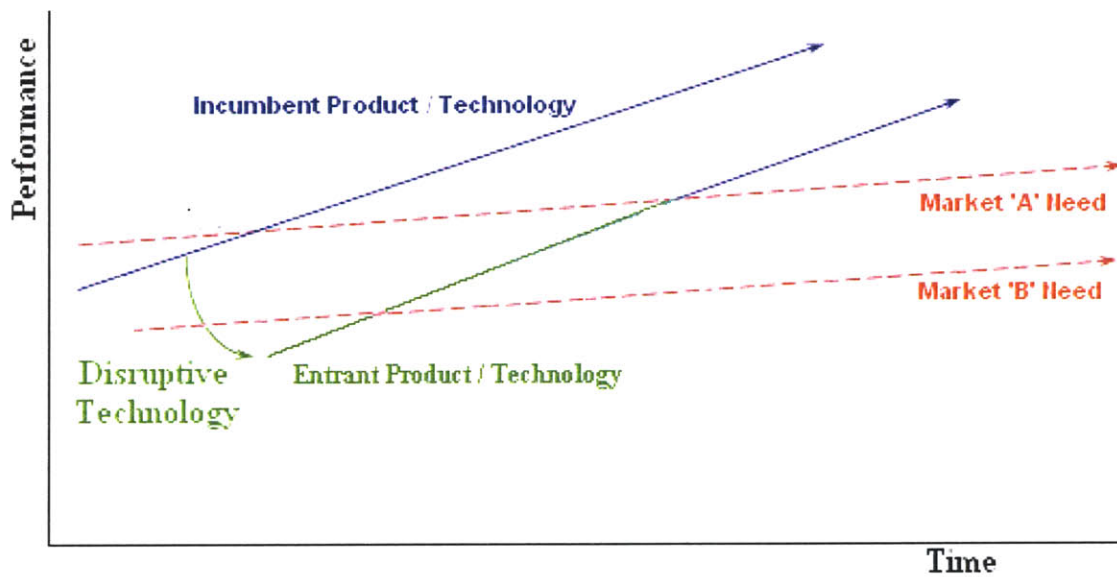


Figure 2: Christensen Model of Disruptive Innovation²

The Christensen model provides a valuable analysis of the long term industry structure that results when firms are too narrowly focused on the short term potential of what is likely a dominant design. These firms have shifted away from product innovation and towards process innovation to increase output and lower costs. In the process, they have reduced the organizational and functional bandwidth available to satisfy the requirements of all potential customers allowing niche market entry to future direct competitors.

² Clayton M. Christensen, *The Innovator's Dilemma*, (Harvard Business School Press, 1997).

2.3. The Product Life Cycle

Figure 3 depicts a typical product's life cycle. Consumer demand is plotted against time and we see the various stages from development to obsolescence. I have further superimposed a curve depicting the cumulative profit potential over the life cycle of the product.

During the development phase, money and other resources are invested in product development with the hopes of earning a return on that investment through future sales. And when – if – the product is introduced and revenue is generated, the firm begins to see a return on investment. The potential rate of profit growth is highest during the introduction and growth phase because the new product assumably has the most value to the consumer relative to other options. This assumption generally holds true if the product is innovative in performance, design, market application, or even cost basis (process technology). And given this assumption, the company producing this product will likely have the pricing power to generate higher margins.

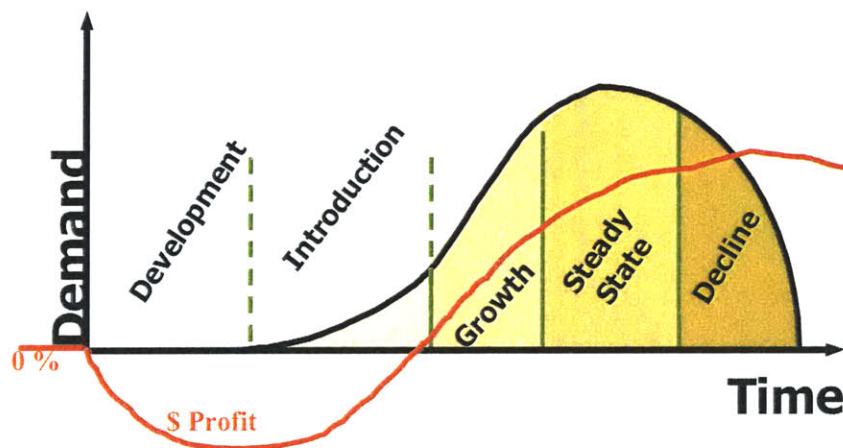


Figure 3: The Product Life Cycle³

As we move further along the product life cycle, competitors enter the market and the key competitive metric becomes cost. Production efficiency is the benchmark, product innovation is minimal, and companies strive for low cost manufacturing. It is at this point

³ Thomas Roemer (2002), *The Art of Forecasting*, Lecture given in 15.761 Operations Management, Massachusetts Institute of Technology, Cambridge, MA.

that margins shrink and the product is commoditized or becomes obsolete. Either way, the ability to gain sizeable profit margins disappears and often the product even creates a drain on the companies resources – particularly as it is end-of-lifed or discontinued.

2.4. A Common Theme – Cost Based Competition

The three models introduced above all result in cost based competition (Fig. 4) for the firm that is unable to adapt to changing market demands. Often, this is the result of inextricably linking the product with the production process such that change is viewed as prohibitively costly and the desire to protect short term interests weighs heavily. Unless the firm has a distinct capability advantage as a low cost manufacturer (labor, experience, product design, input materials, distribution) or a positional advantage resulting from brand name or channel relationships, cost competition is generally not a favorable position for firms to be in because customers have a wide choice of equivalent options to choose from and the products are essentially commoditized.⁴

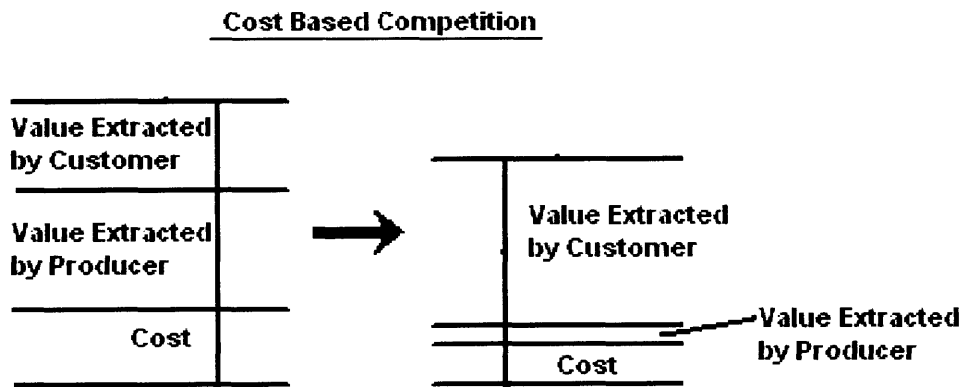


Figure 4: Cost Based Competition⁵

Furthermore, cost competition results in low pricing power, low profit margins and therefore a diminished ability for a producer to extract value from the value chain. It is a no win situation for everyone including the consumer due to slow product innovation.

⁴ Robert Grant, Contemporary Strategy Analysis: Concepts, Techniques, Applications, (Blackwell Publishers, 2002).

⁵ D. Besanko, et al, Economics of Strategy, (John Wiley and Sons, 2004).

Quality is no longer a competitive advantage but a requirement to garner attention from the customer.⁶

2.4.1. The Alternative – Value Based Competition

Ideally, a producer would like to compete not on cost, but instead on value (Figure 5). Notice in cost based competition there is a fundamental lower limit of zero value extracted by the producer. However, in value competition, the potential to add value into the value chain is limitless - as is the producers ability extract value (which would be akin to a monopolistic situation).

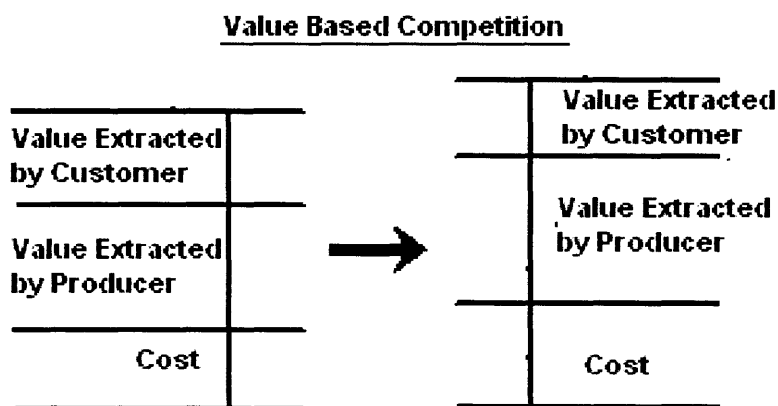


Figure 5: Value Based Competition⁷

Even if the product costs more to produce – resulting from “inefficient” manufacturing practices – the producer is able to both charge and extract more because it remains in the introduction and growth phase of the product lifecycle. Customers in turn are willing to pay the higher price because they are receiving more value.

The question then becomes, what can a manufacturing firm do to avoid cost based competition and position itself to both create and capture value for its customers? The next section discusses two alternatives to low cost manufacturing. Namely, time and customization.

⁶ Rajan Suri, Quick Response Manufacturing, (Productivity Press, 1998).

⁷ D. Besanko, et al, Economics of Strategy, (John Wiley and Sons, 2004).

Chapter 3. Value Based Competition

3.1. Time Based Competition

As a strategic weapon, time is the equivalent of money, productivity, quality, and innovation.⁸

I was home for the holidays and frequently borrowed my father's car to run errands and meet friends. On my way out one day, he gave me \$15 and a coupon for a \$14.99 oil change (regularly \$19.99) at a well known auto service retailer. I stopped at the store and the attendant said it would be 2-4 hours and that I could leave the car and pick it up either later that day or the next morning. I asked how long the actual oil change would take and they told me 45 minutes to 1 hour. I consequently chose not to leave the car and instead drove down the street to another retailer I knew specialized in fast oil changes with little waiting. There were two garages with a waiting car in front of one. I pulled in front of the second and 25 minutes later I had paid \$24.99 and was leaving.

I paid a 67% premium over the first retailer because to me, time was the critical decision factor. I assumed the quality of service was equivalent and further assumed there would be some sort of guarantee on the work performed because I view an oil change as essentially a commodity product. In this example, the quick-change retailer differentiated itself and was able to both create and extract value from the consumer at a substantial price premium.

In their book, *Competing Against Time*, George Stalk and Thomas Hout present examples of companies that have used time compression to improve productivity, increase profit margins, reduce risk and grow market share. These are businesses that have changed their mission from "the most value at the lowest cost" to "the most value in the least amount of time" and have been substantially rewarded with growth and profits.⁹

⁸ George Stalk, Jr., and Thomas M. Hout, *Competing Against Time*, (Free Press, 1990).

⁹ Ibid.

Returning to the oil change example, the faster retailer has almost 50% higher productivity (from my unscientific inquiry into how long the actual oil change would take). Profit margins are higher, and their market share is growing at the expense of the cost based retailer if you assume there are other people like me. Even if the cost of goods sold or labor input is higher, the time based competitor will have increased overall value to the consumer more than enough to overcome this (see Figure 5).

Additionally, Stalk and Hout present the argument that overall business risk is reduced with time compression. This is because there is less reliance on demand forecasting and make to stock planning. And in dynamic systems, time delays add to the instability of the system, increasing the chance for large variations in predicted outcome.¹⁰

3.2. Mass Customization

Mass Customization is positioned as the opposite of mass production with all other forms of large scale production lying somewhere in between (Fig. 6).

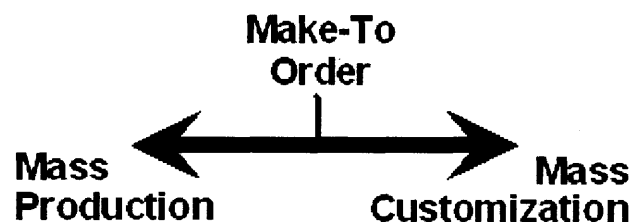


Figure 6: Framework of large scale manufacturing

The extreme of mass production is exemplified by the first mass produced shoes in America, called “straights” because there was no differentiation between the right and left shoe¹¹. Now, however, Nike.com has a link, “Customize”, on their website where not only can customers order a right and a left shoe, but they can modify the color of nine different areas on the shoe (3 billion different combinations) and add a personalized ID label.¹² The next step for true mass customization would be to use an exact mold of

¹⁰ John Sterman, *Business Dynamics*, (McGraw Hill, 2000)

¹¹ Robert Reich, *The Future of Success*, (Vintage, 2002)

¹² Homepage <<http://www.nike.com>>

customers' feet to properly size the shoe. The make to order concept lies approximately in the between mass production and mass customization – offering a more limited set of color and size options with the key concept being that the product is not manufactured until the customer chooses to purchase it.

Also included in the concept of mass customization is the flexibility to adapt to emergent and niche segments of the market.¹³ Not only does an athletic shoe manufacturer want to produce a variety of shoes for larger segments (basketball, tennis, running, etc) instead of a general purpose athletic shoe, but it also should be able to supply small emerging segments such as skateboarding rather than allow a competitor entry. Being able to satisfy these emerging markets guards against disruption from below.

In the book, *Mass Customization*, B. Joseph Pine describes modern mass production as the continuation of decades of management thought stemming from the influence of Taylorism, economies of scale and standardized interchangeable parts. He argues that this paradigm evolved to include specialized machines that augmented low cost manufacturing; and the system in turn was reinforced by a relatively localized, stable and content market.¹⁴

Market conditions have changed, however, such that there is less demand stability for the singular products many of today's large organizations are aligned to produce. Global markets want localization and customers want individualization. This does not mean firms must always compete in times of turbulence. In fact, firms can diversify risk and experience stable growth by offering customers a variety of products and options with more frequent innovation cycles. However, this requires the realization that the modern mass production system is ill suited to perform this task given its focus on economies of scale.¹⁵

¹³ B. Joseph Pine, *Mass Customization*, (Harvard Business School Press, 1993).

¹⁴ Ibid.

¹⁵ Ibid.

3.3. Responsiveness

For the remainder of this thesis, I will describe speed and customization together with one word— *responsiveness*. Competing based on responsiveness has the effect of keeping the firm in or near the growth phase of the product life cycle where pricing power and profit margins are sustainable. This is because the firm is able to adapt to and quickly implement the incremental and simple changes required by customers that plague the incumbent in Christensen's model.

The disruptive technology in Christensen's model is not disruptive to the customer. Rather, it is value added to the customer. It is only disruptive to the incumbent firm that fails to acknowledge or accept it. Furthermore, the disruptive technology is generally not considered a technological breakthrough. Instead it is a simple adaptation of existing knowledge to new markets and applications.¹⁶ These insights are important because it means a firm that is able to adapt to minor product and market dynamics is able to remain in a sustainable competitive position without major technological strides¹⁷.

Being responsive also prevents the organization from progressing into the specific phase detailed by the Utterback-Abernathy model. When responsiveness is in place, the product and production process should never become so narrowly defined so as to make change in either prohibitive. Furthermore, over time the organization will excel not only at managing transitions, but at managing transitions when time is critical. And this fact should not be overlooked as a valuable capability advantage.¹⁸

Today's consumer has a wealth of information in front of her such that the ability to search for a better product or service is easier than ever.¹⁹ If one firm does not provide the ideal product or service at a competitive price, rest assured another one will.

¹⁶ Clayton M. Christensen, *The Innovator's Dilemma*, (Harvard Business School Press, 1997).

¹⁷ This does not mean major technological innovation is not important to a firm wishing to introduce new product lines. It only refers to allowing the current product line to compete on value rather than cost.

¹⁸ Kathleen M. Eisenhardt, and Shona L. Brown, "Time Pacing: Competing in Markets that Won't Stand Still", *Harvard Business Review*, March-April (1998).

¹⁹ Robert Reich, *The Future of Success*, (Vintage, 2002)

Chapter 4. Implementing Responsiveness - Theory

In order to implement responsiveness as a strategic focus, the manufacturing organization must be aligned to that goal. Bear in mind however, this is no trivial feat and in many ways requires a significantly different thought process towards manufacturing and the factory than found in modern mass production. Most importantly, it requires recognizing that it is both managerially attainable and fiscally desirable to utilize a firm's manufacturing operations as a strategic core competency rather than framing production as a necessary encumbrance and cost burden.

To be sure, responsiveness requires change in all aspects of a corporation from research and development to product design to sales and manufacturing. However, concurrent with the focus of the author's internship this thesis will focus mainly on the factory and production as applied in a make-to-order environment.

4.1. Moving Away from Cost Based Competition

Which came first, cost based competition or cost based performance measures? It is not the purpose here to answer that question, but to point out that the two are one and the same. Fundamentally, cost based performance measurement rewards efficiencies in the production process. And it is this quest for production efficiency - the lowering of per unit costs - that inevitably leads to the specific phase of the Utterback-Abernathy model where inflexibility from product-process linkage is the defining characteristic. Measuring output, utilization and on time delivery are all by-products of this paradigm. So, if cost based competition is the end result, why is it that firms try so hard to get there?

In reality, customers are not concerned with a factory's efficiency or how utilized the equipment is. Customers do not care how much output a factory produces. Customers are indifferent as to a factory's overall quality or first pass yield – as long as their purchase and every other product the factory actually ships is defect free. And customers are uninterested in a factory's overall on time delivery; a factory could have 100% on time delivery but if that time range is beyond the customer's requirement then it doesn't do

much good.²⁰ Customers only care about receiving what they want, when they want it, and at a competitive price to value. And they largely make decisions based on these factors.²¹

The Toyota Production System and Lean Manufacturing have gained wide acclaim as companies have used their implementation to successfully improve their manufacturing operations. However, this philosophy is best suited for high volume product lines with relatively stable demand. Because the focus of lean manufacturing is using continuous improvement practices to eliminate waste, improve quality, and reduce cost²², the end result is a *highly efficient, low cost* factory - a factory that has positioned the firm in the specific phase of the Utterback-Abernathy model and is therefore ill-suited to address a disruptive competitor as described by Christensen. This factory instead competes based on cost in the steady state segment and eventually the decline segment of the product life cycle.

4.2. Lead Time as a Metric

In a responsive organization, the key metric is lead time²³ and the goal is a systematic approach to reducing lead time in the value stream. The beauty of focusing on lead time is the simplicity of having the organization aligned to only one metric.²⁴ Systematically concentrating on lead times enables easy identification of the seven forms of waste commonly associated with the Toyota Production System and Lean Manufacturing:

- *Overproduction*: Overproduction is considered the worst form of waste in a factory.²⁵ In a make to order environment, overproduction results when a customer places an order and then refuses payment or cancels the order after it has started.

²⁰ Rajan Suri, *Quick Response Manufacturing*, (Productivity Press, 1998).

²¹ George Stalk, Jr., and Thomas M. Hout, *Competing Against Time*, (Free Press, 1990).

²² Rajan Suri, *Quick Response Manufacturing*, (Productivity Press, 1998).

²³ Lead time and cycle time are often used interchangeably, however for the purpose of this thesis lead time will refer to the time required from customer order to customer receipt. This thesis will also assume a degree of customization such that production is not started until the customer places the order. Cycle time will refer to the actual in-process time of an individual workstation.

²⁴ Ibid.

²⁵ Kiyoshi Suzuki, *The New Manufacturing Challenge*, (Free Press, 1987)

Removing time from the process reduces this probability and highlights deficient customers. As mentioned previously, in a dynamic system time only adds to the instability of the outcome.

- *Waiting Time*: The Toyota Production System includes idle machines waiting on product as a waste.²⁶ However, when thinking about responsiveness this is not necessarily a concern and will be addressed in detail later. Waiting time for this purpose only refers to anytime the customer's order is not occupying a machine, person or transportation. For example, paperwork requiring a signature could be at the bottom of a pile or a semi-finished product is queued in front of a machine to be worked on.
- *Transportation*: While transportation is not considered waiting time, it is still a burden on overall lead time and unnecessary transportation should be removed from the value stream. This particular waste and its effect on lead time should be studied carefully when making a decision to relocate production overseas based on low labor costs.
- *Excess Processing*: Excess processing of a customer order consumes time and should be removed from the value stream. Excess processing includes non value-added steps prior to beginning production such as signatures or approvals, as well as non value-added production operations such as inspections. Furthermore, operations that can be removed from the flow through a better production process or product design can be considered non value-added.
- *Inventory Waste*: Little's law tells us that high WIP means high lead times. This also will be explored in more detail later. Additionally, excessive time in the supply chain means inventory must be carried at a number of steps in the value stream – tying up cash that could be used otherwise. One final consequence of holding inventory is that as inventory becomes excessive or obsolete, the firm is motivated to promote specific products to customers at discounted prices.

²⁶ Kiyoshi Suzuki, The New Manufacturing Challenge, (Free Press, 1987)

- *Excess Motion*: Employees looking for materials and tools, or walking long distances to obtain required information adds time to the system. Employees should have all required items and information when it is needed.
- *Production Defects*: Quality problems in the manufacturing process add to the overall lead time because defective units spend time in rework loops and producing defective parts utilizes manufacturing resources that could be processing non-defective products. The potential production of defective parts also creates a need for non-value added inspection steps that occupy a significant amount of time and resources.

4.3. Quick Response Manufacturing

Quick Response Manufacturing is a thought process proposed by Rajan Suri in his book, “Quick Response Manufacturing: A Companywide Approach to Reducing Lead Times”. In it, he identifies the pursuit of lead time reduction as the ideal goal for companies wishing to compete on responsiveness. Furthermore, he identifies tenets of modern mass production that must be changed in the minds of managers who wish to compete on responsiveness.

- Traditional belief #1: 100% utilization of people and machines.
- Traditional belief #2: Raise efficiency and lower per unit costs.
- Traditional belief #3: 100% On Time Delivery.

4.3.1. Utilization

4.3.1.1. Variability Amplification

Variability amplification, commonly referred to as the “bull-whip effect” in supply chains, is a result of the Variance Sum Law which states that for two independent random variables, the combined variance is the sum of the individual variances. For supply chains, this represents the minimum potential bull-whip effect.

$$\text{Variance Sum Law: } \sigma_{x+y}^2 = \sigma_x^2 + \sigma_y^2$$

Individual component variances result from distinct boundaries between companies and customers and include independent forecasting, system time delays and a general lack of communication. These same factors can be present within a single factory or company in the form of distinct functional areas, inefficient information mediums and the decoupling of actual production from customer demand and planning processes. The end result is high inventory (material, WIP, FG) and long lead times.

4.3.1.2. Little's Law

To understand the impact of variability on WIP and Lead Times further, we invoke the use of Little's law which states that the total time a unit stays in a system (lead time) equals the total number of units in the system (work in process) divided by the average number of units produced per unit time (throughput²⁷).

$$\text{Lead Time} = \frac{WIP}{\text{Throughput}}$$

Notice the use of the term average in the last statement. When this is applied to manufacturing systems, actual values for throughput are random functions with mean and variance that comes from machine downtime, process time variance, operator variance, etc. However, there exists an upper limit on the throughput of the system. Whereas the system could and does have slower throughput all the way down to zero parts produced per unit time, there is a maximum to how fast the system can produce to catch up. Therefore, if the planning system plans for and releases production jobs based on a 100% capacity, the production system will not be able to clear a buffer formed during low throughput periods resulting in a growing queue of WIP.

²⁷ Throughput = capacity¹

4.3.1.3. From Push to Pull Production

A change from push production to pull production addresses the need to decouple production from customer demand and planning processes by introducing a feedback loop into the system. Instead of releasing jobs into the system based on a start date derived from forecasted demand and capacity, pull systems begin production based on signals from downstream processes - where a downstream process can be either the next operation or a customer order. This means that capacity information from downstream processes is communicated to upstream operations. A common form of intra-factory pull production is the kanban system often mentioned in articles and texts that describe the Toyota Production System or Just-In-Time (JIT) manufacturing philosophies.

4.3.1.4. Kanbans



Figure 7: - Kanban control. Movement of parts shown in blue, circulation of kanbans in red. Machines are shown as circles and buffers as triangles. The last buffer is the finished goods (FG) inventory.²⁸

Kanban systems work by controlling the size of an inventory buffer between operations. If the inventory buffer is full, the upstream operation does not produce another part. Through continuous improvement activities, inventory buffer sizes can gradually be reduced. The limiting of WIP between stations, and therefore the overall WIP in the factory, has tremendous secondary effects. Not only is lead time reduced, but variation resulting from other underlying production problems such as quality, excess inventory and inefficient processes are exposed. Studies have shown that it is the ability of pull production systems to highlight these secondary problems that provides the real performance benefit compared to push systems.²⁹

²⁸ Abjoern M Bonvik, "How to Control a Lean Manufacturing System", <<http://web.mit.edu/manuf-sys/www/amb.summary.html>>

²⁹ Spearman, et al. "CONWIP: a pull alternative to kanban.", *Int. J. Prod. Res.*, 28:5 (1990)

However, kanban systems have a fundamental weakness in that the inventory buffer between operations only protects downstream operations from upstream variation. Upstream operations are still prone to downstream demand variations amplified throughout the system; resulting in excess WIP and inventory.³⁰ For this reason, kanban can be an ineffective solution in factories with job orders or short production runs, processes that have significant setup times or expectedly high yield losses, or customer markets with large demand variation. Therefore, in these situations an alternative pull system is needed.³¹

4.3.1.5. ConWIP

ConWIP (Continuous Work-In-Process) extends the kanban concept to include a larger segment of the production line and potentially the entire production line. Appendix A provides a breakdown of ConWIP parameters.

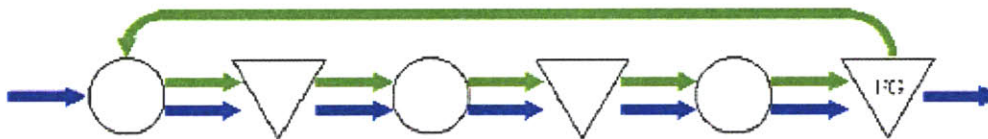


Figure 8: CONWIP control. Movement of parts shown in blue, circulation of release authorizations in green.³²

Whereas kanban feeds demand information upstream through parts inventory at individual operations (succumbing to variability amplification), the ConWIP method controls inventory in the entire line by only allowing a new job to begin production when another job finishes production. This information medium is less susceptible to noise because the flow of information is separated from the flow of parts. As opposed to kanban, the resting state in a ConWIP process is zero buffer inventory which means lower overall inventory during normal operation.³³ And lower overall inventory means lower lead times.

³⁰ Abjoern M Bonvik, "How to Control a Lean Manufacturing System", <<http://web.mit.edu/manuf-sys/www/amb.summary.html>>

³¹ Spearman, et al. "CONWIP: a pull alternative to kanban.", *Int. J. Prod. Res.*, 28:5 (1990)

³² Abjoern M Bonvik, "How to Control a Lean Manufacturing System", <<http://web.mit.edu/manuf-sys/www/amb.summary.html>>

³³ Ibid.

In effect, ConWIP envelops the entire production system under Little's Law. Compared to a push production system, the variable of control is factory WIP instead of factory capacity. This is beneficial because WIP is easy to see and count whereas capacity is difficult to measure and often subjective – especially when applied to high product mix environments.³⁴ Compared to kanban, ConWIP provides greater support to responsiveness because the production philosophy changes from the desire for parts (buffer inventory) being available when the equipment is ready, to the equipment being available when orders arrive. This insight leads to the conclusion that factory managers should account for throughput variability and prevent WIP buildup by strategically planning to operate at 70%-80% of bottleneck capacity. Note that this strategy also takes into account the effects of the upper capacity limit constraint such as inventory queues and long lead times.³⁵

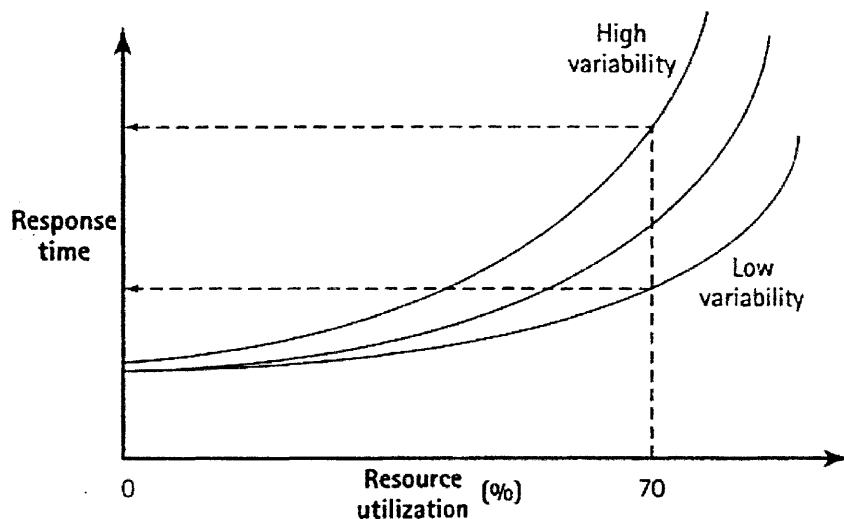


Figure 9: Effect of Utilization and Variability on Lead Time³⁶

4.3.1.6. Utilization

Strategically planning to operate below full capacity should be viewed by managers as an investment rather than a cost. The return on investment comes from higher quality, better productivity, lower material inventory requirements, increased sales and contented

³⁴ Spearman, et al. "CONWIP: a pull alternative to kanban.", *Int. J. Prod. Res.*, 28:5 (1990)

³⁵ Rajan Suri, *Quick Response Manufacturing*, (Productivity Press, 1998).

³⁶ Ibid.

customers, and reduced overhead – all byproducts of reduced lead times. In the long term, this investment in capacity is financially prudent. A simple example is as follows: If one factory operates at 90% utilization and has 70% yields, the net value added output is $.9 \times .7 = 63\%$ of capacity. Whereas another factory operating at 80% utilization with 90% yields has net value added output of $.8 \times .9 = 72\%$ of capacity.³⁷ Remember that customers and their money do not care what the utilization of your machines are, only that they are getting the product they want when they want it. This simple example shows how both parties can benefit from accounting for throughput variability.

4.3.2. Efficiency and Unit Cost

So what is it about excess capacity that makes factory managers cringe at the suggestion of its strategic importance? Frequently, it is high fixed cost investments in specialized machines. One raises production efficiency by spreading machine depreciation and factory overhead costs over a greater number of units. This action indeed presents a logical case for high utilization. However, raising production efficiency encourages behavior that is extremely detrimental to lead times and ultimately negatively impacts the business financials as well as the company's ability to be responsive.

4.3.2.1. Financial Metrics and Operational Decisions

Often in manufacturing organizations there is a disconnect between the financial accounting and the operational practices used to generate those financial requirements. The main financial indicators are profit, return on investment and cash flow. Profit is undoubtedly the goal of the company; but the investment used to generate that profit needs to be understood as well and so we want to include an analysis of return on investment (ROI). Moreover, a company that generates a profit on paper but has negative cash flow will quickly find itself unable to pay its bills and continue operating. Unfortunately, operationally these three financial goals are interpreted as cost performance goals which leads the company into the low cost manufacturing realm.³⁸ The following bullets

³⁷ Rajan Suri, Quick Response Manufacturing, (Productivity Press, 1998).

³⁸ Eliyahu Goldratt, and Robert Fox, The Race, (North River Press, 1986).

represent operational decisions are commonly made in order to lower costs and thereby raise efficiency:

- *Capital equipment evaluations based on reducing per unit costs:* Highly specialized, fixed cost capital investments have been mentioned quite frequently throughout this thesis as an impediment to responsiveness and an impetus towards cost competition. It is typically the forecast of continued or increasing demand for the same product without considering potential value added changes or disruptive innovations that lead companies to invest heavily here.
- *Economic order quantities and batching:* The EOQ analysis attempts to optimize the trade-offs associated with setup costs and inventory holding costs. However, there are other factory dynamics at play especially when a factory produces multiple product configurations. These include the costs of not detecting a quality problem until a large batch has completed, costs attributable to obsolescent material and the need to make engineering revisions, the effect of large batches on lead times and late delivery fees, and the market value of being able to provide the customer an order in less time.³⁹
- *Volume discounts:* Whereas volume discounts are beneficial for ensuring factory loadings, they only encourage decisions that move the organization towards cost competition. This is especially true if the capital equipment reinforces volume discounts or if other customers are turned away because of a lack of capacity. Suri suggests working with customers to reduce the need for volume orders by proving the factory's ability to deliver smaller quantities as needed.⁴⁰
- *Building ahead:* Factories build ahead either to save on setup costs or to occupy slack resources. Building ahead to save on setup costs means that one customer's order is being unintentionally prioritized over another customer. Slack people resources can be put to more long term productive uses such as advanced skill training or lead time reduction projects. Furthermore, slack people resources could

³⁹ Rajan Suri, Quick Response Manufacturing, (Productivity Press, 1998).

⁴⁰ Ibid.

be moved to areas of the factory that are not currently over staffed. As for slack equipment resources and in addition to the argument of excess capacity as an investment, maintenance schedules can be rearranged, the equipment can be used for training, or the equipment could be used to bring another product into the factory.

4.3.2.2. Aligning Finance and Operations

The above operational decisions have a common negative effect on lead time. Parts that are not immediately wanted by a customer are occupying resources that could otherwise be utilized towards producing parts that have been requested. The end result is a negative effect on the lead time of actual customer orders.

As an alternative to cost and efficiency based metrics, Goldratt and Fox identify key operational concepts from *The Goal*⁴¹ that more directly relate to the three key financial metrics mentioned above.⁴²

- **Throughput:** The rate at which money is generated through sales (not production). If something is produced but not sold, then it does not count as throughput. Notice that the last statement also will take into account the negative effects of quality problems.
- **Inventory:** Money invested in purchasing materials intended to be sold.
- **Operating Expenses:** Money spent to turn inventory into sales. Includes direct labor, management, support functions, and equipment depreciation, but excludes as waste any function not related to turning material into sales.

The main idea is that higher throughput, lower inventory, and lower operating expenses all directly improve net profits, return on investment, and cash flow. Operationally, decisions therefore should not be based on the impact to cost but on the net impact to these three

⁴¹ Eliyahu Goldratt, and Jeff Cox, *The Goal*, (Gower Publishing Limited, 1986).

⁴² Eliyahu Goldratt, and Robert Fox, *The Race*, (North River Press, 1986).

categories. Notice also, that through Little's Law we can combine higher throughput and lower inventory (includes WIP) into one metric – lead time.

4.3.3. On Time Delivery

The problem with On Time Delivery as a metric is that it does not reflect the production system's ability to meet customer needs. When customers place an order, the firm tells them the soonest it can provide that product based on its own internal lead time. If that time frame is too long, the customer goes somewhere else (as I did for an oil change). Some customers do choose to wait and the production system's performance to its own internally generated metric is measured. Even if the company is operating at 100% On Time Delivery, where is the fact that some customers are leaving to go elsewhere accounted for? Additionally, what happens when the production system starts falling behind its OTD performance goal? To answer this last question it is appropriate to understand the dynamics of the failure in the first place:

4.3.3.1. The Response Time Spiral

When management sets a target for the OTD performance of the factory, everything becomes aligned to that performance indicator including sales, production scheduling and purchasing. The factory is planned to operate at a high utilization to raise efficiencies and lower per unit costs which, as previously shown, creates long lead times and WIP queues. Upon seeing "important" orders falling behind, management elevates the status of these orders to priority or "hot". They are then able to speed through the factory at the expense of other jobs that then fall behind schedule. Some factories even progress to an out-of-control state where eventually every job had some sort of priority assigned to it.⁴³

The natural response of management is to link lead times as an inevitable byproduct of increased size and output. Therefore, to ensure the company is able to quote customers a realistic delivery date and guarantee on time delivery performance, the projected lead

⁴³ "Vandelay Industries, Inc.", *Harvard Business School Publishing (Cases)*, 698049.

times are increased.⁴⁴ Notice that there is no feedback from the customer in this process and more importantly, from the customer's point of view the value of the metric has in fact worsened.

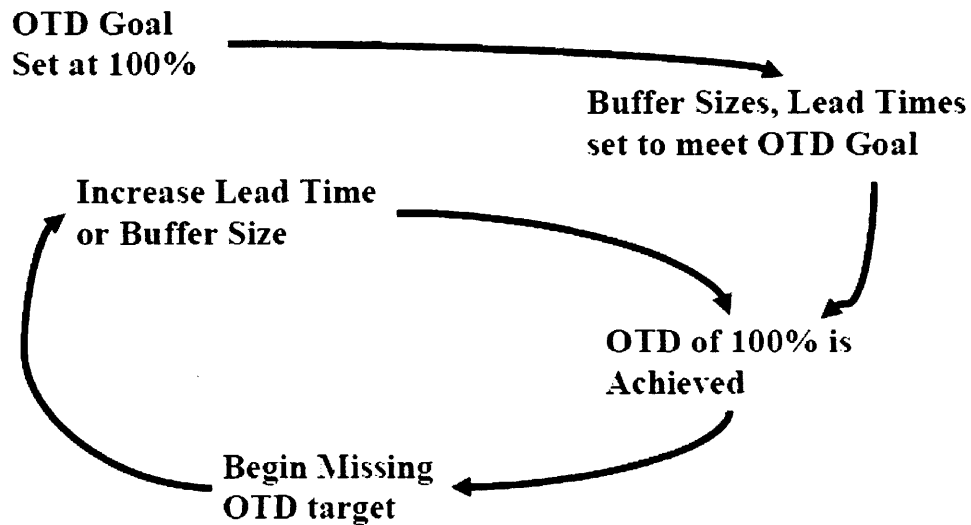


Fig. 10: Response Time Spiral⁴⁵

In order to create a responsive mentality in manufacturing, the organization must embrace lead time as the key success metric. Traditional operations beliefs centered around utilization, costs, efficiencies and on time delivery are not appropriate in today's high clockspeed, global environment where customers have an unprecedented ability to find exactly what they are looking for. Furthermore, focusing on lead times aligns the entire organization towards removing waste and improving the ability of the manufacturing organization to be responsive to customer needs. The next section provides a detailed analysis of actual steps taken to improve responsiveness in a make-to-order environment.

⁴⁴ Rajan Suri, *Quick Response Manufacturing*, (Productivity Press, 1998).

⁴⁵ Matt Joing, "Applicability of Lean Manufacturing and Quick Response Manufacturing in a High-Mix Low-Volume Environment", Masters Thesis, Massachusetts Institute of Technology, 2004.

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Chapter 5. Implementing Responsiveness at ABB CNTDS

5.1. Asea Brown Boveri, Ltd.

We have conducted a thorough review of global market dynamics and our core strengths. We found that we only need to fine-tune operations... We will not base growth on major acquisitions...

–Jurgen Dormann, CEO ABB Ltd., 2003⁴⁶

ABB Ltd. is a global leader in providing utility and industrial customers with automation and power technologies. The company has headquarters in Zurich, Switzerland and was formed in 1988 as the result of a merger between the Swedish Asea and the Swiss Brown Boveri.⁴⁷ As of 2004, the company employs 105,000 employees in 100 countries (down from 140,000 employees at the end of 2002).⁴⁸

ABB is now comprised of two divisions: Automation Technologies and Power Technologies. The Automation Technologies division includes Business Areas for Automation Products, Manufacturing Automation and Process Automation. This division delivers products and services for measurement, control, motion, protection, and plant optimization for process, discrete and utility industries. The Power Technologies division includes Business Areas for Transformers, Medium-Voltage Products, High-Voltage Products, Power Systems, and Utility Automation Systems. This division serves electric, gas and water utilities as well as industrial and commercial customers.

5.2. Approach to Lean in Power Technologies Transformers⁴⁹

ABB's Transformer Business Area (BA) has 58 factories world wide. In 2002 the BA created a structured approach to improving responsiveness⁵⁰ generic enough to implement across the mix of globally dispersed independent factories. The three areas of focus for

⁴⁶ ABB Group Annual Report 2003, Operational Review. Zurich, Switzerland: ABB Group, 2003.

⁴⁷ Ibid.

⁴⁸ Homepage. <<http://www.abb.com/about>>

⁴⁹ Michelle E. Bernson, "The Value of a Common Approach to Lean", Masters Thesis, Massachusetts Institute of Technology, 2004.

⁵⁰ The official documentation for CP3 describes it as an approach to Lean Implementation. However, given the actual goal of reduced lead time in a make-to-order environment this thesis will refer to it as responsiveness.

the Common Pull Production Practices (CP3) are continuous flow, pull production control, and supply chain integration. However, ultimately the desired result is reduced lead times:

- Continuous flow is a combination of eliminating time wasted due to waiting, inventory, and motion.
- Pull production is the elimination of time wasted from overproduction, defects, and excess processing.
- Supply chain integration is an attempt to transfer these principles to suppliers and includes improving sourcing and purchasing procedures.

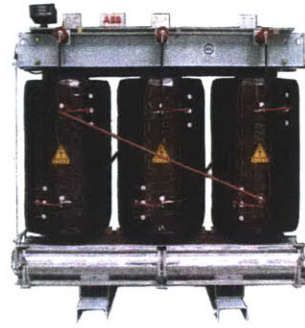
5.3. ABB CNTDS, Shanghai, P.R. China

ABB Shanghai Transformer Co. Ltd. (CNTDS) is a joint venture manufacturer of medium voltage power distribution transformers and part of the PTTR Business Area. The managing partners are ABB Ltd. through its ABB China Investment Ltd. subsidiary (51%) and the state owned Shanghai Electrical Apparatus Co. through the Shanghai Power T&D Co. Ltd. (49%).

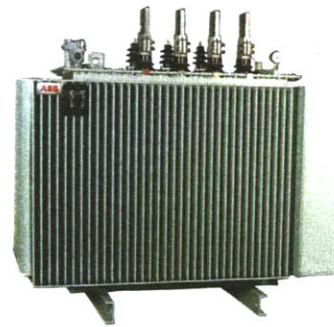
ABB CNTDS was formed on Oct. 6, 1994. Prior to the joint venture the company was known as Shanghai Transformer Works and had been producing transformers at the site since the 1920s - most recently (prior to the joint venture) producing oil-immersed transformers and dry cast transformers. In 1992 the Shanghai Transformer Works began licensing the Resibloc[®] process technology from ABB. Thus, when ABB began looking for entry into the Chinese market, the Shanghai Transformer Works was a natural partner.

ABB CNTDS functions as an individual profit center as part of the Transformers Business Area within the Power Technologies division. The company produces three main product lines all with rated voltage less than 35KV. Dry-type Resibloc[®] transformers range in capacity from 100KVA to 12,500MVA. Medium sized oil-immersed transformers range in capacity from 50KVA to 6.3MVA. Lastly, large oil-immersed distribution transformers range in capacity from 2.5MVA to 25MVA.

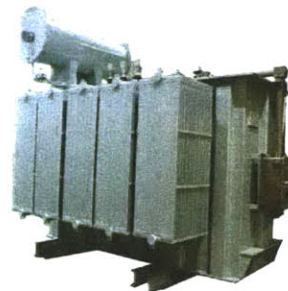
Major customer segments for ABB Shanghai include utilities, industrial end users and construction firms; and are divided into three main geographies: greater Shanghai, China and export, with domestic sales far outweighing exports. Each unit's configuration is specified by the customer and engineered to order. Differentiation occurs at the first step in the process, so units are not started without a specific customer order.



Dry-Type (w/o enclosure)



Oil-Immersed Medium



Oil-Immersed Large

Figure 11: Power Distribution Transformers

At the beginning of June 2004, ABB CNTDS' factory operations could be described as bloated, segmented and misaligned. Revenue growth for the year was projected at 25-30% (with an accompanying unit increase of ~40%); however, after only 5 months material inventory had increased 128% and Finished Goods 50%. This was having a detrimental effect on cash flow (-63%) and placing the company in an undesirable financial situation. This LFM internship was in support of the already planned CP3 (Common Pull Production Practices) implementation.

5.4. Dry Transformer Production Flow

Dry-type Resibloc[®] transformers are used in applications where customers need to minimize environmental contamination and fire hazards. Because of high demand and higher profits from the Resibloc[®] transformer line (compared to oil-filled), this internship focused on improving responsiveness here first. The dry-type assembly process requires two main subassemblies: windings and a core.

The transformer core consists of layered magnetic steel. Rolled magnetic steel is slit to the proper width and then cut to the proper length and shape. The cut pieces are stacked by hand and secured in a frame.

Each transformer has 3 windings. Windings begin with insulation material that is cut and glued. The next step is to wind copper foil⁵¹ and the insulation material to create the low voltage winding. The high voltage windings are created by winding enamel coated copper wire and glass fiber rovings that have been dipped in an epoxy (used for insulation) around the previously constructed low voltage winding. The entire winding is then put into an oven to cure the epoxy. After curing, the windings are cleaned by grinding away the excess, clumped epoxy from the ends. At this point the windings are also given a resistance test. High voltage winding is the designed capacity constraint due to machine speed. Furthermore, in order to maintain the chemical properties of the epoxy the high voltage winding process must be done in a temperature controlled environment.

Final assembly consists of placing each winding around the stacked cores. Additional required assembly parts and optional accessory items such as temperature meters and tap changers are also added. The assembled transformer is then taken to a testing area to check for quality problems such as short circuits and ensure the proper voltage and power ratings are met. The transformer is then placed into an enclosure and prepared for shipment.

⁵¹ Most of the world has switched to Aluminum foil and wire because it is less expensive. However, the Chinese government requires transformers to be constructed of Copper.

5.5. Improving Responsiveness at ABB CNTDS

5.5.1. Production Philosophy

In line with the goal of improving factory responsiveness, lead time became the top metric of focus. Consistent with the CP3 learnings, a ConWIP process was implemented to limit work-in-process. Clipboards were designated as the release cards and stayed with the transformer from insulation through assembly. Test and Enclosure were excluded from the ConWIP process due to the high capacity available in test and the variation in whether a job would have an enclosure assembly or not. A production board was constructed to hold the paperwork corresponding to the sequence of release.

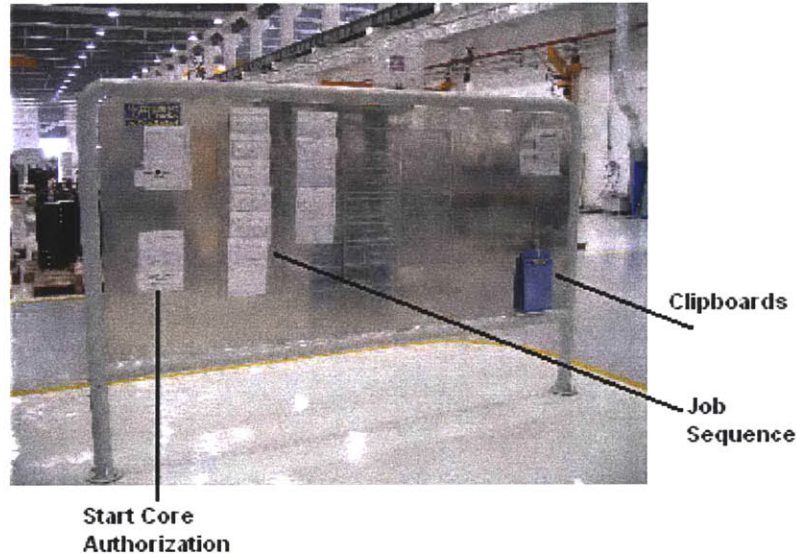


Figure 12: ConWIP Pull Production Board

The winding subassembly process has a much longer throughput time than the core subassembly process. Therefore, when a transformer finished assembly and a clipboard was released, this would signal production to begin the next job's insulation and the clipboard would travel through the winding loop. However, an additional signal was given to the core manufacturing area alerting them to which order number was released and authorizing them to begin construction of the core.

The ConWIP calculation set the target inventory level between 30-35 transformers. This was a substantial reduction from an average of over 60 units in process. To facilitate a gradual implementation, the number of clipboards was initially set at 45 and progressively reduced over a month long period.



Figure 13: ConWIP cards in Insulation

Whereas the key system metric was lead time, an important benefit that should not be overlooked was the following of a production sequence. Jobs were not pushed into the system based on a start date, but were pulled into the system based on the release sequence and an available ConWIP card (Appendix D). The following of a sequence ensured some orders would not be started ahead of others at the request of individuals or because materials were not available. The creation of an agreed upon sequence thereby aligned the entire organization to the system.

5.5.2. Production Planning and Scheduling

Planning and scheduling was being done on a monthly basis during the middle of the preceding month. Therefore, planning was effectively done between 2-6 weeks in advance of actual production – incredible given that the plan included start/finish dates as

well as what days the order should be in High Voltage Winding (the constraint operation). This decidedly “push” method of production planning led to a lack of integration between departments; planning would set schedules for engineering drawings to be completed, materials to be purchased and production to begin and then consider themselves absolved of further responsibility. Additionally, high finished goods, WIP and material inventories resulted as customers would request delays in delivery or even cancel an order. The poor communication meant material arrived as scheduled or the transformer was still produced as scheduled. Cores were often waiting on uncompleted windings or windings were waiting on uncompleted cores. And the push nature of this system only added to the high WIP build up causing delays and missed delivery dates.

Disruptions were common and the sales department would frequently ask production to expedite one order without considering the consequential delays to other orders. The factory had been through many iterations of the response time spiral and was allowing for excessive amounts of buffer time in the system. Actual total cycle-time averaged less than 10 days but production throughput time was close to 30 days.

5.5.2.1. Cross Department Integration

The planning and scheduling process was revamped in order to reduce scheduling commitment from 2-6 weeks to less than 1 week. A weekly meeting was held on Wednesdays to set the schedule for the following week. Required attendees included representatives from manufacturing, sales, materials purchasing, and planning (Appendix E). The sales department was asked to confirm the delivery date with the customer, the material purchasing department confirmed material availability, and the planning department confirmed there was available capacity. If any of the three requirements (order, material, capacity) were not given the go-ahead the job was not added to the production sequence.

The actual scheduling process was time consuming and relied on assumptions, perceptions and experience. The planner would take confirmed job orders and place them in a production schedule based on the KVA rating of the transformer. The KVA rating was

roughly correlated to the process time at the factory constraint, HV Winding; however there were instances where different designs with identical KVA ratings would have large deviations in processing times at HV Winding as well as at other operations. Therefore basing capacity on KVA was error prone and added to delays and high WIP.

It was clear a change in the production scheduling process was needed.

5.5.2.2. Sequencing Software Tool

Meetings were held with production and planning personnel to determine the cycle times at each operation for different designs and KVA ratings. I then developed a Microsoft Excel based scheduling tool that automatically establishes a production start date based on the delivery date and actual cycle times (Appendix F). However, it is important to note that this production start date was not a required start date but instead was used to determine the production sequence and provide a reference point for where the factory was in relation to committed delivery dates. With the understanding that the cycle times were loosely derived and prone to inflation, the software scheduling tool was intentionally configured such that the operation cycle times could be easily updated as necessary.

In addition to creating a production sequence, the scheduling tool was programmed to generate graphs showing daily and weekly capacity usage at the factory constraint (Appendix G). This capacity usage is based on processing time rather than KVA rating and proved to be quite useful and accurate in helping to establish consistency across weeks. Furthermore it provided visibility into future delivery commitments and capacity usage. This visibility allowed the sales department to quickly evaluate and commit to customer orders – reducing front end lead times.

5.5.3. Reducing High Value Material Inventory

5.5.3.1 Copper Wire

Between Dec. 31, 2003 and May 31, 2004 the total quantity by weight of copper wire had increased 110%. This is despite a supplier lead time of less than two weeks. Critical design dimensions are wire thickness and width. Between January, 2003 and July, 2004 ABB Shanghai used approximately 150 different wire types. A transformer's end operating characteristics are largely determined based on the combination of copper wire and copper foil design dimensions. Therefore, in order to allow for a reduction in available copper foil sizes (discussed shortly), a reduction in wire types for standardization purposes was not an option.

ABB CNTDS used two main wire suppliers. Wire was ordered by job number and the order was placed to coincide with the monthly planning process previously described. This unfortunately led to unneeded coils of wire when orders were delayed or cancelled. Furthermore, wire was delivered and placed in the warehouse unsystematically which meant time was spent looking for the appropriate coils.

The quantity of wire ordered was determined based on the engineering drawing with an extra 5% added to compensate for tolerance purposes. This resulted in a large amount of small quantity rolls waiting to be consumed at a later point (wire ends could be welded together). A standing agreement was in place that wire coils less than 40kg would be scrapped⁵² immediately; however, this process was not being followed. Not only was the monetary value of this inventory creating a burden on the balance sheet, but the abundance of wire rolls was taking up a great deal of space.

The first step was to run an inventory report of all wire on hand to provide an analytical framework. The minimum holding requirement was increased to 60kg meaning any rolls less than that amount were automatically scrapped. Additionally, the engineering department was given the list and highlighted additional rolls that could be sold back to

⁵² Copper is a commodity material and, when scrapped, is sold back at the commodity market price. This price is lower than the current purchase price because production costs are included.

the copper suppliers. A resource intensive undertaking to label all remaining wire rolls with a job number was performed and any wire rolls purchased for old or cancelled jobs were red tagged and relocated. Finally, the copper wire suppliers agreed to affix the job number to every new order.

A single copper wire supplier was then identified to be the main supplier and an agreement was made that all orders would be placed with them under the following conditions: the supplier would make three deliveries a week as opposed to once or twice, and the wire would be ordered 10 days in advance of production start but the wire supplier would hold it in their facility until it was “called off” by the wire purchaser. The wire purchaser was responsible for checking the pull production board and alerting the copper wire supplier to which jobs would be needed in the next few days. And only those job number orders would be accepted by the warehouse. This new incoming material policy greatly helped reduce the copper wire inventory on hand and free up space. Additionally, reliance on one supplier was deemed low risk as the second supplier could be used in the future if needed.

5.5.3.2. Core Steel

Core steel is purchased as master coils (1000mm) and then slit on site to the required dimensions, or it can be purchased in pre-slit dimensions. ABB CNTDS transformers typically use steel widths of 100-500mm. Purchasing master coils and slitting on site is preferred due to the varying dimension needs based on transformer parameters.

Corporate ABB negotiates steel contracts with suppliers and rations them across the individual subsidiaries. This gives ABB purchasing power with suppliers due to the quantities of steel negotiated. Therefore, ABB CNTDS has a maximum quantity of master coils it can purchase from certain suppliers whereas other suppliers provide pre-slit material of which there is also a maximum quantity.

Pre-slit steel is provided mainly because the maximum size coil ABB CNTDS’ slitting machine can handle is 1000mm and the suppliers have master coils greater than 1000mm (generally between 1000-1200mm). Slit widths were ordered based on forecasted need

and had a lead-time of 1-2 weeks. This process was altered such that, now, the top 5 most commonly used widths are ordered in constant quantity every month (enough to ensure it will undoubtedly all be consumed). Each of these widths will come off of a larger master coil and the remaining coil (800-1000mm) will not be slit further by the supplier, but instead shipped to ABB CNTDS and used similarly as a normal master coil (Fig. 14).

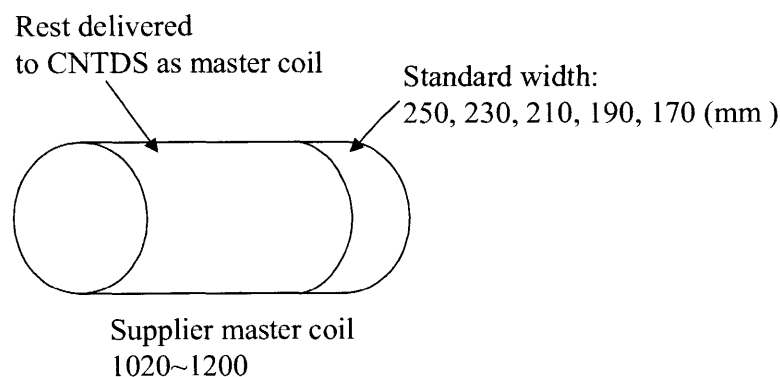


Fig. 14: Core Steel Purchasing

This change reduced the need to forecast specific width needs and gave ABB CNTDS more flexibility. The factory was able to both reduce inventory and become more responsive at the same time because master coils could in turn be cut to any needed dimension.

Engineering drawings for the steel slitting/cutting departments only included width and weight information. This is because steel is stored as inventory by weight given it is easy to weigh. Whereas it may be easy to weigh, the ultimate application requires knowing its length⁵³ as it is unwound and cut. Additionally, steel inventory was being tracked solely for financial purposes and therefore the only value known was the combined weight of all steel.

Engineers are now providing the length of steel required in addition to the weight on the drawings. Furthermore, the factory personnel were given the additional responsibility to maintain a detailed inventory of steel listing the individual coils' weights *and* widths, and

⁵³ The density of the steel is constant at (7650 kg/m³), so conversion between weight and length can be accomplished.

I developed a Microsoft Excel tool to assist them in maintaining this data (Appendix H). The operators only need to enter the inventory coils' weights and the software will perform the calculation and provide a list of the corresponding lengths. Working with length information as opposed to weight allows for faster and more accurate, materially efficient decision-making of which coils to use for each job.

5.5.3.3. Copper Foil

Copper foil is used to create the transformer's low voltage windings. The critical dimensions are thickness and width and it is not slit on site due to stringent quality requirements. Copper foil can be purchased domestically with a 1 month lead time or from Germany with a maximum three month lead time: shipping = one month, production = two weeks, supplier capacity/material allocation = six weeks. However, the domestic foil is 20% more expensive than German foil even after including import taxes and transportation costs. Due to the large cost difference between the local and foreign suppliers, it made practical business sense to purchase abroad despite the long lead time. However, this does not mean ABB CNTDS was not able to make procedural changes that allowed for increased responsiveness despite this predicament.

During the period from January 2003 to June 2004, 60 different foil types were used with large variations in the frequency and quantity of use. Engineers choose one foil type over another because it results in less overall material used. Note that the copper foil dimension chosen affects the quantity of copper foil required as well as the quantity of core steel and copper wire needed.

From the 60 dimensions used over the preceding 18 months, the engineering department developed a list of 33 "standard" foil types that would be able to accommodate all transformer designs. Through critical analysis and unit cost comparison, it was shown that even though a transformer may use less material overall with a non-standard foil type, if it is designed with a standard foil type purchased from Germany and then compared to a design using the ideal non-standard foil assumed purchased locally, the overall cost of transformer material is lower due to the 20% difference in foil cost.

A historical analysis of monthly foil consumption was performed and a target inventory level for each standard foil type was set according to the highest monthly consumption during the preceding 18 months for that foil (Appendix I). The cumulative amount computed was only 43% of the total foil in inventory at the end of May 2004. It was clear that ABB CNTDS would benefit by reducing the number of foil types available to designers and purchasing all foil from Germany. There would not only be a benefit from the reduction in cost of goods sold, inventory burden, and space, but ABB CNTDS could also maintain a drastically lower stock of foil on hand that would still accommodate any normal make-to-order request.

Obviously, a large unit quantity purchase of alike transformers would present a problem if request for delivery was immediate. However, ABB CNTDS' management noted that large quantity orders were almost always negotiated far in advance (nobody needs an immediate delivery of that many units) and the local supplier with a shorter lead time could also be used if necessary. Management benefits and responsiveness gained for an order that would actually require responsiveness more than offset the risk.

Again a change in the purchasing procedures and better visibility into known future needs would be required to make this strategic change a long term success. I developed a Microsoft Excel based tool to provide a link to the planning process and allow visibility into the foil needs of known contracts, planned purchases, and the target inventory levels. By maintaining a month's worth of inventory, the lead-time effectively is reduced assuming non-extravagant changes in demand. At the end of the internship, ABB CNTDS was discussing reserving a certain amount of supplier capacity in advance and providing weekly updates of tentatively planned individual dimension orders. This would effectively cut the lead time of foreign foil down to only the production and transportation time.

5.5.4. Metrics Results

The following charts show the results obtained as a result of the change implementation previously described. It is important to keep in mind that annual revenue growth for 2004 was 35% and the annual unit production volume increased approximately 45% compared to the previous year.

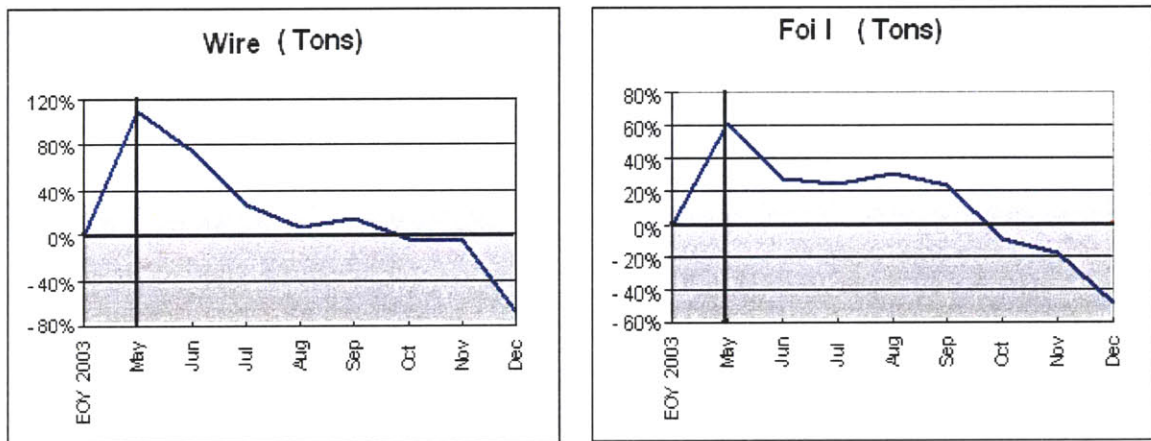


Figure 15: Inventory Reduction Results

Despite the increase in annual revenue and unit volume production, ABB CNTDS was able to reduce both copper foil and copper wire inventories to quantities lower than at the end of 2003. Changes in purchasing procedures, inventory management, and engineering design criteria were implemented as part of the goal to improve responsiveness during this internship (June – December).

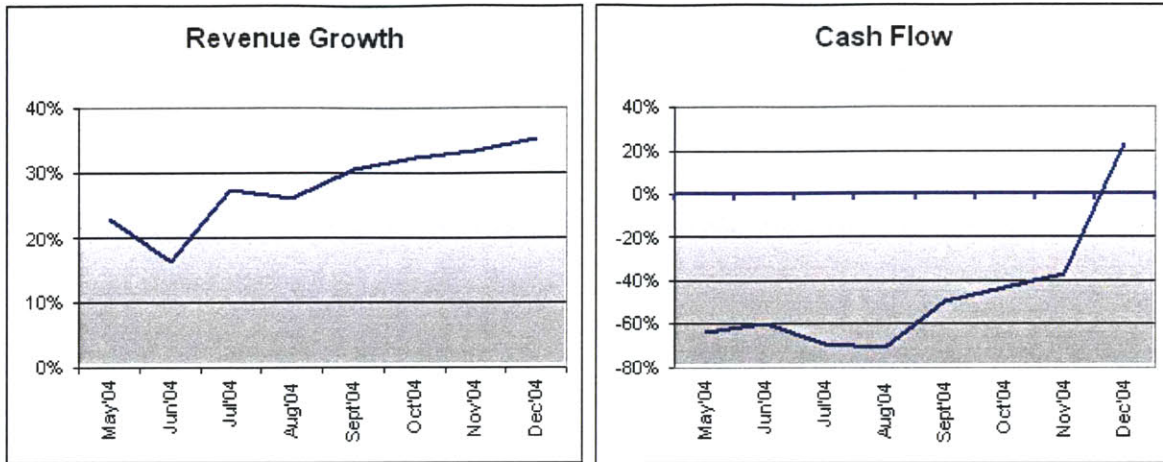


Figure 16: Revenue Growth and Cash Flow

Revenue growth was calculated by extrapolating projected year end revenue from monthly revenue figures. Cash flow improvements from May through December were a result of a decrease in Accounts Receivable, Material Inventory, and Finished Goods inventory over that time period.

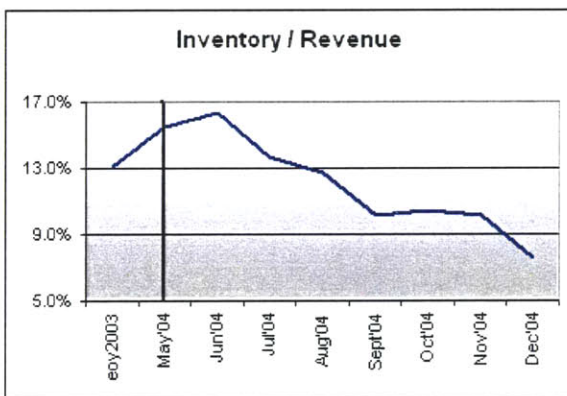


Figure 17: Inventory / Revenue

ABB CNTDS set a goal of 7.5% for inventory as a percentage of revenue. WIP inventory remained approximately the same from May to December; however, it decreased relative to revenue, and was 25% lower than at the end of 2003. The substantial reduction in high-value material inventory previously described also helped to reach this goal.

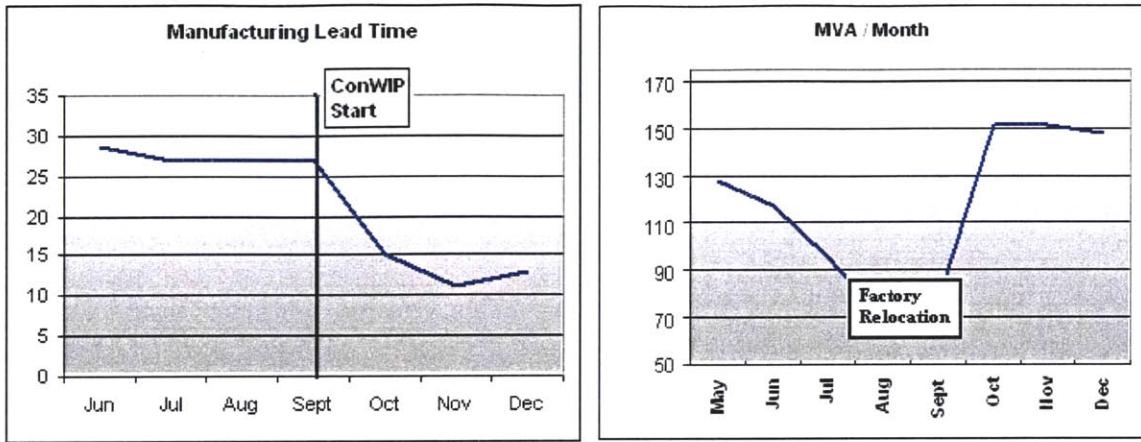


Figure 18: Lead Time and Output

The ConWIP policy implementation reduced production lead time by over 50%. Additionally, overall output increased 15% after ConWIP implementation and factory relocation. However, the factory relocation did not include an increase in equipment or overall floor space.

Chapter 6. Analysis of Change Implementation

6.1. The Three Lenses

Implementing change is a daunting task for any individual in any organization. There are both advantages and disadvantages to being an outsider new to the organization or an insider with a working history within the organization. The one certainty is that there is no recipe for influencing and creating change. A model or step by step guide would be both restrictive and inappropriate due to the intrinsic complexity of organizations. However, one method that has gained acceptance, particularly at the MIT Sloan School of Management, is to view the organization through three lenses: Strategically, Culturally, and Politically (stakeholders). These three lenses provide a framework to locally evaluate change and its effect on the organization.⁵⁴

The strategic lens highlights the strategy and goals of the organization. It is forward looking and rational. Through the strategic lens, the people within the organization have skills and capabilities that can be positioned and linked to optimize the overall value of the organization. It is the strategic lens that brings about words and phrases such as “economies of scope / scale” and “the whole is greater than the parts”. The strategic lens identifies what the end result should look like along with the requirements and tasks to accomplish that result.

The cultural lens attempts to identify beliefs and ideas that have become ingrained within both the organization and individuals. These are the foundations that both consciously and subconsciously influence actions and decisions. Using the cultural lens, one attempts to gain insight into the traditions that add meaning and value to the individuals and momentum to the direction of the organization. The cultural lens is, perhaps, the most difficult and complex of the lenses because one attempts to apply logic to seemingly irrational individual and group behavior.

⁵⁴ Ancona, D. et al, Managing for the Future – Organizational Behavior and Processes, (South-Western College Publishing Co., 1999).

If the strategic lens is forward looking and cultural lens is historically oriented, then the stakeholder lens is an objective view of the present. With the stakeholder lens, one recognizes that the organization is indeed comprised of individuals with their own personal agendas and relationships. There are managers and subordinates, and individuals or groups with influence and interests. The stakeholder lens is polarizing in that it filters claims of responsibility and territories of ownership. A manager who strategically has a roadmap needs the stakeholder lens to recognize potential individuals, groups, and sunk costs that have the resources and influence to hinder or facilitate progress.

6.2. Strategic Lens Analysis

In 2003 an article published in the Harvard Business Review entitled “IT Doesn’t Matter”⁵⁵ was received with great debate. The point author Nicolas Carr argued was that Information Technology was becoming so prevalent in business that it could no longer be considered a competitive advantage for one company over another. Instead, it was a necessity just for entry into the competitive landscape. The same type of argument could be formed for China. Whereas previously companies referred to their China operations as an important competitive cost advantage, today it is uncommon not to have operations in China or sourcing from China. The competitive advantage comes not from cost competition but from the growth opportunities present in the vast Chinese market. And those companies that are responsive to the needs of the Chinese market will ultimately fare the best.

As do most other multinational firms, ABB recognizes China as an important strategic location. However, China’s importance to ABB does not reside in its status as a low cost labor location where products are produced and exported to more lucrative markets. Rather, China represents a source of skilled, innovative employees as well as important growth opportunities for ABB. In fact, in October of 2004 ABB’s CEO outlined a strategy to double revenue in China within 3 years, effectively overtaking Germany as the company’s second largest market (behind the United States). At ABB CNTDS, roughly 90% of all product is shipped to customers within the country.

⁵⁵ Nicholas G. Carr, “IT Doesn’t Matter”, Harvard Business Review, May-June (2003)

ABB CNTDS alone was given the goal of more than doubling revenue within three years. Local management recognized the need to manage growth effectively as the main challenge facing the organization. Accompanying these lofty expectations included a corporate investment in a new factory which ABB CNTDS began relocation to in August of 2004. Furthermore, ABB CNTDS was scheduled to begin production of a new type of transformer, the Vacuum Cast Coil, in the spring of 2005.

The new factory, however, did not increase production floor space nor include new capital equipment. Therefore it was recognized that ABB CNTDS would further require the operational process improvements that were the focus of this internship and the pending relocation provided an ideal coordinating device and timeframe for change. Strategically, the goals were to improve:

- Speed
- Supply Chain
- Technology
- Quality
- Organization

6.3. Cultural Lens Analysis

A thorough educational perspective of the Chinese culture and its effect on the workplace is both beyond the scope of this paper and knowledge of the author. However, I will attempt to share my observations with the understanding that it is a superficial analysis at best.

If there has been one constant in China over the past 10 years it is change. Particularly in the major coastal cities, the gradual opening and transition to a “socialism with Chinese characteristics” economy has led to tremendous growth, construction, employment opportunities and personal freedom compared to the Cultural Revolution in the 1960’s and its aftermath. Coinciding, it is only recently that foreigners have become a not so unusual

sight around China's major cities. From the Communist Revolution in the late 1940's until China's gradual opening during the 1990's, China was, in effect, closed off from the rest of the world.

ABB CNTDS' history is an example of the opening up of the Chinese country and economy. Officially formed in 1994, it is a joint venture between ABB, Ltd. and the Shanghai Electrical Apparatus Corporation. For more than fifty years prior to the joint venture, the company was a state owned entity producing distribution transformers for the local state owned utility. It is very common for foreign companies to enter China with a joint venture partner rather than as a wholly owned entity. China has staked its future on foreign direct investment and views business fundamentals as a key aspect of that investment - in contrast to Japan, which promoted and developed national industries from within and with little foreign investment. In fact, ABB's joint venture partner company also has partnerships with some of ABB's competitors including Siemens and ALSTOM.

To be sure, the Chinese recognize their recent importance in the world economy as a location for relatively low cost labor – both manual and skilled. They also recognize the importance of foreigners in China as representatives of capital and business leadership. There also are a large number of people within the cities and factories who have come from the rural interior regions and provinces and understand the large gap in relative wealth between the coastal cities and those inland.

ABB is a competitive employer in China and has been ranked by Fortune Magazine as one of the top ten employers in China as well as one of the most admired companies in China. Even during my brief internship, there were a few people who retired after long-term careers that began with the state owned company and continued with the joint venture partnership. ABB CNTDS provides all employees with a cafeteria lunch as well as shuttle bus transportation from various points in the city to the factory. Since inception there has been a steady flow of site General Managers all of whom were non-Chinese. Partnering with the General Manager is a Deputy General Manager who is the Chinese joint venture partner representative. It seemed to me most employees felt appreciation for and

commitment to their employer and were eager to affect changes that would have a positive impact on the health of the company.

The larger culture of ABB, Ltd. is not without impact on the local subsidiary. A self described engineering company, ABB prides itself on its engineering competence and ability to provide unique solutions for customer's problems. The projects that ABB promotes internally typically are large scale engineering feats such as the Three Gorges Dam project in China and the "longest underwater power transmission link" soon to be located between Norway and the Netherlands. Locally, this corresponds to a tendency to over-engineer less complicated projects without consideration for the effect on throughput, inventory and operating expenses.

6.4. Stakeholder Lens Analysis

Individual power at ABB CNTDS is derived primarily from two areas:

1. The hierarchical structure of the organization chart
2. Respect for experience and knowledge consistent with Chinese values

The power inherent in the organizational structure presented difficulties implementing change and required cognizant awareness and ultimately a change in the organization structure to achieve the desired goals. Most notable is the control of the sales department by the general manager. This effectively gives the sales department influence over the rest of the organization as issues concerning the sales were frequently escalated upwards through the general manager and then down through the rest of the company. The result was indirect control over manufacturing and planning by the sales department rather than a balanced partnership between departments. Frequent changes in priority and scheduling created disruptions in the factory that contributed to many of the identified concerns including the high material, WIP and finished goods inventory as well as a deteriorating response time spiral.

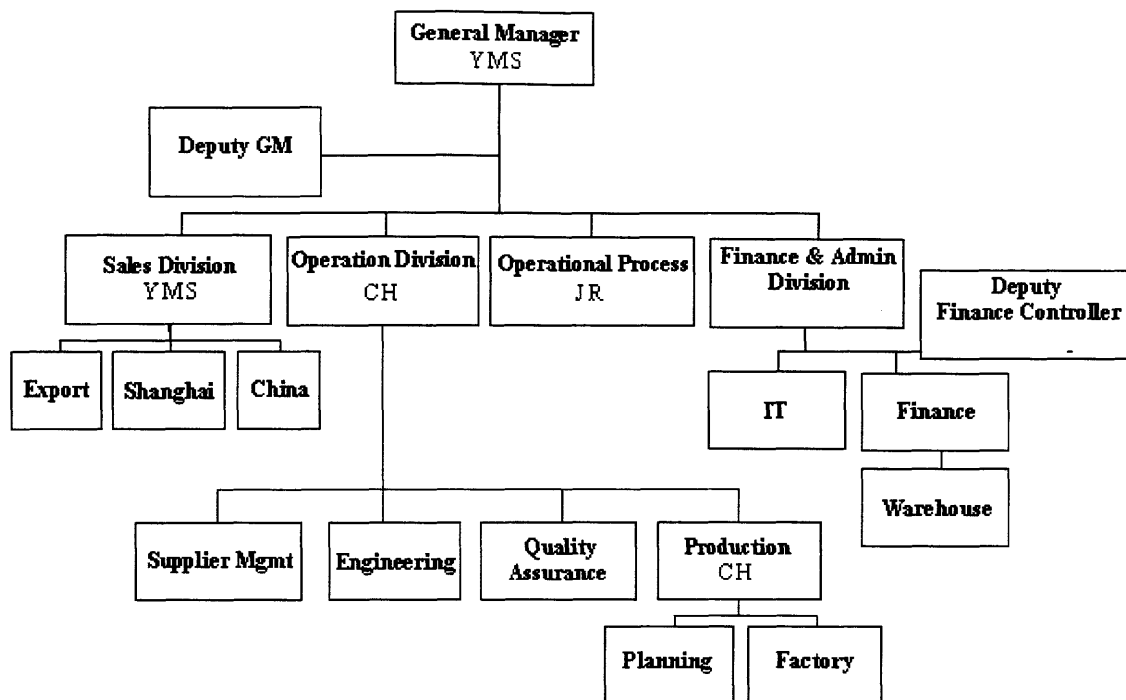


Figure 19: ABB CNTDS Org Chart, June, 2004

An additional by-product of the organizational chart was that subordinates typically did not challenge the status quo. Unfortunately, this is detrimental to the idea of continuous improvement from below. In fact, many factory “blue collar” workers did not view continuous improvement as part of their responsibility. Even within office functions little thought was given to potential improvements that would benefit the company as a whole. Whereas major changes can be implemented effectively with a top down approach, the smaller innovations that occur continuously and require individuals to think outside their standard work procedures are missed when the individual has a narrowly focused work model.

Respect for experience and knowledge is a source of power that should not be overlooked at ABB CNTDS. Inclusive in this is respect for the knowledge and experience that comes with age; however, it is not limited specifically to age. Undeniably, there is a noticeable workplace appreciation for elders that is typically not as prevalent in the United States. But I also found that background information such as education and previous work experience can be a useful source of influence for the individual.

6.6.5. Using the Lenses

In 2003, the Transformers Business Area of ABB initiated an effort to introduce lean concepts into its factories around the world. Common Pull Production Practices (CP3) began at two sites in Europe and was more a set of guidelines and methods to help facilitate operational improvements such as reduced lead times and inventory reduction than a step by step directive. Rightly, ABB recognized that with such a diverse group of factories spread around the world, it would be futile to try to develop an a definitive instruction set.

Additionally, ABB realized the importance of a “pull” approach to implementation - that is, having factories establish a change initiative on their own as opposed to being “pushed” to do so from the corporate business area. This is because when there is a shared vision and common direction among change agents, there a greater likelihood of producing meaningful results.⁵⁶ However, in order to create this pull, ABB needed to prove the program’s potential with results from key sites.

As previously mentioned, ABB CNTDS presented a very good opportunity to showcase improvements as a result of CP3 implementation and therefore the program was pushed upon the factory by the business area. A CP3 project manager from Finland and a part of ABB’s Corporate Research Center was brought in and tasked with the CP3 implementation. He arrived in January of 2004 and this internship in support of his efforts began a few months after.

Many multinational companies that have used ex-pat managers extensively in their China operations are now looking to train and develop local personnel for factory management positions. There still remains a case, however, for using outsiders when significant strategic improvements are pushed from the corporate level. As someone who obviously stands out as different in a homogenous environment such as China, a foreigner is often a visual signal that change is forthcoming, just as it has been since the early 1990s. Not only is an outsider a visual cue, but an outsider can use ignorance as leeway when navigating through the political and cultural barriers.

⁵⁶ Kanter, et al, The Challenge of Organizational Change, (The Free Press, 1992).

I found that being a foreigner, I was given more ‘ignorance flexibility’ than would a local outsider. It seems, however, this approach is appropriate only when the strategic changes are significant and obvious enough to create a barrier to falling back into the old method of operating. Furthermore, I found that by integrating into the culture as much as possible (ex: learning some of the language, trying local cuisine, having an interest in the culture and history) one can avoid an insensitive stigma alongside the useful ignorance flexibility.

Strategically, the goals of CP3 were straightforward. However, with five key objectives different departments or individuals are typically given ownership for only one of the five. This can create barriers against working together. Instead, in line with responsive manufacturing theory, at ABB CNTDS the fundamental goal was fashioned as speed with the other four becoming areas to support the improvement of speed. As discussed previously, aligning the organization to improve speed has tremendous widespread application within a company. Most importantly it requires departments to work together and break down barriers that contribute to waste.

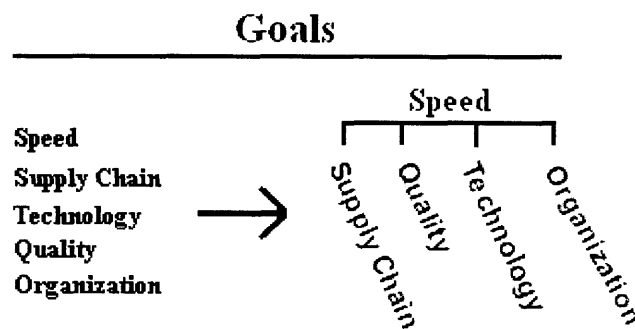


Figure 20: CP3 Goals

Taking into account the influence associated with the organizational hierarchy, ABB CNTDS needed to reorganize the departments in order to increase the rate of implementation and ultimately the success of the strategic vision. In September of 2004 the Operational Process manager responsible for the strategic operational improvements was also given responsibility for overseeing the entire Manufacturing and Operations

department including the Factory, Planning, Purchasing, and the Warehouse (previously under control of the Finance department).

Within this new structure, the factory personnel were more willing to accept operational changes and WIP management policies. The planning department was influenced to change the time scope and planning process to improve responsiveness. Furthermore, the material purchasing department was tasked with reducing inventory and the warehouse was given responsibilities for JIT material delivery to workshop cells and better organization and record-keeping of items in stock.

To be sure, these improvements were not a carte-blanche directive from management. A great deal of teaching, partnering and communication went into ensuring understanding and acceptance. Additionally, implementation was coordinated and meticulous. For example, 5S and cellular layout was done in one area first to allow everyone to see results and “pull” changes in their areas. The ConWIP policy was implemented on the Dry Production line first and subsequently “pulled” to the Oil Production line by line supervisors. Additionally, simple software tools were utilized for inventory management of key items and then new applications developed as requested for other tasks.

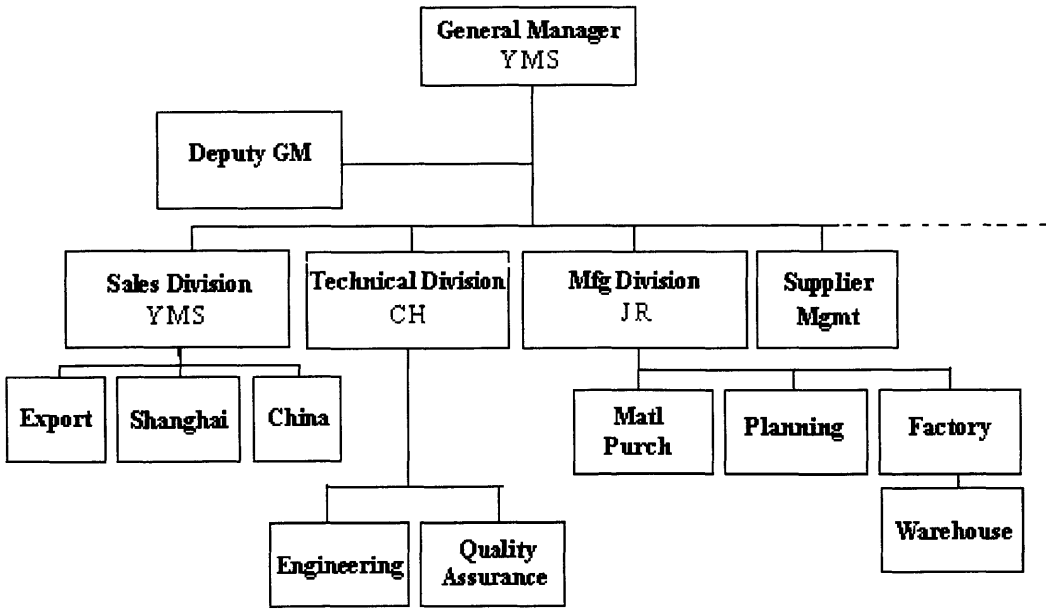


Figure 21: ABB CNTDS Org Chart, September, 2004

Understanding strategically where the organization needs to be in order to succeed is only a portion of what is required to get there. Whether you are an outsider or an insider, in a country native or foreign, working in an organization familiar or new, looking at the situation through of the three lenses can provide valuable insight into how the organization functions on a daily basis and over the long term. It is a critical step in the overall change process and one that is useful when considering strategic initiatives.

Chapter 7. Conclusion

Responsive competition requires a significant change in how the modern production center should prioritize decisions. Table 1 reviews some of these ideas.

| <u>Cost Manufacturing</u> | <u>Responsive Manufacturing</u> |
|---------------------------|---------------------------------|
| Lower Costs | Reduce Time |
| Financial Results | Physical Results |
| Utilization | Throughput |
| Individual / Departments | Teams / Integration |

Table 1: Cost vs. Responsiveness⁵⁷

One would be hard pressed to find a business that does not consider pleasing the customer as a top objective. However, one does have to spend time finding businesses that convert this objective into operational practice. Everybody knows that customers do not want to have a choice between a black car and a black car as Henry Ford originally provided. So why is it then, that while our intuitive concept of what manufacturing should produce has changed, our understanding of how manufacturing firms should operate has not?

I hope this thesis has not presented the reader with the conclusion that factories should operate recklessly with a lack of regard for the costs associated with decisions. But rather that factories should look at more than just short term tangible costs when making operational decisions and designing operational strategies. Furthermore, I hope this thesis has provided the reader with the optimism that manufacturing can be both profitable and responsive while providing an advantage in today's competitive environment.

⁵⁷ George Stalk, Jr., and Thomas M. Hout, Competing Against Time, (Free Press, 1990).

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Appendix A: ConWIP Parameters⁵⁸

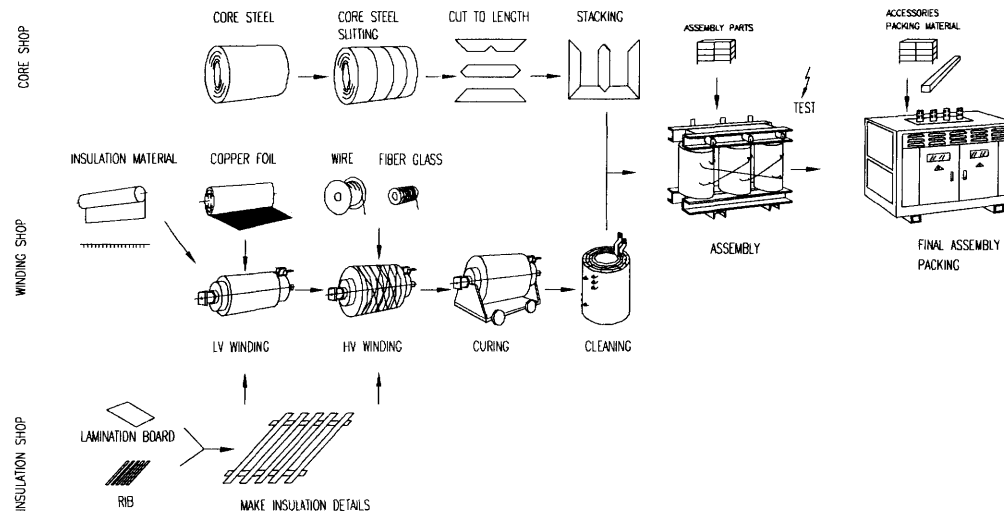
The ConWIP parameters are:

- m : the number of ConWIP cards allowed in the line. Thus, this determines the maximum WIP level for the ConWIP system.
- q : target production quota for a period.
- n : maximum work ahead amount. If $q + n$ is produced during a period, the line is stopped until the next period.
- r : capacity shortage trigger indicating additional capacity is required. Additional capacity can include overtime, bringing idle equipment online, outsourcing, etc. A simple trigger would be if production fails to exceed $q-r$ units during a given time period. A more sophisticated approach would include the probability of not producing $q-r$ units for the time period given the number of units produced up to the current state.

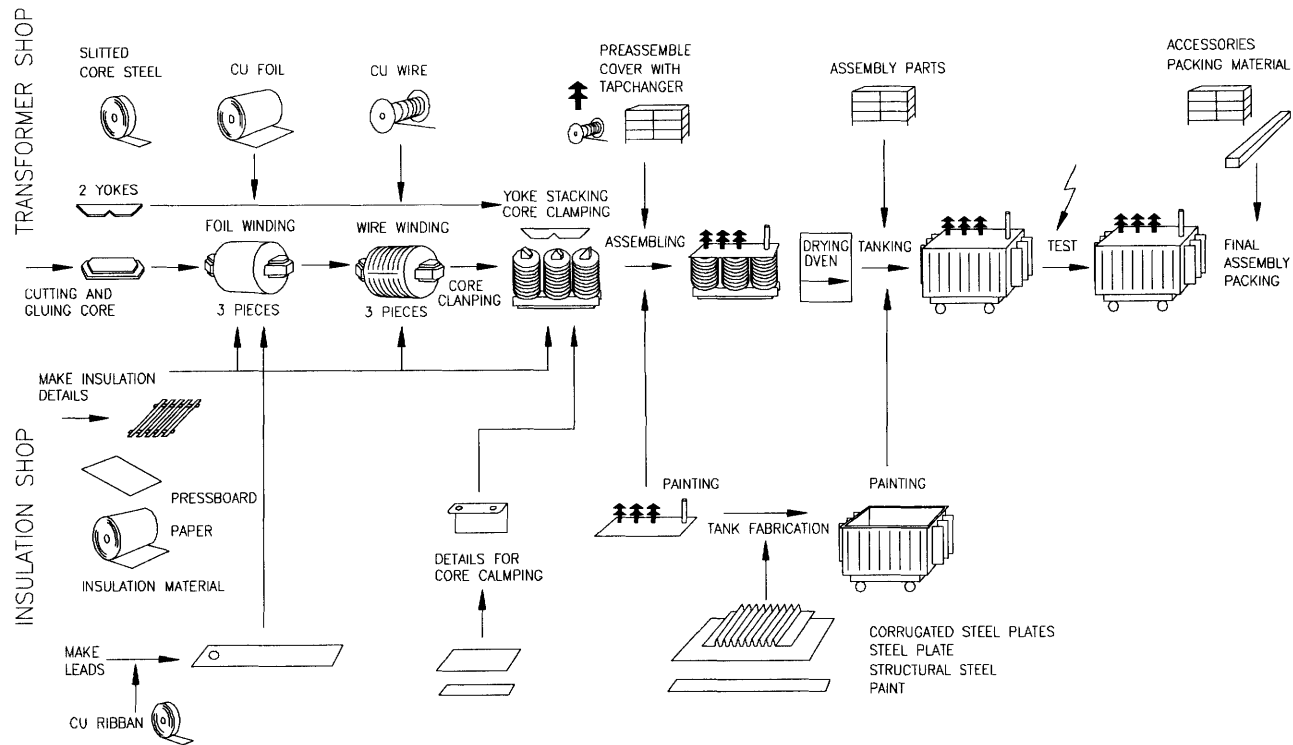
There are economic trade-offs between the parameters. Increasing q tends to increase revenue at the expense of service levels. Increasing m or n increases service levels at the expense of inventory and time.

⁵⁸ Spearman, et al. "CONWIP: a pull alternative to kanban.", *Int. J. Prod. Res.*, 28:5 (1990)

DRY-TYPE TRANSFORMER PRODUCTION PROCESS



OIL IMMERSED TRANSFORMER PRODUCTION PROCESS WINDING ON CORE LEG



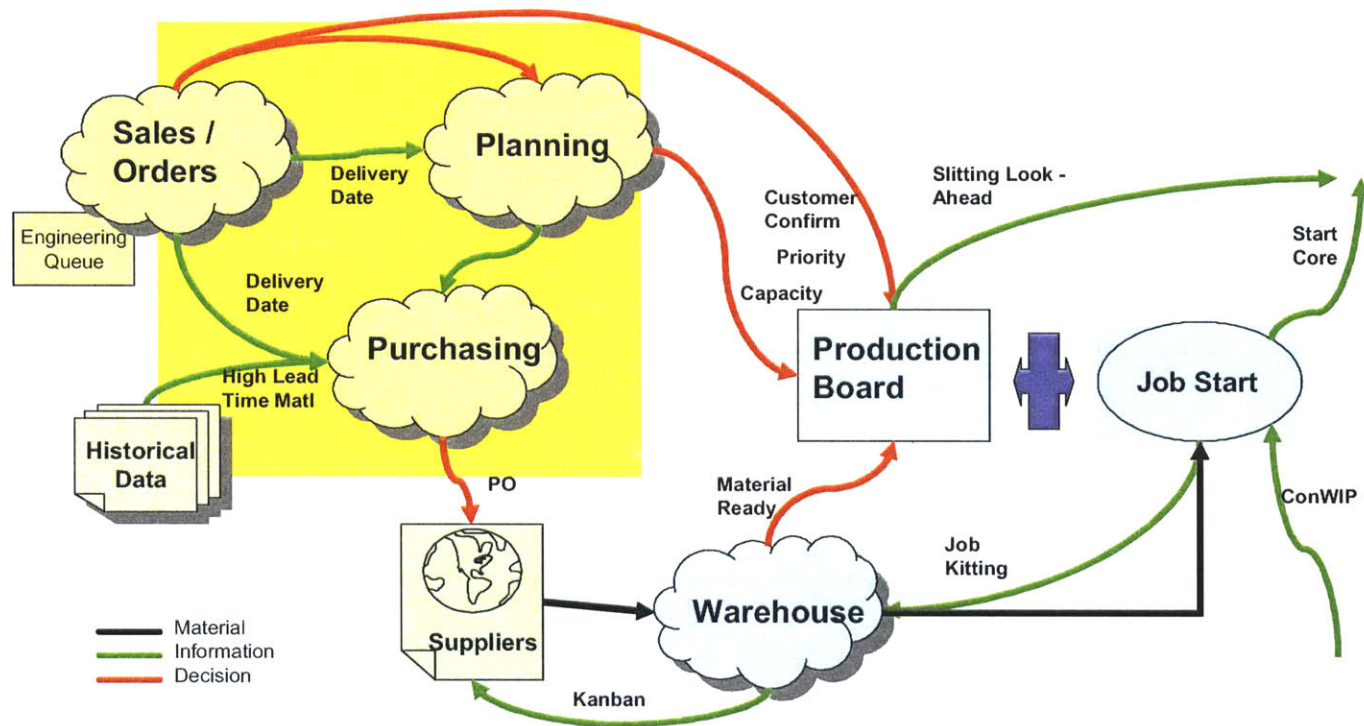
Appendix D: ConWIP Card

| 工作令 Job # | 合同号 Contract | 规格 Type |
|---|-----------------|------------|
| <u>成品日期</u> Finish Production | | |

Notes 说 :

Appendix E: Cross Department Integration pull production plan. The shaded region represents the stakeholders required to participate in the weekly pull production meeting.

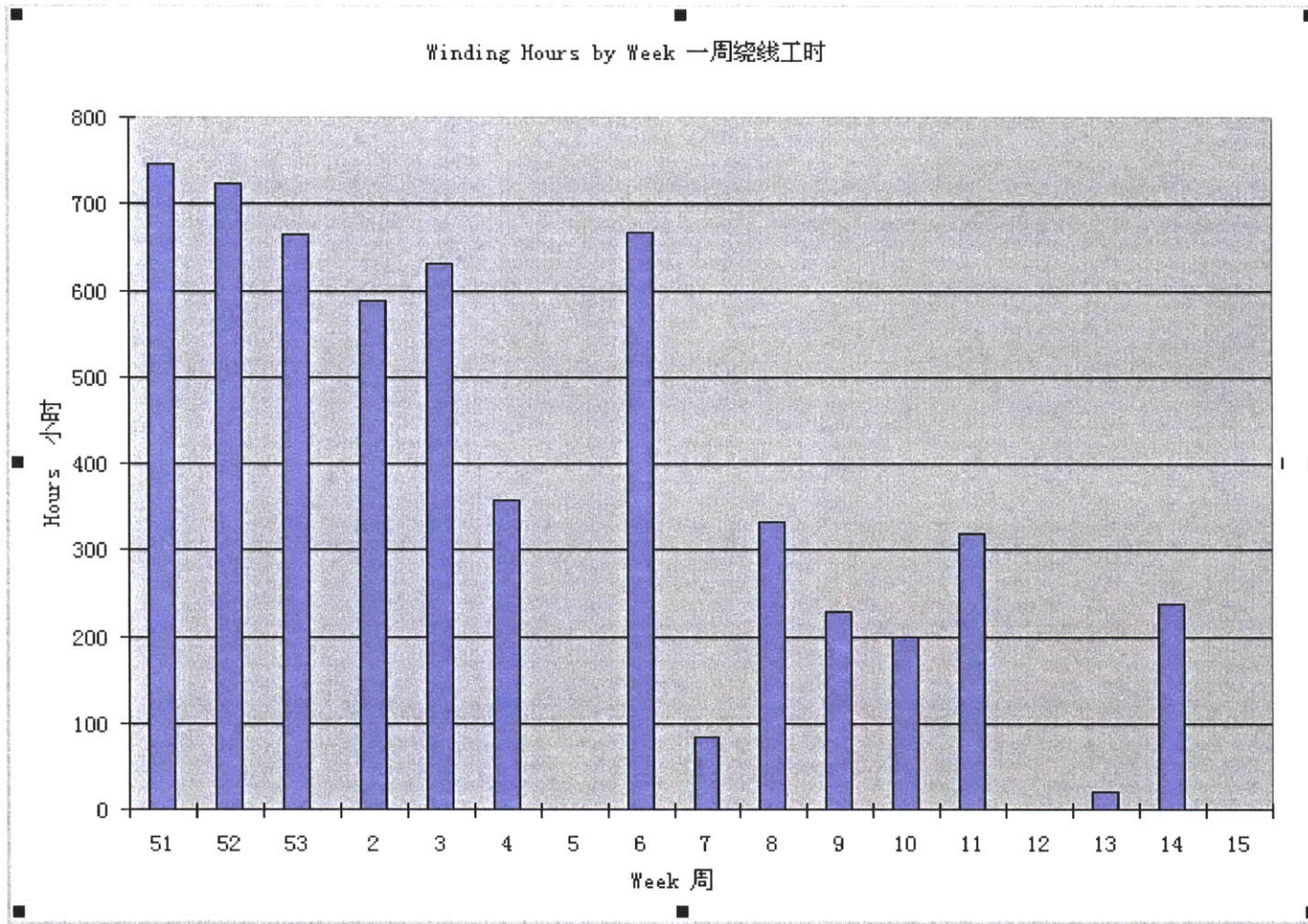
Cross-Department Integration



Appendix F: Production Scheduling Tool sequencing result.

| <u>工作令</u> <u>Job No.</u> | <u>合同号</u> <u>Contract</u> | <u>合同号 日期</u> <u>Contract</u> <u>Review Date</u> <u>(yyyy/mm/dd)</u> | <u>规格</u> <u>Type</u> | <u>相 对 符合的</u> <u>Closest Model</u> <u>Type</u> | <u>成品日期</u> <u>Finish</u> <u>Production</u> <u>(yyyy/mm/dd)</u> | <u>绝缘开始</u> <u>Start</u> <u>Insulation</u> | <u>绕线开始</u> <u>Enter</u> <u>Winding</u> | <u>绕线结束</u> <u>Leave</u> <u>Winding</u> | <u>绕 串</u> <u>Winding</u> <u>Hours</u> | <u>Start</u> <u>Winding</u> | <u>KVA</u> |
|------------------------------|-------------------------------|---|--------------------------|---|--|--|---|---|--|--------------------------------|------------|
| x | x | 12/10/2004 | SCR-3150 | SCR 10 / 3150 KVA | 12/6/2004 | 11/22/2004 | 11/23/2004 | 11/24/2004 | 42 | 48 | 3150 |
| x | x | 12/10/2004 | SCR-2000 | SCR 10 / 2000 KVA | 12/4/2004 | 11/23/2004 | 11/24/2004 | 11/25/2004 | 33 | 48 | 2000 |
| x | x | 12/10/2004 | SCR-2000 | SCR 10 / 2000 KVA | 12/4/2004 | 11/23/2004 | 11/24/2004 | 11/25/2004 | 33 | 48 | 2000 |
| x | x | 1/10/2005 | SCR9-10000 | SCR 35 / 10000 KVA | 1/5/2005 | 11/23/2004 | 11/29/2004 | 12/6/2004 | 189 | 49 | 10000 |
| x | x | 12/13/2004 | SCR-2500 | SCR 10 / 2500 KVA | 12/8/2004 | 11/25/2004 | 11/26/2004 | 11/27/2004 | 39 | 48 | 2500 |
| x | x | 12/13/2004 | SCR-2500 | SCR 10 / 2500 KVA | 12/8/2004 | 11/25/2004 | 11/26/2004 | 11/27/2004 | 39 | 48 | 2500 |
| x | x | 12/10/2004 | SCRZ-5000 | SCRZ 35 / 5000 KVA | 12/31/2004 | 11/26/2004 | 11/29/2004 | 12/3/2004 | 115 | 49 | 5000 |
| x | x | 12/13/2004 | SCR-2500 | SCR 10 / 2500 KVA | 12/12/2004 | 11/29/2004 | 11/30/2004 | 12/1/2004 | 39 | 49 | 2500 |
| x | x | 12/13/2004 | SCR-2500 | SCR 10 / 2500 KVA | 12/12/2004 | 11/29/2004 | 11/30/2004 | 12/1/2004 | 39 | 49 | 2500 |
| x | x | 12/10/2004 | SCR-3150 | SCR 10 / 3150 KVA | 12/13/2004 | 11/29/2004 | 11/30/2004 | 12/1/2004 | 42 | 49 | 3150 |
| x | x | 12/10/2004 | SCR-2000 | SCR 10 / 2000 KVA | 12/10/2004 | 11/30/2004 | 12/1/2004 | 12/2/2004 | 33 | 49 | 2000 |
| x | x | 12/10/2004 | SCR-2000 | SCR 10 / 2000 KVA | 12/10/2004 | 11/30/2004 | 12/1/2004 | 12/2/2004 | 33 | 49 | 2000 |
| x | x | 12/10/2004 | SCR-500 | SCR 10 / 630 KVA | 12/9/2004 | 12/1/2004 | 12/2/2004 | 12/2/2004 | 21 | 49 | 630 |
| x | x | 12/10/2004 | SCRZ-5000 | SCRZ 35 / 5000 KVA | 1/5/2005 | 12/1/2004 | 12/4/2004 | 12/8/2004 | 115 | 49 | 5000 |
| x | x | 1/10/2005 | SCR9-10000 | SCR 35 / 10000 KVA | 1/15/2005 | 12/2/2004 | 12/8/2004 | 12/15/2004 | 189 | 50 | 10000 |
| x | x | 12/20/2004 | SCR-400 | SCR 10 / 400 KVA | 12/10/2004 | 12/3/2004 | 12/4/2004 | 12/4/2004 | 20 | 49 | 400 |
| x | x | 12/10/2004 | SCR-400 | SCR 10 / 400 KVA | 12/14/2004 | 12/5/2004 | 12/6/2004 | 12/6/2004 | 20 | 50 | 400 |
| x | x | 12/10/2004 | SCR-3150 | SCR 10 / 3150 KVA | 12/20/2004 | 12/6/2004 | 12/7/2004 | 12/8/2004 | 42 | 50 | 3150 |
| x | x | 12/15/2004 | SCR9-2000 | SCR 10 / 2000 KVA | 12/16/2004 | 12/6/2004 | 12/7/2004 | 12/8/2004 | 33 | 50 | 2000 |
| x | x | 12/13/2004 | SCR9-1250 | SCR 10 / 1250 KVA | 12/18/2004 | 12/7/2004 | 12/8/2004 | 12/9/2004 | 25 | 50 | 1250 |
| x | x | 12/13/2004 | SCR9-1250 | SCR 10 / 1250 KVA | 12/18/2004 | 12/7/2004 | 12/8/2004 | 12/9/2004 | 25 | 50 | 1250 |
| x | x | 12/13/2004 | SCR9-1250 | SCR 10 / 1250 KVA | 12/18/2004 | 12/7/2004 | 12/8/2004 | 12/9/2004 | 25 | 50 | 1250 |

Appendix G: Production Scheduling Tool chart showing planned weekly capacity. Note: Week 5 is the Chinese New Year Holiday period.



Appendix H: Steel inventory tracking showing inventory weights by width dimension. The weights are converted to a length dimension via the software tool.

30ZH105 矽钢片库存 Steel Inventory

12/ 17

| 规格 (mm) | Weights 重量(kg) | | | | | | | | | | |
|---------|----------------|------|------|------|------|------|------|------|------|------|------|
| 1000 | 2830 | 2600 | 2165 | 2280 | 2845 | 3225 | 2600 | 2440 | 3285 | 2965 | 3180 |
| | 3400 | 3360 | 3460 | 3355 | 3220 | 3285 | 2595 | 2600 | 3265 | 3320 | 2985 |
| | 3215 | 2790 | 3005 | 2445 | 2995 | 3295 | 3265 | 2385 | 2480 | 2145 | |
| | A | B | C | D | E | F | G | H | I | J | K |
| 120 | 312 | | | | | | | | | | |
| 150 | 360 | 243 | 478 | 478 | 358 | | | | | | |
| 160 | 300 | 229 | 261 | 221 | 221 | 233 | 233 | 379 | 325 | 346 | 343 |
| 170 | 327 | | | | | | | | | | |
| 220 | 566 | | | | | | | | | | |
| 270 | 672 | | | | | | | | | | |
| 290 | 480 | | | | | | | | | | |
| 310 | 818 | 787 | 797 | 797 | 815 | 736 | 669 | 572 | 732 | 776 | 672 |
| | 561 | 548 | 602 | 919 | 684 | 810 | | | | | |

30ZH105 矽钢片库存 Steel Inventory

12/ 17

| 规格 (mm) | Lengths 长度(m) | | | | | | | | | | |
|---------|---------------|------|------|------|------|------|------|------|------|------|------|
| 1000 | 1233 | 1133 | 943 | 993 | 1240 | 1405 | 1133 | 1063 | 1431 | 1292 | 1386 |
| | 1481 | 1464 | 1508 | 1462 | 1403 | 1431 | 1131 | 1133 | 1423 | 1447 | 1301 |
| | 1401 | 1216 | 1309 | 1065 | 1305 | 1436 | 1423 | 1039 | 1081 | 935 | |
| | A | B | C | D | E | F | G | H | I | J | K |
| 120 | 1133 | | | | | | | | | | |
| 150 | 1046 | 706 | 1389 | 1389 | 1040 | | | | | | |
| 160 | 817 | 624 | 711 | 602 | 602 | 635 | 635 | 1032 | 885 | 942 | 934 |
| 170 | 838 | | | | | | | | | | |
| 220 | 1121 | | | | | | | | | | |
| 270 | 1084 | | | | | | | | | | |
| 290 | 721 | | | | | | | | | | |
| 310 | 1150 | 1106 | 1120 | 1120 | 1146 | 1035 | 940 | 804 | 1029 | 1091 | 945 |
| | 789 | 770 | 846 | 1292 | 961 | 1139 | | | | | |

Appendix I: Analysis of Monthly Foil Consumption

| Type | Dry | Dry | Dry | Dry | Dry | Dry | Dry | Dry | Dry |
|-------------|--------|--------|--------|--------|--------|--------|-------|-------|---------|
| Size | .5*820 | .5*860 | .6*690 | .6*740 | .8*720 | .8*780 | 1*720 | 1*840 | 1.2*820 |
| Jan '03 | 373 | 0 | 1075 | 934 | 1045 | 0 | 702 | 2090 | 1785 |
| Feb '03 | 0 | 0 | 396 | 0 | 1782 | 761 | 856 | 1505 | 2921 |
| Mar '03 | 743 | 247 | 0 | 1371 | 822 | 1371 | 1463 | 372 | 2597 |
| Apr '03 | 423 | 0 | 580 | 1376 | 2019 | 1156 | 0 | 1811 | 1789 |
| May '03 | 190 | 252 | 1970 | 1442 | 4172 | 838 | 1824 | 730 | 3516 |
| Jun '03 | 642 | 405 | 200 | 440 | 1501 | 0 | 0 | 1088 | 2205 |
| Jul '03 | 380 | 118 | 0 | 458 | 0 | 1204 | 285 | 1790 | 4244 |
| Aug '03 | 0 | 1435 | 195 | 215 | 759 | 1091 | 0 | 3779 | 720 |
| Sep '03 | 173 | 416 | 0 | 0 | 668 | 793 | 1394 | 764 | 2801 |
| Oct '03 | 418 | 1509 | 0 | 851 | 558 | 576 | 738 | 2360 | 723 |
| Nov '03 | 584 | 215 | 0 | 1742 | 503 | 2940 | 0 | 1054 | 1035 |
| Dec '03 | 509 | 0 | 1051 | 1241 | 498 | 300 | 1007 | 6482 | 2229 |
| Jan '04 | 0 | 820 | 0 | 0 | 0 | 550 | 287 | 1443 | 3600 |
| Feb '04 | 196 | 956 | 0 | 2412 | 241 | 1711 | 586 | 3646 | 10098 |
| Mar '04 | 0 | 416 | 190 | 1895 | 786 | 1448 | 873 | 0 | 2396 |
| Apr '04 | 0 | 1699 | 0 | 0 | 501 | 4043 | 292 | 3698 | 2496 |
| May '04 | 340 | 1203 | 377 | 761 | 250 | 857 | 281 | 853 | 3491 |
| Jun '04 | 1574 | 433 | 386 | 876 | 2605 | 1158 | 1699 | 2185 | 1520 |

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