STRATEGY AND OPERATIONAL IMPROVEMENT IN AN ALUMINUM ROLLING PLANT

by

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ABSTRACT

This thesis examines strategy and operational improvements in a manufacturing business. The project focuses on an aluminum can stock plant. A strategic analysis shows that the business should pursue a strategy of differentiation through improved quality and delivery performance.

Quality is identified as the key leverage area for improving plant performance. A cost of quality analysis indicates that quality problems account for a major portion of plant expenses. Because cost accounting systems allocate these poor quality costs over all products, the impact of poor quality is often not recognized by management. The thesis recommends a variety of methods for improving quality and delivery performance levels including: standard operating procedures, statistical process control, set-up time reduction, throughput improvements, better metrics, and flowtime reduction.

Reinforcing feedback systems diagrams are utilized to show the underlying reasons for many of the plant's problems. Attempts to cut costs, for example, increase quality problems which lead to higher costs. As a result of the high level of quality problems, the plant has gained expertise in repairing products. This, however, hides the root problem of high process variability which leads to more quality problems. Systems thinking is also used to show how corporate and internal metrics adversely affect plant performance.

The thesis develops a computer simulation model of the can stock plant which is used to evaluate various modifications to plant operations. The simulation shows that a theory of constraints approach is most appropriate for the plant. Eliminating inventory targets after the bottleneck operation significantly reduces work in process (WIP) inventory without any throughput reduction. The simulation indicates that for a plant with a significant level of non-bottleneck operation downtime, the theory of constraints philosophy results in significantly more throughput (and only slightly more WIP inventory) than a just in time (JIT) philosophy. The simulation is also used to determine appropriate inventory levels before the bottleneck operation, and to evaluate the benefits of potential capital investments. Finally, the thesis summarizes the major recommendations for the plant and the general lessons that were learned as a result of this project.

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Chapter 1: Introduction

1.1 Introduction to Thesis

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1.2 Outline of Thesis

Chapter 2 is an overview of Lakeside - an aluminum can stock manufacturing plant. The chapter describes several different aspects of the plant including: products, the manufacturing process used to produce aluminum can stock, production scheduling, and key metrics used at Lakeside.

Chapter 3 contains a strategic analysis of Lakeside. An overview of current strategic management theory is presented and then applied to the Lakeside business. Based upon a variety of internal and external factors, this thesis recommends a strategy of differentiation through high quality and delivery performance.

Chapter 4 describes the quality problems at Lakeside. An analysis indicates that the cost of poor quality is the second largest expense at Lakeside, after material costs. As such, improving quality is the leverage point in the plant. The chapter explains how internal metrics and downsizing programs lead to increasingly high quality costs. Because of the high level of process variability in the plant, standard operating procedures and statistical processing control systems are recommended for improving quality performance. The chapter also recommends modifying plant metrics to emphasize "first time right quality" rather than "amount of product produced."

Chapter 5 describes the benefits to customers from improved delivery performance. Because delivery performance in the can stock industry is generally poor, can manufacturers have large inventories of can stock - which could be eliminated if a can stock maker could achieve a high delivery performance level. A variety of recommendations for improving delivery performance are presented including: reducing flowtime, decreasing set-up times, installing cooling fans, increasing plant capacity, and emphasizing on-time delivery metrics.

Chapter 6 discusses possible alternative scheduling strategies for Lakeside, and evaluates several of these strategies using the LPM simulation model. A theory of constraints approach to scheduling is recommended.

Chapter 7 contains a summary of recommendations for the Lakeside plant and general lessons learned from this thesis.

Appendix A describes the LPM simulation model that was created to evaluate operational strategies for the Lakeside plant, as well as how the model was validated. Appendix B contains general information on aluminum alloys and aluminum can stock. Appendix C includes some of the parameters that were used in the LPM simulation.

Chapter 2: Case Study of Lakeside

2.1 Global Aluminum

The Global Aluminum corporation (GA) is a leading international producer of aluminum and aluminum products. In addition to mining bauxite and producing raw aluminum, GA fabricates a variety of aluminum products used primarily by packaging, transportation, construction, and industrial customers.

Over the last few years, the aluminum industry has become increasingly competitive. It has been estimated that the average cost to produce a pound of primary aluminum is 53.6¢. The price, however, has declined from $1/lb. in 1988 to approximately 50¢/lb. in 1993. Thus, more than half of all aluminum produced in 1993 was done so at a loss. One of the major reasons for the decline in prices has been the exporting of primary aluminum from Russia. Prior to 1990, Russia exported little aluminum. These exports increased to 350,000 tons in 1990, to 800,000 tons in 1991, and close to 1,000,000 tons in 1992 (worldwide capacity is less than 16,000,000 tons/year).

As a result of Russian dumping, the global recession, and the downturn in the aircraft industry (one of the primary markets for aluminum), prices and profits for aluminum have dwindled. Unlike many other aluminum companies, however, GA has been able to remain profitable during the early 1990s - although profit levels have been significantly less than in previous years. A major emphasis throughout GA has been placed on cost reduction. In addition, top management has attempted to make business unit managers and plant managers more autonomous and accountable for bottom line results.

Lakeside is a European can stock business that is owned by Global Aluminum. Lakeside produces the aluminum alloys that can makers use to fabricate aluminum beverage cans. Appendix B provides a brief overview of aluminum alloy and can nomenclature.

2.2 Overview of Lakeside

The Lakeside Works consists of a large manufacturing plant (which contains all of the production facilities), an office building (which houses plant upper management and the administrative staff), an effluent plant (which treats the used chemicals from the manufacturing process), a couple of smaller office facilities (which house various engineering and administrative personnel), a training center, and various storage facilities. Lakeside's manufacturing operations run 7 days per week on all three shifts - with the exception of the Saturday night shift when the plant is closed.

Market and Products

Lakeside produces aluminum can stock for European and Middle Eastern can makers. There are less than ten major customers that purchase the vast majority of Lakeside's products. Historically, Lakeside has had a 50% share of the European end and tab stock market. Lakeside has also recently begun selling body stock to customers. The final product at Lakeside is a large (up to 12 tons) coil of aluminum can stock.

Specifications for each product include requirements for alloy, width, gauge, and type of coating/surface finish. There are only a few basic alloys which are used for Lakeside products. These alloys can be cast into several different ingot sizes. Thus, at the ingot stage there are about a dozen possible specifications. As a product progresses through the system, there are an increasingly large number of possible intermediate specifications. Currently, there are over 200 active final specifications used by Lakeside.

Aluminum Can Stock Industry Growth

Growth in the aluminum can stock market is dependent upon the amount of beer and soft drinks sold, and the percentage of beverages sold that are packaged in aluminum cans. The amount of beer and soft drinks that are sold varies based upon a number of factors ranging from the marketing ability of large beverage companies, such as Coke and Pepsi, to the weather (beverages sell at higher rates during hot days).

The percentage of beverages sold in aluminum cans also depends upon many factors ranging from the price of aluminum cans versus steel cans and plastic bottles (which, in turn, depends upon the prices of raw materials for these products) to government recycling legislation in each European country. Although the European can stock market has been growing, growth has been less than expected. Whereas Lakeside had been predicting market growth of 8% per year, actual growth has been 3% to 4% per year.

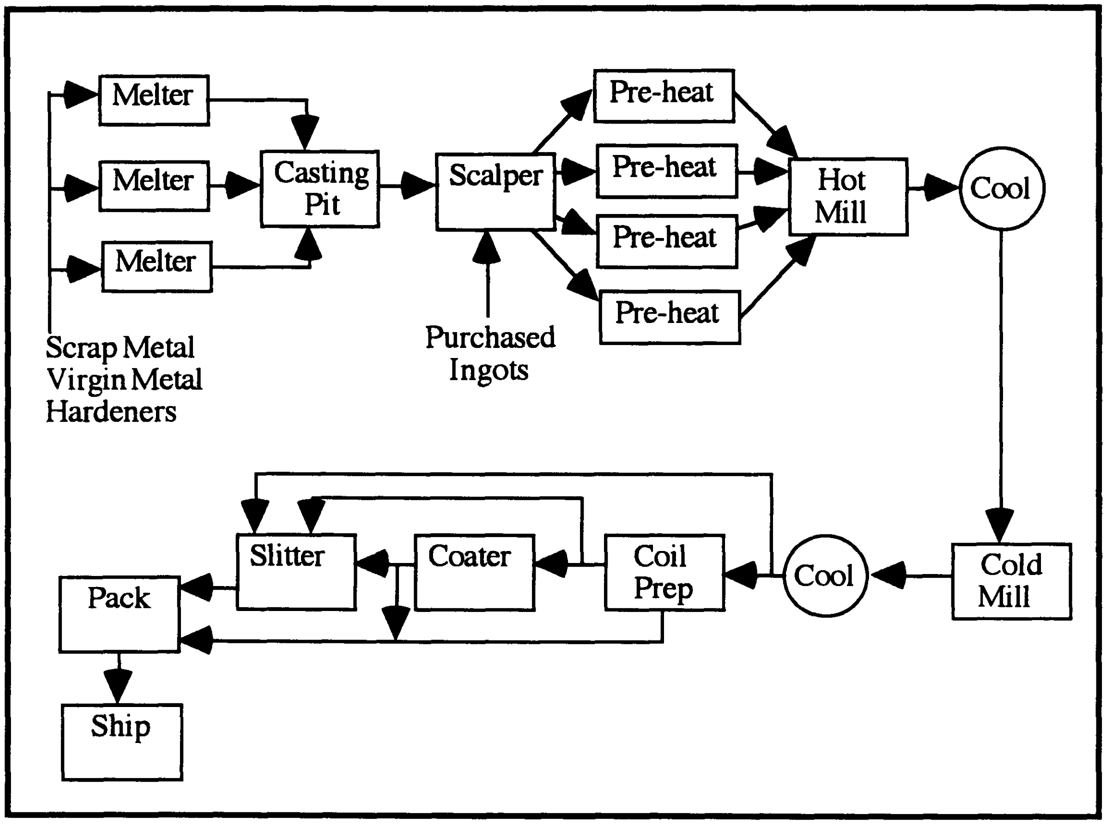
Finance

Unlike many of GA's other can stock plants, Lakeside has been able to remain profitable during most of the past several years. Profit levels and return on investment (ROI) have varied significantly from year to year.

Approximately half of Lakeside's expenses are for the raw materials and ingots used to produce the aluminum can stock. Lakeside purchases metal on the London Metal Exchange. Exchange prices are continually monitored by Lakeside, and prices are generally "locked in" months ahead of the actual delivery dates. Since the vast majority of Lakeside's suppliers, customers, and competitors are located in other countries, exchange rates can have a major impact on Lakeside's competitiveness.

2.3 Lakeside's Manufacturing Process

This section describes the manufacturing process at Lakeside. Figure 2.1 provides an overview of the production sequence.



Note: induction furnace, holding tanks, and annealing furnaces omitted for clarity.

Figure 2.1: Lakeside's Manufacturing Operations

Raw Materials - The key raw materials used in the process are: virgin aluminum (99.5% to 99.8% pure), scrap aluminum (from downstream processes), magnesium, and manganese. All raw materials (except scrap) are purchased from outside suppliers and delivered to the manufacturing plant.

Re-melt Furnaces - Depending upon the type of alloy desired and the amount of scrap aluminum available, a mixture (or "charge") of raw materials for a furnace is determined. The raw materials are loaded into high temperature re-melt furnaces which are heated up until the metals are liquefied. The molten metallic liquid is then released into holding tanks. There are three re-melt furnaces and two holding tanks in the Lakeside plant.

Induction Furnace - Certain types of scrap (e.g., scrap from the scalper and plain edge trim from the coil prep line and slitter) must be melted in an induction furnace prior to being used as aluminum scrap in the re-melt furnace charge. Melted induction furnace scrap is fed directly into one of the re-melt furnaces.

Ingot Casting - Ingots are cast using a conventional casting process. Molten aluminum alloy is poured into ingot molds. Cooling water is used to rapidly cool the metal as it is lifted out of the casting pits. The cooling water solidifies and quenches the molten metal into ingot form. Approximately half of the ingots used at Lakeside are produced in-house, while the other half are purchased from outside suppliers (due to capacity constraints in the ingot plant).

Scalper - The scalper cuts the top and bottom layers off the ingots to eliminate the surface defects that occur on cast ingots. Defects that are not removed will result in surface quality problems during the subsequent rolling operations.

Pre-heat Furnaces - The pre-heat furnaces heat the ingots up to hot rolling temperatures (approximately 500 °C). There are two reasons for heating up the ingots at this point in the process. The first reason is that the high temperatures soften the ingots. The softer the ingot, the easier it is for the hot mill to reduce the ingot thickness during the rolling process. The second reason is to resolve inhomogeneities in the ingots which are formed during the casting process. There are 4 pre-heat furnaces - each of which can heat up to 16 ingots. The time to heat up a batch of ingots depends upon the alloy and size of the ingots. Body stock, 3xxx alloys, contains a relatively large amount of manganese - which diffuses slowly through aluminum. As such, the "soak time" for body stock is significantly longer than for end and tab stock.

Hot Rolling Mill - The heated ingot is rolled back and forth many times through the hot mill until the thickness of ingot is reduced to approximately 3 mm. During the final pass through the hot mill the aluminum is rolled into a coil. The coil is then removed from the hot mill and allowed to cool for approximately 36 hours.

Annealing Furnace - The vast majority of coils coming off the hot mill are self-annealed. Occasionally, however, a coil is not annealed and must be placed in the annealing furnace. Self-annealing failures are held until a sufficient batch of coils are available (e.g., 8 to 16) at which point they are annealed simultaneously.

Cold Rolling Mill - The hot rolled coils are rolled several times through the cold mill until the thickness is reduced to customer specifications (usually in the .24 mm to .33 mm range). In addition to reducing the thickness of the coil, the cold rolling process also work hardens the aluminum alloy - which increases the yield strength of the can stock. At this point, the length of the coil is generally over 7 kilometers. Cold rolled coil is allowed to cool for approximately 36 hours.

Coil Preparation Line - On the Coil Prep line, the edges of the coil are trimmed to meet customer specifications, and the surfaces of the coil are chemically polished. Plain end coils (which do not receive a lacquer coating from the coater line) are sprayed with a special coating to protect the surface quality of the can stock.

Coil Coating Line - The majority of end stock produced at Lakeside must be coated on one or both sides of the aluminum. These coils are run through the coating line which adds a lacquer coating to the surface of the aluminum alloy. The coils are then fed through an oven which cures the lacquer to the surfaces of the coils.

Coil Slitting Line - On the slitter line, coils are forced through a slitter head which cuts the can stock down the length of the coil in any desired manner (single or multiple cuts). Approximately half of Lakeside's orders are for slit can stock. The slitter line is also used extensively to repair defective coils. For example, if a particular coil has some surface defects along one side of the coil, that side can be removed (using the slitter) and the remainder of the coil used to satisfy another order.

Shrink Pack Line - All finished products are covered with a protective plastic sheet which is then shrink wrapped to the can stock coils. The finished coils are placed in finished goods inventory.

Transportation - Coils are transported throughout Europe using trucking companies. The number of coils a truck can carry is determined by the weight of coils and national restrictions. A typical finished coil will weigh over 7 tons, and each country in Europe has laws on maximum truck load weight (a typical limit is 23 tons). Delivery time varies from one to four days, depending on location. Coils for overseas customers are delivered to an inland clearance depot. A shipping company is then used to pack the product into shipping containers and deliver the coils to customers. Overseas deliveries generally take at least a week.

2.4 Production Scheduling

This section describes how orders are processed through the plant. The order process begins when a customer (a can-maker) calls the sales department to request an order. The customer will identify the desired specifications for the product, the amount of product required, and the required delivery week. All of the customers have their own specifications for can stock. Sales discusses the potential order with the production control supervisor who evaluates whether it is feasible to meet the order requirements. If it is feasible, sales accepts the order - which is then entered into the plant's order book. The production control department is responsible for scheduling products through the plant. All scheduling is performed manually by production control personnel. The plant does not utilize any type of Materials Resource Planning (MRP) software.

The ingot plant is scheduled on a weekly basis. Based upon current inventory levels and the amount of product that needs to be produced over the next couple of weeks, production goals for the ingot plant are determined.

Production control uses the order book to determine what orders should be processed in a given week (based primarily on due date) and how they should be sequenced. Because certain product sequences require long set-up times (e.g., changing the type of coating on the coater line can take well over an hour), production control tries to optimize the sequence of products within a given week to minimize set-ups (e.g., sequencing products through the coater such that coating changes are minimized). If there is excess capacity in a given week, orders from following weeks that fit into current sequences may be pulled forward.

Production control then develops daily schedules for each work center. These daily schedules are take/make (the schedule states which coils should be taken from the previous work center, and what should be done with them). The plant workers use the daily take/make sheets on the shop floor.

There are target inventory ranges at each step in the process, which production control tries to maintain. Because of the variability in the rolling processes, ingots and coils are not assigned to specific orders until after the cold rolling process.

A general scheduling rule used by production control is to schedule coils from widest to narrowest over the course of a few days. This is due to the fact that many of the process centers (hot mill, cold mill, coil prep line, coater) require set-ups when there is a change from narrow coil to wide coil. The coater also requires a significant set-up time when the type of coating is changed.

Reallocation of coils plays a major part in the plant. The metallurgists and managers in each department determine whether a coil is acceptable for its intended specification. If the entire coil is bad, it is scrapped. If only a portion of the coil is bad, then information on the coil is given to the production control department. Production control will then look through the order book to determine whether there are any other orders which the good portion of the coil can be used for. For example, if the edge of a 1600 mm wide coil is damaged, the edge can be cut off using the slitter, and the remaining part of the coil may be used to meet an order for 1060 mm wide coil. Reallocation of coils is based mainly on alloy and thickness.

When a coil reaches finished goods inventory, the transportation department (in conjunction with production control) arranges for the shipment of the product to the customer.

2.5 Metrics

On the plant floor level, the most significant metric used is tons produced. Each year Lakeside develops estimates for the amount of product the plant will produce during each month of the following year, and submits these targets to GA. The amount of aluminum produced is then tracked for each processing center and for the whole plant on a daily, weekly, and monthly basis. Actual production levels are then compared with the targets.

The other two significant metrics used are flowtime and recovery. Flowtime is an average of the period between the time an ingot is cast (or delivered to the plant) and the time it is sent to finished goods inventory as a finished product. Recovery for a process is the ratio of the weight of aluminum alloy at the end of the process over the weight of aluminum alloy at the start of the process. Recovery identifies how much material has been scrapped during a process. Overall recovery is further broken down into different categories (length recovery, width recovery, whole coil recovery, etc.).

From a corporate standpoint, return on investment (ROI) tends to be the most significant metric.

2.6 Organization

Figure 2.2 is an organizational chart of the current Lakeside management structure. Although not shown on the chart, the salesmen at Lakeside report directly to the Managing Director.

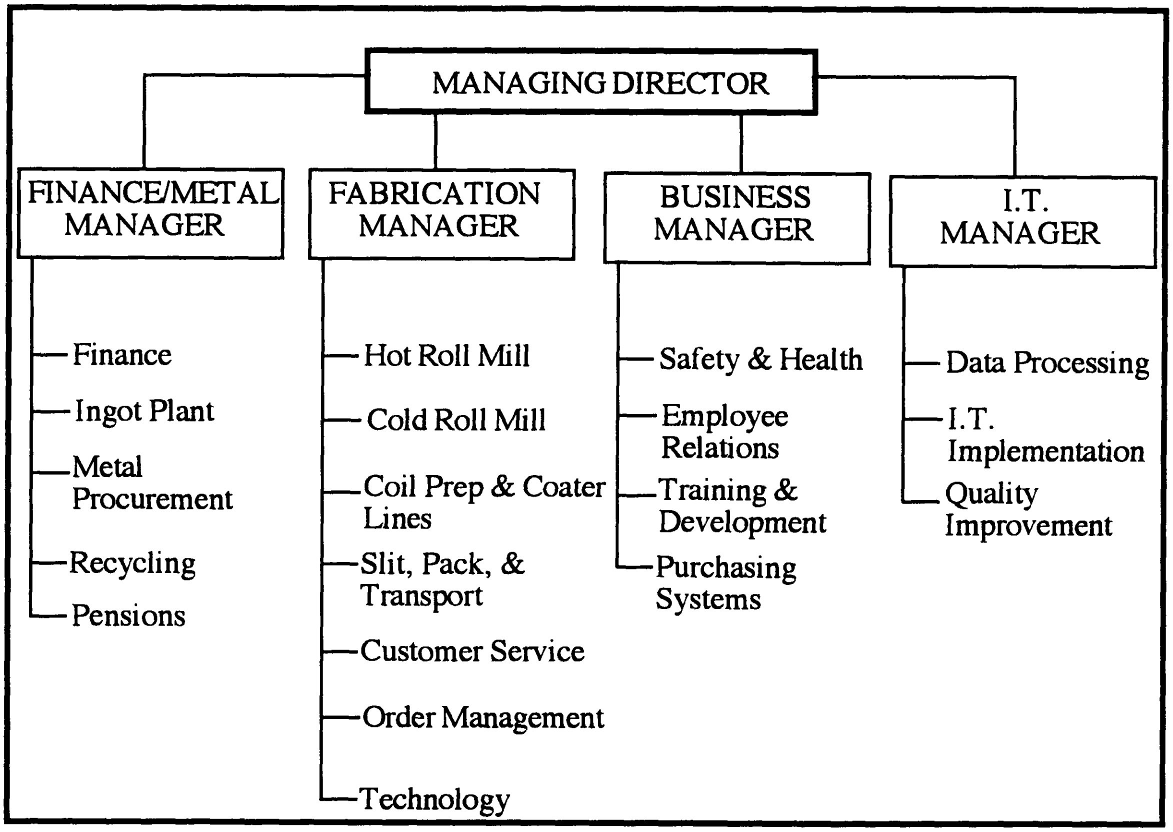


Figure 2.2: Organizational Chart for Lakeside

2.7 Current Issues

While Lakeside has been fairly successful, there are a variety of issues the business is currently facing. This section discusses a few of these problems.

1) Slow Growth of Market - As previously mentioned, the European can stock market has not grown as quickly as Lakeside had expected.

2) Loss of Customers - Two of Lakeside's competitors each recently purchased a European can maker. The effect of this is that Lakeside will lose business from two major customers while its competitors will have a captive market.

3) Overcapacity - Several of Lakeside's competitors have built new large capacity plants during the past few years. As a result of this, and the less than expected growth rate, most of Lakeside's competitors have plants with excess capacity. This has driven prices and profit margins down. It is, therefore, likely that competition in the European can stock market will intensify over the next few years.

4) Inconsistent Production - Lakeside is having difficulties in improving delivery performance. Production output is inconsistent with record output levels one month, and less than average levels the next month.

5) Decreasing Order Times - Customers have become increasingly demanding with respect to shortening delivery times. This has placed a great deal of pressure on manufacturing and has made meeting delivery dates increasingly difficult.

Chapter 3: Strategic Analysis of Lakeside

3.1 Strategy for Lakeside - a Global Aluminum View

In evaluating strategies for Lakeside, it's necessary to first examine Global Aluminum's view of Lakeside. Figure 3.1 is the Boston Consulting Group's Growth Share Matrix[1] which is commonly used by corporations to evaluate business units.

		Relative Market Share	
		High	Low
Market Growth	High	STAR [Invest/Grow]	QUESTION MARK [Divest or Grow]
	Low	CASH COW [Milk]	DOG [Divest]

Figure 3.1: Growth Share Matrix

Within the European end and tab stock market, Lakeside has the largest market share. As such, they would rank high on the market share axis of the Growth Share Matrix. Evaluating whether growth in the can stock market is high or low is somewhat subjective. While the can stock market is expected to grow over the next several years, it isn't clear what the growth rate will be. Most analysts believe that aluminum beverage cans will become increasingly popular as the level of recycling increases in Europe. If this is true, the can stock industry would rank high on the market growth axis, and Lakeside would fall into the "star" category. The appropriate corporate strategy for a "star" is to invest heavily in the business to achieve further growth.

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[1] Hax, Arnoldo and Majluf, Nicolas S. The Strategy Concept and Process. Englewood, NJ: Prentice Hall, 1991, p. 186.

Based upon empirical evidence, it does not appear that GA has pursued a "star strategy" with Lakeside. Whereas Lakeside's competitors, in an effort improve market share, have made large investments (e.g., purchasing can makers, increasing plant capacity, modernizing operations), GA has made few such investments to assist Lakeside. Conversely, GA has not pursued a purely "cash cow strategy" with Lakeside. For example, Lakeside purchased a new coater a few years ago. As such, it is not clear what GA's strategy for the European can market (and Lakeside) is. The rest of this paper assumes that GA's goal is to achieve growth in the European can stock market, as opposed to divesting or milking Lakeside.

3.2 Five Forces Analysis of Lakeside

The following is a brief five forces analysis[2] of Lakeside's can stock business:

Power of Suppliers

The power of suppliers in the aluminum can stock business is limited. The raw materials needed to create aluminum can stock are mostly commodity items. Raw aluminum, for example, can be purchased on the London Metal Exchange. Prices are, therefore, generally determined on the open market, and suppliers have little power in negotiating aluminum prices.

Power of Buyers

There are less than a dozen major can makers in Europe. As such, each of the major can makers has a relatively large amount of power. Losing a single customer can have a significant impact on a can stock producer.

Barriers to Entry/Threat of New Entrants

The only major barrier to entry in the can stock business is capital. Rolling mills and coating machines are very large, expensive pieces of equipment. Provided that a corporation is willing to spend the money, however, the barriers to entry are fairly low. There aren't any formal distribution channels in the can stock business - all a new entrant would need is a telephone to call potential customers. In addition, although being a well recognized company has some value, most can makers make purchase decisions based upon the merits of the products (price, quality, etc.).

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[2] Porter, Michael E. Competitive Strategy. New York, NY: The Free Press, 1980, p. 4.

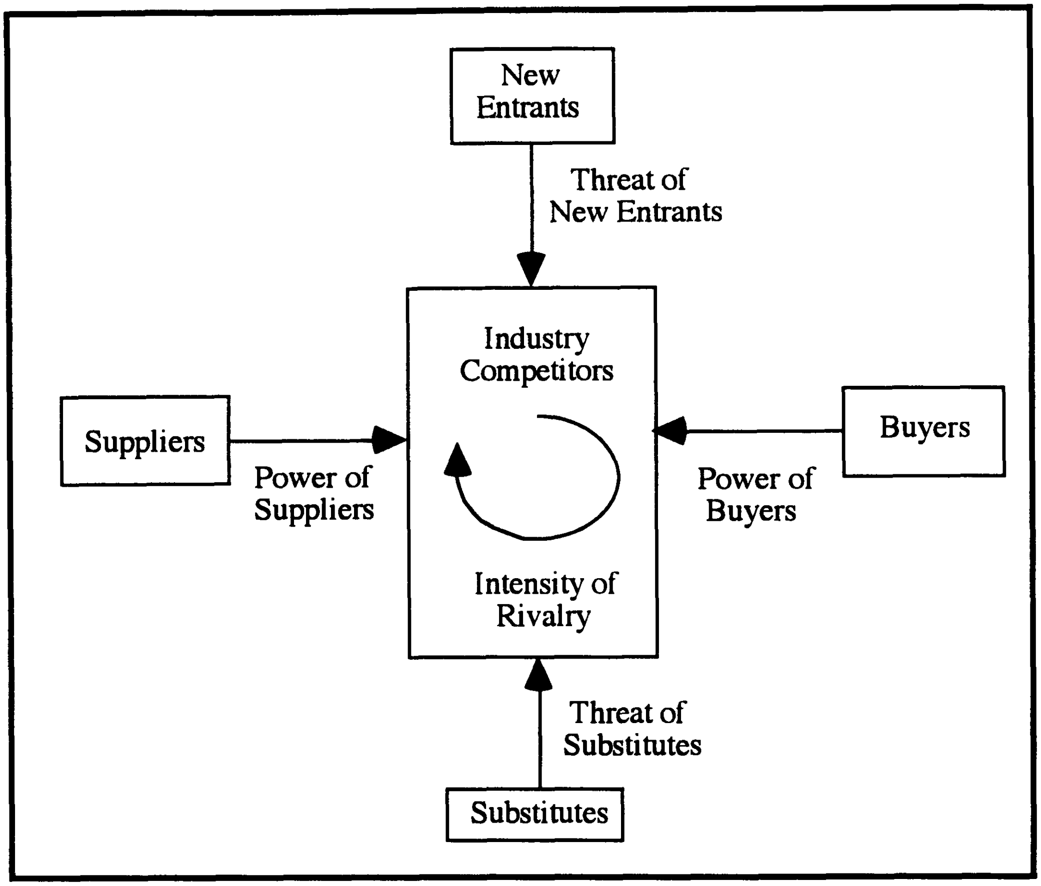

Figure 3.2: Michael Porter's Five Forces Model

Existing aluminum processing businesses that have previously not produced can stock (or have only made body stock and not tab and end stock) are a potential source of new entrants. As a result of the recession in Europe, many of these processing business have significant levels of excess capacity, and may look to fill capacity by modifying their operations to produce other products such as end and tab stock. Whereas all of Lakeside's current competitors are European businesses, another likely source of new entrants is from corporations outside of Europe.

Availability of Substitutes

With respect to Lakeside's direct customers, the can makers, the only substitute is steel. While aluminum cans dominate the U.S. market (over 97% of all U.S. beer and soft drink cans are made from aluminum), steel body beverage cans remain popular in Europe and Japan.[3] In Europe, approximately 40% of can bodies are steel (50% in Japan).

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[3] Hunt, Julian. "All that Glitters is not Gold - Aluminum Can Recycling." Packaging Week, Vol. 8, No. 24, P. 19.

While steel can bodies are still very popular in Europe, the end and tab portions of beverage cans (see appendix B) are predominantly aluminum. This is because the conventional opening tab can not be easily fabricated using steel. Since Lakeside's primary products are end and tab stock, steel body cans have not historically been a threat. Recently, however, several European steel companies have developed an all steel can that uses a push button opening method.[4]

With respect to the downstream customer (the beverage companies), there are a variety of substitutes for aluminum beverage cans including: glass containers, plastic containers, and multi-layered coated paper containers. Which of these packaging methods the beverage companies use depends upon a multitude of factors including:

Customer Preferences - Ultimately, beverage companies are driven by the demands of the consumers. In many European countries, for example, consumers strongly prefer glass bottles for beer.[5]

Recyclability - Recycling is a major reason for the success of aluminum cans. For example, when Pepsi-Cola Bottling Co. of Charlotte decided to switch to all aluminum cans, a Pepsi executive estimated that it would cost Pepsi an extra 6 cents to 12 cents per case for the aluminum cans. Pepsi switched, however, primarily because of pressure by recycling groups. As the Pepsi executive stated, *"The steel industry is 15 years behind aluminum on recycling."* [6]

Regulation - Several countries in Europe that utilize reusable plastic containers (which are sterilized and reused, rather than recycled) have placed taxes on "one-time" containers. Finnish industries have limited aluminum cans to ten percent of the market to preserve the refillable system.[7]

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[4] Munford, Christopher. "Ecotop - All Steel Can." American Metal Market, Vol. 101, No. 126, p. 4.

[5] Ayshford, Hilary. "Quenching the Thirst for Change." Packaging Week, July 22, 1993, P. 13.

[6] Rabb, Will. "Pepsi Plans New Generation of Aluminum Cans." The Business Journal-Charlotte, Vol. 5, No. 19, Sec. 1, p. 1.

[7] McCarthy, Rebecca. "Recycling: Will it Survive?" The Atlanta Journal and Constitution, Dec 6, 1993, Section A, p. 1.

Production Costs - Production costs for each packaging method vary based upon several factors including the cost of the underlying materials (e.g., raw aluminum prices) and the type of design (e.g., can coating used, design of plastic bottle, etc.). In general, metal cans tend to be the least expensive, while multi-layered paper packages are the most expensive.[8]

Transportation/Spoilage Costs - Glass containers are heavier and more fragile than plastic containers. Transportation and breakage costs are, therefore, higher for glass bottles. Steel cans are heavier than aluminum cans, but are less prone to puncture.

Decorative/Design Options - Packaging can have a large impact on beverage sales. For example, when Coke replaced a 20 oz. straight edge bottle with a 20 oz. contoured bottle in one particular city, Coke sales of that sized package jumped by 25%.[9] Plastic containers generally offer the widest design and fabrication freedom.

Most beverage companies package their products in several different types of containers to increase competition among packaging industries and to place downward pressure on prices.

Rivalry among Competitors

While the can stock business has always been competitive, the rivalry among firms has intensified during the past several years. A couple of Lakeside's competitors have recently opened new general aluminum processing plants. As a result of the recession, most of Lakeside's competitors have significant levels of overcapacity, and have attempted to fill capacity by expanding their market share in can stock. This has resulted in lower prices and profit margins in the industry.

Summary of Five Forces Analysis

The analysis clearly indicates that the can stock business will become increasingly competitive during the next several years. Intense pressure from competitors and increasingly demanding customers could result in lower market share and profit margins for Lakeside's products.

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[8] Goddard, Ron. "The Problem of Pack Design." Food Manufacture, Nov 1993, p. 27.
[9] Moore, Martha T. "Coke's Curvy Shape is Back." USA Today, March 28, 1994, Money, p. 1B.

3.3 Generic Strategies

As shown in figure 3.3, there are three generic strategies a business can pursue: cost leadership, differentiation, and focus. The following briefly describes each of these potential strategies, as well as the "non-strategy" of being stuck in the middle.

		ADVANTAGE	
		Uniqueness Perceived by the Customer	Low Cost Position
MARKET	Industrywide	DIFFERENTIATION	COST LEADERSHIP
	Particular Segment	FOCUS	

Figure 3.3: Generic Strategies [10]

Cost Leadership

With a low cost strategy a firm focuses every aspect of the business on cutting costs. Cost advantages are usually achieved through economies of scale, state-of-the-art mass production equipment, products designed for manufacturability, economies in purchasing, and tight control over expenses. According to Michael Porter[11], the low cost strategy generally requires "*high up-front capital investment in state-of-the-art equipment, aggressive pricing, and start-up losses to build market share.*" Porter also states that "*Once achieved, the low cost position provides high margins which can be reinvested in new equipment and modern facilities in order to maintain cost leadership. Such reinvestment may well be a prerequisite to sustaining a low cost position.*"

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[10] Porter, Michael E. Competitive Strategy. New York, NY: The Free Press, 1980, p. 39.

[11] ibid., p. 35-36.

Differentiation

Differentiation involves creating a product or service that is perceived industry-wide as being unique. Differentiation often insulates firms against price wars as customers may be willing to pay extra for the differentiated features. Thus, differentiation leads to increased profit margins. Differentiation does not imply a firm can ignore costs, as customers will be willing to pay only a limited price differential for a unique feature. Companies pursuing a strategy of differentiation, however, focus on providing their customers with a unique feature or service while maintaining a reasonable cost structure, rather than concentrating solely on cutting costs.

Focus

With a focus strategy, a business attempts to establish a specific niche for itself. The business may focus on the high or low end of the market, on a few specific customers, on a specific product line, or on a geographical area. A focus strategy generally involves a trade-off between profitability and market share (i.e., a firm decides to limit market share in order to improve profit levels).

Stuck in the Middle

The worst business strategy is not having a strategy at all. This is often referred to as being "stuck in the middle." Firms that are stuck in the middle generally achieve, at best, low profitability. They often lose the high end of the market to focused or differentiated competitors, and lose the low end to competitors pursuing a cost leadership strategy.

3.4 Focus

Lakeside is already a fairly focused business. Unlike some of its competitors which manufacture a variety of aluminum products, Lakeside produces only can stock - and primarily end and tab stock. This focus strategy, however, has not provided the plant with a significant advantage over competitors.

One potential course of action for Lakeside would be to focus even further by streamlining its product line (e.g., only producing end stock or only producing for particular customers). Eliminating product lines, however, would make it extremely difficult to fill plant capacity (as they are having difficulty filling plant capacity with their current products).

Given the importance of volume in the industry (to allocate fixed costs), further focus would likely hurt Lakeside's profitability. In addition, the process for producing can stock is similar for all products. Therefore, focusing on even fewer products would not provide Lakeside with any significant advantage. Finally, can makers prefer being able to buy all their can stock from a single supplier. Eliminating products lines could hurt Lakeside's marketing ability.

Since focus has not provided Lakeside with a competitive advantage, and further streamlining product lines does not appear to be viable, Lakeside must develop another strategy for obtaining a competitive advantage.

3.5 Cost Leadership

Cost Leadership is a potential strategy for Lakeside. There are, however, a variety of problems that Lakeside could encounter in pursuing this plan.

Aggressive Pricing

One of the key elements of a low cost strategy is aggressive pricing. Competing based upon price alone could be difficult for Lakeside. As previously mentioned, a couple of Lakeside's competitors recently opened large aluminum processing plants that are operating well below capacity levels. These plants will attempt to fill capacity in order to allocate fixed costs. It is entirely likely, therefore, that Lakeside's competitors would be willing to sell products at slightly above the marginal cost of manufacturing the can stock. Price cuts by Lakeside would most likely be met with price cuts by competitors. This will result in a downward spiral of profit margins in the can stock industry, as each company tries to underprice the competition.

A price war will likely result in losses during the next few years. Given GA's corporate strategy of holding businesses accountable for bottom line profits, its not clear whether GA would support Lakeside's strategy after several quarters of losses. Lakeside, therefore, may not have the corporate support to sustain a price war.

State of the Art Equipment

Porter states that a low cost strategy generally requires *"a high up-front capital investment in state-of-the-art equipment"* and *"reinvesting in new equipment and modern facilities in order to maintain cost leadership."* [12] Although Lakeside has recently made a major capital investment for a new coater, most of their process equipment and information technology is relatively old. Given GA's emphasis on cost cutting and achieving ROI numbers, it is unlikely GA would support an investment in new state of the art equipment throughout the plant. In addition, as new capital equipment would make achieving ROI numbers more difficult, Lakeside management would be reluctant to propose major new investments. This would make achieving a cost leadership position difficult.

Unknown Costs

In pursuing a cost leadership strategy, it is important to understand your competitors' costs and possess the ability to control your own costs. Lakeside, however, does not have a strong understanding of what their competitors' costs are. Perhaps even more significant, however, is that Lakeside doesn't have control over many of its own critical costs.

Raw materials are by far the single largest expense for Lakeside. Lakeside purchases many of these materials on futures exchanges - locking in prices months ahead of time. In addition, Lakeside imports many of its raw materials and exports most of its products. Futures markets and foreign exchange rates, therefore, have a major impact on Lakeside's costs and profits. A cost leadership strategy would be difficult to achieve since a significant portion of expenses are based upon uncontrollable factors such as the futures market and exchange rates.

Types of Customers

Customers who make purchases based upon quality are often loyal and willing to stick with a supplier over time. Customers who buy based on price will generally switch to whichever company has the lowest price. Lack of a loyal customer base is, therefore, a probable consequence of an aggressive pricing strategy.

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[12] Porter, Michael E. Competitive Strategy. New York, NY: The Free Press, 1980, p. 35-37.

Conclusion

For the reasons outlined above, it does not appear that aggressive pricing is an appropriate strategy for Lakeside. This does not mean Lakeside should not attempt to reduce expenses in order to remain competitive. Focusing solely on cutting expenses and competing on price, however, will likely result in a downward spiral of profits for Lakeside.

3.6 Differentiation

Given that focus and cost leadership are not viable strategies for Lakeside, the only strategy remaining is differentiation. How can Lakeside differentiate itself? Unlike an automobile which has thousands of differentiating product features (dashboard layout, leg room, seat comfort, gas mileage, etc.), aluminum can stock has few distinguishing features. There are essentially only two ways an aluminum can stock company can differentiate itself: high product quality and excellent delivery performance. The next two chapters discuss each of these differentiating factors in detail.

3.7 General Lessons

The following are some of the general lessons from this chapter:

Strategy versus Financial Goals

A general lesson from this study is the importance of strategy versus financial goals. Corporate evaluation of business units strictly on a financial basis often leads to short term thinking. GA did not provide strategic direction for Lakeside and evaluated the plant based primarily on ROI numbers. The easiest method for achieving a high return on investment (particularly in a capital intensive business such as aluminum processing) is by reducing investments. Over time, as equipment depreciates, ROI goals become less difficult to achieve.

Growing a business, however, often requires a significant level of up front investment - which makes achieving a high ROI difficult. Efforts to achieve ROI numbers can, therefore, limit business growth. Often, the easiest method for achieving financial goals is not in the best interest of the corporation.

Robert Kaplan states:

> *"The most damaging problem with ROI-based measures is the incentive they give managers to reduce expenditures on discretionary and intangible investments. When sluggish sales or growing costs makes profit targets hard to achieve, managers often try to prop up short term earnings by cutting expenditures on R&D, promotion, distribution, quality improvement, applications engineering, human resources, and customer relations - all of which are, of course, vital to a company's long-term performance. The immediate effect of such reductions is to boost reported profitability - but at the risk of sacrificing the company's competitive position."* [13]

In "Subordinate Financial Policy to Corporate Strategy," Richard Ellsworth indicates that in many companies *"financial strategy puts strong constraints on management's ability to implement its strategy ... Too often, top management fails to tailor corporate finance to strategic needs and bases them instead on industry-wide rules of thumb."* Ellsworth argues against turning financial policies into corporate goals, and believes that strategy should be given priority over financial policy.[14]

A study of Fortune 500 and Inc. 100 corporations showed that companies with strong visions/long term strategies outperform non-visionary companies (which are run primarily based upon financial goals) by a wide margin.[15]

Coordinated Strategy

The greater the level of coordinated planning between corporate and the individual business units, the greater the range of strategies that the business units can pursue. For example, since GA takes a "hands off" approach to managing Lakeside provided they achieve their ROI numbers, it would be difficult for Lakeside to pursue a cost leadership strategy which requires high investments and possibly short term losses.

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[13] Kaplan, Robert S. "Yesterday's Accounting Undermines Production." Harvard Business Review, July/Aug 1984, p. 95-101.

[14] Ellsworth, Richard R. "Subordinate Financial Policy to Corporate Strategy." Harvard Business Review, Nov/Dec 1983, p. 170-178.

[15] Lee, Chris. "The Vision Thing," Training, Feb 1993, p. 25.

In "Managing Our Way to Economic Decline," Hayes and Abernathy state:

> *"As more companies decentralize their organizational structures, they tend to fix on profit centers as the primary unit of managerial responsibility. This development necessitates, in turn, greater dependence on short-term financial measurements like return-on-investment (ROI) for evaluating ... performance. Although innovation, the lifeblood of any vital enterprise, is best encouraged by an environment that does not unduly penalize failure, the predictable result of relying too heavily on short-term financial measures - a sort of managerial remote control - is an environment in which no one feels he or she can afford a failure or even a momentary dip in the bottom line."* [16]

An integrated corporate/business unit strategy is particularly valuable in a company whose businesses produce related products. Some of GA's competitors have purchased can makers and have utilized an integrated strategy among various aluminum processing businesses to gain a competitive advantage. Because Lakeside operates as a stand-alone business, it does not have the same range of options as many of its competitors.

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[16] Hayes, Robert H. and Abernathy, William J. "Managing Our Way to Economic Decline." Harvard Business Review, July/Aug 1980, p. 67-77.

Chapter 4: Improving Quality at Lakeside

4.1 Advantages of a Total Quality Organization

As discussed in the previous chapter, Lakeside must differentiate itself from the competition and quality is one of the few areas in which a can stock producer can differentiate itself. There are a variety of benefits associated with becoming a quality oriented organization including:

Premium Product

The quality of can stock has an enormous impact upon the ability of can makers to produce quality beverage cans. As such, if Lakeside could establish a significant quality advantage over competitors, it would make economic sense for the can makers to pay a premium for Lakeside's products - allowing Lakeside to achieve greater profit margins. Establishing itself as the "quality can stock producer" would help insulate Lakeside from price wars and enable them to develop a loyal customer base.

Less Complexity

Quality problems cause a variety of other problems within a plant. As a result of scrapped products and reallocations, on time delivery becomes increasingly difficult. Product returns must be transported back to Lakeside and analyzed. Defective products must be examined and repaired. To deal with high defect rates, inventory is built up. All of these problem make running the plant more complex and difficult to manage.

Lower Costs

In "Three Essentials of Product Quality," Reddy and Berger state that a common misconception is that improving quality increases costs.[17] *"Competitive manufacturers know from experience,"* the article states, *"that dedication to higher quality ... often results in significant reductions in, for instance, scrap, rework, routine inspection, field costs and warranty losses."* As such, quality improvement often reduces costs. The following section provides a brief overview of the cost of quality for Lakeside.

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[17] Reddy, Jack and Berger, Abe. "Three Essentials of Product Quality." Harvard Business Review, July/Aug 1983, p. 153-160.

4.2 Cost of Quality at Lakeside

It is often beneficial to review the cost elements associated with quality problems, and develop a rough estimate for how much poor quality costs a business. Juran refers to this as the cost of poor quality, and indicates that one of the primary benefits of calculating this value is to "*quantify the size of the quality problem in language that will have impact on upper management,*" and to "*identify major opportunities for cost reduction.*" [18] The rest of this section provides a rough estimate for the cost of quality (COQ) at Lakeside.

Scrapped Coils and Ingots

The first obvious cost is for all of the ingots and coils that have to be scrapped during the production process. In most manufacturing environments, the cost of scrapping work in process (WIP) should be the marginal cost (e.g., raw materials and variable processing expenses) of the product that is scrapped. At Lakeside, however, "scrapped" coils and ingots are not actually disposed of, but are re-melted to obtain molten aluminum alloy - which is then used to produce ingots. Thus, the cost of scrapping inventory at Lakeside is equal to the value of inventory (raw material plus marginal processing costs) minus the scrap value (value of re-melted scrapped aluminum minus re-melt costs).

For example, a metric ton of cold mill inventory is worth (using variable costs) approximately $1765. If the inventory were scrapped, the raw materials (worth about $1515) could be recovered by re-melting (which costs $165) the scrap (which is therefore worth $1515 - $165 = $1350). As such, the cost of scrapping a metric ton of cold mill inventory is about: $1765 - $1350 = $415.

Figure 4.1 contains a summary of the scrapping costs (averaged over product groups) at various stages of the plant. Scrapping coils that have been coated is relatively expensive since most of the coated coils can not be re-melted at Lakeside. These coils must be shipped off-site to a subcontractor for re-melting.

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[18] Juran, J.M. Juran's Quality Control Handbook: Fourth Edition. New York, NY: McGraw-Hill, 1988, p.4.3.

Inventory	Scrap Cost/Metric Ton
Ingot	$220
Hot Rolled	$350
Cold Rolled	$415
Coil Prepped	$500
Coated	$1,190
Slit	$1,225

Figure 4.1: Cost of Scrap

The following is an estimate of the cost of scrapped production coils and ingots:

Cost of Scrapped WIP = (5000 metric tons of scrapped ingot/year * $220/metric ton) + (300 scrapped hot rolled coils/year * 10 metric tons/coil * $350/metric ton) + (150 scrapped cold rolled coils/year * 9 metric tons/coil * $415/metric ton) + (100 scrapped prep line coils/year * 8 metric tons/coil * $500/metric ton) + (80 scrapped coated coils/year * 7.2 metric tons/coil * $1190/metric ton) + (70 scrapped slit coils/year * 7.2 metric tons/coil * $1225/metric ton) = $4.4 million/year.

Re-run Coils

Coils are often run through a process more than once to either resolve a quality problem or to reallocate a coil to another specification. This can be calculated by multiplying the number of re-run coils at each process center for a year by the average variable cost to run a coil through the process center - and adding up the sub-totals. For Lakeside, this is equivalent to: (300 re-run coil prep coils/year * 8 metric tons/coil * $84/metric ton) + (800 re-run coater coils/year * 7.2 metric tons/coil * $300/metric ton) + (1200 re-run slitter coils/year * 7.2 metric tons/coil * $180/metric ton) = $3.5 million/year.

Non-Standard Recovery Loss

In any aluminum processing plant there will be a certain level of unavoidable recovery losses during manufacturing operations. The Lakeside plant has determined what it considers to be a reasonable level of recovery losses based upon plant equipment. This quantity is known as the standard level of recovery loss.

The standard level represents the recovery that would be achieved if plant equipment were running properly and there were no quality problems during processing. A small percentage of products processed through the plant actually have lower recovery losses than the standard level. Non-standard recovery loss is the loss above the standard level.

An internal study performed at Lakeside indicated that for a one month period, the cost of non-standard recovery losses generated during the processing of coils from the cold mill onwards was approximately $700,000. Multiplying this by twelve provides an estimated annualized cost of $8.4 million/year.

Returned/Discounted Coils

A small percentage of products are returned by customers to the Lakeside plant because of quality/non conformance problems. Some of these products are scrapped, while others are "repaired" using the slitter to cut off the problem areas. An estimated cost for the scrapped coils, assuming two thirds are coated unslit coils and one third are slit coils, is: (100 scrapped returned coils/year * 7.2 metric tons * ($1225/metric ton * 1/3 + $1190/metric ton * 2/3)) = $865,000. The cost for the repaired coils, based upon a $180/metric ton variable cost for the slitter, is (100 repaired returned coils/year * 7.2 metric tons * $180/metric ton) = $130,000. Since transportation costs for returned coils exceed $100,000, the overall sum is $865,000 + $130,000 + $100,000 = $1.1 million.

Often when a customer finds quality problems with Lakeside's coils, the customer will keep the product. To compensate the customer for problems associated with poor quality, Lakeside will compensate the customer monetarily in the form of discounts. An estimate for these discounts, based upon discussions with Lakeside personnel, is $1.5 million/year.

Lost Capacity

When aluminum is scrapped anywhere after the bottleneck operation (the cold mill), in addition to the costs associated with that particular scrapped aluminum, there is also the added loss of plant capacity (i.e., the opportunity cost of what could have been produced). If Lakeside could produce the “right product first time everytime” not only would the plant save all the scrapping costs previously discussed, but overall capacity of the plant would significantly increase. This added capacity could then be used to sell more product, develop new products, or lower plant costs (e.g., the plant could run with fewer shifts to meet current capacity).

Although lost capacity is a major cost, the value of the lost capacity is difficult to calculate. The maximum value of this extra capacity would be approximately: (16,000 metric tons of non-standard scrap after the bottleneck/year) * ($700 profit margin per metric ton) = $11.2 million. This, however, assumes that all of the extra capacity could be utilized to produce products for customers. Realistically, this extra demand may not exist, and only a portion of the extra capacity would be utilized to increase sales or reduce plant expenses. Multiplying the above maximum value by twenty five percent provides a more realistic value: $11.2 million * 25% = $2.8 million/year.

Total

The sum of the above costs is $21.7 million/year. This is, however, a fairly conservative number as it does not include any of the following:

1) Inventory holding costs due to quality problems.
2) Non-standard hot mill recovery losses.
3) Field service trips to customer sites to resolve quality issues.
4) Management time spent on resolving quality related issues.
5) Metallurgists time spent evaluating defective coils.
6) Lost orders due to quality problems.
7) Customer dissatisfaction.

Although not specifically listed in any financial document, the cost of quality is essentially the second largest expense at Lakeside, after materials. The salaries for all production workers is less than $19 million/year. As such, Lakeside could save more money by resolving its quality problems than by laying off every single production worker. Pursuing a strategy of high-quality would not only differentiate Lakeside from its competitors, but would significantly reduce plant expenses.

Since the COQ of $21.7 million/year is an annual expense, the net present value of the cost of quality (assuming a 10% discount rate) would be $217 million. This is how much it would be worth to Lakeside to have all of their quality problems resolved.

4.3 WHAT QUALITY PROBLEM?

> *"Most organizations have developed a functional blindness to their own defects. They are not suffering because they can't resolve their problems, but because they cannot see their problems."*
>
> \- John Gardner

The biggest problem at the Lakeside plant is the poor "right first time" quality level. A very high portion of Lakeside's products have to be scrapped, reworked, or reallocated (if the product doesn't meet one customer's specifications, it can be reworked to meet another customer's specifications). The major reason the level of right first time products has not improved, however, is because the quality problem is hidden.

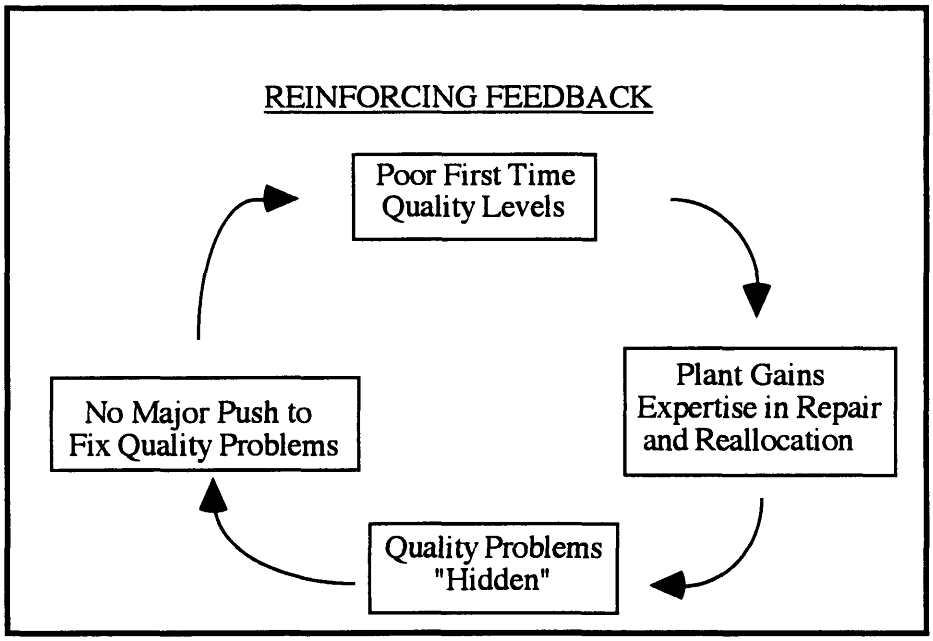

Figure 4.2: Reinforcing Feedback - Quality Problems

As indicated in the figure 4.2 reinforcing feedback systems diagram[19], because Lakeside has difficulty making the "right product - first time," plant workers have become very good at repairing defective products. In addition, the production control department has gained expertise in being able to reallocate products which can't meet one specification to another specification.

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[19] Senge, Peter M. The Fifth Discipline. New York, NY: Doubleday, 1990, p.82.

These actions, however, obscure the root problem at Lakeside - which is that the plant is not in control of many of their processes. As such, there is no significant movement at Lakeside to improve quality (e.g., while workers have received training in SPC and design of experiments, there is little use of these methods in the plant). First time right quality levels have, therefore, not improved.

Another reinforcing mechanism is that production workers have become so used to having coils repaired that they are not committed to ensuring first time right quality. As one production worker stated: *"We [production personnel] all work hard and try to make the best product for the customer, but there is also an attitude that if the quality of a coil isn't so good, it will be fixed downstream."*

The above mental model not only hampers Lakeside's ability to produce quality product, but wastes a huge amount of the plant's resources in the repair and reallocation process. As the production control manager for the plant indicated, *"If Lakeside didn't have to reallocate coils, my job would be about 20 times easier."*

4.4 Why Lakeside's Metrics Contribute to the Quality Problem

As previously mentioned in chapter 2, the primary internal metric used at Lakeside is tons of output. It is the only metric that appears on the weekly Lakeside newsletter, and is the first measurement listed on most of the internal production reports. There are, however, many problems with using tons produced as the main metric for running the plant. Measuring employees based upon output, regardless of the quality of the output, is an incentive for workers to ignore quality issues.

Figure 4.3 is a systems diagram showing one of the problems associated with running a plant based upon production volume metrics. Lakeside has a desired level of output it hopes to produce every month. When the plant falls short of its target, management takes action by putting pressure on process center managers to increase output. The process center managers, in turn, pressure plant workers to increase the production rate. This, however, has the effect of increasing the level of quality problems.

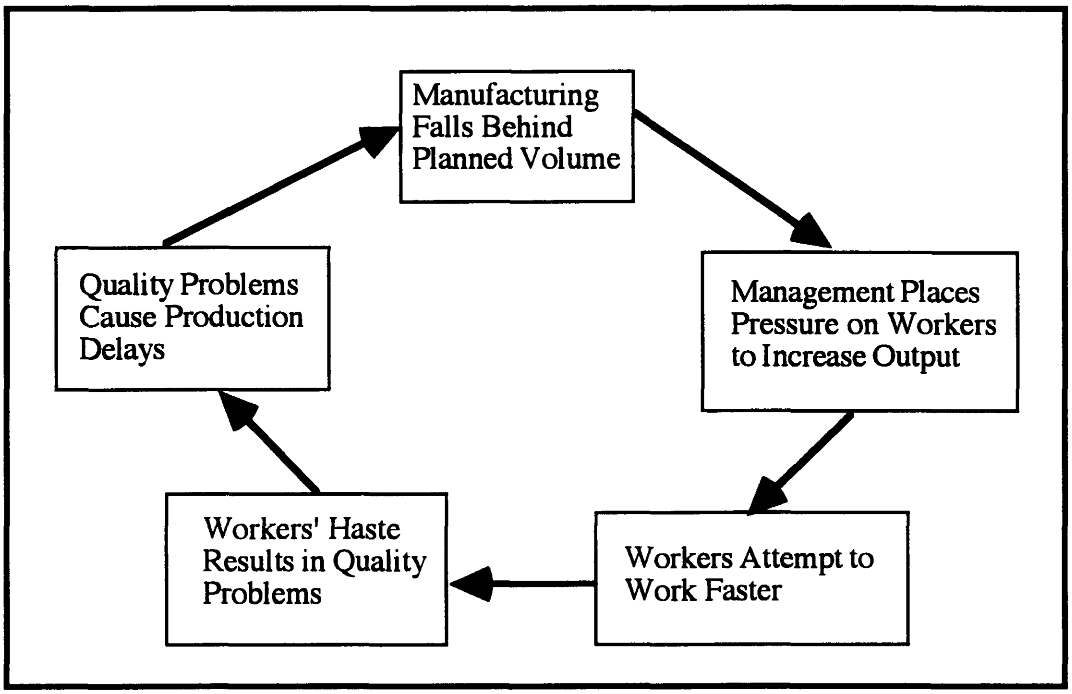

Figure 4.3: Reinforcing Feedback - Quality Problems

While pushing on workers to increase output may result in a short term improvement in tons produced, over time the quality problems caused by these actions decrease output causing further gaps in output levels. This is an example of "the harder you push, the harder the system pushes back" syndrome described in The Fifth Discipline.[20]

Driving workers to increase output without providing them with the means to do so may actually work against the fundamental solution at Lakeside - which is to ensure that the right product is made the first time by improving manufacturing processes. As quality guru Deming has said *"Eliminate numerical goals ... for the workers, asking for new levels of productivity without providing methods."* [21]

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[20] Senge, Peter M. The Fifth Discipline. New York, NY: Doubleday, 1990.

[21] Deming, W. Edwards. Out of the Crisis. Cambridge, MA: MIT Center for Advanced Engineering Study, 1986, p.23.

An example of this may have occurred during one month when Lakeside reached its highest production output level ever. Data from the record month, however, indicates that planned maintenance levels during the record month were significantly less than in other months. In the subsequent months, unplanned downtime was well above average and output levels decreased significantly. Thus, pushing to achieve record levels during one month probably contributed to many plant problems in the following months.

4.5 How a Cost Cutting Strategy Leads to Quality Problems

Lakeside has been trying to cut costs by reducing headcount through generous voluntary early retirement programs. As indicated in figure 4.4, the result of the program has been that the most experienced and skilled production workers have left.

There is certain amount of "art" involved in producing aluminum at Lakeside. When the most experienced employees left, much of the knowledge on how to successfully operate equipment to produce desired results also "left." This is particularly true since Lakeside does not have standard operating procedures. As a result, quality problems have increased since the headcount reductions have occurred. The quality problems have, in turn, increased operating expenses.

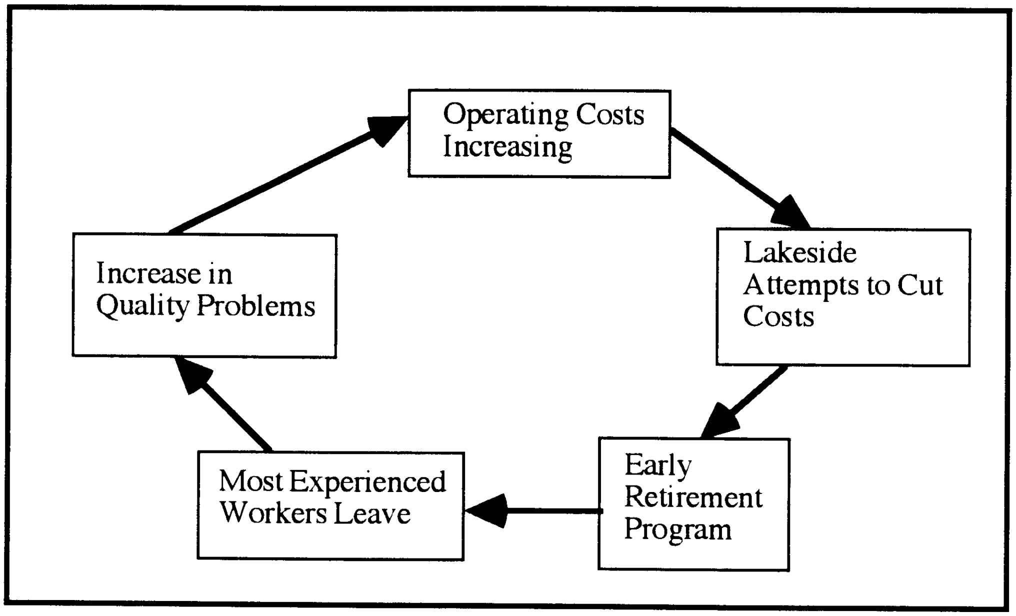

Figure 4.4: Reinforcing Feedback - Cutting Costs

Downsizing may be appropriate for some areas of Lakeside's operation. When reducing the headcount of production workers, however, it is important to consider the impact on product quality. A small increase in quality problems can more than offset potential cost savings from fewer workers. In any case, becoming "in control and capable" of the manufacturing processes is the leverage point in Lakeside's operations. Gaining better control of the production processes will allow Lakeside to improve the quality of its products, reduce scrap levels, and decrease inventory levels - which will result in lower costs, better cash flow, and improved customer satisfaction.

4.6 Strategies for Improving Quality

The previous sections of this chapter explained why improving quality is so critical to Lakeside's operations. This section outlines what needs to be done at Lakeside to improve quality.

Standard Operating Procedures

A key to quality improvement is the use of statistical and analytical methods such as statistical process control (SPC) and design of experiments (DOE). Based upon the current operating practices of the plant, however, implementing SPC or DOE would be very difficult. The reason for this difficulty is the variability in the way each worker operates the production equipment.

In SPC terminology, there are two types of variation. The first type is special variation which results from specific external events or failures in the process. The second type is common variation which is due to the inherent internal variability of any manufacturing process. The first goal in developing an SPC system is to eliminate all of the external special causes (i.e., move the process into a state of "statistical control"). The largest source of special variation in many of Lakeside's processes, however, is operator variability.

As can be seen by observing plant operations, each production worker has his own method for operating equipment. This is evidenced by the fact that some shifts perform significantly better than other shifts on the same equipment. Until special causes are eliminated, it is difficult to draw any conclusions from SPC data. Similarly, variability of worker operation will show up as noise in any DOE analysis - obscuring the meaningful experimental information.

The only way to eliminate special variation is by creating and implementing a system of standard operating procedures (SOPs) for every process and ensuring that workers abide by these rules. As Katsuyoshi Ishikara (a leading Japanese quality expert) has stated: *"Manufacturing good products is possible only if workers rigorously abide by operating standards. An operating standard is a document indicating the proper way to proceed so as to achieve quality. It is not possible to manufacture good products without respecting standards or by letting everyone work according to his own notions."* [22]

The standard operating procedures should be developed by the plant workers, since they are most familiar with the processes and must live by whatever procedures are created. Management should act as a facilitator in the SOP development process. Once a draft procedure is developed, every worker affected by it should be given the opportunity to review and sign off on the procedure.

Management should limit its review of the SOPs to ensuring that the procedures are consistent and logical, and that no safety rules are violated. Once the SOPs are finalized and issued, workers should be encouraged to propose improvements to the procedures.

Standard operating procedures would also eliminate the previously mentioned problem of losing operations knowledge when plant workers retire, since all appropriate knowledge would be captured in the procedures.

Statistical Process Control and Design of Experiments

Once the SOPs have been developed, Lakeside should begin implementing a program of SPC throughout the plant. One of the difficulties in implementing SPC in the Lakeside plant is that many important plant parameters (e.g., cold mill rolling speed) are not currently recorded, much less statistically analyzed. The first step in creating an SPC program at Lakeside should be to install a shop floor data acquisition system to monitor and record key parameters that affect product quality.

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[22] Suzaki, Kiyoshi. The New Manufacturing Challenge. New York, NY: The Free Press, 1987.

A major goal of SPC is to reach a stage in which production workers can evaluate the quality level of a product just by reviewing its control chart data (i.e., without actually inspecting the product). In this way, workers can resolve processing problems (a process variable drifting out of control) before the problem has any effect upon products (rather than waiting until several poor quality products are produced and then investigating the reasons for the poor quality). As Deming states: *"Cease dependence on inspection to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first place."* [23]

Management has already had the forethought to provide training in SPC to many production employees. All that is needed is a strong commitment by management towards implementing statistical methods on the shop floor.

Metrics

Measurements are a key factor in determining how people behave on the shop floor. The phrase *"Tell me how you will measure me, and I will tell you how I will behave."* [24] is directly applicable to the Lakeside works. As previously described, metrics such as amount of can stock produced adversely impact production workers' commitment to quality.

To effectively achieve a world class quality plant, management must place less emphasis on numerical production output, and more emphasis on improving processes and quality. As Deming states: *"The responsibility of supervisors must be changed from sheer numbers to quality."* [25] Trying to run a manufacturing plant by reviewing production numbers is like trying to manage a football team by watching the scoreboard.

The metrics that are used should be directed at the root problems in the plant. A good measurement for Lakeside would, therefore, be the right first time percentage - the percentage of products that have been processed through the Lakeside Works, and delivered to the customer which did not have any quality/processing problems (e.g., reallocation, re-work, customer returns or complaints, excessive recovery loss).

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[23] Deming, W. Edwards. Out of the Crisis. Cambridge, MA: MIT Center for Advanced Engineering Study, 1986, p.23.

[24] Goldratt, Eliyahu. The Haystack Syndrome. Croton-on-Hudson, NY: North River Press, 1990, p.26.

[25] Deming, W. Edwards. Out of the Crisis. Cambridge, MA: MIT Center for Advanced Engineering Study, 1986, p.23.

Suppliers

The phrase "garbage in, garbage out" is often used with respect to computer systems, but applies equally well to manufacturing systems. The quality of Lakeside's products is greatly dependent upon the quality of the ingots and raw materials received from suppliers. Currently, however, there isn't a concerted effort to ensure that vendors are providing Lakeside with the highest possible quality materials.

Lakeside should place greater emphasis on evaluating supplied products and determining how supplied material parameters affect Lakeside's operations. Once Lakeside has its own SPC program in place, it should require the same from its vendors and retain only those suppliers which can provide high quality products. As Deming states *"End the practice of awarding business on the basis of price tag."* [26]

4.7 General Lessons

The following are some of the general lessons from this chapter:

Quality = Leverage Point

This thesis identified the large amount of savings that could be achieved at Lakeside through quality improvements. Lakeside, however, is not unique with respect to high quality costs. Juran has stated that *"... usually, managers are stunned by the size of the [cost of poor quality] total - they had no idea the amount was so big,"* and *"It comes as a shock to managers to learn that quality costs exceed the company's profit (which often they do). A component manufacturer with a strong reputation for quality reported direct costs of scrap and rework of $7.5 million versus a profit of $1.5 million."* [27]

Juran states that in many companies quality costs are in excess of twenty percent of sales revenue. Similarly, in Quality is Free, Philip Crosby describes a case in which management is shocked to learn how high the cost of quality is at their company.[28]

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[26] Deming, W. Edwards. Out of the Crisis. Cambridge, MA: MIT Center for Advanced Engineering Study, 1986, p.23.

[27] Juran, J.M. Juran's Quality Control Handbook: Fourth Edition. New York: McGraw Hill, 1988.

[28] Crosby, Philip B. Quality is Free. New York: McGraw Hill, 1979, p. 207.

A general lesson from this thesis is that the COQ often represents the single greatest area for cost reduction in a manufacturing plant. Good quality also leads to improved customer satisfaction and better delivery performance. Typical cost accounting systems, however, incorporate scrap, rework, and other costs related to poor quality into general overhead - which is then allocated over all products. As such, the high COQ is hidden from management. Thus, the primary benefit of a COQ calculation is to quantify the size of the quality problem in language that will have impact upon upper management. A key element of any manufacturing improvement effort should, therefore, be a calculation of the costs associated with poor quality.

Paradigms

There is a great deal of debate in academic circles over what the next paradigm will be for manufacturing organizations. Agile manufacturing, virtual corporations, and learning organizations are some of the latest guesses about what the future holds. For many businesses, however, this debate is irrelevant. The benefits of statistical process control, experimental design, and standard operating procedures have been well known for decades. Yet, a large percentage of manufacturers (including Lakeside) do not utilize any of these techniques. Rather than contemplating the latest fads, many businesses would be better off concentrating on successfully implementing existing improvement methods.

Metrics

It is often possible to guess what problems a manufacturing plant is experiencing just by reviewing its measurement system. Given that production volume, and not quality, was the primary metric at Lakeside, it is not surprising that the plant had quality problems. In "The Goal," Goldratt describes a plant in which the primary measurement is machine utilization. This encouraged plant operators to use the machines as much as possible (even if not needed to satisfy customer demands). As a result of the utilization metric, inventory at the plant was excessively high.[29] Kaplan and Atkinson state *"People within the system change their behavior as a function of the measure chosen to summarize the performance of their organizational unit."* [30] Since changing the measurement system in a plant costs virtually nothing and can have an enormous impact on performance, it represents one of the most cost effective improvement methods. Management must ensure that the measurement system is well aligned with the desired goals of the plant.

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[29] Goldratt, Eliyahu and Cox, Jeff. The Goal: Second Revised Edition. Croton-on-Hudson, NY: North River Press, 1992.

[30] Kaplan, Robert S. and Atkinson, Anthony A. Advanced Management Accounting: Second Edition. Englewood Cliffs, NJ: Prentice Hall, 1989.

Chapter 5: Improving Delivery Performance at Lakeside

5.1 Importance of Delivery Performance

Delivery performance is the other major area in which Lakeside can differentiate itself from the competition. Improving delivery performance is not, however, a major priority at Lakeside. There are two reasons for this. First, Lakeside's customers rarely complain about delivery performance. This has led to the view that the can makers are not that concerned with on-time delivery. Second, in customer surveys on delivery performance, Lakeside ranks slightly above average with respect to its competitors. As such, Lakeside has concentrated on other areas such as reducing costs.

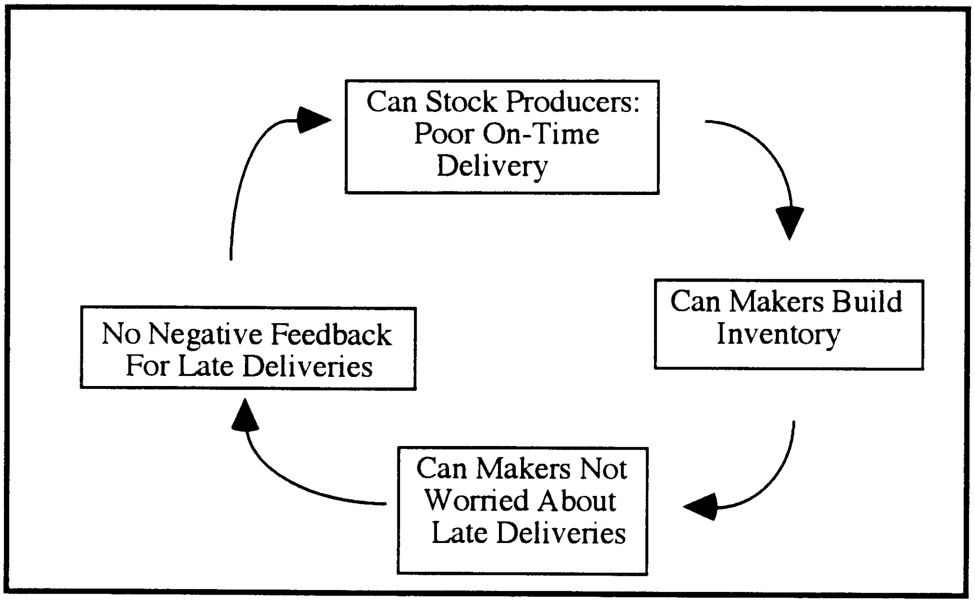

Figure 5.1: Reinforcing Feedback - Delivery Performance

The reason for the lack of concern over on-time delivery can be explained using the systems diagram in figure 5.1. European can stock producers have historically had a poor on-time delivery record. This is verified by the fact that Lakeside's on-time delivery performance is poor compared to their counterparts in America, yet Lakeside's customers ranked Lakeside above average with respect to delivery performance. Because the can stock makers have poor delivery records, the can producers have built-up large inventory levels to ensure that late deliveries do not affect them. As a result, Lakeside (and other can stock makers) rarely receive negative feedback from customers for missing delivery dates. Since there is no criticism for late deliveries, Lakeside assumes that delivery performance isn't important to customers, and makes no effort to improve in this area. The late delivery cycle is, therefore, reinforced.

What the above mental model doesn't take into consideration is that if an aluminum can stock company could consistently provide a high level of delivery performance, the can makers could dramatically reduce their inventory levels - significantly improving cash flow performance. The first European can stock company that can guarantee a high on-time delivery level will have a significant competitive edge in the market.

Regardless of Lakeside's actions, can makers will, as is the general trend in industry, be moving towards leaner production methods. This is evidenced by the fact that requested lead times from Lakeside's customers have become progressively smaller.

If Lakeside retains its mental model that customers don't care about late deliveries, it will likely have major scheduling problems in the future as lead times diminish, and customers become more demanding with respect to delivery performance. If Lakeside can break out of its mental model, and improve its on-time performance level, it could develop a major competitive advantage. The following sections describe how delivery performance can be improved at Lakeside.

5.2 Improving Delivery Performance Through Quality

As discussed in the previous chapter, the inability to routinely produce the "right product, first time" is the fundamental problem at Lakeside. The quality problem is also one of the major barriers to improving delivery performance levels. When a product is scrapped (or reallocated) during the can stock manufacturing process, a new product must generally be produced from scratch to meet the customer's order. Thus, if a coil is scrapped at the end of the manufacturing process, a new coil must be produced from the raw materials stage, and the manufacturing time to satisfy the order is doubled.

Lakeside's high rate of reallocation and scrap, therefore, makes it extremely difficult to achieve an excellent level of delivery performance. Improving quality, as previously discussed in chapter 4, would significantly enhance Lakeside's on-time delivery level.

5.3 Improving Delivery Performance Metrics

Is it good or bad if Lakeside produces a record amount of can stock in a given week? What if the can stock manufactured didn't satisfy the orders that were due during that week? Achieving record levels of output is irrelevant if customer needs aren't satisfied.

This shows another problem with using tons produced as a metric on the shop floor. The amount of can stock produced is not a good indicator of plant performance. What matters is whether the right products are produced at the right time in order to satisfy customer demands. As such, on-time delivery percentage (rather than tons produced) should be a key metric in the plant.

In discussing measurements, it is vital for everyone to have the same definition for a metric. At Lakeside, a variety of different definitions of on-time delivery are used. For example:

1) One definition is based upon whether the goods are placed in finished goods inventory in time to ship to the customer by the due date (i.e., if transport time is three days, the products must be in finished goods inventory three days before the due date to be considered "on time"), while another definition is based upon when the shipment actually reaches the customer.

   The first definition ignores possible delays in transportation, but is easier to determine. This is because Lakeside knows when a product reaches finished goods inventory, but doesn't always know exactly when an order was delivered. Since the ultimate judge of a company is the customer, Lakeside's metrics should be customer oriented. As a customer's only concern is when the goods are ready for use, on-time delivery should be defined in terms of when the shipment reaches the customer (if possible).

2) If the plant is having difficulties meeting a particular delivery date, the production control supervisor will inform the sales department that an order will likely be shipped late. Sales will then call the customer and request that the required due date for the product be moved out a couple of weeks. If the customer agrees to this change, the new due date is entered into the order book. If Lakeside meets the revised due date, some people consider it an on-time delivery, while others view it as being late (since the original date was missed).

   Although a customer may agree to a revision of due dates, the customer is certainly not as satisfied with Lakeside as they would have been had Lakeside delivered to the original date. Every time Lakeside informs the customer of a delivery problem, customer satisfaction and Lakeside's reputation are diminished. Thus, on-time delivery should be based upon initial due dates (unless the customer requests a revised date).

3) If a customer has an order for 10 coils and Lakeside delivers 8 by the required date, is on-time performance 80% (since 80% of the coils were delivered) or 0% (since the overall order was missed). The customer may well need the entire order and would be very dissatisfied with receiving only 8 coils (not 80% satisfied). Thus, delivery performance should be based upon whether an order was met or not (i.e., no partial credit).

A standard definition of delivery performance should be developed and emphasized by management in operating the plant.

5.4 Improving Delivery Performance Through Maintenance

One of the major reasons for missed deliveries is unplanned downtime of manufacturing work centers due to equipment problems. Unplanned downtime is also one of the major causes of inventory building, as the production planners want to ensure that there will be enough inventory available if an upstream process goes down for a day. Lakeside staff (engineers/production workers) are very good at repairing equipment in a timely manner once the equipment goes down. There is a need, however, for greater emphasis on preventing failures rather than repairing them.

5.5 Improving Delivery Performance Through Increased Capacity

For a given demand, increasing capacity will generally improve a plant's ability to produce products on schedule. The capacity of a plant, however, is determined by the bottleneck operation (as discussed in section 6.2). At Lakeside, the bottleneck operation is the cold mill. Any improvements to cold mill cycle time, set-up time, or up-time will improve overall plant capacity.

Set-up Time

There are several different types of set-ups performed on the cold mill. First, approximately once a shift, the cold mill work rolls are changed. This generally takes about 10 minutes. Second, approximately once a week the back-up rolls are changed which takes several hours. Third, there is some set-up required for every single coil that is processed. The time that a coil is on the cold mill, but is not being rolled is referred to as "dead time."

Manufacturing plants that concentrate on reducing set-up times are often able to achieve significant improvements. A popular example is Toyota which was able to reduce the set-up time required for a stamping press from 4 hours to under 3 minutes. Another example is Mazda which was able to reduce the set-up time for a ring gear cutter from over six hours to under 10 minutes.[31]

There are three steps to reducing set-up time. The first step is to separate the work that must be performed while the machine is stopped (internal set-up) from the work that can be performed while the machine is operating (external set-up).

The second step is to reduce internal set-ups by performing more work while the machine is in operation. During back-up roll changes, for example, the new rolls are often not at the cold mill at the time the mill is brought down for the roll change. This delays the start of the changeover. All parts, tools, and personnel should be at the mill as soon as the machinery is brought off-line.

The third step is to have the workers examine each step in the set-up process to determine where unnecessary delays can be eliminated. Videotaping the set-up operation can be especially valuable for analyzing the various delays.

Interestingly, Lakeside management has already trained plant workers on reducing set-up times. All Lakeside production workers have attended an off-site two day team building program. One of the exercises in the program requires teams of workers to fit together a variety of wooden pieces according to a blueprint. Each team initially takes about an hour to complete the exercise. Next, the teams are allowed to use visual aids (i.e., write on the wooden pieces) and practice fitting the pieces together for an hour.

By the end of the hour all of the teams are operating like "well oiled machines" with each member having specific tasks and everyone working in parallel to reduce delays. During their final attempts, most teams are able to complete the exercise in under one minute. Finally, each team must document their method for putting the pieces together (i.e., create a standard operating procedure).

Lakeside management has already had the foresight to develop the above training program. To truly benefit from the training, management must encourage workers to apply the methods learned in the course to the actual plant.

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[31] Suzaki, Kiyoshi. <u>The New Manufacturing Challenge.</u> New York, NY: The Free Press, 1987.

Cycle Time

The actual processing time for each coil through the cold mill (not including the dead cycle time discussed above) is mostly machine dependent. Significantly reducing the processing time for each coil would, therefore, require major technological modifications to the cold mill. These modifications are beyond the scope of this thesis. There are, however, often variations in cycle times between almost identical products. The primary controllable cause of these variations is the lack of standard operating procedures, as discussed in chapter 3. Implementing SOPs would likely reduce cold mill processing time.

Uptime

As mentioned in the previous section, preventative maintenance is the key to ensuring high levels of uptime. Maintenance on the bottleneck is usually a delicate balancing act. Bringing the bottleneck down for maintenance reduces plant capacity. Maintenance, however, can prevent unplanned downtime. A plant needs to determine the proper amount of maintenance necessary. Fortunately for Lakeside, there is a simple solution to this problem. Lakeside shuts down one shift every week. Lakeside could utilize this extra shift for preventative maintenance on the cold mill without reducing current production capacity. The resulting increase in uptime would likely significantly increase throughput.

5.6 Improving Delivery Performance Through Improved Flowtime

Flowtime is the length of time it takes to produce a product. Reducing flowtime is extremely valuable in improving delivery performance. The less time it takes for a plant to produce a product, the easier it is to meet short lead times for customer orders.

Little's Law states that: Inventory = Arrival Rate * Flowtime.[32] Thus, reducing flowtime within a plant is essentially the same as reducing inventory within a plant. There are two types of inventory at Lakeside. First, there are the coils in the cooling process. After the hot mill and cold mill, coils are required to cool off for a significant length of time prior to being processed by the subsequent operation. The cooling off period is actually part of the production process. Second, there are the coils that are held as buffers between operations. Lakeside tries to maintain certain inventory targets between each processing center. Both types of inventory can be reduced, albeit in different manners.

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[32] Little, John D.C. "A Proof of the Queuing Formula: $L=\lambda W$," Operations Research, May 1961, Vol. 67, No. 5, pp. 122-131.

Cooling Inventory

Coils after the cold mill and hot mill are generally allowed to cool for at least 36 hours prior to the next manufacturing step. This cool time was not, however, determined in a scientific manner. In fact, the real parameter that Lakeside is concerned about is the temperature of the coil, and not cool time. The temperature of a coil that has been cooling off depends on a variety of factors (e.g., initial temperature, room temperature, placement within inventory) besides cooling time. Some coils may be ready for processing well before 36 hours while others may require more than 36 hours.

Lakeside needs to perform experiments to determine the maximum temperature at which coils can be processed without causing quality problems, and then determine which coils are ready for processing based upon temperature (rather than cool time). Even if cool time is used for simplicity, the length of cool time needed should be determined based upon experiments. As Lakeside does occasionally process coils after less than a 36 hour cool off, experiments may well indicate that less than 36 hours of cool-off is necessary.

A more aggressive approach to reducing cooling time is the implementation of forced cooling techniques. Other GA can stock plants have installed simple cooling fans above inventory to reduce the necessary cool-off time. In some cases, the required holding time was cut in half. From a financial perspective, purchasing the cooling fans would be justified if:

$$\frac{(I_{hot}+I_{cold})^{*}h_{inv}}{(1+r)} + \frac{(I_{hot}+I_{cold})^{*}h_{inv}}{(1+r)^{2}} + \frac{(I_{hot}+I_{cold})^{*}h_{inv}}{(1+r)^{3}} + \ldots > \begin{array}{l}\text{Total Cost for}\\ \text{Buying and}\\ \text{Installing Fans}\end{array}$$

where I_{hot} and I_{cold} are the values of the inventory after the hot mill and cold mill (respectively) that could be eliminated due to the cooling fans, h_{inv} is the inventory holding cost percentage (including cost of capital, storage costs, inventory damage costs) and r is the discount rate for the business. The present value of the incremental electricity costs and maintenance costs due to the fans could also be added to the right side of the equation, although they would be relatively insignificant.

Assuming that forced cooling would reduce cooling time by 18 hours, inventory after the hot mill and cold mill would be reduced by approximately 22 coils each. These coils have a combined value (using raw material and variable processing costs) of approximately $675,000.

Using a 10% discount rate and a 15% holding cost, the above equation reduces to the following:

$$\frac{(\$675{,}000) *.15}{.1} \approx \$1 \text{ Million} > \begin{array}{l}\text{Total Cost for}\\ \text{Buying and}\\ \text{Installing Fans}\end{array}$$

The cost for purchasing and installing cooling fans at other GA plants was less than $150,000. As such, it appears to make economic sense to install cooling fans at Lakeside (i.e., $1,000,000 > $150,000). This calculation, however, does not include the additional benefit of eliminating one and a half days of flowtime from the production process.

Holding Decisions

When there is a possible quality problem with a coil, it is often placed on hold until the plant metallurgists and engineers decide how the coil should be processed (i.e., scrapped, repaired, or released to the next process center). The length of time a coil remains on hold can vary from hours to weeks. During this period, the aluminum sits as inactive inventory. In the vast majority of cases, the actual analysis time for a coil is a few hours. By implementing a policy of dispositioning coils on hold within 24 hours, Lakeside could reduce inventory and flowtime throughout the plant.

Buffer Inventory

A reduction of inventory will reduce flowtime - which generally improves a plant's ability to meet customer delivery dates. Eliminating too much inventory, however, can cause a variety of problems such as excessive machine set-ups and machine starvation - which can hamper delivery performance. Therefore, the goal isn't to merely eliminate inventory, but to determine the "right" amount of inventory between each process.

Determining the proper levels of inventory within a plant can be difficult, and requires analyzing a variety of factors including: set-up times, machine downtime, maintenance, cycle times, quality levels, and product mix. An effective method for analyzing all of these factors is the use of a simulation of plant operations. Appendix A describes a simulation model that was created to evaluate, among other things, the inventory levels at Lakeside. Chapter 6 includes the results of the simulation.

5.7 General Lessons

The following are some of the general lessons from this chapter:

Determine Value from Customer Perspective - Benchmarking has grown in popularity during the past decade. Often, however, benchmarking can be misleading. Lakeside's on-time delivery performance was better than many of their competitors. This would normally lead management to concentrate on improving another area of business. Analyzing the effects of improving delivery performance from the customer's perspective (as shown in section 5.1), however, clearly shows the enormous value to customers from a consistently high level of on-time delivery. In evaluating potential changes, it is vital to consider the value of the change from the customer's point of view. To accomplish this, management must have a strong understanding of their customers' operations.

Hammer and Champy indicate[33] that in selecting processes to improve it is important to answer the question "*Which processes have the greatest impact on the company's customers?*" Simply asking customers what they want, however, is not enough (according to Hammer and Champy) since customers will *"tend to answer from their own unexpanded mindset."* They will say they want it *"a little faster, a little better, a little less expensive."* This may be true for Lakeside in that the can makers may not realize the benefits of dramatic improvements in delivery performance. Management must, therefore, *"understand the customers better than they understand themselves,"* where understanding means *"considering the customer's underlying goals and problems."*

"*The problem with benchmarking,*" according to Hammer and Champy, *"is it can restrict ... thinking to the framework of what is already being done in the company's own industry. Used this way, benchmarking is just a tool for catching up, not for jumping way ahead.*"

Training - Lakeside provided training to employees in reducing set-up time (as well as SPC). Yet, few of the workers have actually used these techniques in the factory. This is a fairly common problem associated with corporate training programs. There needs to be a much greater link between training and implementation. Juran states "*The ideal approach is to design the course so that the participants must apply the training [on the shop floor] during the course.*" [34] Requiring workers to implement what they learn - as part of the course - helps ensure the training actually benefits the business.

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[33] Hammer, Michael and Champy, James. Reengineering the Corporation. New York, NY, 1993.

[34] Juran, J.M. Juran's Quality Control Handbook: Fourth Edition. New York: McGraw Hill, 1988.

The Trainer's Handbook[35] indicates that often *"... the trainees enjoy the session but fail to put into practice much of what they are taught."* The handbook recommends structuring training in well spaced intervals and requiring workers to apply their knowledge during the periods between training sessions.

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[35] Mitchell, Garry. The Trainer's Handbook: Second Edition. New York, NY: AMACOM, 1993.

Chapter 6: Simulation Analysis of Lakeside

6.1 Introduction to Simulation Results

Computer simulation is commonly used to analyze complex manufacturing plants that can not be easily evaluated using other methods. In this chapter, a simulation of the Lakeside plant is utilized to analyze the effects of modifications to current operations. The chapter reviews the operational theory underlying each potential recommendation, and then presents the simulation results of the modification.

Appendix A contains an overview of the LPM simulation model that was used to evaluate the modifications to Lakeside's operations. For each operational modification, the LPM simulation was run for a simulated ten week period three times (using different random number seeds) with the results averaged. The final results were then compared to the base simulation discussed in appendix A.

6.2 Benefits of Eliminating Post-Bottleneck Inventory Targets

Theory of Constraints

The Theory of Constraints (TOC) philosophy[36] is based upon the idea that the throughput of a manufacturing operation is determined by the throughput of the bottleneck process. For example, consider the simple factory in figure 6.1. Since B can produce only 10 parts per hour, the capacity of the entire factory is 10 parts per hour. Increasing the production rate of A or C to 30/hour, for example, has no effect on overall throughput.[37] Conversely, any improvements to B directly increases the production rate of the entire factory.

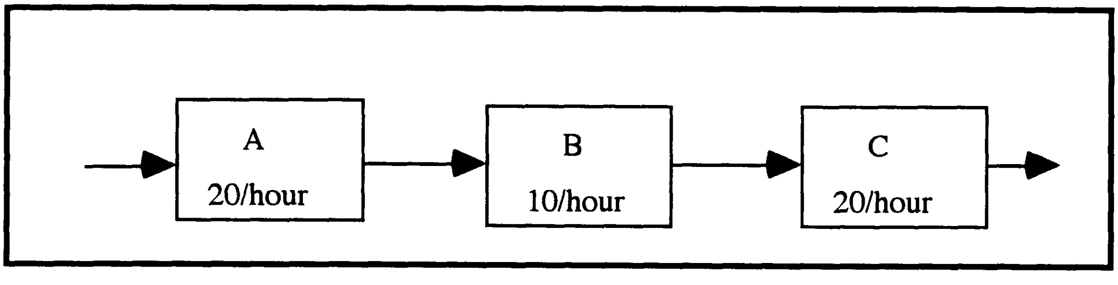

Figure 6.1: Simple Operation

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[36] Goldratt, Eliyahu. The Haystack Syndrome. Croton-on-Hudson, NY: North River Press, 1990.

[37] If production rates are variable and buffer sizes are finite, there could be some throughput improvement as a result of increasing the production rates of A or C.

Some of the key TOC operating principles are:

1) Since the bottleneck determines plant throughput, it is critical to optimize the utilization of the constraining process. This includes placing sufficient levels of inventory before the bottleneck to ensure it is not "starved," and reducing the amount of set-ups at the bottleneck.

2) Increasing the utilization of non-constraining processes does not improve plant operation. In figure 6.1, for example, the optimum utilization of A will be approximately 50%. Trying to increase the utilization of A to 100% will only build unnecessary inventory. Similarly, the benefits of improving the utilization of non-constraining processes through large batch sizes (or long product sequences) are an illusion. For example, if through the use of batching, the production rate of A were increased to 30/hour, overall throughput would still be 10/hour. Large lot sizes at non-constraints should, therefore, be minimized.

3) Material should be released into the factory at approximately the bottleneck processing rate. Once a product has been processed by the constraining operation, it should be moved through the system as quickly as possible.

Bottleneck at Lakeside

At Lakeside, the bottleneck operation is the cold mill. Figure 6.2 shows the average processing times at each work center. Although the slitter has the longest average cycle time, only about half of the coils are processed by the slitter. When the percentage of coils processed at each work center (based upon Lakeside's forecasted product mix for the year) is taken into consideration, it is clear that the cold mill is the bottleneck operation.

Work Center	Average Cycle Time for a Coil Processed at the Work Center (minutes)	% Coils Processed	Average Cycle Time per Coil Processed at the Lakeside Plant (minutes)
Scalper	12	100%	12.0
Hot Mill	22	100%	22.0
Cold Mill	39	100%	39.0
Coil Prep	35	83%	29.1
Coater	39	74%	28.7
Slitter	41	52%	21.3

Figure 6.2: Cycle Time/Capacity Comparison [38]

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[38] This figure could be enhanced by taking into consideration whole coil scrap (i.e., upstream machines process more coils than downstream machines due to scrapped coils) and re-runs (i.e., a small percentage of coils are re-run on some downstream machines). The overall results, however, would not significantly change.

The cold mill is still the constraining operation when set-up time is included. Although the coater may require more set-ups than the cold mill (since the cold mill doesn't require a set-up when there is a coating change), a set-up on the coater generally takes between 30 and 90 minutes. A backup roll change on the cold mill, however, can take an entire shift. A Lakeside report (which includes set-up time) estimates that processing the forecasted orders for the year will require over 100 more shifts of cold mill time than of any of the other work centers.

TOC Applied to Lakeside

The current scheduling philosophy at Lakeside requires a certain level of inventory before each work center - including those operations after the bottleneck cold mill (i.e., the coil prep line, coater, and slitter). These inventory levels are maintained to reduce the number of set-ups required and to ensure maximum equipment utilization. According to the theory of constraints, however, trying to maximize equipment utilization at non-bottleneck processes actually hampers overall plant performance.

Based upon the above, it may be in the best interest of Lakeside to eliminate inventory targets for all operations after the cold mill.

6.3 Simulation Results of Eliminating Post-Bottleneck Inventory Targets

The base simulation was modified by eliminating minimum inventory requirements at all process centers after the cold mill. The result of the simulation is that eliminating the minimum inventory targets for the slitter, coater, and coil prep line has little effect on overall throughput. The base simulation model predicted a throughput of 7.8 prime coils per production shift, while the modified model predicted a throughput of 7.9 prime coils per production shift. This change is not statistically significant since the statistical error for the simulation is at least .44 coils/shift (as discussed in appendix A). Inventory and flowtime, however, were both significantly decreased under the modified inventory rules.

Figure 6.3 shows the predicted inventory levels at the end of each day between the cold mill and finished goods inventory (not including coils that are cooling after the cold mill or coils held for reallocation) for one particular run of each computer simulation model. As shown, inventory levels are significantly reduced under the modified rules.

The spikes in inventory that are common to both simulations are due to equipment maintenance shutdowns which are incorporated into both models. During these shutdowns inventory builds up before the off-line piece of equipment. The spikes which are unique to one or the other model are likely due to random unplanned downtime periods.

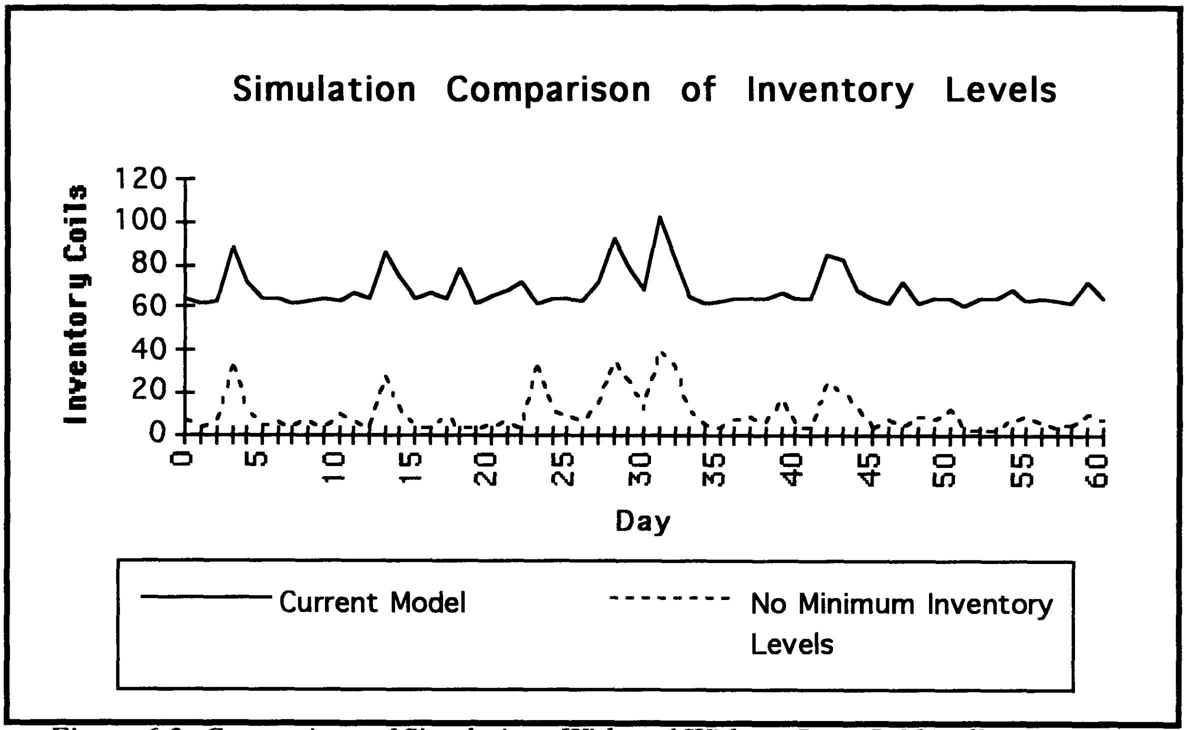
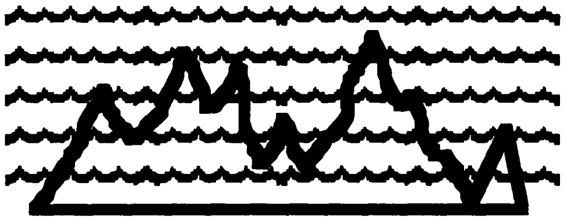


Figure 6.3: Comparison of Simulations With and Without Post-Cold Mill Inventory Targets - Post Cold Mill Inventory Not Including Cooling Coils or Reallocated Coils

The average of the inventory levels in figure 6.3 is almost 70 coils for the current plant model, and less than 13 coils for the modified model - a reduction of 57 coils. The value of these coils is approximately $800,000. Assuming a holding cost of 15%, the monetary savings of eliminating this inventory would be $120,000 per year. In addition, flowtime was reduced from 15 days 3 hours to 13 days 1 hour - a reduction of over 2 days. This would improve Lakeside's on-time delivery performance.

6.4 Benefits of a JIT/Kanban System

The Just-in Time (JIT) production system was first developed by Mr. Taiichi Ohno of Toyota. JIT is a pull system. The main tenets of JIT are inventory elimination, small batch sizes, and an emphasis on process control and set-up time reduction. A common analogy used in describing the benefits of JIT/reduced inventory is shown in figure 6.4.



Water Covers Rocks - Excess Inventory Masks Problems

Rocks are Visible - Reduced Inventory Exposes Problems

Figure 6.4: Inventory/River Analogy

Large levels of inventory cover up many of the problems that exist within a plant - just as a high level of water covers up the rocks on the floor of a river bed. When buffer sizes are reduced, the underlying problems in the plant are revealed - just as the hidden rocks are revealed when the water level decreases. When there is less inventory, it becomes increasingly critical to ensure processing problems are quickly resolved.

Common methodologies utilized for implementing a JIT system include kanbans and "kanban squares." Kanban uses a system of cards and containers to limit the amount of inventory at each stage in the manufacturing process. With kanban squares, areas for inventory are clearly marked (one square per inventory item). When the kanban squares are filled, the upstream operation stops producing. Both of these methods limit the amount of inventory at each step in the process to a very small specific level.

JIT systems are generally more successful in plants which have stable demand and consistent processes. Because of the limited inventory in the system, a JIT plant is vulnerable to disruptions. If a single machine stops producing, the entire plant may quickly shut down. As previously mentioned, a JIT system exposes the underlying manufacturing problems. The plant, however, must be able to resolve these problems for the system to be successful. As such, a variety of other programs (statistical process control, quality circles, total preventative maintenance) are often implemented along with JIT.

6.5 Simulation Results of a JIT System

A post-cold mill JIT system was evaluated in which buffer size at each operation after the cold mill cooling process was limited to three coils. Compared to the TOC results discussed in section 6.3, the post cold mill JIT system had slightly less inventory (an average of 7 coils of inventory versus 13). Throughput, however, was significantly less under the JIT system (7.0 prime coils/shift versus 7.8 prime coils/shift).

Under "normal" operations, there is little difference between the JIT and TOC systems. The major differences occur during equipment downtime. Under JIT, when a machine is down, the entire plant is affected. For example, if the coater goes down, the maximum inventory level before the coater is quickly reached - which causes the coil prep line to stop producing coils. This chain reaction can continue until the entire plant shuts down - dramatically reducing throughput. In the TOC system, when a machine after the bottleneck goes down, the bottleneck continues to produce - maintaining throughput levels. During these periods, WIP is higher under TOC than under JIT.

For Lakeside, the value of producing an extra .8 coils per shift (≈16 coils every week) is worth significantly more than the costs associated with holding an extra six coils of inventory. As such, the TOC changes discussed in section 6.3 provide a superior operational strategy in comparison to the post cold mill JIT scheduling system.

6.6 Benefits of Reducing Cold Mill Dead Cycle Time

An important part of the TOC philosophy is reducing cycle and set-up times for the bottleneck operation. At Lakeside, there are numerous opportunities for improving cold mill throughput. Between cold mill passes, for example, operators have to make adjustments to the controls to ensure the proper gauges are set. The time that a coil is on the cold mill but is not actually being processed is referred to as dead cycle time. Currently dead cycle time averages approximately 7.5 minutes per coil. An internal study at Lakeside indicates that the dead cycle time could be reduced to 3.5 minutes per coil by automating presets as parallel operations and optimizing procedures associated with the cold mill.

6.7 Simulation Results of Reducing Cold Mill Dead Cycle Time

To evaluate the effect of dead cycle time improvement, dead cycle time for the cold mill was reduced by four minutes for every product group. The results indicate that throughput increases from 7.8 prime coils per shift to 8.5 prime coils per shift. Over the course of a year this is equivalent to over three and a half weeks of extra capacity. This illustrates how small improvements in the proper areas can have an enormous impact on improving overall operations.

6.8 Establishing Optimal Inventory Before Bottleneck

The theory of constraints indicates that there should be just enough inventory before the bottleneck to ensure the bottleneck is not starved. At Lakeside, there are generally between 140 and 160 coils before the cold mill (including coils cooling after the hot mill). Since the cold mill is rarely down due to a lack of coils from the hot mill, the buffer size after the hot mill may be larger than necessary. The simulation does not have a "solver function" to calculate the optimum buffer size. As such, the only method for determining the best inventory target is by trial and error. This approach is discussed in the next section.

6.9 Simulation Results of Various Inventory Levels Before Bottleneck

Maximum levels for post hot mill inventory were lowered in several steps, and the resulting throughput recorded. Figure 6.5 contains the results of the simulation.

Maximum Inventory (coils)	Throughput (coils/shift)
160	7.8
150	7.7
140	7.8
130	7.7
120	7.7
110	7.6
100	7.4
90	7.1
80	6.7
70	6.3
60	5.6

Figure 6.5: Simulation Results of Reducing Pre-Bottleneck Inventory

As shown, for maximum inventory levels at 110 coils and above there is little change in throughput. For maximum inventory levels at 90 and below, throughput is dramatically reduced. As such, the maximum inventory level could be reduced from 160 coils to 110 coils (or certainly to 120 coils) without any significant negative impact on plant performance.

One of the primary reasons for the inventory is hot mill maintenance downtime. At the beginning of every week, the hot mill is down for several shifts while the pre-heat furnaces are heating ingots. To ensure the cold mill isn't starved, a sufficient amount of inventory must be placed before the cold mill at the end of each week - to account for the time the hot mill will be down at the beginning of the following week. Otherwise, the cold mill is starved and throughput decreases. Thus, rather than having a single maximum inventory level, it may be more appropriate to have a dynamic level that changes over the course of the week.

As such, a modified simulation was run in which the maximum inventory level was 90 coils during the first four days of every week, and 120 coils during the last three days. The simulation showed that a dynamic buffer allows even further reductions in inventory while achieving the same throughput (throughput for the model was 7.7 coils/shift). Evaluating other possible dynamic inventory strategies is left for future study.

A previous section discussed the possibility of using JIT after the cold mill. This section clearly indicates the problems associated with implementing a JIT throughout the entire Lakeside plant. Based upon current operations, reducing pre-cold mill inventory to extremely low levels (e.g., below 60 coils) would dramatically reduce plant capacity.

6.10 Using Simulation to Evaluate Investments

In any manufacturing environment, there are hundreds of potential investments a business can make which would benefit the plant (i.e., have a positive net present value). Since businesses have only a limited amount of capital to invest, however, the role of management is to select the investments which provide the highest profitability given their capital constraints. To accomplish this, a profitability index[39] must be calculated for each positive NPV project investment as follows:

$$\text{Profitability Index} = \frac{\text{present value of investment}}{\text{investment}}$$

Projects with the highest indexes should be selected until all of the investment budget is utilized. Calculating the present value of an investment, however, is not always simple. One project may reduce cycle time on a particular piece of equipment while another may improve recovery on a different piece of equipment. Determining the value of these investments requires understanding how the projects affect overall plant performance. The simulation can therefore be utilized to help evaluate the benefits of each potential investment - allowing management to make optimal use of their funds.

6.11 Simulation Results for Two Potential Investments

A potential investment at Lakeside is to modify the hot mill table roller system - which would allow higher rolling speeds during the coiling passes. The estimated cycle time improvement is 52 seconds per coil, while the estimated cost is $150,000. The question is what is the monetary benefit of a 52 second improvement in hot mill cycle time? The LPM model was modified to reduce the cycle time for all products by .87 minutes ($\approx$ 52 seconds).

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[39] Brealey, Richard A. and Myers, Stewart C. Principles of Corporate Finance: Fourth Edition. New York: McGraw Hill, 1991.

The results of the simulation indicate there is little, if any, benefit to reducing hot mill cycle time by .87 minutes. Overall plant throughput remained virtually the same (at 7.8 prime coils per shift). Average flowtime decreased slightly, from 15 days 3.4 hours to 15 days 2.1 hours. This change, however, is not statistically significant (see appendix A). In any case, the project appears to have little value for the plant (i.e., a negative NPV). The value of the project is certainly less than that of forced cooling which, for approximately the same investment, reduces flowtime by over a day.

Another potential investment is for a scrap rewind machine after the coil prep line to reduce the waste of metal when a welded portion of coil is removed. This reduction of scrap should improve coil prep length recovery by 0.6 percent, at a cost of approximately $150,000. The simulation was modified such that average coil prep length recovery for each product group was increased by 0.6%. The simulation tracked scrap levels and converted the results to monetary figures (using variable scrap costs).

According to the simulation, the value of the decrease in scrap is approximately $2800/week (≈$144,000/year). Assuming a 10% discount rate, the project has a positive NPV of $1.3 million, and a profitability index of 9.6. Thus, the project is beneficial to the plant and should be implemented, provided there are sufficient funds to invest in all projects with a higher profitability index.

6.12 Summary of Simulation Results

The simulation indicates that the plant should adopt a theory of constraints approach to production scheduling. Inventory targets after the cold mill should be eliminated - which will significantly reduce inventory levels while maintaining throughput. Plant resources should be concentrated on reducing cold mill set-up and cycle times. Maximum buffer size before the cold mill should be reduced to 110 coils (and even less during the early portion of the week). Over time, as process variability decreases, the buffer size can be further reduced. Actual order scheduling should be based upon cold mill availability. That is, Lakeside should only accept orders if there is available capacity on the cold mill. The capacity of the cold mill must take into consideration the coils that have to be processed because of scrapped coils.

6.13 Potential Recommendations Left for Future Work

The following are possible areas for future work utilizing (and expanding) the LPM simulation:

Ingot Plant - Finished Goods - Ordering System

Obviously, a possible next step would be to expand the LPM model to include the ingot plant, finished goods inventory, and the ordering/delivery system. The simulation could then be used to evaluate a variety of possible improvements such as: improving the synchronization between the ingot plant and the rest of operations (resulting in less inventory in and after the ingot plant), reducing transportation costs (by better utilizing trucking capacities), and optimizing finished goods inventory levels.

Tradeoffs Between Maintenance, Downtime, and Recovery

While preventative maintenance increases the level of planned downtime, it generally reduces the amount of unplanned downtime. At Lakeside, for example, in the months following periods in which there is little or no planned maintenance performed on equipment, unplanned downtime levels generally increase. Preventative maintenance also tends to improve quality and recovery levels.

Simulation techniques could be used to analyze the trade-offs between preventative maintenance downtime and overall plant performance - in order to determine the optimum maintenance level. This analysis, however, requires establishing a quantitative relationship between all of the variables. At present, there is no well established relationship between preventative maintenance and recovery at Lakeside. As such, this is left for future work.

Product Mix

The LPM simulation assumed a particular mix of products (based upon Lakeside demand projections for an upcoming quarter). Significant deviations from the product mix used in LPM would change the simulation results. As Lakeside's product mix changes over time, the LPM simulation should be re-run periodically with the appropriate demand changes incorporated.

Maintenance Periods

Currently, many of the planned maintenance periods at Lakeside last for an entire day. These long downtime periods are extremely disruptive to operations and cause large inventory buildups. It may be preferable to have a greater number of shorter maintenance periods (e.g., one shift of maintenance every week rather than a single four shift maintenance period every month).

6.14 General Lessons

The following are some of the general lessons from this chapter:

TOC versus JIT

Choosing between a TOC and JIT system depends upon the context of the manufacturing plant. JIT/kanban systems work well in balanced assembly line type plants with fairly consistent demand, but not as well in operations with bottlenecks and large demand fluctuations (such as Lakeside). Aggarwal states "*Kanban assumes that the production rate at the assembly line is even. [Kanban] cannot tolerate load fluctuations of more than ten percent and starts breaking down under large deviations from average conditions,*" and that "*Kanban can not tolerate a constantly changing master production schedule.*" [40]

Simulation modeling showed that TOC and JIT scheduling methodologies would significantly reduce inventory in Lakeside's manufacturing system. Although JIT eliminated slightly more WIP inventory than TOC, TOC achieved significantly greater throughput. Other studies of these scheduling philosophies for plants with bottlenecks have provided similar results. Simulations performed by Fogarty, Blackstone, and Hoffmann for a factory (with a bottleneck operation) showed that TOC provides approximately 2% more output than JIT and only slightly higher levels of WIP inventory.[41] Another study showed that while TOC sometimes has more WIP inventory, "*TOC produces a significantly larger amount of product than does JIT.*" [42]

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[40] Aggarwal, Sumer C. "MRP, JIT, OPT, FMS?" Harvard Business Review, Sep/Oct 1985, p. 8.

[41] Fogarty, D.W., J.H. Blackstone, Jr., Hoffman, T.R. Production and Inventory Management: Second Edition. Cincinnati, OH: South Western Publishing, 1991.

[42] Cook, David P. "A Simulation Comparison of Traditional, JIT, and TOC Manufacturing Systems in a Flow Shop with Bottlenecks." Production and Inventory Management Journal, First Quarter - 1994, p.73-78.

Neither of the above studies included maintenance or unplanned downtime periods in the models of the factories. It is during non-bottleneck downtime periods that the differences between the two scheduling philosophies are most visible. With JIT, the plant quickly shuts down when one piece of equipment is not operating. Under TOC, the bottleneck continues to produce and builds up inventory before the disabled machine (the inventory is reduced once the equipment comes back on-line).

Thus, both throughput and inventory are higher under the TOC system when there are non-constraining equipment downtime periods. The large differential in throughput is generally more valuable than the difference in WIP. Thus, from an analytical perspective, TOC is superior to JIT in unbalanced plants with bottleneck operations.

Leverage Points

In any manufacturing plant there will be a multitude of potential areas for improvement. An important role for management is to determine which of these improvements will have the greatest positive impact relative to the effort required. As shown by the simulation, reducing cold mill dead cycle time by only four minutes per coil results in a large improvement in overall throughput. Conversely, improving hot mill cycle time has little impact on plant performance. By determining the leverage points in a business, management can direct its efforts on improving the few areas that will have the greatest overall impact.

Senge states "*Often, leverage follows the principle of economy of means: where the best results come not from large scale efforts, but from well-focused actions.*" However, "*The leverage in most real-life systems, such as most organizations, is not obvious to most of the actors in those systems.*" [43] Management should ensure that it has a strong understanding of the leverage points within an organization prior to allocating resources to improvement projects that may have little benefit to the overall business.

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[43] Senge, Peter M. The Fifth Discipline. New York, NY: Doubleday, 1990, p.114.

Chapter 7: Summary of Recommendations and Lessons

7.1 Recommendations for Lakeside

This following summarizes some of the previously made recommendations for improving operations at Lakeside:

Strategy - Lakeside should pursue a strategy of differentiation through improved quality and delivery performance.

Focus on Quality - As the cost of quality represents a major portion of expenses, Lakeside should focus on improving quality rather than cutting costs.

Measurements - To facilitate improvements in quality and delivery performance, the metrics in the plant need to be modified. Right first time quality levels and on-time delivery performance need to be emphasized, as opposed to tons of metal produced.

Standard Operating Procedures - To eliminate processing variability, capture production workers' knowledge, and share best practices across shifts, a system of standard operating procedures should be developed and implemented at Lakeside.

Statistical Process Control/Design of Experiments - To improve quality levels at Lakeside, there must be a greater understanding of how processing variables affect product quality. As such, a program of statistical process control and design of experiments should be implemented at the plant. To obtain the necessary data to utilize these tools, a shop floor data acquisition information system must be implemented.

Preventative Maintenance - Greater emphasis should be placed on preventing equipment failures as opposed to repairing failures. Preventative maintenance should be performed during the "21st shift" when the plant is shut down.

Reduce Set-up Time - Changeover time, particularly at the bottleneck cold mill, should be reduced. This can be accomplished by videotaping set-ups and having teams of workers evaluate and improve set-up procedures. This also applies to cold mill dead time cycle time.

Limit Time for Holding Coils - Any coil placed on hold for quality problems should be dispositioned (i.e., taken off hold) within 24 hours.

Forced Cooling - Lakeside should purchase and install cooling fans to reduce cooling time after the hot mill and cold mill. The savings in inventory holding costs easily justifies the investment from a financial perspective. In addition, flowtime in the plant would be reduced by over a day.

Scrap Rewind - The plant should purchase and implement a scrap rewind facility at the coil prep line to improve recovery. In general, projects associated with recovery improvements will have a high impact on plant profitability.

TOC Scheduling - Lakeside should adopt a theory of constraints scheduling philosophy. Minimum inventory levels and target inventory levels for post-cold mill operations should be eliminated. The maximum buffer size before the cold mill should be reduced to 120 coils (and even less during the early portion of the week). Plant scheduling should be based upon cold mill availability.

7.2 Implementation/Vision

This thesis has concentrated on the strategies and tactics that Lakeside should select for improving operations. Actually implementing a major change in any organization is generally difficult and requires strong support from upper management over a long period of time.

In attempting to change an organization, it is often beneficial to have a vision for what the business should be in the future. In "The Vision Thing," Lee states "*A vision, when shared by employees can keep an entire company moving forward in the face of difficulties. When employees understand a leader's vision, they understand what the organization is trying to accomplish and what it stands for. Moving towards the same goal, individuals work together rather than as disconnected people.*" [44]

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[44] Lee, Chris. "The Vision Thing," Training, Feb 1993, p. 25.

The following is one possible vision for Lakeside:

Lakeside 2000

Lakeside has fully implemented a TOC scheduling system. As a result of flowtime reductions and other plant improvements, Lakeside has been able to guarantee customers a 99% on-time delivery record. This has enabled many of the can makers to eliminate much of their raw material inventory, providing them with large cash flow improvements. The can makers now expect almost perfect delivery performance from all can stock makers. Many of Lakeside's competitors, however, are not able to meet this high level of delivery performance and, therefore, can not effectively compete with Lakeside.

An integrated shop floor information system has been implemented which the workers utilize to ensure processing parameters are within acceptable tolerances. Production workers have gained a strong understanding of how production parameters affect product quality, and can resolve potential problems before there is any negative impact to the product.

Lakeside has formed an electronic link with its material suppliers which allows Lakeside's engineers to analyze statistical data on incoming material. Engineers can evaluate how raw material processing affects quality levels at Lakeside, and provide feedback to suppliers to help them improve their products. Similarly, the plant has established electronic links with several customers - allowing Lakeside to understand how can stock parameters affect can production. As such, Lakeside can modify products and processes to meet customers' true needs.

The key metrics in the plant are right first time quality and delivery performance. The culture at Lakeside is such that quality problems are abhorred. For any significant processing deviation, a team of workers is immediately formed to resolve (using experimental design and other analytical methods) the underlying problems. Set-up times for each of the machines have been dramatically slashed, and a strong preventative maintenance program has almost eliminated unplanned downtime.

Lakeside has initiated a marketing campaign asking customers to evaluate the cost of quality associated with Lakeside's can stock versus competitors' can stock. Customers that perform this calculation are shocked by the amount of money they save by purchasing Lakeside's high quality products (e.g., less scrap, less inventory, etc.). This has made Lakeside the natural choice among can makers.

As a result of quality improvements, the cost of quality at Lakeside has been slashed. Because of Lakeside's high quality and excellent delivery performance, customers are willing to pay a premium for Lakeside products. The combination of low expenses and premium prices has provided Lakeside with the highest profit margins in the industry. Several competitors have downsized to become more cost effective. This, however, has hurt their quality and delivery performance levels - which has actually increased Lakeside's market share.

Not happy with the status quo, however, Lakeside is continuing to develop new methodologies for improving operations and customer satisfaction.

7.3 Review of General Lessons

This following summarizes some of the general lessons previously discussed in this thesis:

Strategy - Corporate evaluation of business units based strictly upon financial numbers leads to short term thinking and can adversely affect business growth. Long term growth generally requires large investments and some risk taking. Financial goals such as ROI, however, encourage risk averse policies and investment reductions. It is critical for corporate executives to work closely with business managers to develop long-term strategies for the businesses.

Quality = Leverage Point - Quality often represents one of the most important areas for improvement in a manufacturing organization. In addition to increasing customer satisfaction and on-time delivery performance, quality improvement often significantly reduces manufacturing costs. The costs associated with poor quality are often hidden from management as a result of cost accounting methods and workers' ability to repair defects. Therefore, it is vital for management to perform a cost of quality analysis to determine the full impact of their quality problems.

Paradigms - There is certainly no lack of new manufacturing paradigms. Rather than contemplating the latest buzzwords, however, many businesses would be better off concentrating on implementing established improvement techniques such as standard operating procedures, statistical process control, and experimental design.

Metrics - The measurements that a business emphasizes have an enormous impact on how employees behave. For example, emphasis on metrics such as "amount produced" often leads to quality problems. It is critical for management to align plant metrics with business goals.

Customer Perspective - Changes to operations should be evaluated from the customer's perspective. Management must try to understand customers' underlying problems - and help solve them. While there is some value to benchmarking, it often limits thinking to what is already done in the industry.

Training - After completing educational courses, workers commonly do not apply what they have learned in the class to the plant. As such, the training is wasted. Training programs should be structured such that workers must apply what they learn in the plant as part of the course.

Leverage Points - In any manufacturing plant, there are a multitude of potential improvement projects. Since businesses have only a limited amount of resources, it is critical for management to identify the projects that will have the greatest positive impact on the entire operation. Improving the cycle time of one machine, for example, may significantly increase plant throughput, while improving the cycle time of another machine may have no impact at all. Determining the leverage points allows management to make significant improvements to plant performance with the least amount of effort.

TOC versus JIT - In manufacturing plants that have bottleneck operations and significant levels of equipment downtime, TOC provides significantly more throughput than JIT while allowing only slightly more inventory. In this type of manufacturing environment, TOC is superior to JIT.

Vision - Communicating a business vision to employees helps unify and focus workers on achieving long term goals.

Appendix A: Overview of the LPM Simulation Model

This appendix describes the details of the Lakeside Production Model (LPM) simulation that was created to emulate the Lakeside plant. The validation and statistical significance of the LPM simulation is also discussed in this appendix.

A.1 Simulation of Lakeside

Lakeside, as with most other manufacturing plants, is an extremely complex system. It is, therefore, not feasible to model every aspect of Lakeside. Indeed, no matter how complex the simulation, it can never exactly emulate a real manufacturing plant. By making some simplifying assumptions, however, it is possible to create a simulation with characteristics resembling that of an actual manufacturing operation. This model can then be used to evaluate how changes in operations will affect overall plant performance.

The LPM simulation was created using Micro Saint[45] - a computer software simulation shell which runs on personal computers. Figure A.1 illustrates the overall LPM model. The ovals represent the process centers and the boxes are areas for inventory. The following are some of the key features and assumption of the simulation:

Products

Lakeside has well over 200 different final product specifications. Many of these specifications are very similar, and have virtually identical processing characteristics (e.g., cycle times, recovery rates, etc.). Grouping products with similar processing characteristics results in 17 product families. For simplification, therefore, LPM assumes that there are 17 product families. As a product is processed in the simulation, the processing parameters (e.g., cycle time, recovery, set-up time) are determined based upon which family the product is from.

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[45] Micro Saint is a product of Micro Analysis & Design Simulation Software, Inc.

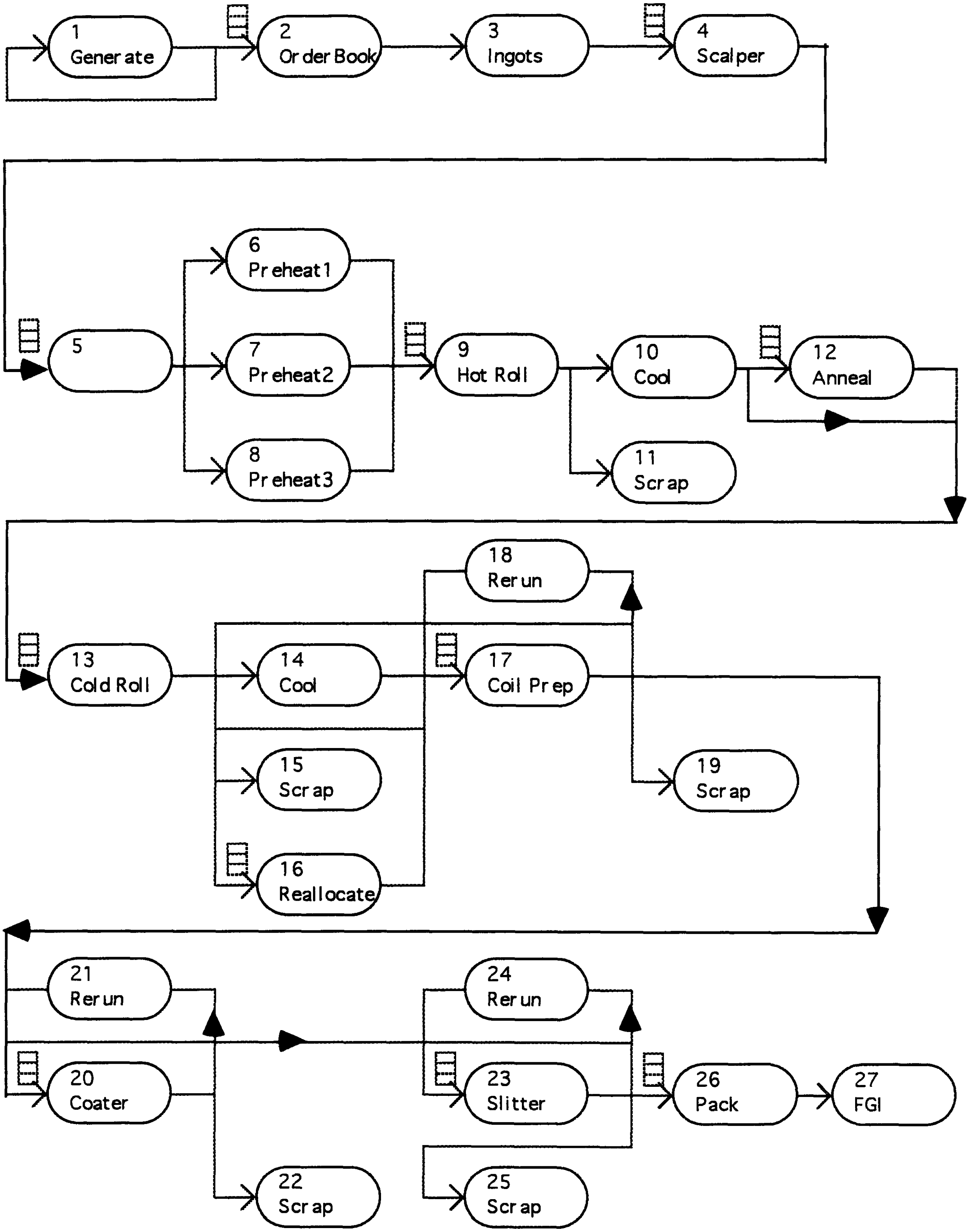

Figure A.1: LPM Diagram

Ingot Plant/Transportation

The simulation models product flow through Lakeside from the ingot stage until finished goods inventory. The simulation does not model the ingot plant (or ingot delivery from vendors), finished goods inventory, or transportation to customers. LPM assumes that ingots are almost immediately produced when needed.

Flowpath

All products at Lakeside are processed through the scalper, hot mill, and cold mill. Whether a coil is processed through the prep line, coater, or slitter, however, depends upon the specification for the product. In the simulation, all products within a product family have the same processing routes through the plant. For example, product family 3 includes only unslit coated end stock. As such, LPM routes products from family 3 through the prep line and coater, but not the slitter.

Cycle Times

Cycle time at each process center depends upon a variety of factors such as the product being processed and/or the length of a coil at a particular stage in the process. The coater, for example, operates at approximately the same speed for all products. The mean cycle time for a product through the coater is simply the length of the coil at the coater divided by 200 meters/sec (the speed of the coater). In the pre-heat furnace, cycle time depends upon the product family.

For the cold mill, the mean cycle time is based upon several factors. The cycle time for each pass of the cold mill is equal to the length of the coil times the rolling speed. Thus, the cycle time for a product that requires three passes is:

$$\text{Cycle Time} = (L_1 * S_1) + (L_2 * S_2) + (L_3 * S_3)$$

where L_n is the length of the coil after the n^{th} pass and S_n is the rolling speed during the n^{th} pass. The length of the coil, however, increases significantly during each pass. The length of a coil after the first pass is given by $L_1 = L_0 * (G_1/G_0)$ where L_0 is the length off the hot mill, G_0 is the gauge off the hot mill, and G_1 is the gauge after the first pass. Similarly, $L_2 = L_1 * (G_2/G_1)$ and $L_3 = L_2 * (G_3/G_2)$. Substituting these equalities into the cycle time equation, and simplifying, results in the following general equation for the cycle time of the rolling mill:

$$\text{Cycle Time} = G_0 * L_0 * [(S_1/G_1) + (S_2/G_2) + (S_3/G_3) + \ldots + (S_n/G_n)]$$

The number of passes required, rolling speeds, and gauge reductions for each pass are determined based upon product family. LPM uses the above formula to calculate the mean cold mill cycle time for each coil. This does not include the dead cycle time (time between passes) which is accounted for under set-up time.

Due to the variability of each process, the actual cycle time for two identical products through a process center can differ. To account for this, cycle times are represented by probability distributions. Cycle times at Lakeside, as in most plants, do not exactly follow a standard distribution. One major reason for this is that machinery is physically limited with respect to how fast it can process a coil. Conversely, as a result of machine problems or operator error, there is no limit to how long cycle time can be. As such, cycle times are slightly skewed.

Because of the skewed nature of the actual cycle times, the gamma distribution is slightly superior to the standard simulation assumption of a normal distribution and is, therefore, used throughout LPM for cycle time variability.

Figure A.2 illustrates the historical cumulative density function of cold mill cycle time for 200 coils of the same product family. The figure also includes the gamma distribution for the same mean and standard deviation (18.9 minutes and 2.2 minutes, respectively). As shown, the gamma distribution provides a fairly good representation of the actual cycle time variability. Similar comparisons for cycle times of a product family on the hot mill, coil prep line, and coater show that the gamma distribution is a good model of cycle time variability.

The necessary data to calculate the variance of cycle time for every product family at each process center was not available at Lakeside. The data that was available indicated that the standard deviation of cycle time is generally about ten percent of the mean cycle time. As previously mentioned, the mean and standard deviation of the cycle times (processing time) for the 200 coils discussed above are 18.9 minutes and 2.2 minutes, respectively. As such, the standard deviation is 11.6% of the mean. Because of the lack of data, the simulation assumes that the standard deviation of cycle time is equal to ten percent of the mean cycle time for each product group.

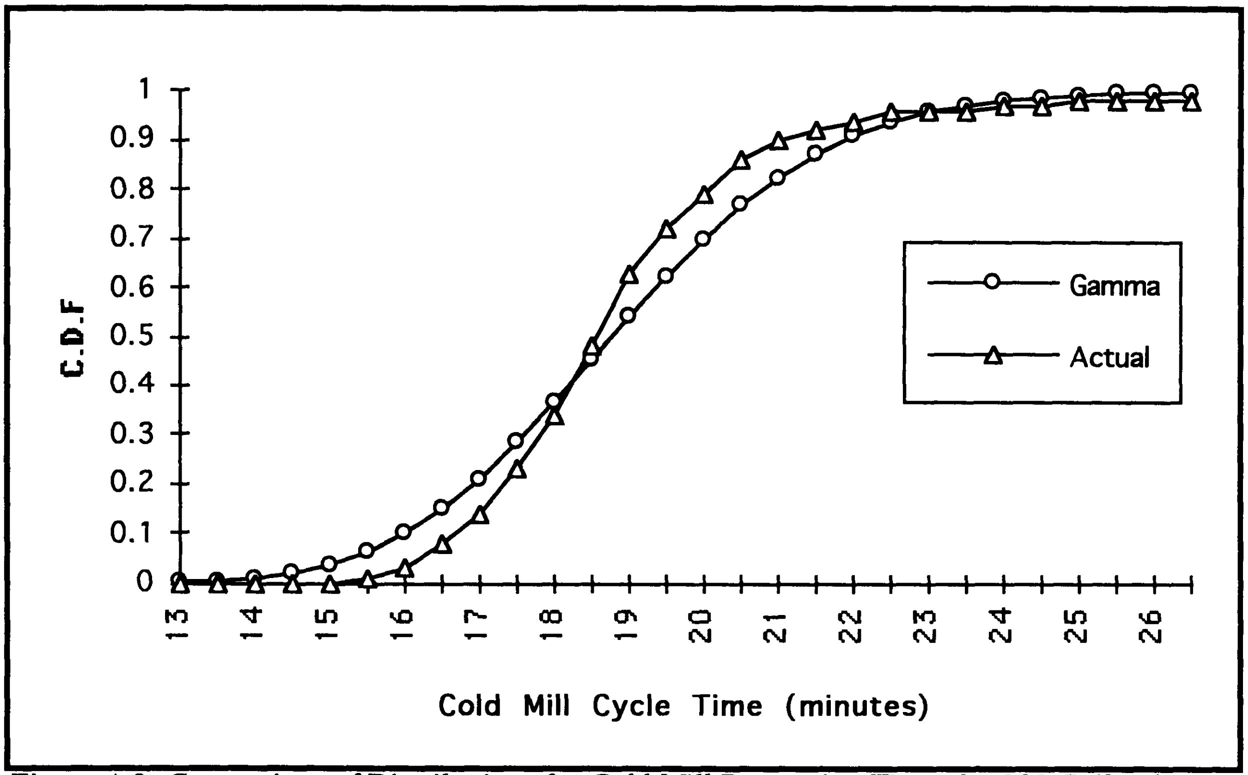

Figure A.2: Comparison of Distributions for Cold Mill Processing Times for 200 Coils of a Specific Product at Lakeside - Actual versus Gamma Distribution

Recovery

As a product is manufactured, LPM tracks its length, width, and weight. At many of the process centers, the widths of the coils are trimmed and/or the ends of coils are cut off - which result in recovery losses. The simulation calculates the appropriate length and width recovery at each process center based upon product family. For example, the mean length recovery for product family 1 at the hot mill is 94%.

Occasionally, a coil in process must be entirely scrapped due to quality problems. In the simulation, a certain percentage of coils (based upon product family) are randomly scrapped after each of the major process centers.

Inventory

Lakeside has inventory targets and ranges for each step in the production process. These ranges are incorporated into the LPM simulation. For example, if the inventory before the cold mill exceeds 160 coils, the hot mill stops operating. Similarly, the coater will not operate until there are at least 20 coils waiting to be coated.

Rework

For the coil prep line, the coater, and the slitter, a certain percentage of coils must be reworked due to processing problems. In general, these coils are not re-run immediately as they must be examined to determine exactly what needs to be done to repair them. In LPM, a certain percentage of coils (based upon actual plant data) through the prep line, coater and slitter are randomly selected for re-run. These coils are held for one day, and then placed back into the inventory of the process for which it has to be re-run. The coils are then scheduled according to the normal scheduling rules of the process center.

Planned Downtime

There are three types of planned downtime at Lakeside. First, the entire plant shuts down for one shift every week. LPM takes this into account by assuming that there are only 9600 minutes per week (rather than the actual 10080).

Second, there is the downtime which occurs as a result of the "21st shift" shutdown. For example, during the four shifts prior to the 21st shift, no new ingots are placed into the preheat ovens. Similarly, during the first four shifts of a new week, the hot mill is not operated (to allow time for the preheat ovens to heat up the ingots). The simulation includes these. The simulated hot mill, for example, does not operate during the first 1920 minutes (= 4 shifts) of the week.

Third, there are the planned maintenance activities for each machine. To account for maintenance, each of the major simulated process centers is shut down at regular intervals. The simulated coater, for example, shuts down for slightly over a day every month.

Unplanned Downtime

Unplanned downtime occurs when a piece of machinery must be shut down due to equipment failure or serious quality problems that can not be repaired while the equipment is in operation. Unplanned downtime can occur at anytime and can last for an indefinite period of time. As such, it is more difficult to simulate than planned downtime.

A review of actual machine downtime data for Lakeside shows that the distribution of downtime length for a shutdown tends to be bi-modal. Most of the shutdowns are due to easily fixed problems (e.g., an obvious part failure) which take approximately an hour to repair. Occasionally, however, there are more serious problems which can cause an entire shift or more of downtime. For example, during one month the cold mill had one downtime period which lasted slightly over a shift, while the other downtime periods ranged from a few minutes to three hours (with an average of 48 minutes). To account for this, LPM utilizes two separate random downtime generators for each of the major process centers.

The first generator selects a random number every hour. If the random number is greater than a specific value (which is based upon actual machine downtime), the process center shuts down for an hour. The second generator works the same except it selects a random number every eight hours, and shuts the process center down for eight hours if the random number is above a specific value.

Pre-heat Furnaces

There are four pre-heat furnaces at Lakeside. In general, however, one furnace is down for maintenance, while the other three are operating. To simplify the simulation, the model assumes that there are only three operating furnaces which are never down for maintenance - as opposed to four with one down for maintenance.

The simulation emulates actual pre-heat furnace operation by batching ingots into the furnaces in groups of sixteen. When a pre-heat cycle is completed, and while the hot mill is operating, the furnace will unload ingots one at a time until empty. At that time, the empty furnace can accept a new batch of ingots, and one of the other furnaces can begin unloading.

Annealing Furnace

Only a small percentage of coils are not self-annealed after the hot mill. In the simulation, a small percentage of coils are randomly selected for annealing. These coils are routed to annealing inventory, rather than the cold mill. When a sufficient batch size is reached, the coils are batch processed in the annealing furnace, and then released to cold mill inventory.

Reallocation

After the cold mill, coils often have roll marks or other types of surface defects on them. Rather than scrapping these coils, Lakeside often reallocates the coils to another specification. The most common type of reallocation is from unslit product to slit product. That is, a coil which was originally intended to be unslit, can be run through the slitter. The portion of the slit coil that has roll marks is scrapped while the remaining portion can be used to satisfy an order for slit coil. LPM incorporates this type of reallocation. A percentage of wide unslit products after the cold mill are randomly selected for reallocation. These coils are held in reallocation inventory. When a new order can be satisfied by the reallocated inventory, the appropriate coil from reallocated inventory is released, and the order is removed (i.e., not processed through the plant).

There are other types of less common reallocations. For simplicity, however, other types of reallocation are not included in the model.

Set-up Times

Many of the process centers require a set-up when there is an increase in the width of the coils being processed. In addition, the coater requires a set-up when there is a change in coating. The simulation tracks the width and coating for each coil and simulates a set-up under the appropriate conditions. The simulation also includes set-ups for cold mill work roll changes (which occur at random intervals) and for cold mill dead cycle time (which occurs for every processed coil).

Scheduling

Scheduling at Lakeside is performed manually by the production control department. As such, it is impossible to exactly duplicate the scheduling in a model. LPM, however, uses a few simple rules to emulate Lakeside. Because most of the processing centers require a set-up when there is an increase in coil width, coils are generally scheduled from wide to narrow through the plant. As such, the primary scheduling rule used in the simulation is that coils are selected from inventory from widest to narrowest over the course of a week. If there aren't any narrower coils available, the widest coil is selected and the wide to narrow selection process repeats. If there are two or more coils with the same width in inventory, coils are selected on a first in first out (FIFO) basis.

For the coater, the simulation schedules coils with the same coatings from wide to narrow. If there are no other coils with the same top and bottom coating available in inventory, the simulation selects a coil that has one of the same coatings (top or bottom), if available. For the slitter, coils are scheduled to minimize slitter head changes. The simulation attempts to select coils from product families that require the same slitter head as the most recently processed coil. If two or more coils equally satisfy the scheduling criteria, the coils are selected on a FIFO basis.

Simulation Parameters

Appendix C contains some of the parameters that were used in LPM to simulate current plant operating conditions at Lakeside.

A.2 LPM Validation

Although a simulation can not exactly emulate a manufacturing plant, it is important to ensure that the simulation produces results similar to that of the actual plant. Lakeside has a capacity planning model of the manufacturing plant which calculates overall plant throughput, machine uptime, and recovery for a given demand and product mix. The capacity planning model uses a top down approach and utilizes historical aggregate plant numbers in its calculations (as opposed to the simulation which uses a bottom up approach).

Since the capacity planning model is based on aggregate historical numbers, it can not be used to evaluate the effects of changes to plant operations. It does, however, provide fairly accurate calculations for overall plant performance over a long period of time based upon current operations. To validate the simulation model, forecasted product mix and demand for an upcoming ten week period were entered into both the simulation model of current operations and the capacity planning model. For LPM, the simulation was run three times (using different random seeds) with the results being averaged. The results of the two models were then compared.

Recovery - The simulation model predicted an average overall recovery for the plant of 57.0%, while the capacity planning model calculated a recovery of 57.4%. Actual overall recovery for Lakeside during recent quarters has hovered around 58%.

Throughput - Both the simulation model and the capacity planner predicted that the plant would produce 7.8 prime coils/production shift.

Uptime - Figure A.3 compares the predicted calendar uptime by the simulation model and capacity planning model for several work centers. Calendar uptime is the percent of time the work center is actually processing a product.

Calendar Uptime	Simulation	Capacity Planner
Hot Mill	43%	37%
Cold Mill	68%	63%
Coil Prep	52%	48%
Coater	50%	49%

Figure A.3: Calendar Uptime Comparison

Flowtime - The simulation predicted an average flowtime of 15 days and 3.4 hours. The capacity planner does not calculate flowtimes. Actual plant flowtime is currently about 17 days. It should be expected that the simulation flowtime is slightly less than actual flowtime since certain aspects of the plant are not included in the simulation model. For example, if a coil has a quality problem it may be placed "on hold" for an indefinite period while it is evaluated. This increases flowtime, but is not incorporated into the simulation model.

Inventory - The average amount of WIP inventory during one simulation run (measuring WIP once per day and averaging over ten weeks) was 3062 metric tons. Lakeside's production plan is to maintain a WIP level of 3100 metric tons. Actual WIP levels tend to exceed this goal. For example, average WIP levels during a recent three month period was 3256 metric tons. As mentioned in the above flowtime paragraph, the simulation does not model certain aspects of the plant such as coils placed on hold. As such, it is expected that inventory in the simulation would be slightly less than in the actual plant.

Conclusion - For the purposes that the simulation will be used for, it appears (based upon the above analysis) that LPM accurately models plant operation.

A.3 Statistical Significance of LPM Simulation

The standard deviation of the number of coils produced per shift over a two hundred shift simulation period was 3.1 coils/shift. If each shift were independent, the statistical error (standard deviation of the estimate of the mean) would be given by:

$$\text{Statistical Error} = \sigma/\sqrt{n} = 3.1/\sqrt{200} = .22 \text{ coils/shift}$$

Thus, a modification to the simulation would have to result in a change in throughput of over .44 coils/shift ($2\sigma = 2 * .22$ coils/shift =.44 coils/shift) to be statistically significant - assuming a two sigma bandwidth, or 95% confidence level.

Similarly, the standard deviation of flowtime for two hundred coils was 62.2 hours. The statistical error (if the flowtimes were independent) would be:

$$\text{Statistical Error} = \sigma/\sqrt{n} = 62.2 \text{ hours}/\sqrt{200} = 4.4 \text{ hours}$$

Therefore, a modification would have to result in a flowtime change of at least 8.8 hours ($2\sigma = 2 * 4.4$ hours = 8.8 hours) to be statistically significant - assuming a two sigma bandwidth, or 95% confidence level.

In actuality, since the shifts are dependent, the actual errors are larger. These figures, however, give at least a sense for the accuracy of the simulation.[46]

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[46] Hogg, Robert and Ledolter, Johannes. Applied Statistics for Engineers and Physical Scientists: Second Edition. New York, NY: Macmillan Publishing, 1992.

Appendix B: Overview of Aluminum Alloys and Cans

Aluminum Alloys

The properties of aluminum can be significantly modified by alloying additions. While aluminum readily alloys with most metals, only a few are important major ingredients in commercial aluminum based alloys. The strength of pure aluminum is generally lower than many other metals. By alloying aluminum with other materials, however, it is possible to increase the strength of aluminum while maintaining many of the desirable properties of pure aluminum such as low density.

Aluminum alloys are identified by numerical code numbers. Figure B.1 provides an overview of the nomenclature for wrought (mechanically worked) alloys.

WROUGHT ALLOYS

Code	Alloying Element	Properties
1xxx	Pure Aluminum (99% minimum purity)	High electric and thermal conductivity, good workability and corrosion resistance, low strength. The last two digits indicate the purity (e.g., 1080 indicates aluminum with 99.80% purity).
2xxx	Copper	Heat treatable, high strength to weight ratio, low corrosion resistance.
3xxx	Manganese	Good workability, generally non heat treatable. Only up to 1.5% manganese can be effectively added to Al.
4xxx	Silicon	Lower melting point.
5xxx	Magnesium	Moderate to high strength, good corrosion resistance and weldability.
6xxx	Magnesium and Silicon	Good formability, machinability, weldability, and corrosion resistance. Heat treatable, moderate strength.
7xxx	Zinc	Moderate to very high strength (particularly when coupled with some magnesium), heat treatable.
8xxx	Other	Varied.

Note: "x" denotes a digit. The second digit in each of the above groups indicates alloy modifications. For example, 1050 indicates 99.50% pure aluminum without any control on what the .50% impurities are, and 1350 indicates the same 99.50% pure aluminum with special control on what the impurities are. For groups 2xxx through 8xxx, the last two digits serve to identify different alloys and are assigned consecutively when an alloy is first used commercially. Variations of an existing alloy are identified by a letter designation after the numerical designation starting with A.

Figure B.1: Aluminum Alloy Numerical Codes

Aluminum Beverage Can

Aluminum beverage cans consist of three parts which are fabricated separately and then assembled. As shown in Figure B.2, the three parts are referred to as the body, the end, and the tab. Each of the three parts are made from different alloys.

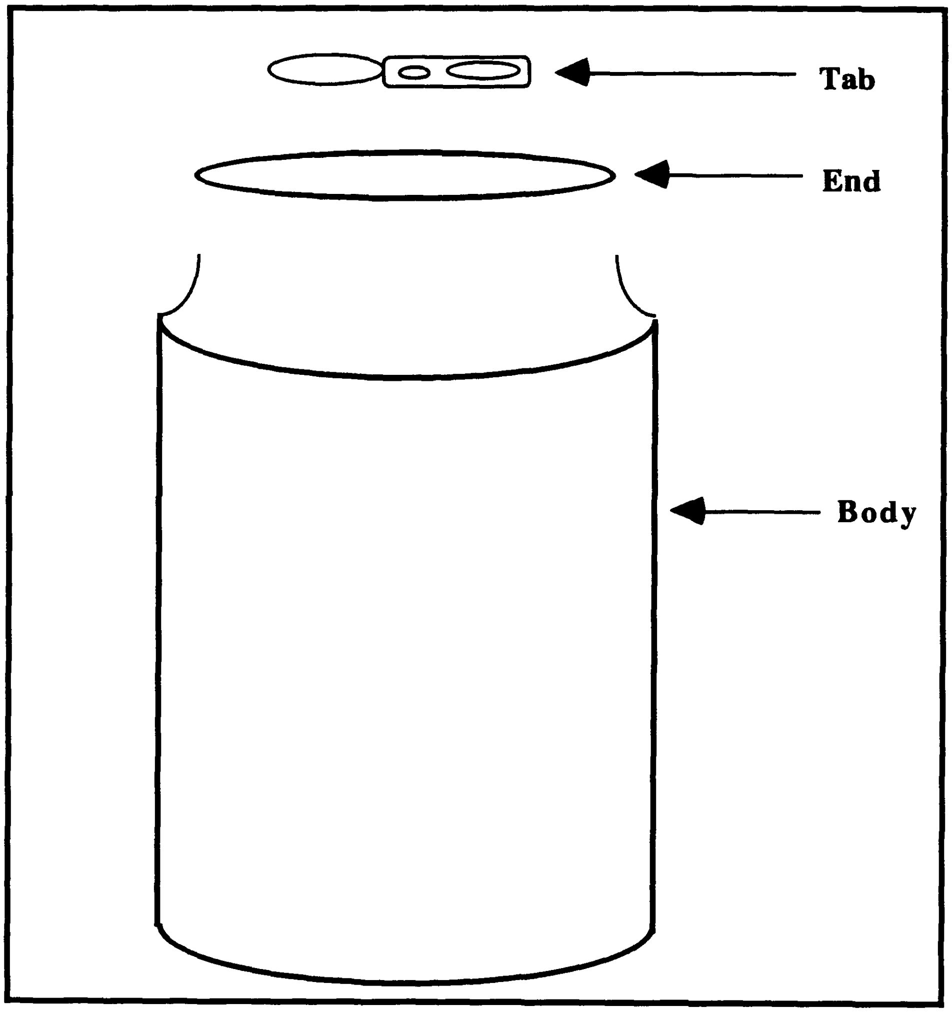

Figure B.2: Parts of an Aluminum Can

The process by which body stock is fabricated into a can body is known as "draw and iron." Draw and iron is a deformation process and requires a relatively soft alloy. As such, 3xxx alloys are used for body stock. Can ends and tabs, conversely, must be rigid enough to allow the can to be opened using the tab mechanism and to prevent the end from bursting under pressure. Therefore, 5xxx alloys are used for tab stock and end stock.

Appendix C: LPM Parameters

The following are some of the parameters used in the LPM model. Many of the parameters depend upon which of the seventeen families a product is from.

Ingot Width

```
widtha[1]:=1.060; widtha[2]:=1.680;widtha[3]:=1.650;
widtha[4]:=1.420;widtha[5]:=1.060;widtha[6]:=1.680;
widtha[7]:=1.650;widtha[8]:=1.650;widtha[9]:=1.570;
widtha[10]:=1.420;widtha[11]:=1.680;widtha[12]:=1.680;
widtha[13]:=1.680;widtha[14]:=1.420;widtha[15]:=1.570;
widtha[16]:=1.650;widtha[17]:=1.420;
```

Alloy Density

```
density[1]:=2652;density[2]:=2652;density[3]:=2652;
density[4]:=2652;density[5]:=2652;density[6]:=2652;
density[7]:=2652;density[8]:=2648;density[9]:=2648;
density[10]:=2648;density[11]:=2659;density[12]:=2659;
density[13]:=2659;density[14]:=2659;density[15]:=2718;
density[16]:=2718;density[17]:=2718;
```

Hot Mill Processing Time

```
hotcyca[1]:=21;hotcyca[2]:=23;hotcyca[3]:=23;
hotcyca[4]:=20;hotcyca[5]:=21;hotcyca[6]:=23;
hotcyca[7]:=23;hotcyca[8]:=23;hotcyca[9]:=23;
hotcyca[10]:=20;hotcyca[11]:=19.5;hotcyca[12]:=19.5;
hotcyca[13]:=19.5;hotcyca[14]:=19.5;hotcyca[15]:=21.5;
hotcyca[16]:=21.5;hotcyca[17]:=21.5;
```

Hot Mill Whole Coil Recovery

```
hot_wcra[1]:=.975;hot_wcra[2]:=.97;hot_wcra[3]:=.97;
hot_wcra[4]:=.985;hot_wcra[5]:=.975;hot_wcra[6]:=.97;
hot_wcra[7]:=.97;hot_wcra[8]:=.965;hot_wcra[9]:=.965;
hot_wcra[10]:=.965;hot_wcra[11]:=.985;hot_wcra[12]:=.985;
hot_wcra[13]:=.985;hot_wcra[14]:=.985;hot_wcra[15]:=.96;
hot_wcra[16]:=.96;hot_wcra[17]:=.96;
```

Hot Mill Length Recovery

```
hot_lra[1]:=.94;hot_lra[2]:=.945;hot_lra[3]:=.945;
hot_lra[4]:=.96;hot_lra[5]:=.945;hot_lra[6]:=.945;
hot_lra[7]:=.945;hot_lra[8]:=.94;hot_lra[9]:=.94;
hot_lra[10]:=.94;hot_lra[11]:=.95;hot_lra[12]:=.95;
hot_lra[13]:=.95;hot_lra[14]:=.96;hot_lra[15]:=.945;
hot_lra[16]:=.945;hot_lra[17]:=.945;
```

Hot Mill Width Trim

```
hottrima[1]:=.125;hottrima[2]:=.115;hottrima[3]:=.115;
hottrima[4]:=.125;hottrima[5]:=.125;hottrima[6]:=.125;
hottrima[7]:=.115;hottrima[8]:=.115;hottrima[9]:=.115;
hottrima[10]:=.125;hottrima[11]:=.145;hottrima[12]:=.145;
hottrima[13]:=.145;hottrima[14]:=.115;hottrima[15]:=.100;
hottrima[16]:=.100;hottrima[17]:=.100;
```

Cold Mill Whole Coil Recovery

```
cold_wcra[1]:=.985;cold_wcra[2]:=.985;cold_wcra[3]:=.985;
cold_wcra[4]:=.985;cold_wcra[5]:=.985;cold_wcra[6]:=.985;
cold_wcra[7]:=.985;cold_wcra[8]:=.98;cold_wcra[9]:=.98;
cold_wcra[10]:=.98;cold_wcra[11]:=.995;cold_wcra[12]:=.995;
cold_wcra[13]:=.995;cold_wcra[14]:=.995;cold_wcra[15]:=.90;
cold_wcra[16]:=.90;cold_wcra[17]:=.90;
```

Cold Mill Length Recovery

```
cold_lra[1]:=.905;cold_lra[2]:=.905;cold_lra[3]:=.905;
cold_lra[4]:=.905;cold_lra[5]:=.905;cold_lra[6]:=.905;
cold_lra[7]:=.905;cold_lra[8]:=.895;cold_lra[9]:=.895;
cold_lra[10]:=.895;cold_lra[11]:=.91;cold_lra[12]:=.91;
cold_lra[13]:=.91;cold_lra[14]:=.91;cold_lra[15]:=.88;
cold_lra[16]:=.88;cold_lra[17]:=.88;
```

Cold Mill Rolling Speed Pass 1

```
coldp1[1]:=330;coldp1[2]:=290;coldp1[3]:=290;
coldp1[4]:=285;coldp1[5]:=330;coldp1[6]:=290;
coldp1[7]:=290;coldp1[8]:=290;coldp1[9]:=290;
coldp1[10]:=285;coldp1[11]:=330;coldp1[12]:=330;
coldp1[13]:=330;coldp1[14]:=330;coldp1[15]:=330;
coldp1[16]:=330;coldp1[17]:=330;
```

Cold Mill Rolling Speed Pass 2

```
coldp2[1]:=475;coldp2[2]:=475;coldp2[3]:=475;
coldp2[4]:=465;coldp2[5]:=475;coldp2[6]:=475;
coldp2[7]:=475;coldp2[8]:=475;coldp2[9]:=475;
coldp2[10]:=465;coldp2[11]:=475;coldp2[12]:=475;
coldp2[13]:=475;coldp2[14]:=515;coldp2[15]:=450;
coldp2[16]:=450;coldp2[17]:=450;
```

Cold Mill Rolling Speed Pass 3

```
coldp3[1]:=670;coldp3[2]:=670;coldp3[3]:=670;
coldp3[4]:=660;coldp3[5]:=670;coldp3[6]:=670;
coldp3[7]:=670;coldp3[8]:=670;coldp3[9]:=670;
coldp3[10]:=660;coldp3[11]:=625;coldp3[12]:=625;
coldp3[13]:=625;coldp3[14]:=665;coldp3[15]:=100000;
coldp3[16]:=100000;coldp3[17]:=100000;
```

Coil Prep Line Whole Coil Recovery

```
prep_wcra[1]:=.995;prep_wcra[2]:=.99;prep_wcra[3]:=.99;
prep_wcra[4]:=.995;prep_wcra[5]:=.995;prep_wcra[6]:=.99;
prep_wcra[7]:=.99;prep_wcra[8]:=.99;prep_wcra[9]:=.99;
prep_wcra[10]:=.99;prep_wcra[11]:=.995;prep_wcra[12]:=.995;
prep_wcra[13]:=.995;prep_wcra[14]:=.99;
```

Coil Prep Line Length Recovery

```
prep_lra[1]:=.88;prep_lra[2]:=.95;prep_lra[3]:=.95;
prep_lra[4]:=.95;prep_lra[5]:=.88;prep_lra[6]:=.95;
prep_lra[7]:=.95;prep_lra[8]:=.95;prep_lra[9]:=.95;
prep_lra[10]:=.95;prep_lra[11]:=.95;prep_lra[12]:=.95;
prep_lra[13]:=.95;prep_lra[14]:=.90;
```

Final Width (not including slitting)

```
widthb[1]:=.87;widthb[2]:=1.52;widthb[3]:=1.48;
widthb[4]:=.95;widthb[5]:=.866;widthb[6]:=1.52;
widthb[7]:=1.49;widthb[8]:=1.478;widthb[9]:=1.405;
widthb[10]:=1.26;widthb[11]:=1.535;widthb[12]:=1.535;
widthb[13]:=1.535;widthb[14]:=1.305;
```

Preheat Furnace Cycle Time

```
if width[tag]>1500 then cycle time:=13.9*60;
if width[tag]<1400 then cycle time:=10.6*60;
if width[tag]>=1400 & width[tag]<=1500 then cycle time:=12*60;
if fam[tag]>=15 then cycle time:=33*60;
```

Scalper

Cycle Time = 12 minutes
Recovery = (466/486) if family is between 8 and 14
(460/486) otherwise

Slitter Whole Coil Recovery

= 98% if family is 1 to 14
= 99% if family is 15 to 17

Coater Mean Cycle Time

= length/200 meters/sec

Coil Prep Line Cycle Time

```
prepcycle:= 10.52+((length[tag]-884)/298);
```

Reruns

Coil Prep Line = 3%
Coater rerun = 10%
Slitter rerun = 10% if family is 15 to 17, otherwise 25%

Typical Simulated Product Mix (family, final gauge, top coating, bottom coating)

```
fam[1]:=2;gauge[1]:=0.270;coat1[1]:=0;coat2[1]:=0;
fam[2]:=2;gauge[2]:=0.270;coat1[2]:=0;coat2[2]:=0;
fam[3]:=2;gauge[3]:=0.270;coat1[3]:=0;coat2[3]:=0;
fam[4]:=2;gauge[4]:=0.270;coat1[4]:=0;coat2[4]:=0;
fam[5]:=2;gauge[5]:=0.270;coat1[5]:=0;coat2[5]:=0;
fam[6]:=2;gauge[6]:=0.270;coat1[6]:=0;coat2[6]:=0;
fam[7]:=6;gauge[7]:=0.280;coat1[7]:=100;coat2[7]:=610;
fam[8]:=6;gauge[8]:=0.280;coat1[8]:=100;coat2[8]:=610;
fam[9]:=6;gauge[9]:=0.280;coat1[9]:=100;coat2[9]:=610;
fam[10]:=6;gauge[10]:=0.280;coat1[10]:=100;coat2[10]:=610;
fam[11]:=6;gauge[11]:=0.280;coat1[11]:=100;coat2[11]:=610;
fam[12]:=6;gauge[12]:=0.280;coat1[12]:=100;coat2[12]:=610;
fam[13]:=6;gauge[13]:=0.280;coat1[13]:=100;coat2[13]:=610;
fam[14]:=6;gauge[14]:=0.280;coat1[14]:=100;coat2[14]:=610;
fam[15]:=6;gauge[15]:=0.280;coat1[15]:=100;coat2[15]:=610;
fam[16]:=6;gauge[16]:=0.280;coat1[16]:=100;coat2[16]:=610;
fam[17]:=11;gauge[17]:=0.280;coat1[17]:=0;coat2[17]:=0;
fam[18]:=11;gauge[18]:=0.280;coat1[18]:=0;coat2[18]:=0;
fam[19]:=11;gauge[19]:=0.280;coat1[19]:=0;coat2[19]:=0;
fam[20]:=11;gauge[20]:=0.280;coat1[20]:=0;coat2[20]:=0;
fam[21]:=11;gauge[21]:=0.280;coat1[21]:=0;coat2[21]:=0;
fam[22]:=11;gauge[22]:=0.280;coat1[22]:=0;coat2[22]:=0;
fam[23]:=11;gauge[23]:=0.280;coat1[23]:=0;coat2[23]:=0;
fam[24]:=11;gauge[24]:=0.280;coat1[24]:=0;coat2[24]:=0;
fam[25]:=12;gauge[25]:=0.220;coat1[25]:=144;coat2[25]:=144;
fam[26]:=12;gauge[26]:=0.220;coat1[26]:=144;coat2[26]:=144;
fam[27]:=12;gauge[27]:=0.220;coat1[27]:=144;coat2[27]:=144;
fam[28]:=12;gauge[28]:=0.220;coat1[28]:=144;coat2[28]:=144;
fam[29]:=12;gauge[29]:=0.220;coat1[29]:=144;coat2[29]:=144;
fam[30]:=12;gauge[30]:=0.220;coat1[30]:=144;coat2[30]:=144;
fam[31]:=12;gauge[31]:=0.220;coat1[31]:=144;coat2[31]:=144;
fam[32]:=12;gauge[32]:=0.220;coat1[32]:=144;coat2[32]:=144;
fam[33]:=3;gauge[33]:=0.280;coat1[33]:=100;coat2[33]:=610;
fam[34]:=3;gauge[34]:=0.280;coat1[34]:=100;coat2[34]:=610;
fam[35]:=3;gauge[35]:=0.280;coat1[35]:=100;coat2[35]:=610;
fam[36]:=3;gauge[36]:=0.280;coat1[36]:=100;coat2[36]:=610;
fam[37]:=3;gauge[37]:=0.280;coat1[37]:=100;coat2[37]:=610;
fam[38]:=3;gauge[38]:=0.280;coat1[38]:=100;coat2[38]:=610;
fam[39]:=3;gauge[39]:=0.280;coat1[39]:=100;coat2[39]:=610;
fam[40]:=3;gauge[40]:=0.280;coat1[40]:=100;coat2[40]:=610;
fam[41]:=3;gauge[41]:=0.280;coat1[41]:=100;coat2[41]:=610;
fam[42]:=3;gauge[42]:=0.280;coat1[42]:=100;coat2[42]:=610;
fam[43]:=3;gauge[43]:=0.280;coat1[43]:=100;coat2[43]:=610;
fam[44]:=3;gauge[44]:=0.280;coat1[44]:=100;coat2[44]:=610;
fam[45]:=3;gauge[45]:=0.280;coat1[45]:=100;coat2[45]:=610;
fam[46]:=3;gauge[46]:=0.280;coat1[46]:=100;coat2[46]:=610;
fam[47]:=3;gauge[47]:=0.280;coat1[47]:=100;coat2[47]:=610;
fam[48]:=3;gauge[48]:=0.280;coat1[48]:=100;coat2[48]:=610;
fam[49]:=3;gauge[49]:=0.280;coat1[49]:=100;coat2[49]:=610;
fam[50]:=3;gauge[50]:=0.280;coat1[50]:=100;coat2[50]:=610;
fam[51]:=3;gauge[51]:=0.280;coat1[51]:=100;coat2[51]:=610;
fam[52]:=3;gauge[52]:=0.280;coat1[52]:=100;coat2[52]:=610;
```

```
fam[53]:=3;gauge[53]:=0.280;coat1[53]:=100;coat2[53]:=610;
fam[54]:=3;gauge[54]:=0.280;coat1[54]:=100;coat2[54]:=610;
fam[55]:=3;gauge[55]:=0.280;coat1[55]:=100;coat2[55]:=610;
fam[56]:=3;gauge[56]:=0.280;coat1[56]:=100;coat2[56]:=610;
fam[57]:=3;gauge[57]:=0.280;coat1[57]:=100;coat2[57]:=610;
fam[58]:=3;gauge[58]:=0.280;coat1[58]:=100;coat2[58]:=610;
fam[59]:=3;gauge[59]:=0.280;coat1[59]:=100;coat2[59]:=610;
fam[60]:=3;gauge[60]:=0.280;coat1[60]:=100;coat2[60]:=610;
fam[61]:=3;gauge[61]:=0.280;coat1[61]:=100;coat2[61]:=610;
fam[62]:=3;gauge[62]:=0.280;coat1[62]:=100;coat2[62]:=610;
fam[63]:=3;gauge[63]:=0.280;coat1[63]:=100;coat2[63]:=610;
fam[64]:=3;gauge[64]:=0.280;coat1[64]:=100;coat2[64]:=610;
fam[65]:=3;gauge[65]:=0.240;coat1[65]:=146;coat2[65]:=610;
fam[66]:=3;gauge[66]:=0.240;coat1[66]:=146;coat2[66]:=610;
fam[67]:=3;gauge[67]:=0.240;coat1[67]:=146;coat2[67]:=610;
fam[68]:=3;gauge[68]:=0.240;coat1[68]:=146;coat2[68]:=610;
fam[69]:=3;gauge[69]:=0.240;coat1[69]:=146;coat2[69]:=610;
fam[70]:=3;gauge[70]:=0.240;coat1[70]:=146;coat2[70]:=610;
fam[71]:=3;gauge[71]:=0.240;coat1[71]:=146;coat2[71]:=610;
fam[72]:=3;gauge[72]:=0.240;coat1[72]:=146;coat2[72]:=610;
fam[73]:=3;gauge[73]:=0.240;coat1[73]:=146;coat2[73]:=610;
fam[74]:=3;gauge[74]:=0.240;coat1[74]:=146;coat2[74]:=610;
fam[75]:=3;gauge[75]:=0.240;coat1[75]:=146;coat2[75]:=610;
fam[76]:=3;gauge[76]:=0.240;coat1[76]:=146;coat2[76]:=610;
fam[77]:=3;gauge[77]:=0.240;coat1[77]:=146;coat2[77]:=610;
fam[78]:=3;gauge[78]:=0.240;coat1[78]:=146;coat2[78]:=610;
fam[79]:=3;gauge[79]:=0.240;coat1[79]:=146;coat2[79]:=610;
fam[80]:=3;gauge[80]:=0.240;coat1[80]:=146;coat2[80]:=610;
fam[81]:=3;gauge[81]:=0.240;coat1[81]:=146;coat2[81]:=610;
fam[82]:=3;gauge[82]:=0.240;coat1[82]:=146;coat2[82]:=610;
fam[83]:=3;gauge[83]:=0.240;coat1[83]:=146;coat2[83]:=610;
fam[84]:=3;gauge[84]:=0.240;coat1[84]:=146;coat2[84]:=610;
fam[85]:=3;gauge[85]:=0.240;coat1[85]:=146;coat2[85]:=610;
fam[86]:=3;gauge[86]:=0.240;coat1[86]:=146;coat2[86]:=610;
fam[87]:=3;gauge[87]:=0.240;coat1[87]:=146;coat2[87]:=610;
fam[88]:=3;gauge[88]:=0.240;coat1[88]:=146;coat2[88]:=610;
fam[89]:=3;gauge[89]:=0.240;coat1[89]:=146;coat2[89]:=610;
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fam[93]:=3;gauge[93]:=0.240;coat1[93]:=146;coat2[93]:=610;
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fam[96]:=3;gauge[96]:=0.240;coat1[96]:=146;coat2[96]:=610;
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fam[103]:=8;gauge[103]:=0.220;coat1[103]:=100;coat2[103]:=100;
fam[104]:=8;gauge[104]:=0.220;coat1[104]:=100;coat2[104]:=100;
fam[105]:=8;gauge[105]:=0.220;coat1[105]:=100;coat2[105]:=100;
fam[106]:=8;gauge[106]:=0.220;coat1[106]:=100;coat2[106]:=100;
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fam[107]:=8;gauge[107]:=0.220;coat1[107]:=100;coat2[107]:=100;
fam[108]:=8;gauge[108]:=0.220;coat1[108]:=100;coat2[108]:=100;
fam[109]:=8;gauge[109]:=0.220;coat1[109]:=100;coat2[109]:=100;
fam[110]:=8;gauge[110]:=0.220;coat1[110]:=100;coat2[110]:=100;
fam[111]:=8;gauge[111]:=0.220;coat1[111]:=100;coat2[111]:=100;
fam[112]:=8;gauge[112]:=0.220;coat1[112]:=100;coat2[112]:=100;
fam[113]:=8;gauge[113]:=0.260;coat1[113]:=100;coat2[113]:=100;
fam[114]:=8;gauge[114]:=0.260;coat1[114]:=100;coat2[114]:=100;
fam[115]:=8;gauge[115]:=0.260;coat1[115]:=100;coat2[115]:=100;
fam[116]:=8;gauge[116]:=0.260;coat1[116]:=100;coat2[116]:=100;
fam[117]:=8;gauge[117]:=0.260;coat1[117]:=100;coat2[117]:=100;
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fam[122]:=8;gauge[122]:=0.260;coat1[122]:=100;coat2[122]:=100;
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fam[135]:=15;gauge[135]:=0.330;coat1[135]:=0;coat2[135]:=0;
fam[136]:=15;gauge[136]:=0.330;coat1[136]:=0;coat2[136]:=0;
fam[137]:=15;gauge[137]:=0.330;coat1[137]:=0;coat2[137]:=0;
fam[138]:=15;gauge[138]:=0.330;coat1[138]:=0;coat2[138]:=0;
fam[139]:=15;gauge[139]:=0.330;coat1[139]:=0;coat2[139]:=0;
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fam[142]:=15;gauge[142]:=0.330;coat1[142]:=0;coat2[142]:=0;
fam[143]:=15;gauge[143]:=0.330;coat1[143]:=0;coat2[143]:=0;
fam[144]:=15;gauge[144]:=0.330;coat1[144]:=0;coat2[144]:=0;
fam[145]:=9;gauge[145]:=0.240;coat1[145]:=102;coat2[145]:=610;
fam[146]:=9;gauge[146]:=0.240;coat1[146]:=102;coat2[146]:=610;
fam[147]:=9;gauge[147]:=0.240;coat1[147]:=102;coat2[147]:=610;
fam[148]:=9;gauge[148]:=0.240;coat1[148]:=102;coat2[148]:=610;
fam[149]:=9;gauge[149]:=0.240;coat1[149]:=102;coat2[149]:=610;
fam[150]:=9;gauge[150]:=0.240;coat1[150]:=102;coat2[150]:=610;
fam[151]:=9;gauge[151]:=0.240;coat1[151]:=102;coat2[151]:=610;
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fam[154]:=9;gauge[154]:=0.240;coat1[154]:=102;coat2[154]:=610;
fam[155]:=9;gauge[155]:=0.240;coat1[155]:=102;coat2[155]:=610;
fam[156]:=9;gauge[156]:=0.240;coat1[156]:=102;coat2[156]:=610;
fam[157]:=9;gauge[157]:=0.240;coat1[157]:=102;coat2[157]:=610;
fam[158]:=9;gauge[158]:=0.240;coat1[158]:=102;coat2[158]:=610;
fam[159]:=9;gauge[159]:=0.240;coat1[159]:=102;coat2[159]:=610;
fam[160]:=9;gauge[160]:=0.240;coat1[160]:=102;coat2[160]:=610;
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fam[161]:=1;gauge[161]:=0.270;coat1[161]:=0;coat2[161]:=0;
fam[162]:=1;gauge[162]:=0.270;coat1[162]:=0;coat2[162]:=0;
fam[163]:=1;gauge[163]:=0.270;coat1[163]:=0;coat2[163]:=0;
fam[164]:=1;gauge[164]:=0.270;coat1[164]:=0;coat2[164]:=0;
fam[165]:=1;gauge[165]:=0.270;coat1[165]:=0;coat2[165]:=0;
fam[166]:=1;gauge[166]:=0.270;coat1[166]:=0;coat2[166]:=0;
fam[167]:=1;gauge[167]:=0.270;coat1[167]:=0;coat2[167]:=0;
fam[168]:=1;gauge[168]:=0.270;coat1[168]:=0;coat2[168]:=0;
fam[169]:=5;gauge[169]:=0.300;coat1[169]:=102;coat2[169]:=102;
fam[170]:=5;gauge[170]:=0.300;coat1[170]:=102;coat2[170]:=102;
fam[171]:=5;gauge[171]:=0.300;coat1[171]:=102;coat2[171]:=102;
fam[172]:=5;gauge[172]:=0.300;coat1[172]:=102;coat2[172]:=102;
fam[173]:=5;gauge[173]:=0.300;coat1[173]:=102;coat2[173]:=102;
fam[174]:=5;gauge[174]:=0.300;coat1[174]:=102;coat2[174]:=102;
fam[175]:=5;gauge[175]:=0.300;coat1[175]:=102;coat2[175]:=102;
fam[176]:=5;gauge[176]:=0.300;coat1[176]:=102;coat2[176]:=102;
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