19

A Constraint Based Optimization of Manufacturing and Sales in The Copper Tubing Industry

by

Jonathan M. Strimling

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Signature of Author . . . .
Department of Mechanical Engineering
Sloan School of Management

Certified by. . . . .
Thomas W. Eagar
POSCO Professor of Materials Engineering and
Head, Department of Materials Science and Engineering

Certified by. . . . .
Vien Nguyen
Robert N. Noyce Associate Professor of Management Science

Accepted by. . . . .
Ain A. Sonin
Chairman, Department Committee on Graduate Students

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Abstract

Manufacturing firms often find themselves struggling to define whether they are manufacturing or sales driven organizations. The answer, of course, is that success lies in a clear understanding of the tradeoffs inherent in sales and manufacturing decisions. What follows is a description of work carried out in the copper tubing industry for Reading Tube Corporation (RTC), in which manufacturing and sales tradeoffs are modeled.

The tools developed are:

- A Manufacturing Capacity Model
- An Activities Based Costing System
- A Market Model

An overall **Business Model** is developed as well, encompassing data from all three of the preliminary models above.

The models were used to help direct sales and manufacturing strategies, both in the short and long term. In particular, the business model was used to assess the value of additional capacity in the firm's annealing furnace. With a clear financial analysis supporting the work, a capacity ramp was implemented that resulted in a 20-25% increase in throughput at that station. The financial benefit is estimated at a minimum of $500,000 annually for less than a $75,000 one time investment.

In addition, opportunities for further work are presented. The overall business model developed in the internship is somewhat simplified, and a broader model is outlined. Because of the stochastic nature of the copper tubing markets, preliminary models are discussed which deal with the market volatility in valuing capacity additions or commercial sales contracts. Finally, it was noted that the existing incentive systems can undermine effective cooperation between the sales and manufacturing organizations, and a recommendation is made to focus on the overall business profitability rather than manufacturing variances or sales contribution.

Thesis Advisors: Thomas W. Eagar, POSCO Professor of Materials Engineering and Head, Department of Materials Science and Engineering

Vien Nguyen, Robert N. Noyce Associate Professor of Management Science

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Table Of Contents

List of Figures

List Of Tables

1 Introduction And Overview

1.1 Problem Description

Reading Tube Corporation (RTC) is a $200 million producer of copper tubing products. With approximately a 15-20% market share, RTC is a significant, but not dominant player in the domestic market, selling over 500 products into approximately 12 different market segments. The production processes used to manufacture the products range from the refining of copper all the way through the annealing and packaging of finished coils.

This thesis represents the culmination of six months of work in conjunction with RTC through MIT's Leaders For Manufacturing Internship Program. The focus and scope of this work was developed in the six months preceding the internship period through a series of monthly visits to the facility and through discussions with *all* of Reading Tube's functional organizations. In order to operate the business most profitably, top management desired:

- An improved understanding of product costs
- An analysis of business profitability by market segment
- An analysis of the value of capacity expansion at various processing stations
- Implementation of the process changes on the plant floor which would most directly impact profitability.

In particular, one key operational decision being considered regarded the plant's annealing furnace. The question was whether a new atmosphere for the plant's annealing furnace would increase throughput sufficiently to offset its $30,000 added monthly cost. However, it was immediately apparent that the answer to that question was critically dependent upon what market segments the additional capacity would target, and what would be the profitability of those segments. Hence, before resolving the question of the value of the additional capacity, it was first necessary to develop a thorough understanding of both internal costs and external market opportunities.

1.2 Company Overview

Overview of RTC's Customers and Markets

Reading Tube is one of the top four domestic producers of copper tubing products, with annual sales on the order of $200 million, or approximately 100 million tons of copper products. Roughly speaking, Reading Tube Corporation's customers could be classified as belonging to one of the following two groups.

- Tubing Wholesalers
- Commercial Customers

The behavior of price and demand in these two distinct markets can be markedly different, as described below. In addition, there is a certain amount of cross-supplying among the copper tubing manufacturers, so that particular items can either be outsourced or supplied to competing vendors. There are also large distributors in some regions that then, in turn, supply the tubing wholesalers of those areas.

Tubing Wholesalers

Major Products and Purchasing Patterns

Tubing wholesalers buy a broad variety of products, and they, in turn, supply the products to the marketplace. Wholesaler orders are typically truckload quantities to minimize freight charges, and there may be anywhere from 10 to 40 different products on a truck in various volumes. Some items, such as the "major straights", are tube sizes that sell in great quantity to nearly all wholesalers and distributors, with six of these tube sizes comprising about 45% of total sales from approximately 500 available tube sizes. On the other hand, it is imperative that RTC is able to supply all available products in a timely manner since customers want to bring in all of their product requirements on a single truckload.

Commercial Markets

Major Products and Purchasing Patterns

Reading Tube Corporation engages in contracts with other manufacturers which it refers to as "commercial sales." In such contracts, typically a small number of products, on the order of one to five, will be supplied in regular shipments over the course of the contract, which is usually about a year. These manufacturers will either use the tubing in the assembly or installation of heating or cooling systems, or continue to draw and process the tubing to their desired form.

As part of the ongoing nationwide initiative on the part of many firms to reduce the number of suppliers with whom they work[1], RTC may be the only supplier of copper tubing or one of a small number of suppliers qualified to supply a given commercial customer. Because delays in shipments or quality problems can prevent these vendors from shipping complete assemblies, RTC's ability to sell in these markets in the long term is controlled by its reputation for meeting such commitments.

Producer-To-Producer Market

Opportunities to buy & sell between tubing manufacturers

It is not uncommon for competing producers to supply each other with particular items over various periods of time. For example, certain suppliers do not have the equipment to manufacture particularly large diameter tubing, and may purchase the tubing from another vendor with excess capacity. In other instances, a supplier may have a breakdown on a particular piece of machinery and need a short term supply of particular products. Such purchases are naturally priced slightly below market price levels, but above production costs, so that both the purchasing and selling firm see some benefit from the transactions.

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[1] In "Made in America", Dertouzos, Lester and Solow document the emerging trend across a variety of industries towards closer collaboration with decreasing numbers of suppliers both in this country and abroad.

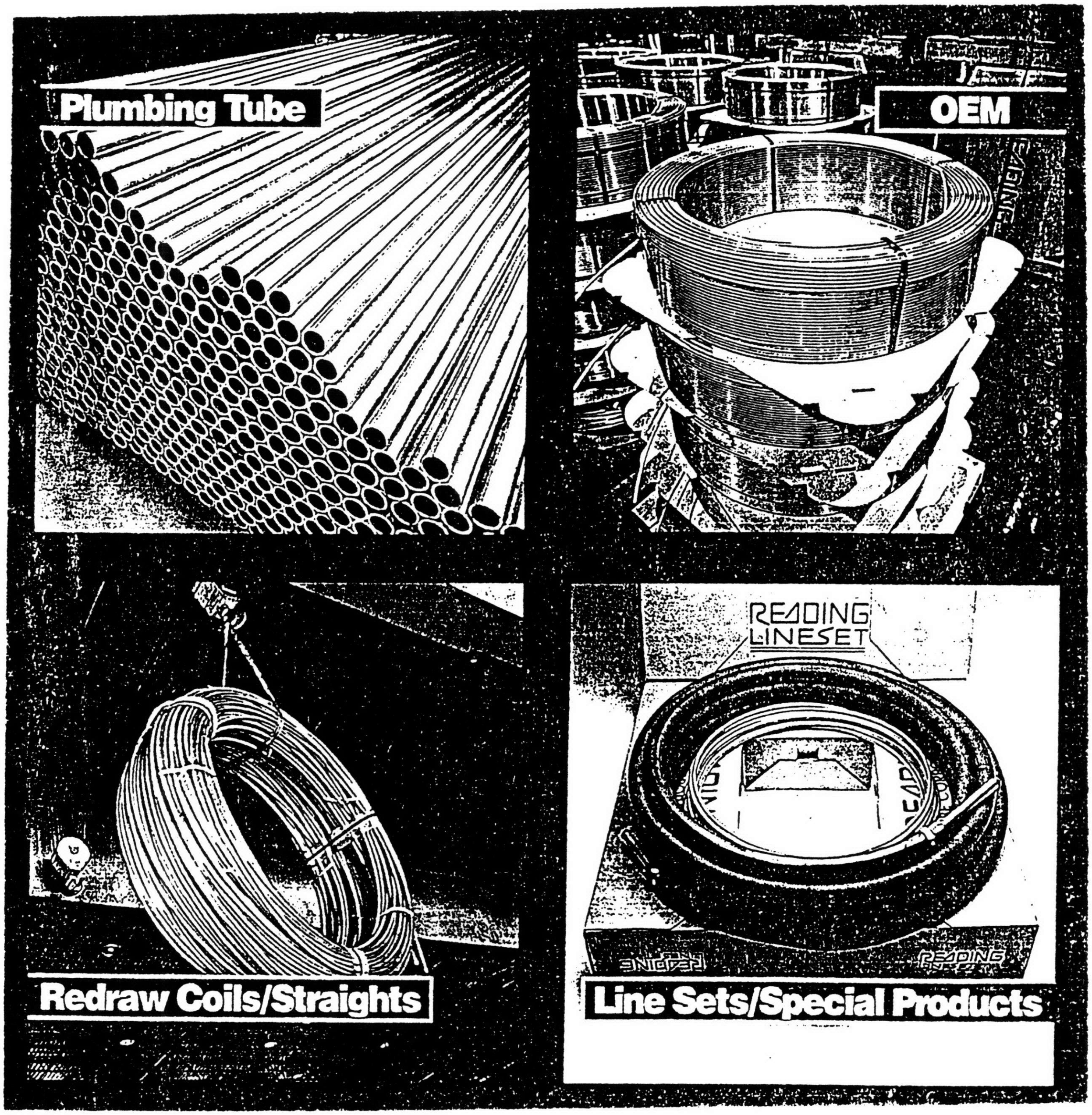
Overview of RTC's Products & Production Processes

Products

Overview

Reading Tube Corporation produces approximately 500 copper products for a variety of uses. Its principal products are tubes for water, air conditioning and heating lines that are sold to tubing wholesalers, but RTC also supplies a variety of commercial products to other manufacturers. RTC's main commercial products are copper slabs supplied to rolling mills and a variety of tubing products. Commercial customers may assemble the tubing into products such as air conditioners, or they may continue to draw the tubing to smaller dimensions.

Figure 1-1 Types of Products



Shown in Figure 1-1 are several of RTC's products, including plumbing tubing, (top left), which comes in a variety of straight and coiled dimensions. The commercial products shown are level wound coils (top right) and redraw coils (bottom left.) These commercial products may be drawn to smaller dimensions by other manufacturers or cut and assembled into heating or cooling appliances. The line sets shown (bottom right) are supplied to installers of heat pump systems.

Production Processes

Overview

Product manufacture is composed of the following steps:

1. Casting
2. Extrusion
3. Drawing
4. Finishing
5. Annealing

While some products may go through all of these processes, others may follow only part of the sequence. For example, cast slabs only go through process 1, whereas annealed coils will go through processes 1-5.

Casting

All production begins in the refinery, where #1 grade copper scrap is melted and refined. Purchased copper scrap and recovered scrap are refined as necessary to produce the required chemical purity (better than 99.9%.) The melt is then cast into logs of copper that are subsequently cut to supply billets to the tubing fabrication plants.

Extrusion

Incoming billets from the refinery are stored in a billet inventory and then heated to extrusion temperature in one of RTC's two billet furnaces. Then the heated billets are pierced with a mandrel and extruded to form the required starting tube geometry.

Drawing

The extruded product is then drawn through a succession of dies to achieve the desired final dimensions. Depending on the dimensions of the product, it may be drawn either in straight length or coiled form. The plant's drawing equipment consists of:

- *Drop Blocks:* Used for the first and heaviest drawing passes of coils.
- *Spinners:* Used for subsequent lighter drawing passes of coils.
- *Draw Bench:* Used for the drawing of large diameter straight lengths.

Finishing & Inspection

The drawn tubes are "finished" by precisely sizing the outside diameter, cutting to length, and by straightening or coiling the tube. A variety of finishing machines are used, depending upon the incoming and outgoing tubing form, and there is a moderate amount of flexibility between machines so that the same product may be finished on any of several pieces of equipment. Ultrasonic inspection for defects in 100% of the tubing is performed during the finishing process, and any defective tubing is immediately scrapped.

Annealing

The final stage of processing, primarily for coiled products, is to anneal the tubing to a soft temper according to American Standards for Testing Materials (ASTM) specifications. The products are fed into one of RTC's annealing furnaces, and then packaged for shipment.

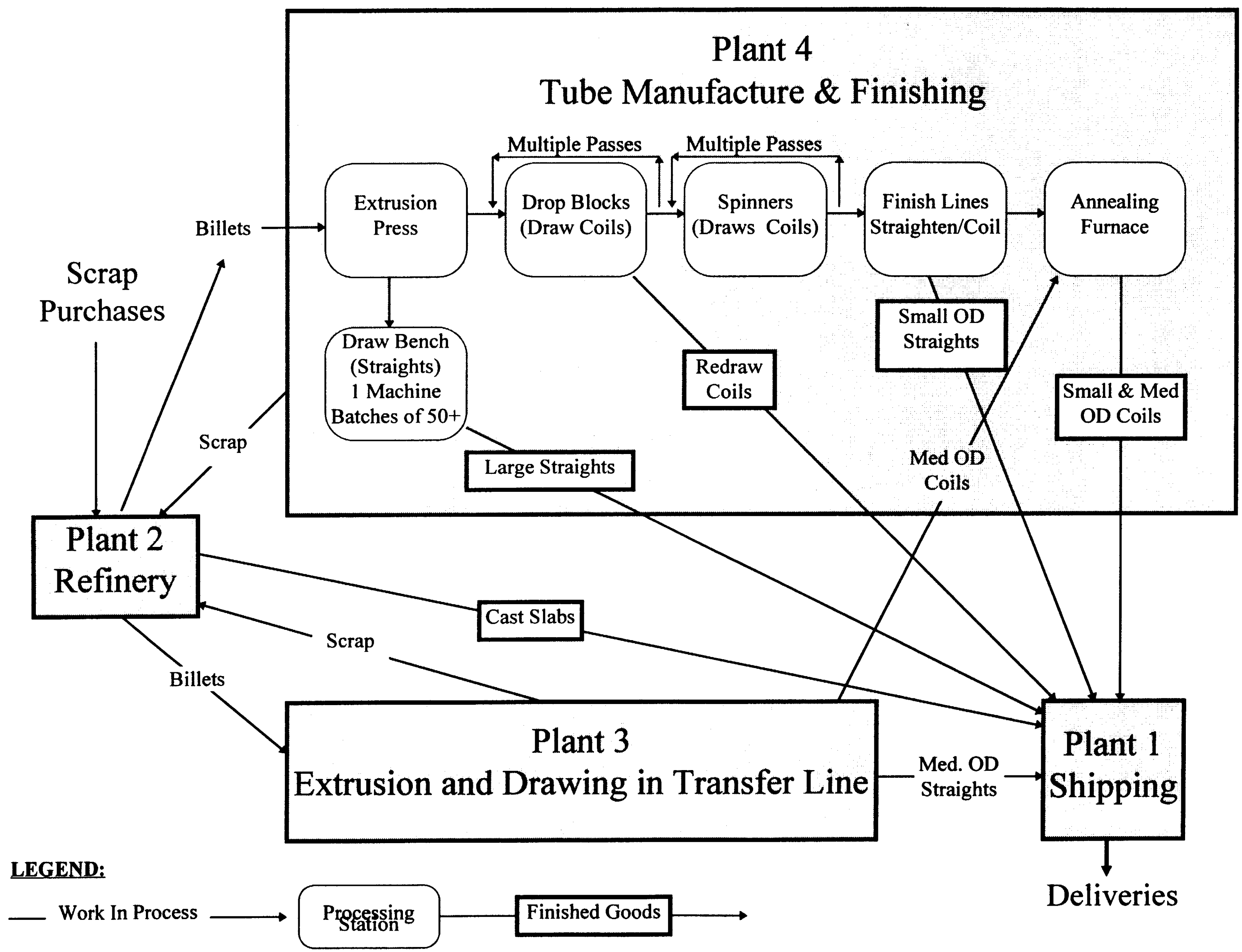
Product Routings & Equipment Utilization

As previously mentioned, not all products may go through every stage of processing. Products can be roughly broken down into the following product groups:

- Cast Slabs
- Large Diameter Straight Tubing
- Large Diameter Coils
- Medium Diameter Straights
- Medium Diameter Coils
- Small Diameter Straights
- Small Diameter Coils
- Redraw
- Laywind Coils

Shown below is a rough schematic of the production paths of the major product groups:

Figure 1-2 Production Paths of Various Product Groups



As can been seen in Figure 1-2, there are a wide variety of processing requirements for the various product types. While small and medium coils go through casting, extrusion, two drawing stations, finishing lines and annealing, cast slabs will go directly from the refinery to shipping. Redraw coils are extruded and drawn, but do not pass through any of the finishing operations. *Changes in the levels of sales of particular product groups will therefore strongly influence utilization of various processing stations.*

Plants

Various products may be routed through different facilities, as was also illustrated in Figure 1-2. All casting is performed at Plant 2, the refinery. Tube forming for medium diameter tubing is accomplished in Plant 3, while all other production, including annealing of all coils is completed in Plant 4. Plant 1 is used as a shipping warehouse and distribution facility. RTC also maintains a line set[2] assembly plant in Hannibal, Missouri.

1.3 Summary of Results

Models Developed

The focus of all analysis performed at Reading Tube Corporation(RTC) was on fairly simple models that would have direct impact on operations. The work can be broken down into the following components:

- A Capacity Analysis
- An Activities Based Costing (ABC) System
- A Market Analysis

These separate analyses were then combined into an ***overall business model*** that was used for the following purposes:

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[2] Line sets are assembled and insulated pair of tubes used for heat pump field installations.

- To Optimize Sales Strategies Under Varying Market Conditions
- To Evaluate Additions of Capacity

Impact on Sales

One of the great benefits of the ABC costing model is that it clarified long-standing disputes between senior management of the sales and manufacturing organizations. With detailed data on a product and process level, and with clearly stated and agreed upon assumptions, a comprehensive picture of production costs is now available to management. Furthermore, the system is not static, but can be updated periodically through an Oracle database system which includes such cost drivers as labor pay rates.

While it is not appropriate to comment here in any specific way, the market model has resulted in changes to both short term and long term market strategies at the firm. Perhaps as important as the changes in strategy themselves was the impact of the models in terms of building consensus in support of the plans. This first pass at an activities based costing system demonstrated its own value in terms of assisting with decision making, and will also be helpful in building support for a second pass, or more refined costing system.

Impact on Operations

The models impact operations in two ways, through scheduling and project priorities. Quantifying the value of additional capacity under particular market conditions permits investment costs to be weighed against potential additional revenues. In addition, where several production improvement projects are underway concurrently, the model gives financial measurements that can be used to prioritize the efforts.

For example, in one constrained area of the plant, the annealing furnace, the model predicted that a proposed capacity expansion project would have a payback of less than one month. That project was immediately give top priority and the appropriate level of resources were immediately allocated. The project, which had been moving slowly for nearly two years was suddenly accelerated and completed in two months, resulting in a

20-25% increase in throughput. The upward trend in tons of annealing output achieved per shift during the internship[3] is shown in the attached normalized plot (Figure 1-3).

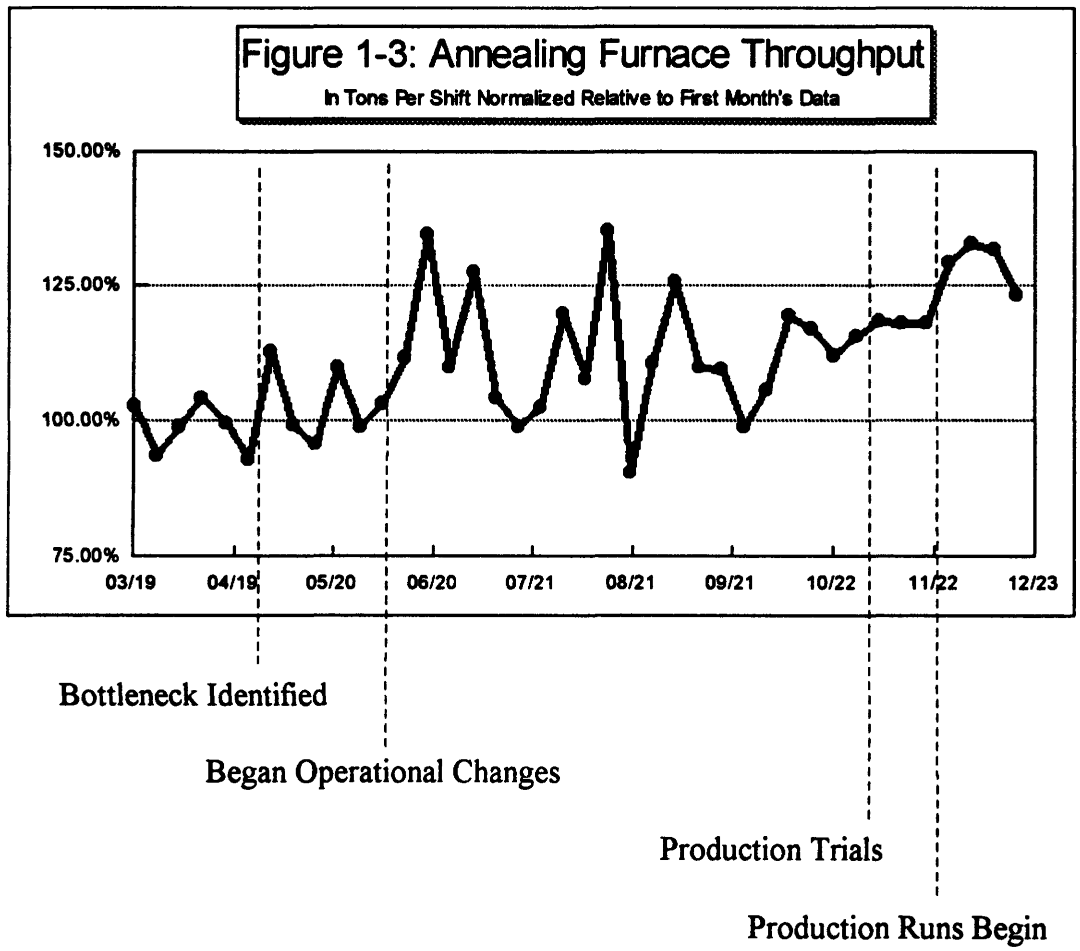

Figure 1-3: Annealing Furnace Throughput
In Tons Per Shift Normalized Relative to First Month's Data

The upward trend results from both operational and physical changes to the annealing operations, as will be discussed in Chapter 6.2. While operational changes such as running a relief schedule to eliminate breaks could be implemented immediately, other

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[3] It should be noted that the preliminary identification of the bottleneck occurred in April, before the beginning of the on-site internship. This was possible due to analytical work based on seven full day visits to the site during the six months preceding the internship period as part of an independent study project during the spring semester of 1995.

modifications, such as changes to the physical loading configuration of the furnace required longer periods of preparation.

Financial Impact

The 20-25% improvement in annealing throughput shown in Figure 1-3 actually understates the business value of the gains, since the markets targeted with the additional capacity at the furnace were of higher than average return. The financial impact on net income as sales fills the added capacity is estimated at $0.5 million to $2 million annually, depending on market conditions, for less than a $75,000 one-time investment.

The alternative for increasing annealing capacity would have been to purchase another annealing furnace. However, this would have cost at least $1 million and would have required a significant expansion of the plant's footprint as well. The throughput increases at the existing annealing furnace allowed production to meet sales expectations in the short term without the substantially larger investment that might otherwise have been required. It remains to be seen whether the added capacity will be sufficient to meet growing demand, or whether, at some later date, a new furnace will be required as well.

1.4 Overviews of Following Chapters

Chapter 2: The Capacity Model

The capacity model is designed to translate production schedules into the utilization levels of each piece of equipment. The sales plan, defined in terms of product volumes, can thereby be directly tied to the mills' operating plans, defined in terms of shifts of work at particular processing stations. Individual product yields are accounted for in a consistent manner throughout the model.

Chapter 3: The ABC Costing System

An Activities Based Costing (ABC) system is used to estimate fixed and variable costs associated with production of individual products. The model is based on the production data gathered in the capacity model and historical financial data. Line items from financial statements are linked to manufacturing processes by several "cost drivers." Cost drivers in this analysis used include:

- Per Finished Pound
- Per Billet Pound
- Per Hour
- Per Item

For example, shipping costs are dependent on finished product weight, and would therefore fall under the "per finished pound" cost driver. Casting utility costs are dependent both on yields and the weight of product shipped and are therefore driven on a "billet pound" basis[4]. Processing stations with known throughputs such as drawing processes are best modeled using production rates from the capacity model and costs on a "per hour" basis. Packaging costs, of course, are driven by the number of units, or on a "per item" basis.

Critical to any cost analysis is the distinction between fixed and variable costs. Regressions of historical data were performed to approximate the fixed and variable components of any line item. For example, it was observed that maintenance labor tended follow production volumes less directly than direct labor at particular processing stations. The model therefore accounts for this by assigning a higher percentage of maintenance costs to fixed costs, and a lower percentage of direct labor costs to fixed costs.

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[4] The weight of castings transferred from the refinery to the tubing mills is measured in "billet pounds," or the weight of copper in a form ready for extrusion.

Chapter 4: The Market Model

In the copper tubing industry, tubing wholesalers rarely buy individual products, but instead purchase truckload quantities of "mixes" of products which they, in turn, supply to their customers. Particular groups of customers, for example, distributors in the Southwest, may have particular buying patterns based on the types of home construction in their areas. Reading Tube cannot choose what products to sell to individual customers, but the corporation is free to decide which market segments it will target for growth.

The market model identifies and quantifies Reading Tube's marketing options. The "mixes" of products sold to particular market segments are quantified, and the pricing structure of each market segment is included separately. Finally, because of the commodity nature of the market and the concern with flooding particular segments, market share limitations on sales volumes are introduced.

Chapter 5: The Business Model

For any given market condition, the business model calculates an "optimum" distribution of sales to each market segment. The model's input streams for each of ten market segments considered are:

- Pricing Levels
- Volume Limitations
- Variable Production Costs

The business model then unifies the preceding analyses, maximizing net income subject to the market and production constraints, and using variable cost data from the ABC cost analysis.

The two key applications of the business model are:

- Identifying optimal product mixes under varying market conditions
- Quantifying the value of additional capacity at individual manufacturing processes.

Chapter 6: Impact of The Business Model

The business model was critical in:

- Identifying market segments for growth
- Quantifying the value of additional capacity at the annealing furnace

The model helped build management support for both the financial and manpower investment required to increase the annealing furnace capacity. In the final analysis, although the additional throughput would have warranted installation the new atmospheric system, other alternatives were implemented to achieve the same throughput at significantly lower cost (less than a $75,000 one time investment as compared with the $30,000 monthly added cost of the new atmosphere being considered.) The improvements to the furnace included both new loading configurations and operational changes such as running relief to reduce downtime due to lunch breaks.

Chapter 7: Areas For Further Development

While the business model developed in Chapter 5 was a major step towards clarifying the tradeoffs inherent in sales and production planning, it is not an all encompassing solution. Weaknesses of the model include:

1. RTC has the option to purchase or sell particular items to or from competing producers. The model as currently developed does not reflect these possibilities.
2. The business model assumes a single production process is used for each production item. However, in reality, there can be several different routes by which a given item can be manufactured. A comprehensive sales and operations model would simultaneously solve for the optimal sales mix and production process selection.
3. The business model is an analysis of a particular market condition at a given point in time. Because commercial contracts represent commitments of capacity of a year or more, a model that accounts for the historical variability in the market is desired.

The analytical framework needed to include the above considerations in the business model is developed in Chapter 7. In addition, the current incentive systems are examined and recommendations are made with respect to linking incentives more directly to overall corporate profitability.

2 The Capacity Model

2.1 Goals

The intent of the capacity model is to provide a clearer understanding of the manufacturing capabilities at each stage of the manufacturing process. In other words, given a sales forecast of production volumes, the capacity model will:

1. Calculate the required time on each piece of processing equipment for each product and in total.
2. Compare with the available time on that piece of equipment.

The capacity model is also the crucial foundation for the costing and business models developed below.

2.2 Model Overview

Production Possibilities

A given product may be manufactured in a number of ways. Various pieces of equipment can be used in the drawing and finishing processes, with typically one or two routings being most common for a particular product. An example of production routings is shown below:

Table 2-1 Production Rate and Capacity Model

Table 2-1-A Product Processing Rates

		Processing Hours Per Ton Of Finished Product						
Product	Routing	Casting	Extrusion	Draw Station 1	Draw Station 2	Finishing Station 1	Finishing Station 2	Anneal
Product 1	1	0.1	0.2	0	0.3	0.05	0	0
Product 2	1	0.1	0.2	0.4	0	0.03	0	0.2
Product 2	2	0.1	0.2	0	0.4	0.03	0	0.2
Product 3	1	0.1	0.2	0.4	0	0	0.04	0
Product 4	1	0.1	0.2	0.3	0	0.02	0	0.2
Product 4	2	0.1	0.2	0	0.2	0	0.03	0.2

Table 2-1-B Production Plan and Capacity Requirements

			Hours Of Processing Required						
Product	Process Number	Tons By This Routing	Casting	Extrusion	Draw Station 1	Draw Station 2	Finishing Station 1	Finishing Station 2	Anneal
Product 1	1	220	22.0	44.0	0.0	66.0	11.0	0.0	0.0
Product 2	1	50	5.0	10.0	20.0	0.0	1.5	0.0	10.0
Product 2	2	50	5.0	10.0	0.0	20.0	1.5	0.0	10.0
Product 3	1	100	10.0	20.0	40.0	0.0	0.0	4.0	0.0
Product 4	1	50	5.0	10.0	15.0	0.0	1.0	0.0	10.0
Product 4	2	150	15.0	30.0	0.0	30.0	0.0	4.5	30.0
Total Hours Required			**62.0**	**124.0**	**75.0**	**116.0**	**15.0**	**8.5**	**60.0**

At Draw Station 2, requirements exceed available capacity.

Table 2-1-B Equipment Availability

	Casting	Extrusion	Draw Station 1	Draw Station 2	Finishing Station 1	Finishing Station 2	Anneal
Number of Shifts Available	15	15	15	15	10	10	15.0
Number of Hours Per Shift	8	8	8	8	10	10	8.0
Number of Machines	1	2	1	1	1	1	1.0
Percent Downtime	5%	15%	10%	20%	5%	5%	10%
Total Available Hours	**114.0**	**204.0**	**108.0**	**96.0**	**95.0**	**95.0**	**108.0**

As can be seen in Table 2-1-A, For each product , there may be multiple processes with different throughput rates. For Product 1, there is only one possible routing, consisting of casting, extrusion, drawing at Draw Station 2 and finishing at Finishing Station 1. Product 2, however, can be produced by either of two methods, one utilizing Draw Station 1 and the other using Draw Station 2. One possible, but not necessarily optimal, production plan is shown in the shaded boxes of Table 2-1-B.

By entering a production plan into the shaded boxes[5], management can estimate the total hours that will be consumed by each process at each station (Table 2-1-B). Finally the "Total Hours Required" by the production plan can be compared to the "Total Available Hours" based on the current shift and equipment schedules (Table 2-1-C).

In a case such as Draw Station 2, where requirements for processing at Draw Station 2 exceed capacity, alternatives such as shifting Product 2 to Draw Station 1 or adding a shift at Draw Station 2 could be considered. However, the critical elements of cost and market conditions are missing from this model, and these will be developed in subsequent Chapters.

2.3 Details of The Model

Plant 2 - Casting

Since nearly all products undergo the same refining process, casting capacity is simply the maximum sustainable weekly output of the refinery.[6] Capacity consumed by production of a particular product is calculated as:

Capacity Consumption = 1/ (Casting Rate x Yield For That Product)

where the capacity consumption is in hours per finished ton, the casting rate is in tons per hour and the yield used is fraction of finished product produced from cast log.

Since the casting rate for all products is essentially the same, the yield from billet therefore becomes a critical driver in both capacity consumption and cost of casting. This same yield effect will hold true for nearly all processing stations.

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[5] Shading in subsequent tables will always indicate a decision variable.

[6] Although certain commercial customers specify chemistries that may require longer or shorter casting cycles, the approximation of one rate for all was not a significant source of error in the overall model. Deviations from the standard casting plan are typically less than 2 days a month, and the deviations rarely cause the casting plant to slip out of its 24 hour casting cycle.

Plant 3 - Proprietary Tube Mill

Plant 3's tube manufacturing processes are reasonably modeled as a single transfer line. The source of information for this plant is historical production for each product, as is illustrated in Table 2-2.

Table 2-2 - Plant 3 Production Estimates

	Processing Hours Per Ton Started	Average Yield	Processing Hours Per Finished Ton
Product 1	0.63	80%	0.78
Product 2	0.48	83%	0.58
Product 3	0.35	86%	0.41
Product 4	0.28	87%	0.32
Product 5	0.38	79%	0.48
Product 6	0.44	91%	0.48
Product 7	0.38	79%	0.48
Product 8	0.24	83%	0.29
Product 9	0.70	86%	0.81
Product 10	0.90	78%	1.15

Plant 4 - Tube Extrusion, Drawing, Finishing and Annealing

Yield From Billet

Yield from billet is a critical factor driving both the throughput and the cost of every product. Portions of a billet may be scrapped at any of several stages of tube formation including both normal process losses and defect driven losses.

Terminology: Yield From Cast Log vs. Yield From Billet

There are two yields commonly cited in the context of tube manufacturing:

Yield From Cast Log = (Weight of Good Product Shipped)/(Weight of Cast Logs)

Yield From Billet = (Weight of Good Product Shipped)/(Weight of Billets)

The difference between the two arises from the fact that the as cast logs are cut into billets, there is always scrap left at either end, so that

Weight of Cast Log = Weight of Billets + Scrap Losses

Therefore, yield from cast log will always be lower than yield from billet on any given product.

Normal Process Losses Include:

- the butt, head and tail of extrusions[7];
- the points of the coils that are cut off after each successive stage of drawing;
- tube ends that are lost when cutting tubes to finished length.

Defect Driven Losses Occur:

- at inspection of coils following extrusion, where surface quality or tube eccentricity may be found unacceptable;
- during the drawing process, when portions of coils may be scrapped due to coil breakage;
- during ultrasonic inspection at the finishing lines where oxide or metallic inclusions may be identified;
- at visual inspection for blistering or scale following annealing..

Accounting For Yield In The Capacity Model

Yield is a critical driving factor in the capacity model. Extrusion and drawing processes work with one coil at a time, so that the processing rate can be expressed in terms of coils processed per hour. However, yields will impact the volume of finished material from any given coil. The production rate in terms of finished goods is shown below:

Production Rate of Finished Product = (Processing Rate) * (Yield From Billet)

---

[7] The butt is the portion of the billet remaining in the extrusion press at the completion of the ram stroke, the head and tail of the extruded length are solid seals at either end of the extrusion that must be removed before drawing.

where the "Production Rate of Finished Product" is in pounds per hour, the "Processing Rate" is in pounds processed per hour, and the "Yield From Billet" is the product specific yield.

Although material may be scrapped during any of the drawing or finishing processes, it is actually not critical to know where in the process the material is scrapped, just that it did not make it to the customer. It will take the roughly the same time to draw, cut or coil a product regardless of the number of defects. In other words, knowing production rate and yield from billet is sufficient to calculate the consumption of capacity at each stage of the tube formation process.[8]

Extrusion

There is only one billet geometry used in Plant 4's extrusion process, and the billet is extruded into only a small number (<10) distinct geometries. Historical production data was available for each of these extrusion products. The use of this data is illustrated in Table 2-3, below:

[8] In "A Constraint-Based Revenue-Maximizing Line Yield Strategy For Wafer Fabs," Viju Mennen of Intel Corp. points out that yield losses in processes downstream of the bottleneck process can have significantly greater impact on throughput than those upstream of bottleneck processes. However, in the case of coil processing, whatever portion of the coil that is not scrapped will pass through all subsequent operations and consume approximately the same level of resources. While some effort was made to identify and screen coils prior to passage through bottleneck processes, the approximation of finished goods production rate as a function of processing rate per billet and yield from billet is fairly accurate, and is analogous to the use of die yield in the semiconductor industry.

Table 2-3 - Extrusion Model

Table 2-3-A Extrusion Rates By Extrusion Form

	Extrusion Rate
Extruded Form A	15 tons/hr
Extruded Form B	14 tons/hr
Extruded Form C	17 tons/hr
Extruded Form D	20 tons/hr
Extruded Form E	10 tons/hr

Table 2-3-B Extrusion Capacity Consumption By Product

	Extruded Form	Extrusion Hours Per Billet Ton	Yield	Extrusion Hours Per Finish Ton
Product 1	A	0.067 hrs/ton	85%	0.078 hrs/ton
Product 2	B	0.071 hrs/ton	90%	0.079 hrs/ton
Product 3	A	0.067 hrs/ton	78%	0.085 hrs/ton
Product 4	A	0.067 hrs/ton	86%	0.078 hrs/ton
Product 5	C	0.059 hrs/ton	94%	0.063 hrs/ton
Product 6	A	0.067 hrs/ton	73%	0.091 hrs/ton
Product 7	A	0.067 hrs/ton	82%	0.081 hrs/ton

As shown in Table 2-3, each extruded form has a different production rate though the press. But the extrusion capacity consumed by each product depends not only on that product's extruded form, but also on the yield from billet of that product. The rightmost column "Extrusion Hours per Finished Ton" reflects the influence of both of these parameters, according to the following calculation:

Extrusion Hours Per Finished Ton = Extrusion Hours Per Billet Ton / Product Yield

Similar yield-adjusted production rates are used throughout all equipment models below.

Drawing

Drop Blocks and Spinners

While historical production rates were readily available for the small number of products produced by the drop blocks (less than 10), it was not possible to gather such information for the multitude of spinner products (over 100). Accordingly, two methods of estimation were considered. First, a numerical model based on indexing rates and run rates for the various products was developed. Then estimates were solicited from experienced drawing foremen. The results of the two methods were close enough that the deviation between the two was not considered to be significant to the overall model.[9]

In the end, the foremen's estimates were included because some of the complexities of production could not be captured by the theoretical model. For example, the tendency of particular products to break frequently during drawing could not be incorporated easily in the theoretical model. In the near future, actual historical production rates will be drawn from a plant production performance database currently being developed by RTC.

Draw Benches

Because this area of the plant was used relatively infrequently, the area's foremen were less confident of their understanding of run rates. A simple analytical model was developed that accounted for setup and run times on a per product basis. Because material handling in this area of the plant is a particular concern, the model also included the estimated material transport delays. The results of the model agreed well with the foremen's estimates of the more common products through the area, but were general enough to encompass all products passing through that processing stage. Factors included in the draw bench model are:

- setup and run times for pointing, drawing, straightening and cutting operation;
- number of pieces per billet and per drawn shell for each product;
- number of pieces per lift bundle, and average material delay on material movement;
- average downtime and crane availability delays.

---

[9] On an individual product through an individual process, the discrepancy between the two models could be as much as 10%. However, when product groups were aggregated by sales "mixes", so that many products were included in the production plan being considered, discrepancies on individual products tended to be offset. The theoretical model was actually tuned to match production historical data for the overall sales mix.

Finish Lines

Again, both theoretical and foremen's estimates were considered as sources of production rates, with foremen's estimates being included in the final model.

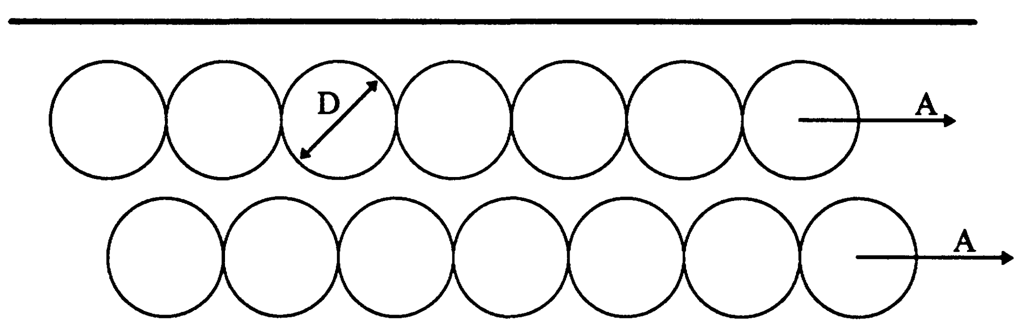
Annealing Furnace & Packing

Because of the strict controls required to produce the desired grain size in annealed products, the quality department had already specified run rates for each of the furnace products.

Example 2-1

Product X is loaded into the annealing furnace at A inches per minute. in two columns of D inch coils placed adjacent to one another, illustrated below:

Figure 2-1 Annealing Furnace Loading Configuration



The theoretical throughput[10] is:

Theoretical Throughput = (A in/min.)*(B columns)*(C lb./coil) / (D in/coil)

[10] Credit for the bulk of the annealing furnace theoretical model should go to RTC's quality and production departments, who had previously developed the model. Their work made possible the integration of the furnace data into an overall capacity model; otherwise, with the complexity of the possible loading schemes, development of the overall model in the short internship time frame would have been prohibitively complex.

where the theoretical throughput is given in pounds per minute, A is the travel rate through the furnace, B is the number of columns (2 above), and C and D are the coil weight and diameter, respectively.

However, because of set-ups and loading inefficiencies, actual output was on the order of 10-20% below theoretical. Comparing production histories to theoretical run rates for the same products yielded an average production efficiency that was then applied across the board to all theoretical rates as a basis for modeling actual production rates. The estimated actual throughput is:

Actual Throughput = (Efficiency) * (Theoretical Throughput)

Yields At The Annealing Furnace

Although yield was a critical factor in all other production processes, yields were close enough to 100% to be approximated as perfect because the great majority of defective coils were identified and scrapped upstream of the furnace.

3 The ABC Costing System[11]

3.1 Motivation

The concerns raised by management with respect to the existing cost system included:

- A lack of detailed routing data on particular products
- Unclear associations between overhead allocations and production processes
- Unclear differentiation between fixed and variable components of costs.

In addition, management desired to have a "viable," or living, cost system tied directly to labor and production rates rather than the existing static cost system which was only an estimate of costs at a single point in time.

Based on the above concerns, an Activities Based Costing system was developed. The costing data is based on the preceding capacity study which developed detailed product routing data. Overhead is allocated based on several cost drivers, described below. Costs were determined to be fixed or variable based on historical plant production and payroll data. Finally, the system was implemented in a standard database format with a Microsoft Access front end and the power of an Oracle database behind it, linking the data to production and payroll data for periodic update.

[11] Excluded from this section's analysis are opportunity costs that may arise from constrained resources. These will be developed and discussed in Chapter 5.

3.2 Cost Drivers

An Activities Based Costing (ABC) system is used to estimate fixed and variable costs associated with production of individual products. Cost drivers used include:

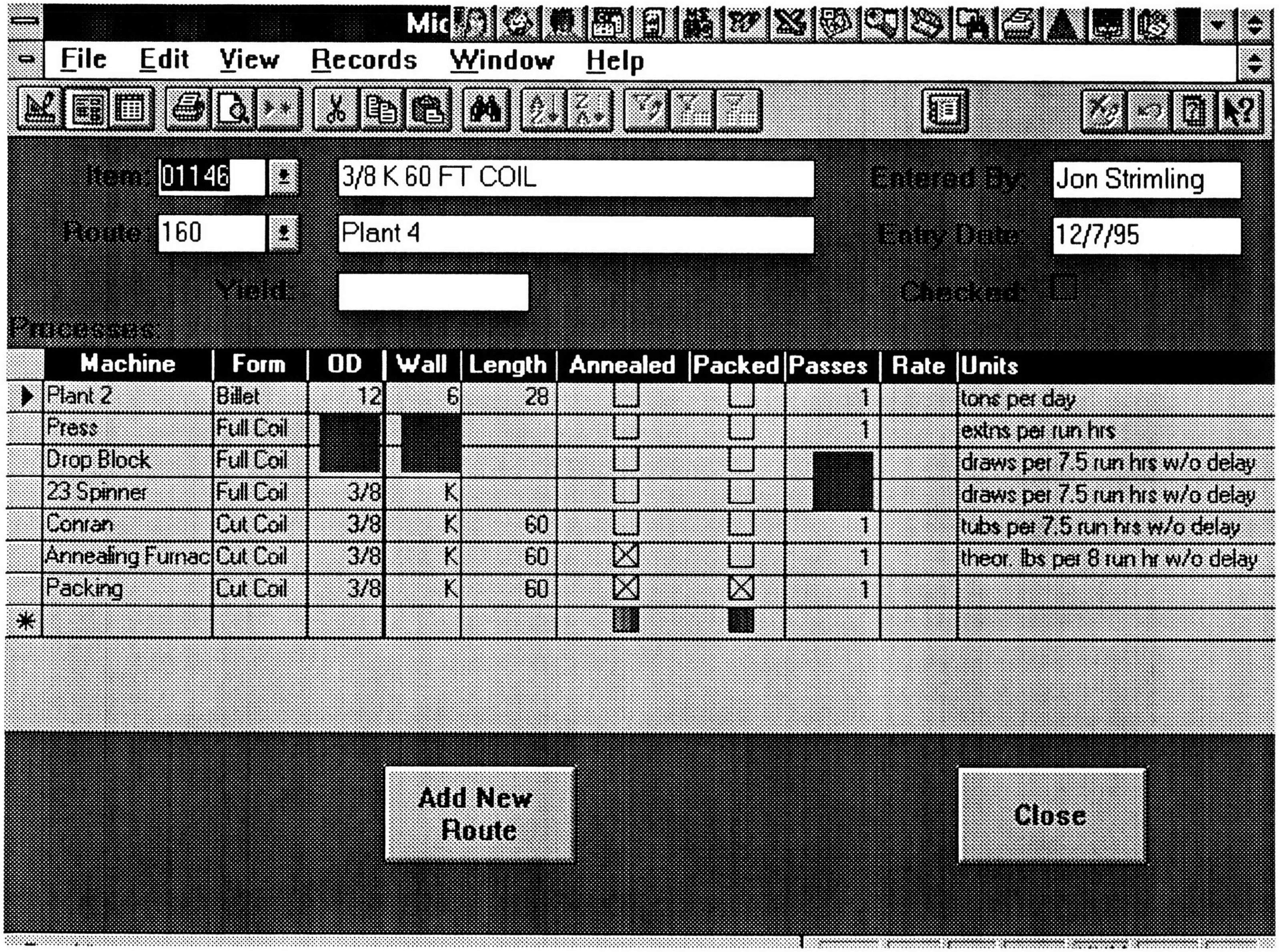
- Per Finished Pound
- Per Billet Pound
- Per Hour
- Per Item

For example, shipping costs are dependent on finished product weight, and would therefore fall under the "per finished pound" cost driver. Casting utility costs are dependent both on yields and the weight of product shipped and are therefore driven on a "billet pound" basis. Processing stations with known throughputs such as drawing processes are best modeled using production rates, and costs are modeled on a "per hour" basis. Packaging costs, of course, are driven by the number of units, or on a "per item" basis.

3.3 Production Routings

Figure 3-1, below, is an example of a product routing pulled from the ABC cost system.

Figure 3-1 A Product Routing



At the top of Figure 3-1 is the item for which the cost analysis is being performed, in this case "3/8 K 60 FT COIL" (or product number 01146.) But perhaps this product could be manufactured either in Plant 3 or in Plant 4, and of course the costs would be different. Below the item identification is a routing identifier, in this case "Plant 4," (or production routing number 160). Because products can be manufactured by any number of different methods, it is possible to select any available routing to examine the manufacturing cost by that particular routing. In some cases, it would be necessary to be more specific on the routing description, for example, "Extruded in Plant 4, Drawn at Station X, Finished at Station Y."

On the right hand side of the header are simply the name of the person who entered the data and the date of entry, for records tracking purposes.

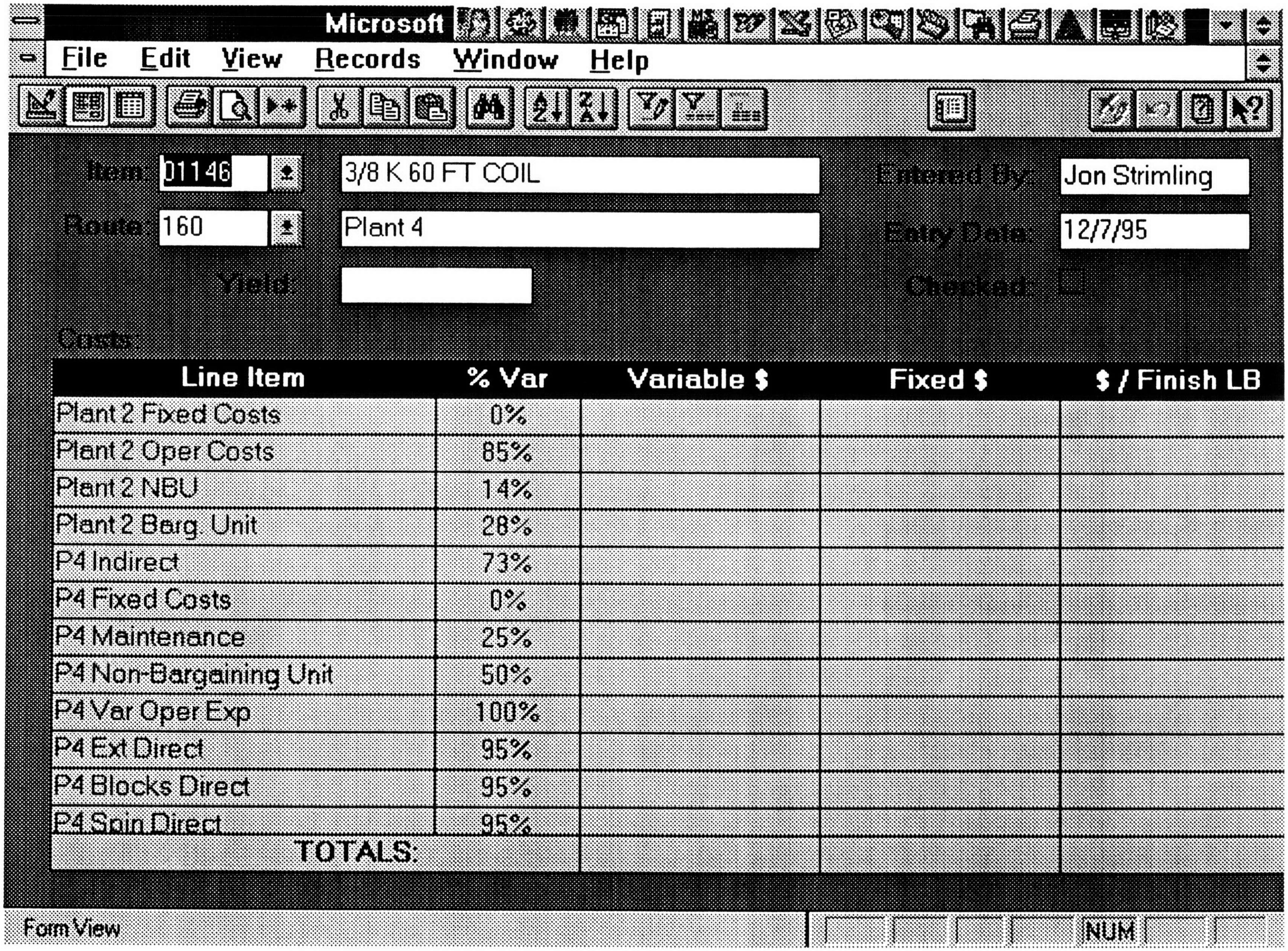
The routing sequence of the product is tabulated below the header block, identifying each process required to produce that product by that particular routing. The production processes are in the leftmost column; the form of the product at the completion of a particular process is shown in the middle columns, and then the number of passes, production rate and units are shown towards the right.

In this example, this product is cast in "Plant 2", extruded at the "Press," drawn through several passes at the "Drop Blocks," and at "23 Spinner," cut to 60 feet and coiled on the "Conran," and then annealed and packed. For each process there is a known production rate, but this column has been hidden here to protect proprietary information. For example, the casting rate is defined in terms of tons cast per day, and the drawing rates in terms of draws per shift, as shown in the units column.

3.4 Cost Analysis By Processing Step

What is desired, of course, is to use the production routing data gathered above to accurately estimate production costs. For the product and routing shown in Figure 3-1, costs are summarized in Figure 3-2, below.

Figure 3-2 Cost Analysis of A Particular Production Routing



For the "3/8 K 60 FT COIL," manufactured by the "Plant 4" routing which was described in Figure 3-1, the associated costs are described in Figure 3-2, above. For example, the product is cast in Plant 2, and the costs associated with casting can be broken into

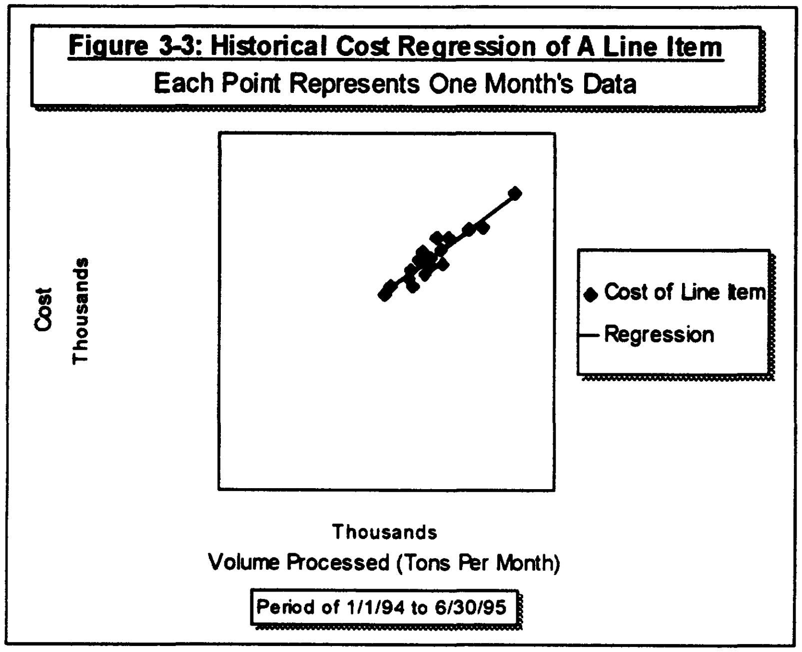
- Plant 2 Fixed Costs (Insurance and Depreciation)
- Plant 2 Operating Costs (Utilities and Other Operating Costs.)
- Plant 2 Non-Bargaining Unit Costs (Supervisory Salaries)
- Plant 2 Bargaining Unit Labor (Hourly Labor Costs)

For each line item, fixed and variable components are broken out separately and totaled at the right. (Actual cost figures hidden to protect proprietary data.) For example, "Plant 2 Fixed Costs" are 0% variable, because insurance and depreciation are not dependent upon output. "Plant 2 Operating Costs" are estimated at 85% variable because while most of the operating costs are variable with tonnage, some are not, for example, the lights and ventilation systems have the same electrical power cost, regardless of the tonnage produced. The estimate of the fixed and variable portions of particular cost drivers is a critical factor in overall cost figures, and therefore, some significant analysis is warranted to generate reasonable estimates. The details of how these estimates are performed are elaborated on below.

3.5 Fixed vs. Variable Costs

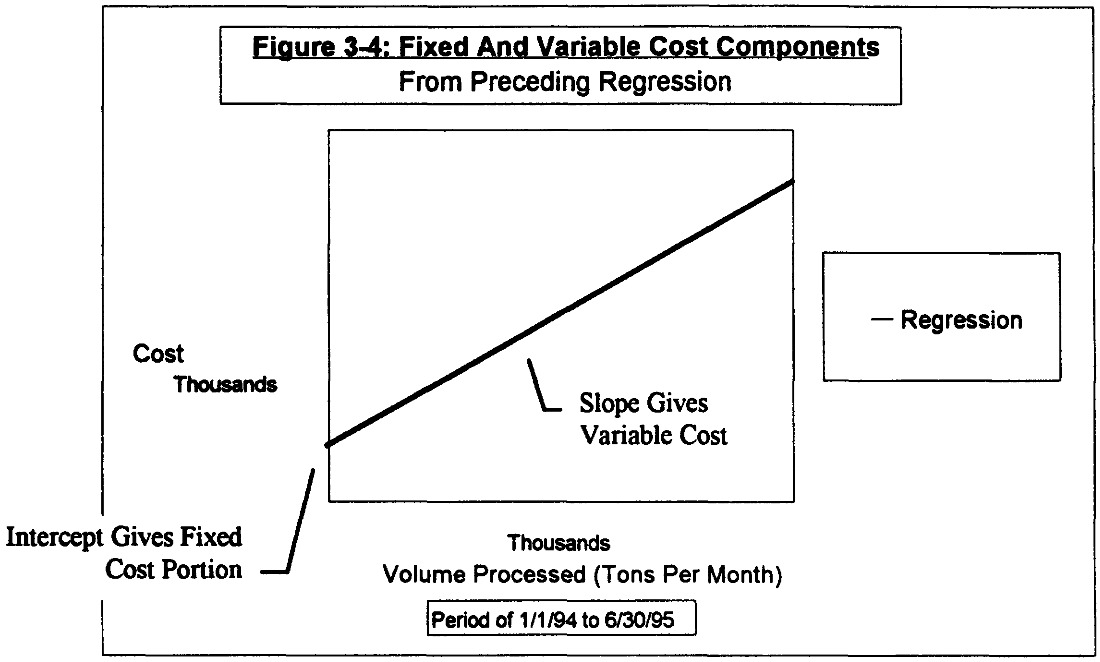
Critical to any cost analysis is the distinction between fixed and variable costs. Regressions of historical data were performed to approximate the fixed and variable components of any line item. For example, it was observed that maintenance labor tended follow production volumes less directly than direct labor at particular processing stations. The model therefore accounts for this by treating a higher percentage of maintenance costs as fixed costs.

Specifically, the determination of the fixed and variable components of a particular line item was accomplished through the use of regressions of historical production data. An example of such a regression is shown in Figure 3-3, below:



Each point in Figure 3-3 represents one of the 18 months preceding the analysis. The vertical axis is the total cost of that line item for a given month, while the horizontal axis shows the tonnage produced through the station associated with the line item. For example, if this were a plot of extrusion direct labor, the vertical height of one of the points would be total direct labor expenditures for last month, and the X location would be the tonnage extruded. The line is a best fitting regression of the points.

From Figure 3-3, it should be immediately clear that both production volumes and costs are highly variable, but in fact, the costs associated with this line item are best modeled with both fixed and variable components. Extrapolation of the regression to the vertical axis indicates a fixed cost component, as shown below, in Figure 3-4:



This fixed cost component may be associated with vacation pay & health benefits, or it may also be a result of efficiencies that are gained when the plant operates at high volumes.

3.6 Material Costs

Material costs are the single largest operating cost of copper tubing production, typically accounting for 70% to 75% of the sale price. Because Reading Tube purchases copper scrap on a daily or weekly basis, the cost of incoming material at a given point in time is readily available, and this cost is updated before each use of the cost model.

4 The Market Model

4.1 Segmentation of Markets

Sales Mixes

As previously mentioned, a customer's tubing needs are typically fixed, and there is little opportunity to convince either the tubing wholesaler or a commercial customer to purchase a different product based on price or delivery. Because of the reluctance of consumers to purchase less than truckload quantities, there is also little opportunity to suggest to a customer that they go to a different vendor for a particular item. Therefore, RTC is typically in the position of supplying either all of a customer's needs, or none[12].

Different types of customers, however, may purchase different types of products. Certain groups of wholesalers will have common buying tendencies, perhaps because of the type of home construction in their geographic area. *The types of products that a particular market segment will purchase in their approximate percentages is referred to as its* ***sales mix***. This is illustrated in Table 4-1, below.

[12] In some instances, where a large distributor is serving as an inventory buffer between RTC and tubing wholesalers, this may not hold true. In such cases, the distributor may be supplied by more than one manufacturer, and may purchase subsets of his requirements from each producer.

Table 4-1 Market Segment Model

Table 4-1-A Sales Mixes

Product	Sales Mixes By Percentage		
	Market Segment A	Market Segment B	Market Segment C
Product 1	10%	25%	0%
Product 2	0%	0%	100%
Product 3	30%	40%	0%
Product 4	60%	35%	0%
Total	**100%**	**100%**	**100%**

Table 4-1-B Volume By Segment

	Sales Volume			Total Tons of Sales
	Market Segment A	Market Segment B	Market Segment C	
Tons of Sales	200	100	500	**800**

Table 4-1-C Sales By Product And Segment

Product	Sales Tons By Market & Item			Total Tons By Product
	Market Segment A	Market Segment B	Market Segment C	
Product 1	20	25	0	**45**
Product 2	0	0	500	**500**
Product 3	60	40	0	**100**
Product 4	120	35	0	**155**
Total	200	100	500	**800**

Table 4-1-A shows sales mixes by product for several market segments. Since it is nearly impossible to change the mix within a market segment, the only way to influence the mix of products being produced is by changing the relative levels of sales to different market segments. This is shown in Table 4-1-B as the shaded "Tons of Sales" entries that are at management's discretion. The values shown here might represent a proposed level of weekly sales. Given these levels of sales to the respective market segments, the volumes required of each product are readily calculated by multiplying the times the volume to that segment. For example, the amount of Product 1 sold to Segment A (20 tons) is the product of the overall segment volume (200 tons) and the percentage of that segment's purchasing that is Product 1 (10%.) (Table 4-1-C)

4.2 Volume Limitations

Market Share Limitations

Reading Tube's sales volume into a particular market segment is a function of both the overall size of that market segment and RTC's market share. Because of the commodity nature of the market, price is strongly driven by supply levels. In a low market, there is always excess capacity, and the producers, being part of an oligopoly, continually face a "prisoner's dilemma."[13] If a single producer increases production, that producer will benefit, but if all producers join in, they will flood the market, and all will suffer. Perhaps due to the history of costly price wars in the industry, most of the major players now generally strive to maintain their own levels of market share, rather than producing to full capacity.

Therefore, at a given level of overall market sales in a particular segment, sales management may wish to restrict the level of sales to a particular market share percentage.

Model of Segment Volume Limits

Table 4-2, below, illustrates the model of market volume limits:

[13] Further discussion of the "prisoner's dilemma" and its implications for business policy can be found in Pindyck's "Economic Analysis for Business Policy."

Table 4-2 - Market Limits on Sales

Table 4-2-A Reading Tube Corporation

	Sales Volume			Total Tons of Sales Weekly
	Market Segment A	Market Segment B	Market Segment C	
Tons of RTC Sales	200	100	500	**800**

RTC is market limited in Segment A

Table 4-2-B Market Segment Limits

	Sales Volume			Total Tons of Sales Weekly
	Market Segment A	Market Segment B	Market Segment C	
Overall Market Volume	2,000	3,000	10,000	**15,000**
Hypothetical Max Mkt Share	10%	5%	10%	**9%**
Sales Volume Limit	200	150	1,000	**1,350**

The analytical model for the sales volume limitations is shown in Table 4-2, using hypothetical data. Table 4-2-A shows RTC's overall sales volume into particular market segments. The cells which are shaded are the decision variables, how much to supply each segment. Table 4-2-B shows the volume constraints obtained from the sales organizations. "Overall Market Volumes" and "Hypothetical Maximum Market Share" limitations are then multiplied to produce a "Sales Volume Limit". In solving for the optimal sales and operations strategy, sales volumes are always constrained to be below the "Sales Volume Limit" in each segment to avoid plans that could flood particular market segments.

4.3 Pricing and Revenue Models

Tubing Wholesaler Price Structure

Price in the tubing wholesaler markets is highly competitive, and tends to be set by the market leaders. Reading Tube Corporation has less than half of the sales of its largest competitor, and because the product is essentially a non-differentiated commodity, RTC is generally bound by overall market pricing. Virtually all producers use the same list price sheets, with competition being waged in terms of "multipliers," or the discount off of the price sheet awarded to particular customers.[14] In some instances, rebates and volume incentive programs are also given to high volume customers. While Reading Tube has historically differentiated itself on the basis of service and quality, RTC has not been able to earn a premium in terms of its products' pricing.

Also of critical importance in understanding this market is the fact that price levels are not directly tied to the market price of copper itself. In other words, the financial commodity markets may bid up the price of RTC's raw materials by as much as 10% without an immediate corresponding change in the pricing structure of RTC's products. And as raw materials are 70% to 90% of production costs, the movement of copper in financial markets is a key risk for copper tubing suppliers.

Commercial Pricing Structure

Because it is generally in the interest of both the supplier and the customer to minimize risk, commercial contracts are tied directly to market copper prices. In addition to material costs, there are two different types of charges associated with particular

[14] Reading Tube Corporation experimented several years ago with deviations from the industry standard list pricing of products. However, customers found that quotes from competing vendors were no longer directly comparable purely in terms of the discount offered off of list. This led to confusion in the market-place and a market wide downward spiral in pricing, as each producer feared being undercut by the others. Accordingly, management was hesitant to deviate again from the industry standard pricing structure.

contracts, a "metal premium," and a "fabrication charge." The metal premium nominally represents the value of the refining of the copper itself to better than commercial grade purity. The fabrication charge is associated with the work required to form the particular product. When RTC ships to a commercial customer on a given day, the price on the invoice will be the current price of copper plus "metal premium" plus a per pound fabrication charge[15].

Invoice Price = COMEX Copper Price + Metal Premium + Fabrication Charge.

For example, for a given product with a quoted fabrication charge and premium of \$0.25/lb. and \$0.06/lb., respectively, RTC would be assured of \$0.31/lb. regardless of the market price of copper.

Because of this immunity from the variations in market copper prices, and also because of the stability in demand, the commercial markets are very attractive, particularly when the tubing wholesaler side of the business is in a cyclical downturn. However, in a tubing wholesaler market with excess demand, margins skyrocket, and commercial commitments become a burdensome drain on capacity with lower than average returns. Hence, RTC strives to balance its level of commercial commitments with the opportunities in the tubing wholesaler market.

[15] Although this arrangement is typical, sometimes contracts are made at fixed sale prices. In such cases, the market for copper futures then used to reduce the risk of these agreements through hedging.

Pricing and Revenue Models

Table 4-3, below, illustrates the pricing model for wholesaler and commercial sales:

Table 4-3 Market Pricing Model

	Sales Multipliers (Discounts)		
	Market Segment A (Wholesaler)	Market Segment B (Wholesaler)	Market Segment C (Commercial)
Sales Multiplier	0.43	0.35	

For Wholesaler Markets

COMEX Copper Price	$1.40

For Commercial Markets

Product	List Price	Fab Price	Metal Premium	Sales Prices: Market Segment A (Water Tubing)	Sales Prices: Market Segment B (Water Tubing)	Sales Prices: Market Segment C (Commercial)
Product 1 (Wholesaler)	$4.00			$1.72	$1.40	
Product 2 (Commercial)		$0.25	$0.06			$1.71
Product 3 (Wholesaler)	$6.00			$2.58	$2.10	
Product 4 (Wholesaler)	$5.50			$2.37	$1.93	

For each tubing wholesaler market segment a multiplier is listed that corresponds the prevailing level of discounts in that particular market segment. This was a necessary component of the model since the same product can sell into different market segments at significantly different prices at the same time. For tubing wholesaler items, this multiplier is multiplied by the list price for each item to determine the sale price of that item into that particular market segment. For example, Product 1 with a list price of $4 sells into Market Segment B with a multiplier of 0.35 for an invoice price of $1.40.

For commercial items, a different pricing system entirely is used. As mentioned previously, to reduce risk, all commercial contracts are tied to the current COMEX copper price.[16] Pricing of commercial items is simply the current COMEX cost plus the negotiated fabrication charge and metal premium. As an example, Product 2 with a fabrication charge of $0.25 and a metal premium of $0.06 sells for $1.71 if copper is trading for $1.40.

Given market pricing levels and a particular choice of sales volumes to each segment, revenues are easily determined, as illustrated in Table 4-4, below:

[16] In some contracts, the sale price is not tied to the current market price, but is instead fixed. For such a contract, however, RTC would use financial instruments in the copper market to hedge its exposure to the risk of copper market fluctuations.

Table 4-4 - Sales Revenue Model

Table 4-4-A Sales Prices By Product And Market

Product	Sales Prices		
	Market Segment A (Water Tubing)	Market Segment B (Water Tubing)	Market Segment C (Commercial)
Product 1	$1.72	$1.40	
Product 2			$1.71
Product 3	$2.58	$2.10	
Product 4	$2.37	$1.93	

Table 4-4-B Sales Volume By Market And Item

Product	Tons of Sales			Total Tons By Product
	Market Segment A (Water Tubing)	Market Segment B (Water Tubing)	Market Segment C (Commercial)	
Product 1	20	25	0	**45**
Product 2	0	0	500	**500**
Product 3	60	40	0	**100**
Product 4	120	35	0	**155**

Table 4-4-C Sales Revenues By Market And Item And In Total

Product	Sales Revenues			Total Revenues By Product
	Market Segment A (Water Tubing)	Market Segment B (Water Tubing)	Market Segment C (Commercial)	
Product 1	$68,800	$70,000	$0	**$138,800**
Product 2	$0	$0	$1,710,000	**$1,710,000**
Product 3	$309,600	$168,000	$0	**$477,600**
Product 4	$567,600	$134,750	$0	**$702,350**
Tot Rev's By Market	**$946,000**	**$372,750**	**$1,710,000**	
		Total Revenues		**$3,028,750**

The sales prices by item and market (Table 4-4-A) are simply multiplied by the volume of sales by item and market (Table 4-4-B) to determine the levels of revenue (Table 4-4-C).

5 The Business Model

5.1 Model Summary

As is described in more detail below, Reading Tube Corporation sells into a variety of market segments, each with varying levels of demand for particular products. The needs of a particular market segment are fixed, but RTC can choose which segments to target for growth. This decision of where to focus limited production capacity is a key consideration for corporate management and plans are reviewed monthly at executive level sessions.

The business model optimizes sales volumes into particular market segments subject to production and market constraints. The model is also useful in quantifying the value of additional capacity at particular processing stations.

5.2 Illustration of Model

The overall business model is illustrated in Table 5-1 below and is based on the capacity, costing and market models described in Chapters 2-4.

Table 5-1 - The Business Model

Revenues	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	300	200	300	200	1,000	tons/week
List Price	$4.00	$4.50	$3.50	$4.00		per pound
Discount	50%	50%	50%	50%		
Sale Price	$2.00	$1.75	$2.25	$2.00	$2.03	per pound
Revenues	$1,200,000	$700,000	$1,350,000	$800,000	**$4,050,000**	per week
Variable Costs	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	300	200	300	200	1000	tons/week
Metal Cost/lb	$1.25	$1.25	$1.25	$1.25	$1.25	per pound
Metal Cost	$750,000	$500,000	$750,000	$500,000	$2,500,000	per week
Var Cost/lb	$0.20	$0.15	$0.25	$0.20	$0.25	per pound
Var Cost	$120,000	$60,000	$150,000	$80,000	$410,000	per week
Total Cost	$870,000	$560,000	$900,000	$580,000	**$2,910,000**	per week
Contribution	**Market A**	**Market B**	**Market C**	**Market D**	**TOTAL**	**Units**
Contribution	$330,000	$140,000	$450,000	$220,000	**$1,140,000**	per week
Contrib. Per Pound	$0.55	$0.35	$0.75	$0.55		per pound
Market Limits	**Market A**	**Market B**	**Market C**	**Market D**		**Units**
Market Size	2,500	1500	2000	2000		tons/week
Hypothetical Max Mkt Share	15%	20%	15%	10%		
Sales Volume Limit	*375*	*300*	*300*	*200*		tons/week
Actual Tonnage	*300*	*200*	*300*	*200*		tons/week
Capacity Limits						
Process 1	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	300	200	300	200	1,000	tons/week
Average Tons/Shift	15	40	30	28.6	23.8	tons/shift
Shifts Required	20	5	10	7	*42*	*shifts/week*
Total Machine-Shifts Available (From Two Pieces of Equipment)					*42*	*shifts/week*
Process 2	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	300	200	300	200	1,000	tons/week
Average Tons/Shift	100	100	100	100	100.0	tons/shift
Shifts Required	3	2	3	2	*10*	*shifts/week*
Total Machine-Shifts Available (From One Piece of Equipment)					*21*	*shifts/week*

Legend

Decision Variables | Market Conditions | Maximization Cell | *Constraints*

Business Model Overview

The business model, illustrated above in Table 5-1, is broken into four sections: revenues, variable costs, market limits, and capacity limits. The previously developed models are incorporated into this model in each of the appropriate sections.

The decision variables of the analysis are the tons of product allocated to each of the four markets shown (shaded cells).[17] The market conditions relevant to the analysis are the discount rates to particular market segments and the metal cost per pound (cells with dashed outline). The goal of the model is to maximize the total contribution figure (double boxed cell), which represents the difference between revenues and variable costs, subject to production and market constraints (boxed, italicized cells.)

Revenues and Costs

The revenue portion of the analysis multiplies the list prices for particular product mixes by the prevailing discounts in the appropriate market segment to calculate an average sale price per pound. This sale price per pound is simply multiplied by the tonnage figure for that market segment to calculate revenues by market segment, which are then totaled at the right of the model, as the bolded "Total Revenues."

Variable costs are a function of both metal costs and variable fabrication costs. Metal cost is easily calculated from tonnage and market metal price levels. The ABC cost analysis developed previously is used to calculate an aggregated average fabrication cost per pound for a particular product mix, which is then used to calculate variable production costs. The total variable costs for each market segment are then totaled at the right.

Under the contribution heading, variable costs are subtracted from revenues for each of the market segments. These are then totaled at the right in the box labeled "Total

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17 In the actual analysis performed at Reading Tube, ten different market segments were considered, but the analysis has been simplified for presentation purposes.

Contribution." (Double boxed cell) The objective of maximizing this total contribution cell is achieved by modifying the decision variables of tons sold to each market segment.

Market and Capacity Constraints

Without market or capacity limits, however, the model would simply suggest making infinite amounts of any profitable product. Therefore the market and capacity limits need to be applied to the model before proceeding with the optimization.

The market limit section of the analysis closely mimics the previously developed market limit model, using the market segment size and hypothetical maximum market share to calculate a sales volume limit in tons. The "actual tonnage" of the production plan is constrained to be less than this "sales volume limit." (Boxed, italicized cells)

Production capacity limits are added for processing stations in the plants. For example, at Process 1, where the aggregated average production rate is 15 tons/shift and 300 Tons are required for Market A, 20 shifts of capacity would be consumed. The shifts of capacity consumed by each market segment are then totaled at the right of the table, in this case as 42 machine-shifts required. The distinction between machine shifts and shifts is simply that for this operation, there might be two machines working 21 shifts a week to produce the required 42 machine-shifts of material. In optimizing total contribution, the model constrains "Total Machine-Shifts Required" to be less than the "Total Machine Shifts Available."

5.3 Using the Model to Optimize Sales Mix

Consider a current market situation, "Scenario 1," as shown Table 5-2-A, below, which might represent Reading Tube's current weekly average sales. (Note that this is precisely the same model as shown above in Table 5-1, above.)

Table 5-2-A Scenario 1

Revenues	Market A	Market B	Market C	Market D	Total/ Avg	Units
Tons	300	200	300	200	1,000	tons/week
List Price	$4.00	$4.50	$3.50	$4.00		per pound
Discount	50%	50%	50%	50%		
Sale Price	$2.00	$1.75	$2.25	$2.00	$2.03	per pound
Revenues	$1,200,000	$700,000	$1,350,000	$800,000	**$4,050,000**	per week

Variable Costs	Market A	Market B	Market C	Market D	Total/ Avg	Units
Tons	300	200	300	200	1000	tons/week
Metal Cost/lb	$1.25	$1.25	$1.25	$1.25	$1.25	per pound
Metal Cost	$750,000	$500,000	$750,000	$500,000	$2,500,000	per week
Var Cost/lb	$0.20	$0.15	$0.25	$0.20	$0.25	per pound
Var Cost	$120,000	$60,000	$150,000	$80,000	$410,000	per week
Total Cost	$870,000	$560,000	$900,000	$580,000	**$2,910,000**	per week

Contribution	Market A	Market B	Market C	Market D	TOTAL	Units
Contribution	$330,000	$140,000	$450,000	$220,000	$1,140,000	per week
Contrib. Per Pound	$0.55	$0.35	$0.75	$0.55		per pound

Market Limits	Market A	Market B	Market C	Market D		Units
Market Size	2,500	1500	2000	2000		tons/week
Hypothetical Max Mkt Share	15%	20%	15%	10%		
Sales Volume Limit	*375*	*300*	*300*	*200*		tons/week
Actual Tonnage	*300*	*200*	*300*	*200*		tons/week

Capacity Limits

Process 1	Market A	Market B	Market C	Market D	Total/ Avg	Units
Tons	300	200	300	200	1,000	tons/week
Average Tons/Shift	15	40	30	28.6	23.8	tons/shift
Shifts Required	20	5	10	7	*42*	*shifts/week*
Total Machine-Shifts Available (From Two Pieces of Equipment)					*42*	*shifts/week*

Process 2	Market A	Market B	Market C	Market D	Total/ Avg	Units
Tons	300	200	300	200	1,000	tons/week
Average Tons/Shift	100	100	100	100	100.0	tons/shift
Shifts Required	3	2	3	2	*10*	*shifts/week*
Total Machine-Shifts Available (From One Piece of Equipment)					*21*	*shifts/week*

Legend

Decision Variables	Market Conditions	Maximization Cell	*Constraints*

Notable features of Scenario 1 are that:

- Markets A and B are not market constrained, but Markets C and D are.
- Process 1 is a constrained operation, but Process 2 is not.
- Market A has higher contribution per pound than Market B.
- Total Contribution is $1,140,000/wk

Because Market A has a higher contribution per pound than Market B, management may then want to consider decreasing sales into Market B to free up capacity at Process 1 in order to sell additional volume into Market A. The problem with this logic is that Market A's products have significantly lower throughput at Process 1 (15 tons/shift as compared with 40 tons/shift.) The value of the business model is that it can maximize contribution analytically, subject to the market and capacity constraints given. The optimized scenario is shown in Table 5-2-B, below

Table 5-2-B Scenario 2

Revenues	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	262.5	300	300	200	1,063	tons/week
List Price	$4.00	$4.50	$3.50	$4.00		per pound
Discount	50%	50%	50%	50%		
Sale Price	$2.00	$1.75	$2.25	$2.00	$2.00	per pound
Revenues	$1,050,000	$1,050,000	$1,350,000	$800,000	**$4,250,000**	per week

Variable Costs	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	262.5	300	300	200	1062.5	tons/week
Metal Cost/lb	$1.25	$1.25	$1.25	$1.25	$1.25	per pound
Metal Cost	$656,250	$750,000	$750,000	$500,000	$2,656,250	per week
Var Cost/lb	$0.20	$0.15	$0.25	$0.20	$0.25	per pound
Var Cost	$105,000	$90,000	$150,000	$80,000	$425,000	per week
Total Cost	$761,250	$840,000	$900,000	$580,000	**$3,081,250**	per week

Contribution	**Market A**	**Market B**	**Market C**	**Market D**	**TOTAL**	**Units**
Contribution	$288,750	$210,000	$450,000	$220,000	**$1,168,750**	per week
Contrib. Per Pound	$0.55	$0.35	$0.75	$0.55		per pound

Market Limits	**Market A**	**Market B**	**Market C**	**Market D**	**Units**
Market Size	2,500	1500	2000	2000	tons/week
Hypothetical Max Mkt Share	15%	20%	15%	10%	
Sales Volume Limit	*375*	*300*	*300*	*200*	tons/week
Actual Tonnage	*262.5*	*300*	*300*	*200*	tons/week

Capacity Limits

Process 1	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	262.5	300	300	200	1,000	tons/week
Average Tons/Shift	15	40	30	28.6	23.8	tons/shift
Shifts Required	17.5	7.5	10	7	*42*	*shifts/week*
Total Machine-Shifts Available (From Two Pieces of Equipment)					*42*	*shifts/week*

Process 2	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	262.5	300	300	200	1,000	tons/week
Average Tons/Shift	100	100	100	100	94.1	tons/shift
Shifts Required	2.625	3	3	2	*10.625*	*shifts/week*
Total Machine-Shifts Available (From One Piece of Equipment)					*21*	*shifts/week*

Legend

Decision Variables	Market Conditions	Maximization Cell	*Constraints*

Notable features of Scenario 2 are that:

- Market A is not market constrained, but Markets B, C and D are.
- Process 1 is a constrained operation, but Process 2 is not.
- Total Contribution is $1,168,750/week

From this analysis, it is clear that the optimum solution is actually to reduce sales into the higher margin Market A, freeing up capacity at Process 1, so that sales to Market B can be increased. In this case, by optimizing the mix of products sold into each of the market segments, the model shows that an increase in contribution of $28,750/week could be realized.

The optimization is performed using the "Solver" function of a Lotus-123 spreadsheet. Because the model is linear, convergence is fairly rapid.

Example of Impact of Changing Market Conditions

While this analysis is incomplete in that it assumes constant market conditions and metal prices, it does provide a quantitative analysis of the value of additional capacity at a given market condition. Precisely because market conditions are volatile, this simple analytical model was helpful in understanding the optimum positioning of the firm under varying market conditions. For example, consider Table 5-2-C, on the following page.

Table 5-2-C, is based on the same data as Table 5-2-A and Table 5-2-B, with the exception that the market conditions have been changed to reflect a higher metal price of $1.50 per pound of copper. The optimum solution to the sales mix is no longer the solution shown in Table 5-2-B, but is as shown above in Table 5-2-C.

Table 5-2-C Scenario 3

Revenues	Market A	Market B	Market C	Market D	Total/ Avg	Units
Tons	375	0	300	200	875	tons/week
List Price	$4.00	$4.50	$3.50	$4.00		per pound
Discount	50%	50%	50%	50%		
Sale Price	$2.00	$1.75	$2.25	$2.00	$2.09	per pound
Revenues	$1,500,000	$0	$1,350,000	$800,000	**$3,650,000**	per week

Variable Costs	Market A	Market B	Market C	Market D	Total/ Avg	Units
Tons	374.999996	0	300	200	874.999996	tons/week
Metal Cost/lb	$1.50	$1.50	$1.50	$1.50	$1.50	per pound
Metal Cost	$1,125,000	$0	$900,000	$600,000	$2,625,000	per week
Var Cost/lb	$0.20	$0.15	$0.25	$0.20	$0.25	per pound
Var Cost	$150,000	$0	$150,000	$80,000	$380,000	per week
Total Cost	$1,275,000	$0	$1,050,000	$680,000	**$3,005,000**	per week

Contribution	Market A	Market B	Market C	Market D	TOTAL	Units
Contribution	$225,000	$0	$300,000	$120,000	**$645,000**	per week
Contrib. Per Pound	$0.30	$0.10	$0.50	$0.30		per pound

Market Limits	Market A	Market B	Market C	Market D		Units
Market Size	2,500	1500	2000	2000		tons/week
Hypothetical Max Mkt Share	15%	20%	15%	10%		
Sales Volume Limit	*375*	*300*	*300*	*200*		tons/week
Actual Tonnage	*374.999996*	*0*	*300*	*200*		tons/week

Capacity Limits

Process 1	Market A	Market B	Market C	Market D	Total/ Avg	Units
Tons	375	0	300	200	1,000	tons/week
Average Tons/Shift	15	40	30	28.6	23.8	tons/shift
Shifts Required	24.9999997	0	10	7	*41.9999997*	*shifts/week*
Total Machine-Shifts Available (From Two Pieces of Equipment)					*42*	*shifts/week*

Process 2	Market A	Market B	Market C	Market D	Total/ Avg	Units
Tons	374.999996	0	300	200	1,000	tons/week
Average Tons/Shift	100	100	100	100	114.3	tons/shift
Shifts Required	3.74999996	0	3	2	*8.74999996*	*shifts/week*
Total Machine-Shifts Available (From One Piece of Equipment)					*21*	*shifts/week*

Legend

Decision Variables	Market Conditions	Maximization Cell	*Constraints*

Notable features of Scenario 3 are that:

- Markets A, C and D are market constrained, but there are no sales into Market B.
- Process 1 is capacity constrained, but Process 2 is not.
- Total Contribution is $645,000/week which is a maximum, given the new and less favorable market conditions of increased metal cost without sales price increases.
- Note that RTC will now be better off targeting sales opportunities in Market A rather than Market B, as opposed to the market conditions illustrated in Table 5-2-B

It is precisely because of the highly variable nature of the copper tubing market that the business model developed here is required to assess sales and operational plans in light of ever-changing market conditions.

Applicability to Sales Strategy

Short Term Market Positioning

For given market conditions at a particular point in time the business model can compute the optimum levels of sales into particular market segments. However, in reality, RTC is not free to move between markets at whim; commercial sales are fixed over the period of their contract, typically a year, and even wholesalers have repeat buying patterns in that they tend to be loyal to particular producers. (Approximately 80% of RTC's wholesaler sales are repeat customers[18].)

However, in the short term there are two actions that the sales department can take to improve contribution.

1. In periods of excess demand, it is possible to "cherry pick" the orders that move the firm towards the optimal product mix.
2. At other times, it is possible to sell of large volumes of particular products by slightly undercutting market prices. The model developed above proved a valuable tool in evaluating whether such transactions were truly profitable.

Long Term Market Positioning

In the long run, it is certainly possible to move the customer base towards desirable product mixes by selecting customers with needs that closely reflect the desired mix. The analytical business model enables "playing out" various scenarios in a variety of market conditions, and this exercise proved invaluable in understanding the long term impact of market positioning.

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[18] From Dave Zellers, Water Tubing Sales Manager at Reading Tube Corporation.

In particular, the model was helpful in assessing the value of commercial contracts, which typically are one year agreements. Because such an agreement represents a fixed commitment of manufacturing capacity, it is important to consider not only the margins of the contract, but also the opportunity costs associated with the loss of productive capacity available to other markets. See Chapter 7 for further development of "hurdle rates" or break-even margins that warrant the commitment of capacity at particular manufacturing processing stations.

The model was helpful as well in considering how the company will break even in a down market.

5.4 Using the Model to Evaluate Additions of Capacity

Consider the scenario in the preceding three examples, where Process 1 was found to be constrained in each example. In such a case, the firm's management may wish to consider adding capacity at that station. The critical question is the return on the investment, which is determined by the additional contribution generated by the added capacity. In Table 5-2-D, below, a third processing station has been added for Process 1, shifting the available weekly machine-shifts from 42 to 63 and eliminating the capacity shortage at that station. The model was then re-optimized.

Table 5-2-D Scenario 4

Revenues	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	375	300	300	200	1,175	tons/week
List Price	$4.00	$4.50	$3.50	$4.00		per pound
Discount	50%	50%	50%	50%		
Sale Price	$2.00	$1.75	$2.25	$2.00	$2.00	per pound
Revenues	$1,500,000	$1,050,000	$1,350,000	$800,000	$4,700,000	per week

Variable Costs	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	375	300	300	200	1175	tons/week
Metal Cost/lb	$1.25	$1.25	$1.25	$1.25	$1.25	per pound
Metal Cost	$937,500	$750,000	$750,000	$500,000	$2,937,500	per week
Var Cost/lb	$0.20	$0.15	$0.25	$0.20	$0.25	per pound
Var Cost	$150,000	$90,000	$150,000	$80,000	$470,000	per week
Total Cost	$1,087,500	$840,000	$900,000	$580,000	$3,407,500	per week

Contribution	**Market A**	**Market B**	**Market C**	**Market D**	**TOTAL**	**Units**
Contribution	$412,500	$210,000	$450,000	$220,000	$1,292,500	per week
Contrib. Per Pound	$0.55	$0.35	$0.75	$0.55		per pound

Market Limits	**Market A**	**Market B**	**Market C**	**Market D**		**Units**
Market Size	2,500	1500	2000	2000		tons/week
Hypothetical Max Mkt Share	15%	20%	15%	10%		
Sales Volume Limit	*375*	*300*	*300*	*200*		tons/week
Actual Tonnage	*375*	*300*	*300*	*200*		tons/week

Capacity Limits

Process 1	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	375	300	300	200	1,000	tons/week
Average Tons/Shift	15	40	30	28.6	20.2	tons/shift
Shifts Required	25	7.5	10	7	*49.5*	*shifts/week*
Total Machine-Shifts Available (From Three Pieces of Equipment)					*63*	*shifts/week*

Process 2	**Market A**	**Market B**	**Market C**	**Market D**	**Total/ Avg**	**Units**
Tons	375	300	300	200	1,000	tons/week
Average Tons/Shift	100	100	100	100	85.1	tons/shift
Shifts Required	3.75	3	3	2	*11.75*	*shifts/week*
Total Machine-Shifts Available (From One Piece of Equipment)					*21*	*shifts/week*

Legend

Decision Variables	Market Conditions	Maximization Cell	*Constraints*

Notable features of Scenario 4 are that:

- Markets A, B, C and D are all market constrained.
- Neither Process 1 or Process 2 is constrained.
- Total Contribution is $1,292,500/week

By subtracting the total contribution from Scenario 2, an additional contribution of $123,750 a week can be expected due to the capacity addition at Process 1. This weekly return figure can then be used in evaluating the cost and benefits of capacity addition.

While the business model can calculate the value of additional capacity at any given market conditions, it is not able, in and of itself, to assess the value of additional capacity given uncertain future market conditions. A methodology for accounting for the stochastic nature of prices and demand is included under "Areas For Further Development" in Chapter 7.

5.5 Using the Model To Evaluate Production Routing

Optimal Routing of Products Under Various Operating Conditions

Because of the cyclical nature of demand in the tubing industry, it is common for particular capacity constraints to become binding only at particular times of the year. This can lead to different operating guidelines at different times of the year. An example is considered below:

Example 5-1

Suppose management wishes to consider two possible ways to draw a particular product from extruded form to finished dimensions, one in 4 passes, the other in 5 passes. The expected yields from the two processes were 75% and 85% for the aggressive and conservative draw schedules, respectively. The two scenarios and their financial implications are shown below in Table 5-2.

Table 5-3 - Impact of Market Conditions on Optimal Draw Schedule

Table 5-3-A Drawing Operations During Low Volume

	Aggressive	Conservative	
Number of Passes Per Coil	4	5	passes
X Average Time Per Pass	0.05	0.06	hrs/pass
Average Time Per Coil	0.2	0.3	hours
X Station Variable Costs	$ 65	$ 65	per hour
Cost Per Coil	13	19.5	
Divided By Billet Weight	1,000	1,000	lb.
Drawing Cost Per Billet Pound	$ 0.013	$ 0.020	per pound
All Other Variable Costs Per Billet Pound	$ 0.200	$ 0.200	per pound
Total Cost Per Billet Pound	$ 0.213	$ 0.220	per pound
Divided By Average Yield	75%	85%	
Total Cost Per Finished Pound	$ 0.284	$ 0.258	per pound
X Production Volume in Low Volume Market	**400,000**	**400,000**	per week
Total Variable Cost	$ 113,600	$ 103,294	per week
Savings From Conservative Draw		$ 10,306	per week

Table 5-3-B Drawing Operations During Peak Demand

	Aggressive	Conservative	
Product Price	$ 2.000	$ 2.000	per lb.
- Metal Cost	$ 1.250	$ 1.250	per lb.
Margin Over Metal	$ 0.750	$ 0.750	per lb.
- Manufacturing Cost	$ 0.284	$ 0.258	per lb.
Margin	$ 0.466	$ 0.492	per lb

	Aggressive	Conservative	
Shifts Per Week	21	21	shifts/wk
X Hours Per Shift	8	9	hrs/shift
Hours Per Week	168	189	hrs/wk
Divided By Hours Per Coil	0.20	0.30	lb./shift
Coil Production	840	630	lb./wk
X Weight Per Coil	1,000	1,000	lb/coil
Billet Pounds Started	840,000	630,000	lb./wk
X Yield From Billet	75%	85%	
Production Volume in Peak Market	**630,000**	**535,500**	**lb./wk**
X Margin At Peak Demand	$ 0.466	$ 0.492	per lb.
Contribution	$ 293,580	$ 263,340	weekly
Added income from aggressive schedule		$ 30,240	per week

As shown in Table 5-3-A, above, during low volume production periods, where 300,000 tons of the product are required, there is a substantial cost savings to improving the yield, because the yield influences not only the cost of drawing, but of casting, extrusion and finishing as well. On the other hand, as shown in Table 5-3-B, during peak demand periods, when demand for the product exceeds production capacity, the value of the additional throughput from the aggressive schedule is preferable.[19]

Although this example does not use the business model directly, some of the numbers in the model such as production volumes and margins are drawn from it. Ideally, one would desire to have a comprehensive model that made the production routing decisions concurrently with the selection of an optimal marketing strategy, as is discussed in Chapter 7. But for now, it is necessary to manually extract values from particular scenarios of the business model and then to perform a separate analysis of production routings, as shown here.

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[19] This example was simplified to production of a single product at the drawing station. In fact, multiple products are produced through the same station, and a more elaborate analysis is necessary. However, a simple example like this was useful as a tool in illustrating the principle that the optimum drawing schedule depends not only on production rates and yields, but also on market conditions. The operations and sales model described previously accounts for the numerous possibilities and tradeoffs that arise from multiple products and multiple potential routings per product.

6 Impact of The Business Model

6.1 Summary of Impact

The business model allowed for the analytical solution of two of the key problems initially posed by corporate management:

- Which markets to target.
- Whether a new atmospheric generation and delivery system was warranted at the annealing furnace.

Details of the strategic marketing decisions are not appropriate for public disclosure, but the bottom line of the analyses was that market segments for potential growth were identified. In assessing the value of increased furnace throughput, the effect of the sales mix of particular market segments was crucial. Since, in some markets, there are two pounds of non-annealed tubing for every pound of annealed tubing, every pound of additional furnace throughput translated into three pounds of tubing sales in those market segments. The bottom line of the analysis of the value of furnace capacity was that the nitrogen/hydrogen atmosphere being considered would more than pay for itself, even at the expected additional cost of $30,000/month.

The analytical model played a central role in enabling improvements to be implemented at the annealing furnace. A Continuous Improvement (CI) team had been formed to develop methods of increasing throughput at the furnace more than a year before the business model was in place. Although the team had identified several potential gains, the actual implementation of the changes was lagging. One of the critical problems the team faced was building strong management support for their work, both in terms of financial support as well as getting a high priority within the organization.

Once the business model was in place and upper management had been alerted to the quick payback of the project (about 1 month), the team quickly had the support it needed to carry out its work. The prototyping efforts accelerated from one prototype a month to three prototypes a week. External suppliers were brought in for consultation on the designs. The project was made a top priority for the internal engineering department and was ramped from concept to production in just two months.

6.2 Implementation of The Furnace Capacity Expansion

Elimination of The Purging Constraint

With the existing production system, annealed coils were purged manually on roller tables after exiting the annealing furnace[20]. Because a maximum of three people can work at the purging station, there was a maximum throughput that can be achieved for a given product determined by the available human resources. For some products, the purging station, rather than the furnace, was the constrained operation. The rationale for the nitrogen/hydrogen atmosphere was that it would eliminate the manual operation of purging coils as they exited the furnace, alleviating this bottleneck, and therefore allowing for additional throughput.

The solution developed to address the purging constraint was not a new atmosphere, but simply setting up a fork to multiple lines and multiple purging stations at the back end of the furnace. The labor and scheduling issues of doing so were non-trivial, but they were addressed in order to achieve the required throughput. In addition, multiple lines were also placed at the front end of the furnace which helped eliminate setup delays, as the lines not in use could be set up in advance for the next product type.

Maximizing Furnace Loading

One of the ideas proposed to increase furnace throughput was the loading of coils on trays into the furnace. The hope was that by resting the coils on trays, the coils would

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[20] The existing atmoshpere in the annealing furnace is a combusted atmosphere that reduces oxidation of the coils. However, upon exiting the furnace, particular grades of coils need to be purged in order to remove the remaining furnace gases from their interiaor surface in order to prevent discoloration.

be more stable, and could be placed across a wider area of the furnace without the risk of being caught on the edge rails inside of the furnace.

However, the challenges of designing such trays were that:

1. The trays needed to be of minimum weight to avoid soaking the heat of the furnace, thereby reducing the volume of copper coils they could carry.
2. The trays needed to be strong enough to support the weight of the copper coils and to carry them across the rolls without deforming, even at sustained temperatures exceeding 1300 F.
3. The trays needed to support the coils without marking them. At annealing temperatures, copper becomes extremely soft, and if not supported by a broad surface, the coils will visibly deform under their own weight.
4. The trays needed to allow for sufficient airflow through the tray for proper radiative and convective heating of both the coils and the trays.
5. The trays had to be sturdy enough for shop floor usage, and for transport by forklift.

After a month of aggressive design and prototyping, an acceptable solution was reached that met all of the above design criteria. An outside supplier then supplied a sufficient quantity of these trays for production over the period of a month. Concurrent with the delivery of batches of production trays, quality assurance trials were performed, so that as the final trays arrived, full production could immediately be implemented.

Other Operational Improvements

Other actions taken by the Continuous Improvement (CI) team included:

- Minimizing setup times (through the multiple lines)
- Maximizing batch sizes to reduce the number of setups
- Adding an inventory buffer upstream of the furnace
- Optimizing feed rates and loading configurations to maximize throughput

- Running relief to reduce production losses due to lunch breaks
- Adding a signal siren at the furnace to alert supervisory staff to any delays

The final item, the signal light and siren could be activated by the operator if he anticipated any imminent delays, and is intended to eventually activate automatically upon any actual delays. This served to focus the mill on the problem of always keeping the bottleneck supplied with material.[21]

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[21] In "The Toyota Production System," Bowen points out the importance of the use of the Andon cord in the Toyota factories to immediately focus attention on any defects. In a constrained system, perhaps the most costly "defect" of all is failing to utilize the bottleneck to the fullest. Accordingly, an "Andon" button was added to the plant's bottleneck operations.

7 Areas For Further Development

7.1 Comprehensive Sales & Operations Model

Features Lacking From Current Model

While the business model developed in Chapter 5 was a major step towards clarifying the tradeoffs inherent in sales and production planning, it is not an all-encompassing solution. Weaknesses of the model are:

- RTC has the option to purchase or sell particular items to or from competing producers. This model as currently developed does not reflect these possibilities.
- The business model assumes a single production process is used for each production item. However, in reality, there can be several different routes by which a given item can be manufactured. A comprehensive sales and operations model would simultaneously solve for the optimal sales mix and production process selection.

A Lotus-123 spreadsheet model was developed that in theory would simultaneously solve for optimal marketing, production routings and purchasing strategies. However, due to the size and complexity of the model, it was not possible, in the Lotus-123 setup, to gather all of the relevant data for input to the model. From a practical perspective, while only a simultaneous solution will be rigorously mathematically correct, it not expected that the simultaneous solution of the market, production and purchasing strategies would result in any major deviations from the strategies developed through the application of the simplified business model.

7.2 Dealing With Uncertain Future Market Conditions

In Assessing the Value of Capacity

For larger, longer term investments, the variability of demand is a key consideration in the evaluation of potential additions of capacity. The ability of the model to rapidly calculate the value of added capacity under a variety of operating conditions allows a rough estimation of the expected value of the investment[22]:

Table 7-1 Expected Value of a Capacity Addition

Historical Period	Overall Market Volume (Tons/Wk)	Hypothetical Desired Market Share	RTC's Hypothetical Desired Sales Volume (Tons/Wk)	Sales With Current Capacity (900 tons/wk)	Sales With Proposed Capacity (1,000 tons/wk)	Delta Due to Addition of Capacity (tons/wk)	Average Margins On Sales Delta ($/lb)	Additional Contrib'n ($/wk)
Jan-90	10,000	10%	1,000	900	1,000	100	$ 0.50	$ 100,000
Feb-90	9,889	10%	989	900	989	89	$ 0.49	$ 86,913
Mar-90	9,708	10%	971	900	971	71	$ 0.47	$ 66,655
Apr-90	8,425	10%	842	842	842	-	$ 0.34	$ -
May-90	8,865	10%	887	887	887	-	$ 0.39	$ -
Jun-90	10,275	10%	1,028	900	1,000	100	$ 0.53	$ 105,505
Jul-90	10,008	10%	1,001	900	1,000	100	$ 0.50	$ 100,166
Aug-90	9,933	10%	993	900	993	93	$ 0.49	$ 92,006
Sep-90	8,237	10%	824	824	824	-	$ 0.32	$ -
Oct-90	8,769	10%	877	877	877	-	$ 0.38	$ -
Nov-90	7,447	10%	745	745	745	-	$ 0.24	$ -
Dec-90	8,093	10%	809	809	809	-	$ 0.31	$ -
Jan-95	9,024	10%	902	900	902	2	$ 0.40	$ 1,913
Feb-95	10,104	10%	1,010	900	1,000	100	$ 0.51	$ 102,088
Mar-95	11,000	10%	1,100	900	1,000	100	$ 0.62	$ 124,000
Apr-95	9,830	10%	983	900	983	83	$ 0.45	$ 74,700
May-95	8,520	10%	852	852	852	-	$ 0.35	$ -
Jun-95	8,030	10%	803	803	803	-	$ 0.30	$ -
Average Over Historical Scenarios								**$ 47,441**

It is impossible to absolutely predict the future sales, but the value of additional capacity can be estimated by examining a representative historical period, as shown in

[22] For a more sophisticated method of estimation of the expected value of capacity addition given uncertain demand, refer to Dixit & Pindyck's, "Investment Under Uncertainty," which applies stock market based options analysis to investment decisions.

Table 7-1, above. In this case, a period of four and a half years is shown, from January of 1990 to June of 1995.

From a table such as this, that shows the overall market volume, and RTC's hypothetical desired share, RTC's hypothetical desired volume can then be calculated. Two capacity conditions at a particular processing station can then be considered - in this case shown as a 900 ton/wk current capacity as compared to a 1,000 ton/wk proposed capacity. As shown in the "Delta due to Addition of Capacity" column, the capacity addition only results in increased sales during periods where the desired sales volume exceeds the current productive capacity.

Running the business model at each month's market conditions for each of the two cases, the existing capacity and the proposed capacity, would yield both an average margin on the additional sales volume and a net difference in overall contribution, shown in the rightmost column. By taking a time weighted average of the rightmost column, a rough estimate of the weekly value of an addition of capacity at this station can be generated.

Evaluation of Commercial Contracts

Setting "Hurdle Rates" for Commitments of Capacity

Commercial sales are usually negotiated on a yearly basis, as previously mentioned. If all stations were always unconstrained, then commercial contracts could be evaluated purely on a revenue vs. variable cost basis. But because each commercial contract constitutes a commitment of processing capacity at each station, and because particular processes are at times constrained, the opportunity costs of capacity must be accounted for in considering the value of commercial contracts. In other words, if additional capacity at a constrained station has value, then certainly the commitment of that capacity to a commercial customer also has an associated cost.

What follows is a development of "hurdle rates" whereby the cost of capacity is figured into a cost per pound that a commercial contract must exceed before it is truly profitable. If markets were constant, the business model would be sufficient to determine the cost of capacity allocated to a particular commercial contract. But because markets are volatile, a model is needed that accounts for the potential value of the capacity under a variety of market conditions, as well as the probability of those market conditions occurring.

Example 7-1

Consider two 600 ton/yr. commercial contracts that pass through a constrained station at two different rates, Product A at 10 tons/shift and product B at 5 tons/shift, as shown below:

Table 7-2 - Development of Commercial "Hurdle Rates"

Table 7-2-A: Estimation of Opportunity Costs

Line			Commercial Product A		Commercial Product B	
1	Commercial Production Contract		600		600	tons/yr
2	Divided By Months Per Year		12		12	months
3	Sales Per Month		50		50	tons/month
4	Divided By Finishing Hours Per Ton		10		5	tons/shift
5	Finishing Capacity Commitment		5		10	shifts/month
6	X Months of Year Constrained at That Station		6		6	months/yr
7	Constrained Shifts Allotted to Contract		30		60	shifts/yr
8	Opportunity Costs During Constrained Months	$	7,000	$	7,000	per shift
9	Total Opportunity Cost At That Station	$	210,000	$	420,000	per annum
10	Divided By Total Yearly Volume		600		600	tons/yr
11	**Avg Opportunity Cost**	**$**	**0.18**	**$**	**0.35**	**per pound**

Table 7-2-B: Impact Of Opportunity Costs On Profitability

Line			Commercial Product A		Commercial Product B	
12	Revenues	$	2.00	$	2.00	per lb.
13	- Metal Costs	$	1.50	$	1.50	per lb.
14	Margin Over Metal	$	0.50	$	0.50	per lb.
15	- Manufacturing Costs	$	0.25	$	0.25	per lb.
16	**Margin Under Current Pricing System**	**$**	**0.25**	**$**	**0.25**	**per lb.**
17	- Opportunity Costs	$	0.18	$	0.35	per lb.
18	**Net Margin After Opportunity Costs**	**$**	**0.08**	**$**	**(0.10)**	**per lb.**

As shown above in Table 7-2, since commercial contracts are typically at constant volume year-round, production in any given month is readily determined, both in tons, then in shifts.[23] (Table 7-2-A) Line 1 is simply the volume of the commercial production contract, which is 600 tons per year for both products A and B. Sales per month (Line 3) is then calculated by dividing by 12. However, Product A and Product B have substantially different production rates through the finishing lines as shown on Line 4. The finishing capacity commitment (Line 5) is simply the monthly sales (Line 3) divided by the finishing rate (Line 4.) The finishing capacity commitment represents the number of shifts of capacity that will be required to complete production for a given contract.

Line 6 shows the number of months of the year that the firm expects the finishing lines to be at capacity. Because of the cyclical nature of the market, and drawing on historical data, the estimate used here is 6 months of the year. When the finishing lines are not constrained, there is no opportunity cost to the allocation of the capacity to the commercial contract. But when the station is constrained, the lost production due to the commercial contract can be significant. The product of the finishing capacity commitment per month (Line 5) times the months of year the station is constrained (Line 6) gives the number of constrained shifts expected to be allotted to the contract over the course of the year (Line 7).

Based on historical sales and production data during periods when the finishing lines are constrained, a typical opportunity cost, for the station is estimated using the business model. (Line 8). Multiplying the shadow price by the number of constrained shifts gives the yearly total opportunity cost at that station (Line 9). This opportunity cost, when divided by the annual sales volume gives an average opportunity cost per pound of commercial product (Line 11.)

This opportunity cost can be considered a "hurdle rate." If Product A had revenues exactly equal to variable cost, entering into the contract would represent a loss of capacity during peak periods, with no offsetting increase in income. The break-even

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[23] One avenue that was suggested to commercial sales management following these analyses would be to try to time commercial shipment volumes counter to the seasonal trends in the tubing wholesaler markets so as to face a lower "hurdle rate."

point at which Product A becomes profitable in light of its consumption of finishing line capacity is not at (revenues - variable costs) = $0, but at (revenues - variable costs) = average opportunity cost per pound, or $0.18, in this example.

Table 7-2-B shows this type of an analysis. Line 14 shows the margin over metal for each product, or revenues (Line 12) less metal costs (Line 13). Variable production costs (Line 15) are then subtracted to calculate a contribution margin (Line 16), labeled "Margin under Current Pricing System." However, what is lacking is a valuation of the capacity that is effectively sold off with this contract. Line 17 represents the value of the capacity allocated to the contract (From Line 11). The "Net margin after opportunity costs" represents the "real" value of the contract to the firm, in light of both the profitability of the commercial product itself and of the production losses that will be associated with the commercial contract during peak periods.

As shown in Table 7-2-B, in a case where production costs and sale prices are identical this opportunity cost can have a significant impact on the "net margin after opportunity costs," and can be decisive in whether or not a commercial contract is truly worthwhile.

7.3 Accounting Systems & Incentives

Measurements

Manufacturing Variances

Manufacturing management is measured on the metric of manufacturing variances, or the difference between the actual production costs and the "standard" production costs developed in accounting. The existing standards, besides being outdated (last revised in 1986), did not differentiate between products or product classes. For example, the Plant 4 manufacturing variance determined as shown below:

Standard Value of Product = (Tons Produced) * (Standard Value Per Ton)

Manufacturing Variance = (Standard Value of Product) - (Actual Manufacturing Costs)

The "Standard Value Per Ton" is a fixed number drawn from historical financial data that approximates the cost of manufacturing a ton of a broad mix of products. It can be thought of as the total of manufacturing costs divided by the total output tonnage of the plant over a long period such as a year. This metric tends to reward manufacturing for producing heavier walled tubing than lighter walled tubing, because the lighter walled tubing requires more drawing per pound, and the manufacturing organization gets no added "standard value" for the added labor. Indeed, towards the end of a given month, the plant is apt to be producing heavy walled tubing than light walled tubing, regardless of customer needs.

Sales Variances

There are three types of margins used in the copper tubing industry: margins over metal, margins over standard cost, and margins over actual variable costs. They are defined as:

Margin over Metal = Revenue - Metal Cost

Margin over Std. Cost = Revenue - Metal Cost - Standard Value For All Products

Margin over Actual Variable Cost =
Revenue - Metal Cost - Actual Variable Costs For That Product

Note that since the accounting "standard value" is the same for all products and represents only the aggregate average costs of production. Only the margin over actual variable costs accounts for the difference in variable costs between products.

Sales representatives are compensated on the basis of two factors:

- Average margin over standard costs
- Overall sales volume

Of note is that this incentive system does not account for the variable manufacturing costs of particular products. In other words, sales is driven to sell the highest cost per pound products, regardless of whether or not the sales price offsets the difficulty of manufacturing such typically harder to manufacture products. A further weakness of the incentive system is that it does not necessarily encourage the most prudent use of productive capacity.

Recommendations

Manufacturing Incentives

A change to the manufacturing incentive system is being considered and is illustrated below[24]. For example, consider four products, with manufacturing and standard costs as shown below.

Table 7-3-A Proposed Incentive System

Item	Product A	Product B	Product C	Product D
Manufacturing Cost	$0.20	$0.25	$0.35	$0.35
Old Accounting "Standard Cost"	$0.25	$0.25	$0.25	$0.25
New Accounting "Standard Cost"	$0.20	$0.25	$0.35	$0.35

As shown above in Table 7-3, under the old incentive system, the accounting "Standard Cost" was the same for all products. When the mill produced an unusually large quantity of an item such as products C or D, which have higher than average manufacturing costs, the plant would have a negative manufacturing variance at the end of the week, because actual costs would exceed "standard" costs.

Under the new accounting system, this will no longer be a problem. The "standard" manufacturing costs are much closer to actual production costs of individual products. Therefore, the plant's manufacturing variance should be indifferent to the product mix flowing through the mill. The incentive system would tend to focus the manufacturing organization on cutting costs on each product.

A weakness of the proposed manufacturing variance metric is that it fails to make a distinction between production at bottleneck and non-bottleneck processes. At a non-

[24] As of April, 1996, a change to the standard costs has been implemented that differentiates between annealed and non-annealed product, based on the costing work developed in the cost analysis.

bottleneck process, inefficiencies may add incremental cost per pound. But at a bottleneck process, inefficiencies will cost not only an additional cost per pound, but will decrease the overall volume of sales. The flaw in the proposed system is that manufacturing becomes indifferent to product mix and volume, rather than being pushed to focus on the products that will bring in the most revenues. This is illustrated in Table 7-3-B, below:

Table 7-3-B Proposed Incentive System With Rate of Contribution Generated

Item	Product A	Product B	Product C	Product D
Manufacturing Cost	$0.20	$0.25	$0.35	$0.35
Old Accounting "Standard Cost"	$0.25	$0.25	$0.25	$0.25
New Accounting "Standard Cost"	$0.20	$0.25	$0.35	$0.35
Sales Margin over Material Cost	$0.50	$0.60	$0.70	$0.60
Margin over Variable Costs	$0.30	$0.35	$0.35	$0.25
Production Rate Through Bottleneck	1 ton/hr	2 ton/hr	2 ton/hr	1 ton/hr
Rate of Contribution Generated	$600/hr	$1,400/hr	$1,400/hr	$500/hr

As shown above in Table 7-3, manufacturing costs have may little correlation to margins over material costs. In the case illustrated, the higher margins over variable costs combined with higher production rates make Products B and C substantially more valuable to Reading Tube than Products A and B, in terms of the rate of generation of contribution to the bottom line. Thus, Reading Tube as a whole would see the greatest benefit from production of Products B and C. When there is excess demand priority should be placed on production of Products B and C in the mills.

Under the proposed accounting system, manufacturing management is no longer penalized for producing Product C. The manufacturing variance is expected to be unchanged by the mix of products flowing through the mill since the new "standard costs" closely match actual production costs. However, there is nothing in the existing or proposed incentive systems that will reward production for focusing on the throughput of Products B and C. Thus the manufacturing variance metric is sub-optimal in that it tends to focus manufacturing management on reducing the cost of all products rather than on increasing the throughput of the particular products most directly tied to overall corporate profitability.

Sales Incentives

The first step to improving sales incentives might be to tie sales commissions to margins over actual production costs rather than to margins over standard costs. The second, perhaps even more important step would be to factor in the costs of capacity consumption on a per product basis. The problem with doing so, however, is the variability in the value of capacity with market conditions. The problem with not doing so, however, is that the cost of capacity can be easily forgotten by sales representatives. At a minimum, utilizing "hurdle rates" as developed in Chapter 7 will help screen out commercial commitments with excessive opportunity costs.

Linking Incentives Directly To Profitability

A weakness of the current incentive system is that neither sales nor manufacturing is driven to grow the bottom line directly. Perhaps partly because of the existing incentive systems, and perhaps also because until recently clear cost data was not available, sales and manufacturing have historically tended to have different priorities. There was an underlying tension between sales and manufacturing as sales tried to grow revenue per pound (favoring light walled products) and production tried to reduce cost per pound (favoring heavy walled products.) With clearer cost and market analyses, there is a growing consensus between the functional organizations in terms of an overall business strategy.

One possibility for further strengthening inter-functional cooperation might be to tie a portion of sales and manufacturing management's staff's compensation directly to the bottom line. Put differently, would a professional basketball team be wise to reward its players based upon the number of baskets they scored individually, or on the number of wins they achieved as a team? The previously developed models served to "marry" sales plans to production capabilities through numerical optimization, but perhaps a common goal would further strengthen that "marriage."

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