ANALYSIS OF GLOBAL MANUFACTURING STRATEGIES FOR HIGH VOLUME HIGH TECHNOLOGY PRODUCTS

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Abstract

Companies making the transition from low volume manufacturing to dramatically higher volumes may find themselves pondering the viability of what has previously constituted a tried and true strategy of regional placement. If demand is predicted to grow exponentially, the company may need to look at the costs and benefits inherent in a range of manufacturing options, none of which can be implemented from a blank slate.

This study focuses on one company whose demand for its suite of products was growing rapidly around the world. The company's current manufacturing sites could be used as the foundation for a regional manufacturing structure; a region's demand for a particular product could be supplied, in whole or in part, by that regional manufacturing site. In order to compare such scenarios with the current approach being used by the company, one in which products and processes are developed at domestic centers and then are moved overseas, this thesis focuses on the development of a model capable of calculating overall operating costs over multiple years. The model was used to compare a continuation of the company's current manufacturing strategy with an evolving regional structure over a ten year span. The costs calculated in these two strategies were subjected to various sensitivity analyses in order to model multiple scenarios.

The analysis reveals that the evolution over a seven to ten year period towards a more regional manufacturing structure does not carry a substantial manufacturing cost penalty, as might be expected. The study examines not merely the overall costs, but distinguishes among components as capital depreciation, labor, and duties. By viewing these costs in proportion to one another, it is possible to draw new conclusions regarding the transition from low volume to high volume manufacturing, particularly with the high technology products this company produces.

The thesis concludes by addressing the reality of how manufacturing decisions are made. Although it is important to know the relative costs of various manufacturing strategies, such an analysis may serve as little more than a springboard into discussing whether or not a given strategy fits comfortably within that company's culture.

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On the industrial side, I would like to thank Anne-Murray Allen and Ed Feitzinger for providing me the on site tools needed to analyze manufacturing strategy.

I'd also like to thank Cheddar, for his superior rat catching ability and unsurpassed furriness.

These names are by no means exhaustive; there are many other people who have given time and support to this project. At the same time, I bear the sole blame for any inaccuracies within this thesis and within the software model.

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CHAPTER ONE: INTRODUCTION.

1.1 Overview.

Rapid growth in demand for a company's products is a double-edged sword: on the one hand, it demonstrates that company's prescience in understanding consumers' needs, and on the other, it may require radical reorganization of the way in which the company makes its products. This thesis focuses on a company whose successful introduction of a technology, now some ten years old, is forcing it to rethink its ability to meet burgeoning market demand for its products. The company wishes to meet high service levels for product demand on a global basis. In order to do so, however, the company must carefully chart a manufacturing strategy that builds upon its current infrastructure and is cost-effective at very high manufacturing volumes. An analysis of the overall manufacturing costs inherent in different strategies thus serves as a foundation upon which the company can construct a more qualitative dialogue about which strategy fits most comfortably within its culture.

1.2 Company Background.

What will be referred to in this thesis as "the company" is in fact a largely autonomous division of a corporation solidly established as a major technological innovator in the field of electronics. The division under question is quite young; it was started with the spark of a basic technological application that has spawned other divisions as well as external competitors. Now some ten years old, the company is devoted to the development, manufacture, distribution, and marketing of approximately eight major product families, all of varying stages of maturity. There are currently five manufacturing locations around the globe; at two of the sites, the majority of research and development both for product and process is done. The company is examining possible sixth and seventh manufacturing sites.

1.3 Statement of the Problem.

The company has experienced exponential growth in demand for its products, which draw from a wide range of complex technologies and manufacturing processes. This demand is global in nature and is expected to continue to grow rapidly in the next few years. As a result, the company is interested in investigating the costs and benefits of moving to a regionalized structure for manufacturing, in order to meet growing and changing demands for shortened product delivery lead times, customization capabilities, and decreased costs of distribution.

The manufacture of these products requires an understanding of both strategic external supplier relations and diverse manufacturing techniques, from wafer fabrication to high volume plastic assembly. The supply chain is also affected by the movement of manufactured products to customization facilities and through distribution centers to retail outlets. Finally, the company must manage the flow of product both through existing retail networks and through new outlets in order to satisfy the demand of end users in a timely way.

Given the growing demand for these products, and the changing nature of that demand, the company is interested in examining the costs and benefits inherent in matching regional production to regional demand on a global basis. To date, however, the capital intensive nature of this company's manufacturing process has conspired to keep production of newer technologies close to its two research and development facilities. Additional production sites have been chosen for tax purposes, or on the basis of increased space requirements, without including a clear understanding of the higher costs of complex logistics.

At the same time, current manufacturing sites have sought to minimize production costs through economies of scale. A move to producing a varied mix of product in each region might lose the benefits of economies of scale, even as it reduces the costs of managing logistics. Moreover, it is not clear how inventory costs might increase in moving from a single-site manufacturing strategy to a multiple-site manufacturing strategy.

1.4 Thesis Objective.

This thesis is the outcome of a joint research project between the company and MIT, under the auspices of the Leaders for Manufacturing program. The objective of the study, which was undertaken while we worked on site at the company for six months, is to accurately portray the quantifiable costs associated with pursuing various global manufacturing strategies over the next ten years. In portraying these costs, a model was developed which can serve as a blueprint for those companies wishing to make similar cost-benefit analyses. Actual output from the model, as well as specific inputs which remain confidential, have been disguised or are explained in general terms out of respect for the proprietary nature of the information.

1.5 Scope and Limitations.

This thesis research has been restricted to an analysis of the quantifiable costs of various manufacturing strategies. As such, it does not seek to understand the costs of complexity inherent in different manufacturing organizations. Nor does it examine what other companies in a similar situation have done. Yet these limitations in scope strengthen the thesis; notwithstanding the fact that companies make decisions based on intuition or bizarre logic, they need to have a grasp of the basic costs, if only to know an approximate differential in order to ascertain how much their intuition is costing them.

The analysis is done on a comparative basis; while every attempt was made to portray costs accurately, both in an absolute sense and in a relative sense, more weight should be given to the differentials among the various scenarios. Since many costs are rough approximations, a certain modesty is necessary when interpreting these differentials; any difference of less than five percent is probably statistically insignificant.

The model presented as part of the thesis can serve as a template for those wondering how to go about analyzing the costs of manufacturing. It is almost certainly not the most efficient way of calculating costs; much of its power lies in the fact that it is extremely flexible, more so than was needed to perform the current analysis.

1.6 Specific Deliverables of the Thesis.

This thesis comes out of research and specific recommendations made to the company at the end of a six month internship. Deliverables come in three flavors: first, a description of how to go about doing an analysis of the costs of various manufacturing strategies, second, an Excel model that can serve as a template for similar analyses, and third, a general depiction of the results that the process and model yielded. Once again, it is important to note that within this publication, products, processes, and numbers have largely been masked in order to protect the company's confidentiality.

It is our hope that this research will serve as a beachhead for individuals confronted with the challenge of comparing the costs and benefits of various manufacturing strategies. It will have accomplished this goal if individuals are able to spend substantially less time building models in order to accurately depict costs, and accordingly more time discussing how a particular strategy might fit within that company's culture.

1.7 Methods.

In order to analyze the costs of manufacture, we had to work on both the process needed to collect accurate quantitative data, and the development of a tool that could calculate costs. This two-pronged approach entailed working with three groups of people: first, those individuals within the pertinent groups inside the company who have access to necessary numbers; second, an internal company consultant who is well versed in model construction; and third, advisors at MIT who have experience with similar studies.

The model was constructed in Excel, in order to facilitate widespread use. With the exception of the inventory modeling, the model was constructed completely by the author. Portions of the model were downloaded to advisors at MIT and within the company for feedback. Being on site and working adjacent to the staff strategy planners at the company facilitated data collection. Model development and data collection took place largely in parallel; as data became available, it took the place of dummy numbers within the spreadsheets.

The first three months of the six month internship were spent learning about the company, its culture, its products, and its processes. In addition, rough cuts were made at defining the scope of the problem and a timetable was established for data collection, model completion, and final analysis. Focus on building the model consumed much of the next two months. Finally, the last pieces of data were entered and the final analysis consumed the last two weeks of the internship. A presentation was made of the results of the analysis at the end of the six month period, with specific recommendations. This analysis, along with its supplementary documentation, was left with the company.

1.8 Preview of the Discussion.

This thesis focuses on the process by which we made an analysis of various manufacturing strategies; as such, the discussion roughly parallels the thought process that one might go through in order to repeat such an analysis.

Chapter One is an introduction; it covers the background of the company, the challenges the company faces, how the thesis fits within a broader resolution of these challenges, and what the company and MIT expected the thesis research to deliver.

Chapter Two explains the nature of the company's products. It includes a depiction of the dependency relationship that these products share with other corporate divisions' products. In addition, it addresses the challenges of accurately predicting demand over the next ten years.

Chapter Three focuses on the manufacturing processes used to make these products. It develops an understanding of external suppliers, and follows the manufacturing process from wafer fabrication to packaging and distribution.

Chapter Four delves into the process of identifying which factors are important to measure in estimating the costs of manufacture. It also discusses which groups within the company are important to work with in order to obtain accurate estimates of these costs.

Chapter Five discusses the development of the model used to analyze costs. Readers will benefit from using the software model enclosed with the thesis to follow the logic of the calculations.

Chapter Six addresses how the model is used to calculate results for three different models, ranging from continuation of a conventional strategy to one which relies on a regional manufacturing structure. Results of a general nature are given here.

Chapter Seven provides a conclusion, focusing on the strengths and weaknesses of the described approach. It addresses potential areas for research that would strengthen an understanding of how to go about accurately determining the optimum manufacturing strategy for such a company. In addition, the chapter deals with the often neglected art of translating output into a persuasive presentation, given the understanding of the appropriate audience's preconceptions. It makes mention of discussions that were generated as a result of the analysis.

CHAPTER TWO: COMPANY PRODUCTS.

2.1 Description of the Products.

The products made by the company are separated into eight broad product families, all of varying technological complexity. These products, first introduced in the mid-1980's, have largely enjoyed a great deal of success. One of the more interesting aspects of this company's products is that the most mature product family is not yet obsolete; instead, it enjoys some of its largest volume sales ever as new applications for it are discovered by other companies. For the purposes of this analysis, it is sufficient to limit comparisons of manufacturing strategies to the seven newest product families, as the oldest product family is not made in volumes that would justify its being made in multiple locations.

2.2 Product Dependency on Host Architecture.

One of the more interesting aspects of these products is that their sales and use are dependent on products made by other companies within the corporation. This dependency is most often described as one of a host-trade relationship. A customer first purchases the host product with a trade product installed in it, and occasionally services it by buying more trade products. Depending on the level of the technology, a customer might expect to buy replacement trade products every six months. A roughly analogous product, albeit one which uses a much simpler technology, is that of Gillette Sensor razors and razor blades. Consumers buy the razor with a couple of blades, and then must replenish the razor from time to time by buying Sensor blades or generic knockoffs.

This dependency relationship complicates the design and marketing of the company's trade products. From a design perspective, the company wishes to pass on to consumers its most advanced products; but doing so necessitates the consumer's purchase of a newer host product. The company making host product must in turn make sure that the trade products are seamlessly integrated into the host architecture, and that consumers will find it easy to replenish the host product. From a marketing perspective, there is a tension between the two companies, both of whom are expected to show a profit within the corporation in order to gain more funds for research and development. But each company's decision to maximize its own profits at the cost of the other may result in an overall suboptimal solution. Again, the razor blade example is relevant: Gillette may sell the handle at a loss or at cost and recoup profits through sales of its razors.

2.3 Demand Projections for Host Architecture.

In order to more accurately depict the actual costs and benefits of pursuing one manufacturing strategy over another, the demand projections for the host product become of interest. After all, a consumer will not buy trade product from the company unless he owns a host product. There are currently several divisions within the parent corporation, all of whom make host products. These products may share the same trade product, but are intended for different purposes, and are often sold through different marketing channels.

2.4 Demand Projections for Products.

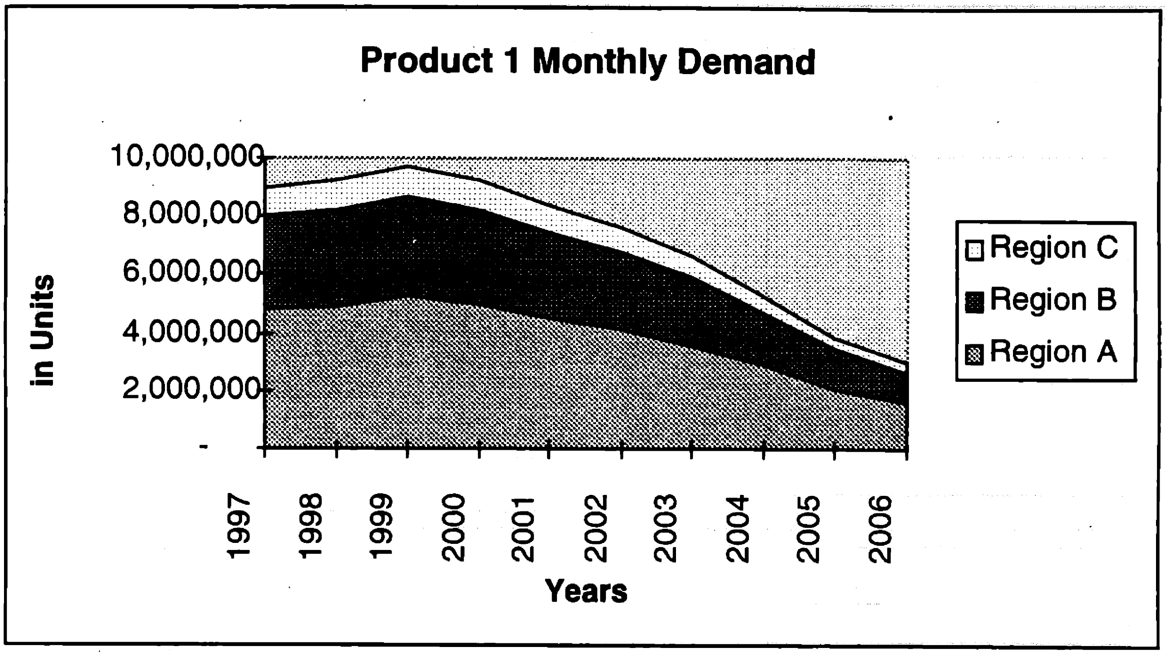
There are seven product families addressed in this analysis, all of varying degrees of technology and life cycle maturity. For the purposes of this thesis, the product families will simply be labeled 1 through 7. The analysis focuses on demand projections out ten years for each of the products. In addition, product demand is broken down into three broad geographical regions which comprise global distribution. It can be assumed that the level of technological complexity follows the product number; product 6, for example, is much more advanced than product 1. Regions are labeled A, B, and C. As is noted later, regions D through H also have demand curves for products 6 and 7.

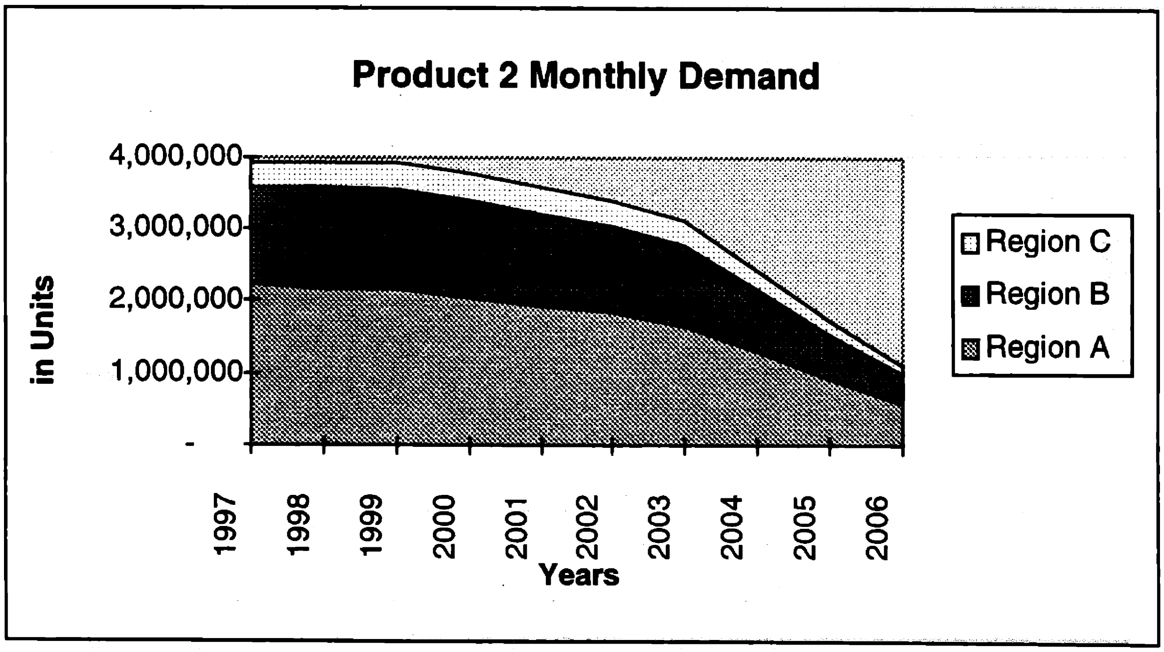
Within the company's strategic marketing division, host product forecasts are taken as a static input. The durability of the host product is then estimated, and usage rates for trade product are estimated. These inputs and estimates are then used to derive a detailed five year forecast, broken down by region. For further projections, a simulation package is run which attempts to follow curves of expected product maturity life cycles. While the simulation package projects demand out ten or fifteen years on a global basis, the regional breakdown can be deduced from more short term market growth rates.

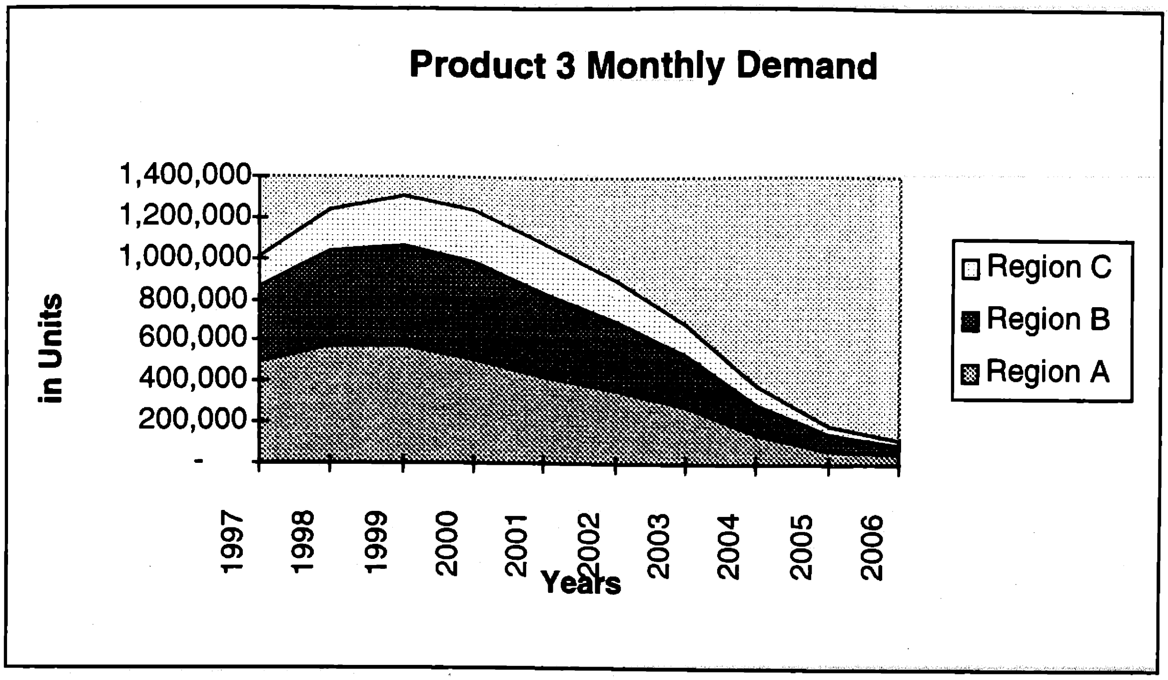
It should be noted here that one of the more interesting reasons given for matching regional production to regional demand is that, within a given region, demand itself can be affected by the very fact that product is being made there. In the case of products such as cars or airplanes, companies must often commit to manufacturing in the local economy to duck under tariffs, national standards, duties, and other obstacles designed to spur import substitution. In addition, a company might expect to be more cognizant of new market channels as well as needed design changes to meet market needs if it is manufacturing in that region. But for the purposes of this analysis forecast demand is NOT assumed to be affected by different manufacturing strategies.

For current technology products the breakdown of demand into three broad regions is sufficient. But for the products 6 and 7, there is an attempt to increase the durability so that it can be considered a more integral part of the host architecture. As a result, the proportion of product sold with host product increases relative to trade product. More importantly, however, the more complex integration of host and trade architecture necessitates installation of the trade product before a host product is shipped. Whereas consumers are expected to assemble current technology, the newest technology may require factory installation. From the point of view of regional demand analysis, this last point is tricky. Since the host and trade companies are making manufacturing decisions independently, there is a potential loss of overall efficiency in the system.

As is shown in the graphs of forecast demand for products 6 and 7, there are not three but eight regions of demand. The five additional regions represent host product manufacturing sites, which require trade product for final assembly and test. A manufacturing strategy which matches regional manufacturing to regional demand may thus have the perverse effect of making trade product in one region not because the consumer buys it there, but because the host product is made there.



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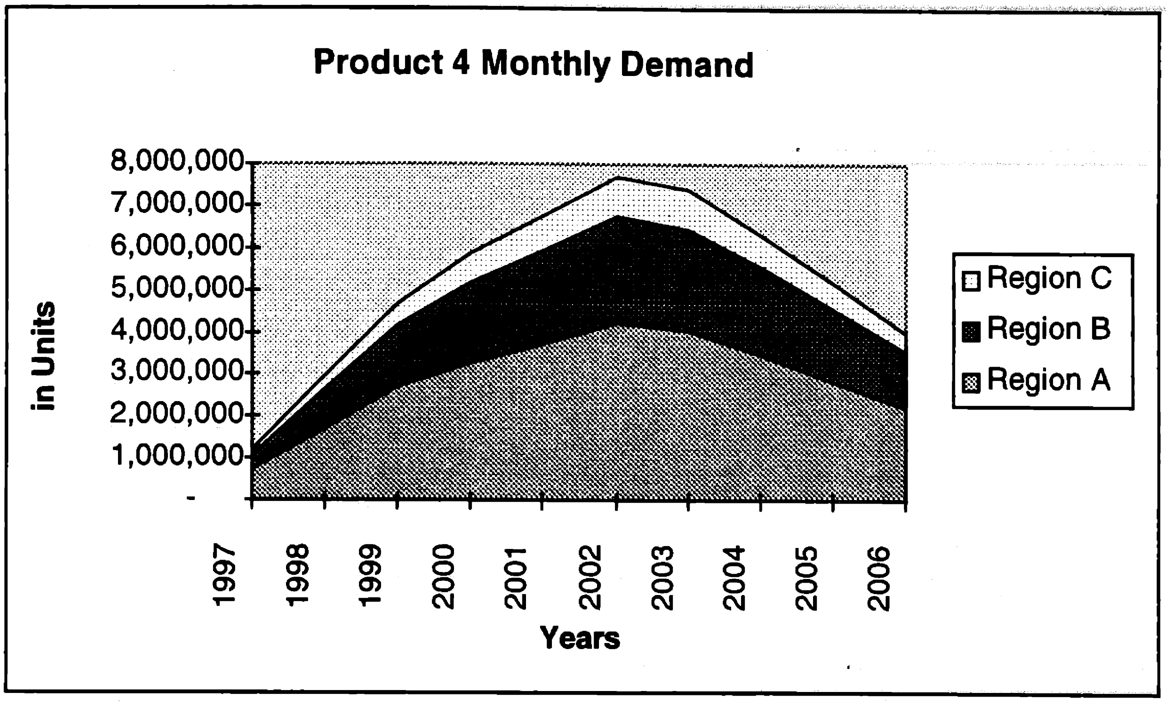
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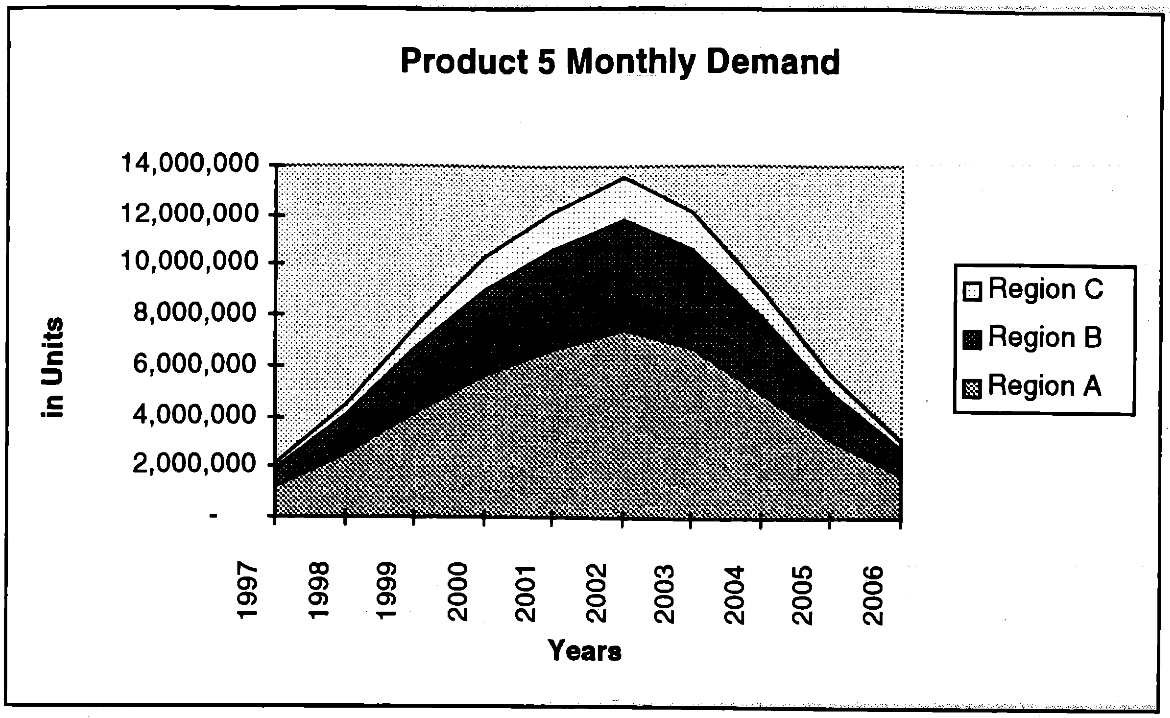
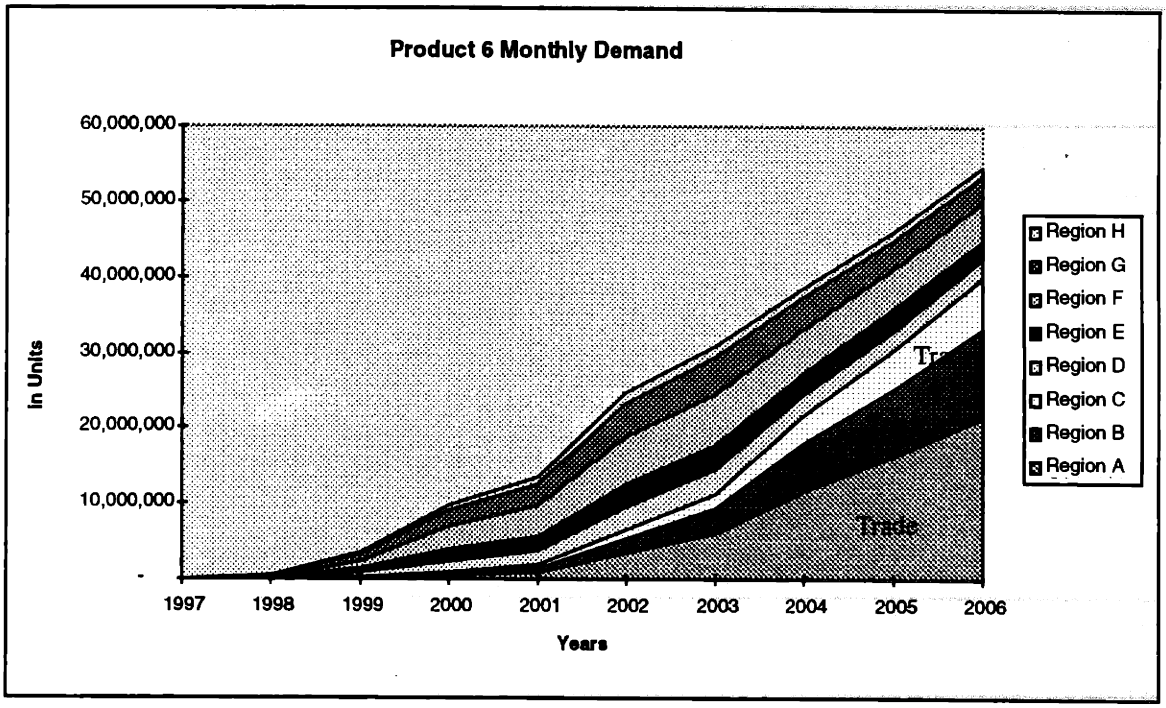

Product 5 Monthly Demand
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
-
in Units
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Years
Region C
Region B
Region A


Product 6 Monthly Demand
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
-
In Units
1997
1998
1999
2000
2001
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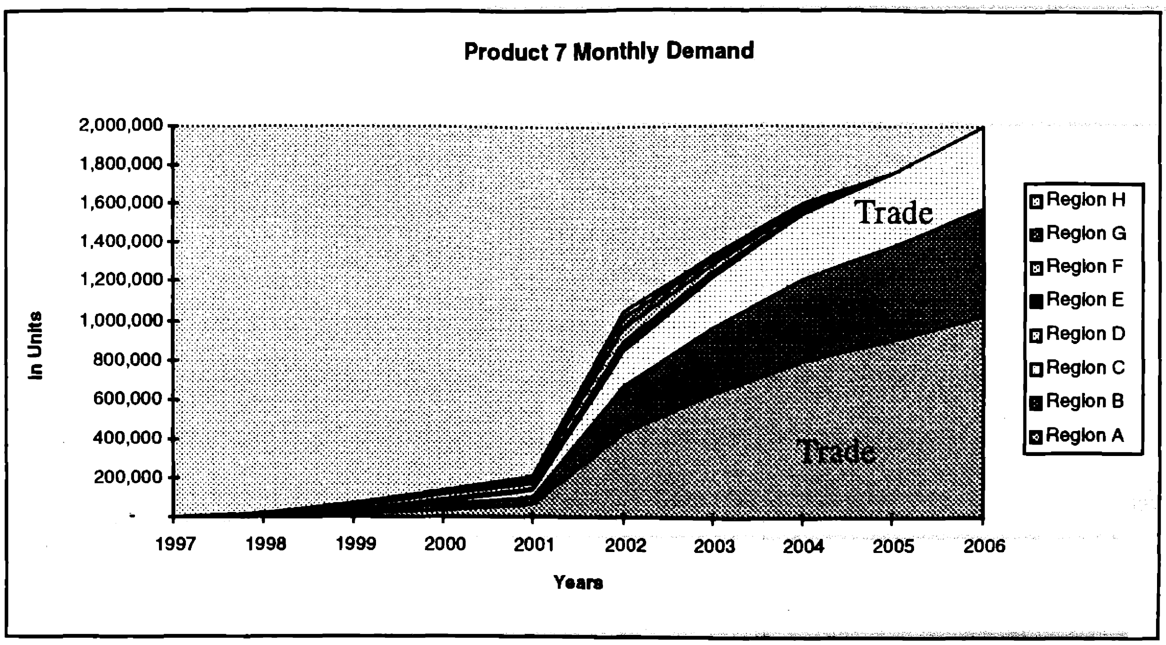
Trade



2.5 Challenges in Forecasting Demand.

There are substantial challenges in accurately forecasting demand for the company's products. First, the company's culture of engineering excellence mitigates against its ability to grow adequate marketing talent in house or hire it from the outside. The company is quite young, and until recently has been more concerned with the technological excellence of its products; the engineering culture pushes the newest technological frontier, often at the expense of establishing a stable base of consumer demand for its current technology products.

Perhaps more importantly, even the most mature products the company sells are less than ten years old. Not only have they not been phased out, but new marketing channels continue to appear, both within and without the corporation, for the products. The life cycle depicted in the above graphs, then, is a best guess at what a phase out might look like; there is no real life experience to draw from.

It is the newest products that are projected to increase the company's business most substantially. But since these products have not yet been introduced on the market, it is not at all clear that these volumes will materialize. Indeed, the products rely not only on exponential growth in the sales of host product, but on increased usage rates by consumers. In short, much of the demand growth is predicated on a sea change in the way that consumers view this product.

To the extent that the company is successful in growing the business so dramatically, it should expect to see unbridled competition in two areas: first, in its ability to manage large volume distribution networks effectively so that consumers can buy its products, and second, from would-be competitors who can leverage their expertise in similar technologies or low-cost manufacturing. This second point is cause for concern; although the market is currently small enough that consumers largely buy trade product on the basis of the company's strong brand name, a larger volume growth will encourage other strong brand names to enter the market. Xerox's media division serves as an analogy; when its copiers first came out, Xerox was able to convince consumers that their media was necessary. But as the volume of copying grew, other paper manufacturers redirected their efforts to make competitively priced and at times superior paper products for Xerox's copiers. The market has grown enormously, but Xerox has not managed to continue its initial monopoly of media products.

To date, some attempts have been made to estimate past error in forecasting. But these efforts serve less as corrective measures than as documentation. With the markets projected to grow by 50% a year, it is difficult to pin down usage rates, host product sales, and host product life cycles.

If the regional markets that comprise global demand are viewed as a portfolio, the variability around expected demand in each region will be higher than that for the portfolio as a whole. But in fact, some regions show more stable, and hence more predictable, demand growth. Other regions' demand profiles, which are expected to grow more rapidly, are less well understood by the company; as a result, we might expect to see much greater variability around projected demand in these regions. At this point, the company estimates global variability, as opposed to regional variability. While such a measure complements its current strategy of decoupling the location of its manufacturing operations from demand, it makes it more difficult to estimate the needed manufacturing buffers should the company move to a regionalized strategy of manufacturing. For the purposes of this analysis, the head of the company has decreed that manufacturing capacity be matched to the upper end of the marketing team's forecast range in variability.

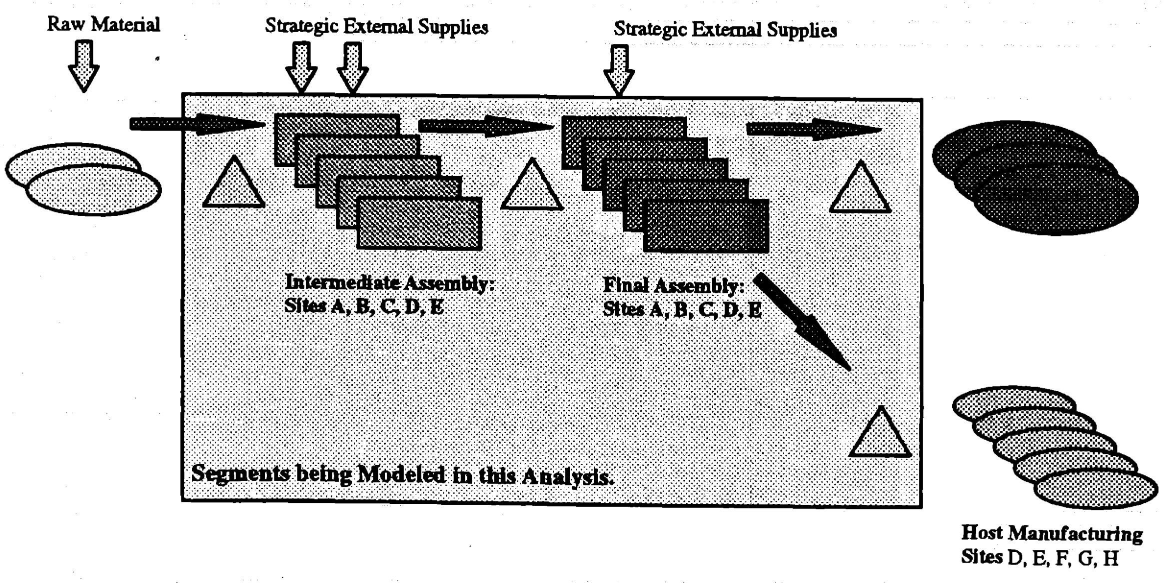
CHAPTER THREE - MANUFACTURING PROCESS.

3.1 Upstream Supply of Raw Materials.

In this section we follow the logical flow of the manufacturing process for making the seven products discussed in the second chapter. The company is currently considering increasingly outsourcing the manufacturing of its products at both the upstream and downstream stages; a discussion of the calculus being used to make these decisions falls outside the scope of this study, however.

Any manufacturing process entails the sourcing and management of external supplies, both from a tactical and strategic point of view. Generally speaking, external supplies can be broken into two categories: strategic and nonstrategic. The company tends to assume that nonstrategic external supplies, e.g. nails, can be locally sourced and do not require as close a management of supplier relationships. In contrast, strategic supplies often come from a single source, or have a high degree of technical content.

In this company, there are three points of entry for strategic external supplies: at the first stage, the second stage, and the third stage of the manufacturing process (see diagram).



For the purposes of this analysis, it is assumed that nonstrategic external supplies can be regionally sourced where needed. Strategic external supplies, while not regionally sourced, can be shipped to any point; contract negotiations with these suppliers often include global shipping cost estimations, and differentials in these costs are thus judged to be marginal to the analysis. As a result, supplies generally fall outside the scope of the analysis. In reality, careful consideration would need to be made about the ease with which suppliers could co-locate, or alternatively ship larger amounts of material longer distances. In addition, such issues as product shelf life and inventory costs for external supplies could become areas of focus.

3.2 First Stage of Manufacturing Process.

The first stage of the manufacturing process is currently conducted in three locations: two within the company structure and one externally. The nature of this stage of the process requires substantial capital investments and careful environmental controls. As a result, the company would probably try to capitalize on the economies of scale both of its existing manufacturing facilities and the capacities of other manufacturers devoted to producing this component. It is perhaps fair to characterize this aspect of the manufacturing process as one in which the company is not as capable as its would-be suppliers; given the enormous up front cost of building a plant devoted to this stage, production will most probably be outsourced in the future.

When comparing manufacturing strategies, then, the first stage of the manufacturing process can be characterized as an internal component supplier that need not be co-located with the downstream process. These components are durable and can be air shipped efficiently, reducing potential problems with feedback loops. Notwithstanding the fact that these components are being made upstream, however, they are the most technical part of the product and are thus costly in terms of in-process inventory. The first buffer, between first and second manufacturing stages, is important to model.

3.3 Second Stage of the Manufacturing Process.

The second stage of the manufacturing company, shown on the diagram as one module, is in fact a complex series of steps involving many pieces of equipment. In terms of modeling, the complexity results from the fact that each set of equipment constituting a step within the stage has a different level of flexibility and a different capacity, as well as a different footprint and capital cost.

Machine X, for instance, can run products 2,3, and 4, but not 1, 5,6, and 7. It is one of 12 machines that comprise the fourth step of the second stage of the manufacturing process. Products 2 and 3 have a quicker cycle time than product 4; as a result, Machine X's overall capacity depends on the overall levels of each product run on it. Machine Y can run products 5, 6, and 7; but its capacity to run each product is different as well, and its capital cost is higher than Machine X. Product 1 does not need to be run through either machine.

The inherent complexity of this stage presents a peculiar challenge for modeling capacity, and correspondingly, the number of machines needed at each site to meet demand. While the details of the cost sub models developed to model this aspect accurately are more fully explained in the fifth chapter, it bears mention here that the model gains credibility by accurately depicting capacity needs down to the individual machine level.

This stage is considered by the manufacturing managers in the company to be a core competency for the company; whereas the upstream and downstream portions of manufacturing might be outsourced, this stage is where a substantial portion of value that can't be easily outsourced is added. Yet this stage does not incur the high up-front costs that the first stage of manufacturing bears. As a result, it is plausible to consider placing second stage manufacturing capacity in all of the five manufacturing sites; a fully regionalized scheme might have second stage capacity for products in all locations.

Another important note to make is that the shelf life of finished components within this stage is limited; if second and third stages are not co-located, there is a potential for a breakdown in the feedback loop between the two stages.

3.4 Third Stage of Manufacturing Process.

The third stage of the manufacturing process is substantially easier to understand; it involves high volume, dedicated lines which can be easily transported to lower cost manufacturing locations. In order to add capacity, another line is simply transferred or purchased outright. For more mature products, consideration is being given to the outsourcing of this stage. But for the purposes of this analysis, a partially regionalized manufacturing structure might entail placing third stage manufacturing lines in each of the regions, allowing a matched regional capacity.

3.5 Packaging of Products.

As a consumer item, the company's products benefit from a relatively sophisticated packaging policy. In a sense, this step could be described as the final stage in the manufacturing process. Packaging of the product is done in three locations, each within a region of demand. The three locations are strategically placed to correspond to the region's demand, and thus represent a first step on the road to regionalizing upstream stages. Packaging in the regions allows the company to change the language content, coloring schemes, brand tie-ins, and promotions to fall in line with local tastes.

For modeling purposes, the packaging centers thus represent demand nodes for each region. Even if products are made in another region, they will flow through the packaging center located in the region in which the company expects to sell them.

When host products are sold to the customer, the trade product is typically included in the box. For the company's current technology products, this method is sufficient and simplifies its logistics flows; product can go through the normal packaging and distribution centers. There are two exceptions to these rules: products 6 and 7 must be installed in the host product before it is packaged. In order to do so, the company must ship its third stage products not only to packaging centers but to the host product factories. There are five of these factories around the world, each with a different demand profile.

3.6 Distribution of Finished Goods.

Products are shipped from the packaging centers to major wholesalers as well as retail outlets. Given the regional placement of the packaging centers, which can be modeled as regional demand nodes, the final distribution falls outside the scope of this analysis. Once again, the only exceptions to this rule are those portions of products 6 and 7 which flow directly from the third manufacturing stage to host manufacturing sites.

CHAPTER 4 - IDENTIFICATION OF QUANTIFIABLE COST FACTORS.

4.1 Scope of Manufacturing Process Analyzed.

A model must inevitably make simplifications of reality; the one developed for this thesis is no exception. The challenge in doing so is to maintain some level of accuracy in the output while identifying those factors in the manufacturing strategy which represent the most salient costs. When comparing strategies, for instance, it is of little use to extend the model so as to include those costs which remain relatively fixed over a wide range of scenarios.

Such is the case with both upstream and downstream activities in the manufacturing process. The supply of external materials, both strategic and nonstrategic, do not at first pass appear to unduly influence the cost of manufacture in different regions. The first stage of manufacturing for the company will increasingly be outsourced; what is done in-house requires such economies of scale that it cannot easily be regionalized. And the packaging and distribution of products in the final stage is already largely regionalized; as a result, regional packaging centers can be considered relatively fixed demand nodes over the next ten years.

This chapter concentrates on the identification and collection of those costs which do change in a comparative study of manufacturing strategies. Doing so entails an inevitable judgment about which costs are most important, as well as the relative magnitude of the costs. Our judgment in this matter rested on interviews with key customers within the company, the corporate consultant who had engaged in similar analyses at other divisions, and advisors' recommendations. It should be noted that even if a key area of costs, e.g. shipping, is relatively small compared to other costs, its inclusion may encourage overall acceptance of the validity of the model. The model does not, however, seek to quantify the readily recognizable costs of managing different strategies. Again, the goal of a model is to provide some, not all, of the real costs of following a strategy. As such, it serves as a foundation for more nuanced discussions about how a particular strategy might fit within the company's ability to managed centralized or decentralized manufacturing empires.

4.2 Capital Equipment Costs.

After a cautionary note on the need to make simplifications for modeling purposes, the following section may seem unnecessarily complicated. Instead of coming up with step functions that approximated the cost of adding on capacity at each manufacturing stage, we broke down each stage into individual sets of equipment, each with its own capacity, flexibility, and capital costs. While this approach has the drawback of being more complicated in terms of calculations, it does have the advantage of presenting a much more accurate snapshot of equipment costs.

If the reader chooses to do a similar analysis, he will need to decide at an early stage what level of complexity is needed for two purposes: first, for an accurate estimation of the costs, and second, for the appropriate level of credibility from his audience. The latter consideration, given the engineering culture within the company and the relative skepticism with which the strategy group's work was treated, was an overriding concern for us.

The *second stage of the manufacturing process* can be broken into five processes, each of which is composed of multiple pieces of equipment. Treatment of the five processes entails an understanding of the capacity, utilization, and capital cost of each piece of equipment used. For each of the processes, capacity is measured in daily units, with a certain number of shifts and up time assumed.

The first process is comprised of eight different machines. Each machine has a daily output which is measured in what might be called wafers. While all of the machines in this process can run all seven products, the ultimate capacity is different. This difference is due to the fact that, depending on the product run, the number of units on a wafer changes. Thus an understanding not only of the wafer capacity but of the units/wafer for each product is important. For example, machine 1 may be able to make 100 wafers a day, assuming three shifts and a machine utilization of 80%. But Product 1 may have a ratio of 600 units/wafer, whereas Product 2 may have a ratio of 300 units/wafer. As a result, the daily capacity of Machine 1 for Product 1 is 60,000 units; for Product 2 its daily capacity is 30,000 units.

The second process is comprised of nine different machines. Each of these nine machines can run Products 1 - 4; Products 5, 6, and 7 don't go through this process. Once again, capacity is measured in wafers, but the output depends on each product's ratios.

The third process is comprised of six different machines. Like the second process, only Products 1 - 4 need to go through this step. But capacity is measured in sheets as opposed to wafers. Each product has a different unit/sheet ratio, changing the effective output of each machine with the product run on it. Machines 1, 2, and 3 are capable of making Products 1 - 4. Machine 5 is used to make Products 1 and 2, and Machine 6 is used to make Products 2, 3, and 4. It should be noted here that the third process is run in parallel with Processes 1 and 2.

The fourth process is comprised of four different machines. Each machine is capable of making all seven products, but each product takes a different cycle time. As a result, the effective daily capacity in units depends on which product is being run on each machine.

The fifth and final process is comprised of six different machines. Machines 1, 2, and 3 are used to make Products 1 - 4. Machine 4 is dedicated to making Product 4, Machine 5 is dedicated to making Product 5, and Machine 6 can make Products 6 and 7. Daily output is measured in units.

The percentage of good product out of each process, or process yield, is measured at the process level, as opposed to the machine level. These yields, especially those for the production of newer technology products, are expected to increase over time. Yields are measured in the units of the process; for the first process, for example, yields are in terms of good wafers out. While individual chips within a wafer may be bad, the wafer could be considered good; a bad chip will be captured in the yield figures for a downstream process. Each piece of equipment has a capital cost attached to it, which is depreciated over the space of five years.

Changeover times are generally considered to be rolled into a machine's effective capacity figures. In reality, if a machine is flexible enough to run six or seven products and is changed over several times a day to run varieties, there will be a loss in the effective productivity. Yet the volumes discussed in the company's growth projections are sufficiently large to allow each manufacturing site to run substantial enough batches of each product to allow us to ignore the cost of changeovers.

The *third stage of the manufacturing process* is substantially easier to model in terms of costs. At this stage, each set of equipment is bought as a unit and carries with it a certain capacity. Given the high volume nature of manufacture, each set of equipment is dedicated to a single product. In order to add capacity, another set of equipment must be purchased. Capacity is measured in daily units, assuming a certain number of shifts are run on the equipment. A certain percentage of downtime is also incorporated into the capacity figures, allowing for preventive maintenance and unplanned breakdowns and stockouts of work in process. Each set of equipment carries with it a percentage yield figure (good products out/products run through the machine), which may change over time. Finally, a capital cost is attached to the purchase of the line; it is depreciated away over three years. As is the case with the second stage manufacturing equipment, these costs and capacities do not change depending on where they are sited.

Collection of capital costs involved working with two distinct groups - the finance division and the capacity planning division. Within the company, the finance group concentrates on the cost of capital equipment; the capacity planning division concentrates on how many units can be expected from the capital equipment. While one might expect alignment between the two divisions, this was not always the case; we found it necessary to choose among conflicting assumptions made within each division regarding capacity and yield assumptions. The costs portrayed at the machine level reflect the finance group's ability to work closely with industrial engineers on the plant floor and thus gain a realistic understanding of cost for capacity at each stage. In addition, we found that the finance group was more familiar with modeling and was thus able to point to simplifying assumptions about costs in general.

Lead time issues are important at the tactical level; for the purposes of this model, however, a ten year projection of demand allowed sufficient lead times to order most capital equipment. The finance group suggested breaking down demand into one year increments and assuming that manufacturing would order equipment with a six- to twelve-month lead time.

4.3 Space Costs.

The cost of adding new space is appreciably easier to estimate than capital equipment costs. New space is not typically added incrementally; a plant is typically built with extra space and then capital equipment and labor fill it up over time. Moreover, it is not at all clear who actually pays for new space; often the corporate level makes the actual purchases through its corporate real estate finance group. As a result, we have assumed that the relative difference in costs between adding marginal manufacturing capacity in one site or another will be insignificant for modeling purposes.

New space costs are broken down into the two manufacturing stages under question. The second manufacturing stage requires tighter environmental controls and is thus substantially more expensive to build. For each product, a rough step function can be derived; to make 1000 units/day of Product 1, for instance, the company must build 40,000 square feet of clean space. The costs of building this space are measured in dollars/square foot, and may vary by manufacturing site. The third manufacturing stage has a fixed amount of space attached to the installation of each set of equipment; the space includes room for inventory buffers and movement among operators. Once again, the cost of space is measured in dollars/square foot, but is substantially less expensive. since the space is not under as tight an environmental control.

Peripheral, or overhead space is not included in this analysis. Note that the five possible manufacturing sites already exist; the model merely concentrates on the relative growth and corresponding costs of each site. Cafeterias, bathrooms, parking lots, and bicycle racks are necessary but either already exist in sufficient quantity or can be added on at a marginal cost.

Once again, the finance group was the primary source for these costs. There is an area of responsibility within the capacity planning group for space, but it concentrates on the availability as opposed to the costs. In this analysis, each of the sites is assumed capable of growing enough to sufficiently match regional manufacturing capacity to regional demand. In reality, there may be real limitations to growing a site's space. We chose not to constrain the analysis by this parameter in order to generate discussions regarding the strategic value of each site.

4.4 Occupancy Costs.

Occupancy costs are a rough cut at activity-based costing; what portion of the lights burned, for instance, can be attributed to the manufacture of a particular product? The second stage of manufacturing has an appreciably higher occupancy cost than does the third stage due to its tighter environmental controls. As is the case with new build space, occupancy cost is measured in dollars per square foot. It is obtained primarily from the finance group.

4.5 Labor Costs.

Costs for labor vary dramatically by manufacturing site. There are five levels of labor which are directly affected in a comparative analysis of manufacturing strategy: operators, technicians, engineers, supervisors, and managers. The monthly costs for each of these levels were obtained from the finance group; costs include salary, training, and benefits.

Labor is tied to unit capacity in both the second and third manufacturing stages. It varies by site, however, as some sites are more productive than others. In the second stage, each of the processes has a certain number of units produced per operator, by site. This ratio is independent from which products are produced in the process. In the third stage, each set of equipment is dedicated to a product; in order to produce 1,000 daily units of Product 1, for instance, the company might need to have two operators. Operators, technicians, and engineers are directly tied to unit output; the number of supervisors and managers, however, is derived from a ratio of supervisors to operators and technicians and a ratio of managers to supervisors. Again, these ratios might be different for each of the five manufacturing sites.

As workers move through the learning curve on a new process, they should generally become more productive. Within the model this learning is captured through increased process yields over time, rather than improved unit output/headcount ratios. In doing a similar analysis, the reader should take care not to double count this improvement effect over time by accounting for it in both labor and equipment yields.

4.6 Shipping Costs.

Two points of shipping fall within the scope of this analysis: shipment from the second to the third stage of the manufacturing process and shipment from the third stage to the packaging and distribution centers (or, for Products 6 and 7, shipment to host manufacturing sites). As mentioned in sections 3.1 and 3.2, both upstream materials and first stage manufactured components need to be shipped, but their shipping costs are negligible relative to the other costs in this analysis.

Shipping costs are measured in dollars per pound, from point to point. There are two shipping modes: shipping by air (including truck runs at either end) and shipping by surface (either ship or truck). Not surprisingly, the cost of shipping by air is substantially more expensive; but the importance of having quick feedback loops for quality control and lessened work in process in the pipeline may outweigh such costs. In addition, the products made by the company are relatively lightweight and pack well. Finally, there may be shelf-life issues for some work in process which negate the slow boat from China option. These costs were obtained from logistics specialists in both the strategy group and in the finance group.

Overall shipping costs depend on the unit weight of the components, as well as the percentage of product shipped by air instead of surface. The actual amount shipped from point to point largely depends on the allocation strategy that will be explained in chapter five. Co-location of the second and third stages of the manufacturing process and close proximity of the regional packaging center should thus prove to be the lowest cost shipping alternative.

4.7 External Supplier Costs.

As noted in section 3.1, the costs of external supplies fall outside the scope of this analysis. But to say that they are not treated in this thesis is not to say that they shouldn't be considered quite seriously by the reader. In general, the leaner a company's production process, the more attention it must pay to managing the long term relationships with its suppliers.

In this case, the company is in a situation where supplier contracts stipulate global shipping and unit costs; most supplies are air shipped, the cost of the unit includes worldwide delivery, and the relative costs of shipping are insignificant when compared to labor and capital costs. Supplier parts are quite light, very compact, and relatively durable. As a result, changing where the company makes its product has little effect on its costs of obtaining strategic supplies. But over time these relationships may change; a dramatic shift in manufacturing patterns may result in a higher price for supplies.

4.8 Inventory Costs.

Inventory costs can be expected to vary depending on the manufacturing strategy used. Three points in the manufacturing process are important to capture in the model. First, inventory from the first manufacturing stage must be sent to the second stage. Second, inventory from the second manufacturing stage must be sent to the third stage. And third, finished goods inventory held at the third stage buffers both packaging and distribution centers (and, in the case of Products 6 and 7, the five host manufacturing sites). These types of inventory can be described as incoming raw materials, work-in-process, and finished goods inventory. In addition, the components that comprise inventory - safety stock, cycle stock, and in-transit stock - are modeled at each of the three stages.

A number of factors go into determining overall cost of inventory at each stage. The unit cost or value of the product at each stage was obtained from both the logistics and finance groups. A desired service level at each stage of the process needed to be determined. The frequency with which reorders were made at each stage is necessary, as is the delivery frequency of the upstream flow. Other factors that play into the cost are demand variation, lead time for the upstream suppliers, shipping in transit time, and replenishment time. Approximations for these factors came through discussions with the planning group as well as a corporate level consultant.

Inventory costs for external supplies were assumed to fall outside the scope of the analysis. If dramatic shifts in manufacturing strategy caused a ripple effect in the ability of external suppliers to deliver their goods in a timely fashion, a more robust analysis might take these buffer points into account as well. For the purposes of this company, the material costs of the external supplies are not sufficient to have an appreciable effect on the outcome of the analysis.

4.9 Duty Costs.

The company has been successful at negotiating favorable arrangements so as to minimize duty costs to its products. A static analysis might thus ignore the impact of duties altogether. However, we decided to include an engine for estimating duty costs with the model in order to run sensitivity analyses and to enhance flexibility for further use with other companies.

Duties are examined at two points: between the second and third manufacturing stages, and between the third stage and the packaging centers or host manufacturing sites. Duty rates (as a percentage of dutiable value of a part) are from point to point: from manufacturing site 1 to manufacturing site 2, for instance. Of course, vertical integration of the manufacturing process within each region would sidestep the eventuality of having to pay duties. The rates, which are currently assumed to remain at zero, were obtained from the logistics group.

Dutiable value is determined for both work in process and for the finished good prior to packaging, for each product. The value is assumed to be independent of the location of its manufacture. Note that dutiable value is expected to change over time, particularly on the newest technology products.

4.95 Taxes.

As will be noted in the sixth chapter, the company has a strong interest in manufacturing its higher profit products in those regions where the tax code is most lenient. Any adjustment to this manufacturing strategy might be expected to affect profits; a site formerly devoted to making high margin products might need to make lower margin products if its mission is defined as meeting the demand for a full suite of products within that region.

Rather than try to calculate the actual profits and then apply a taxation to them, a tax differential estimator is used. If we estimate the cost of manufacture of product 1 to be X, then making it in a site with a 90% tax differential results in effective manufacturing costs of .9X. The default is 100% in the case of a product made in a tax-neutral site. Two of the five sites can be considered tax-neutral; none of the products warrant a tax break. The other three sites have special tax breaks for industrial welfare or for manufacture of newer technology products. The reader is advised to be very cautious in interpreting the results of this tax treatment; it is a very rough measure constructed by the finance group, and contains built-in assumptions about the overall profitability of each product.

CHAPTER FIVE - DEVELOPMENT OF MODEL USED TO ANALYZE COSTS.

This chapter focuses on the drivers used to estimate costs of comparative manufacturing strategies. The thread of the discussion will closely follow the structure of the one-year model which is included on disk. Accordingly, the reader is encouraged to find a computer, plug the disk in, open the file up in Excel, and follow it. Within the software model itself are more detailed formulations; using the auditing toolbar, the reader can trace formulas as well as review notes containing assumptions. In building the model, we used the note tool extensively to document sources for hard data and assumptions. This technique, although a little tedious during construction, can save time in the long run as new data filters in and assumptions change.

This chapter can be skipped without any loss of the gist of performing a manufacturing strategy analysis. However, we strongly encourage any would-be analyst to review the model in Excel in order to save time for the more valuable work of data collection and analysis validation.

5.1 Selection of Software.

The model used to analyze costs was constructed in Excel for several reasons. First, within the company most analysts have a higher comfort level with analysis done in spreadsheet format; any learning curve associated with a new software program might detract from the credibility of the results of the analysis. Second, we wanted the model to be widely accessible, and easily adjusted to fit the needs of analysts. Since Excel is the predominant spreadsheet package in the U.S., it is easier to follow the logic of cost drivers and make changes as needed. Third, while other software packages offer flashier presentations of the results (in particular, graphical mapping programs lend themselves to a strong visual understanding of the costs and benefits of various logistics strategies), their underlying drivers are spreadsheets. And while the results are easier to understand if shown graphically, they are derived from a calculator which is not as precise.

The reader is encouraged to keep abreast of software developments, however. Mapping programs promise to become both less expensive and substantially more powerful analytical tools than they have been in the past. And the visual understanding of why one global manufacturing strategy is superior to another is a particular selling point when using the analysis effectively.

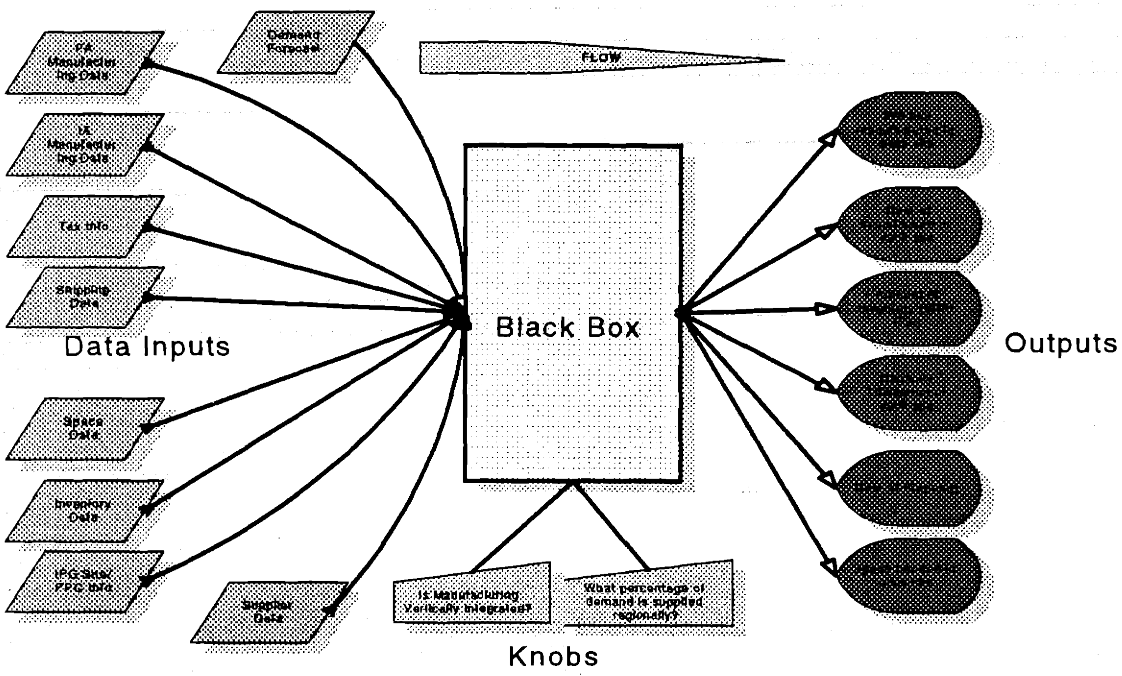
5.2 Determination of Level of Detail.

The determination of the level of detail needed in a model rarely takes place in a vacuum, much as an analyst might like it to do so. This company was no exception: at least two previous analyses had been done on the same subject. Moreover, analysts in both the finance group and the strategy planning group were developing models for scenario building; these models could have captured large chunks of the same information. Yet in none of these cases were the results tied to the specific goal of comparing all of the costs of manufacturing among the proposed strategies. One previous model had focused on logistics; another had captured only a few of the products offered by the company. Another model being developed in parallel with our model ignored the cost of logistics and inventory and focused on the capital equipment needs at each site.

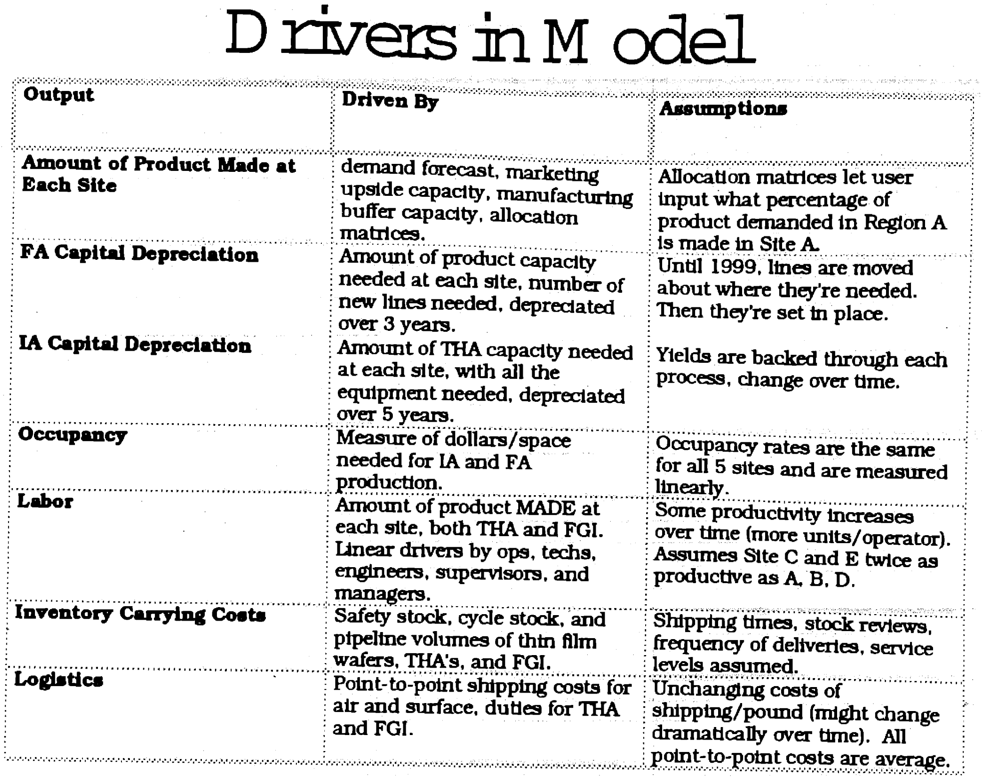
In determining the level of detail of the model, we needed to answer two questions. First, what level of detail is sufficient to give an accurate depiction of the costs, at least on a comparative basis, of competing manufacturing strategies? And second, what level of detail is necessary for the company's various functions to accept this analysis as credible? The first question is somewhat more easy to address; in the case of this analysis, crude approximations, particularly in the area of inventory, duties, shipping, and capital equipment, could have served to shorten the build time of the model and would have still been sufficiently accurate for the purpose at hand. But the second question calls for more attention: would these crude approximations allow groups involved in inventory, duties, shipping, and capital equipment to challenge the results as being based on oversimplification? In the case of this company, we observed competing camps who challenged each other's expertise. And in order to preempt attacks on the results of the model, we sought to incorporate what perhaps might seem to be overly complicated cost drivers for the above-mentioned factors.

5.3 Structure of the Model.

As noted in the second chapter, the model analyzes seven products over a ten year horizon. The model calculates the cost of manufacture for each year; there are thus ten models, loosely linked, that constitute the engine for the analysis. The model included in this thesis is of one year only and is depicted in the diagram below.



The table below lists the primary drivers for each type of output, along with assumptions. Each output is explained in some detail in the following sections.



Drivers in Model

Output	Driven By	Assumptions
Amount of Product Made at Each Site	demand forecast, marketing upside capacity, manufacturing buffer capacity, allocation matrices.	Allocation matrices let user input what percentage of product demanded in Region A is made in Site A.
FA Capital Depreciation	Amount of product capacity needed at each site, number of new lines needed, depreciated over 3 years.	Until 1999, lines are moved about where they're needed. Then they're set in place.
IA Capital Depreciation	Amount of THA capacity needed at each site, with all the equipment needed, depreciated over 5 years.	Yields are backed through each process, change over time.
Occupancy	Measure of dollars/space needed for IA and FA production.	Occupancy rates are the same for all 5 sites and are measured linearly.
Labor	Amount of product MADE at each site, both THA and FGI. Linear drivers by ops, techs, engineers, supervisors, and managers.	Some productivity increases over time (more units/operator). Assumes Site C and E twice as productive as A, B, D.
Inventory Carrying Costs	Safety stock, cycle stock, and pipeline volumes of thin film wafers, THA's, and FGI.	Shipping times, stock reviews, frequency of deliveries, service levels assumed.
Logistics	Point-to-point shipping costs for air and surface, duties for THA and FGI.	Unchanging costs of shipping/pound (might change dramatically over time). All point-to-point costs are average.

Breaking down the model by year carries certain costs and benefits. The clearest benefit is that a one year model is simply more manageable as an entity; cost inputs change over time, equipment is ordered with an approximate one year lead time, and the output can be calculated more efficiently. On the other hand, capital equipment depreciates over time, labor can't be hired and fired at will, and space is not entirely fungible. In order to maintain overall model integrity, an analyst must carefully update each successive year's model to capture the foundation of capital equipment, labor, and space. This updating can either be done manually - the analyst can run each year, take the buildup of equipment, labor, and space for that year, and plug it in to the next year's model before running it - or automatically, through links.

The basic structure is comprised of four components: data inputs, user adjustments or sensitivities, a black box containing the engine, and data outputs. If the reader views the model in Excel he will see it broken up into manageable sheets, of the following functions:

Sheets	What goes in	What comes out
Overview	Allocation schemes, sensitivities	Overall cost of manufacture
Master	Provides coding for entries, lists sites, products, regions	Nothing
Demand	Demand data, allocation matrices from Overview sheet	How much product is made at each site, at both second and third stage manufacturing
Manufacturing Processes	Equipment information, production information from Demand sheet	How much equipment, labor and space is needed at each site.
Manufacturing Costs	Output from Manufacturing Processes sheet, information on capital, labor, space costs, information on equipment from previous models	Costs for equipment, labor, and space for this year.
Inventory	Information from Demand sheet, ordering habits, calculator from SSMacro sheet	Cost and quantity of safety stock, cycle stock, and in-transit stock at each point in the value chain.
Product Info	Weights and values of each product	Nothing
Duties	Duty information from Overview sheet, volumes from Demand sheet, values from Product Info sheet	Cost of duties at each stage of the manufacturing process.
Logistics	Shipping information from Overview sheet, volumes from Demand sheet, weights from Product Info sheet	Cost of shipping from point to point.
Taxes	Differentials from Overview sheet, volumes made from Demand sheet	Relative profitability for each site.
SSMacro	Proprietary macro from internal consulting group, used to calculate safety stock	Note: no output, cannot be included in this thesis.

5.4 Determination of Static Inputs.

Identification and collection of quantifiable cost factors was addressed in some detail in Chapter Four. This section concentrates on those inputs that are considered static, or unchanging, for each year. First, and most important, the demand for each of the three regions and the five host manufacturing sites is taken as known and given for the year. In reality, the demand might be expected to change over the space of a year; but for manufacturing purposes, a year's time frame is necessary to find space, order equipment, and bring labor up to speed. Second, manufacturing capacity, cost, yield, and space needed is fixed for each piece of capital equipment for the year. Third, costs of shipping - duties, transport costs, and classifications - are fixed. Fourth, such product information as weight and value are fixed, although value may be expected to change over time.

5.5 Specification of User Defined Inputs.

The reader is strongly encouraged to read the following sections with the model open in Excel at the same time. It would greatly benefit understanding of how the model's logic works, as well as provide a more interactive experience for the would-be analyst. Two notes on opening up the file. First, it should be opened as a read-only file, and saved under another name should the reader wish to customize it for his use. Doing so on a hard drive will save wear and tear on the floppy disc, as well as make use of it much more efficient. Second, the links that are referred to will need to be altered slightly in order to be useful, as they refer to previous years' models.

The *Overview* sheet is where a user first would define his inputs. It is composed of four components. First, there is a brief explanation of the scope of the analysis and what the user might expect to vary. Second, the user is asked to design an allocation scheme for each of the seven products. Third, the user is asked to designate values for sensitivities. Fourth, the user may view the outputs. This section addresses the second and third components of the sheet.

In this model, user defined inputs allow the user to vary certain factors from year to year, as well as test the robustness of a particular manufacturing strategy against unexpected fluctuations in costs. The most important user defined input is an allocation strategy: given seven products, each using a two stage manufacturing process, and five manufacturing sites, where is each product made? The second facet of this allocation is, given the fact that a product is made at a site, where is it routed among the three regions and five host manufacturing sites for final delivery? Note that the allocation strategy is independent of demand for a given year; allocation is done in terms of percentages. For instance, a user might specify that, of Region A's demand for Product 1, 80% of third stage manufacturing is done at Site B, and 50% of second stage manufacturing is done at Site D. The allocations allow a user to range from complete decoupling of the manufacturing process to complete vertical integration; from specifying a single site for all second stage manufacturing for economies of scale advantages, to complete regionalization for advantages in moving product.

The building block nature of a single year model allows a user to set up an allocation strategy in the initial years which closely replicates the company's current strategy, then gradually move towards a very different endpoint five, ten, or fifteen years out. In this analysis, for instance, two strategies were compared over a ten year period; but it is not until the second year that allocation strategies begin to diverge.

The second aspect of user defined inputs lies in what might be considered a sensitivity analysis. Most important is the accuracy of demand forecasting; the model allows a user to specify drops in forecast demand to see how much costs might change. As might be expected, a drop in demand would constrain the rate of purchase of space, capital equipment, and labor; but the foundation of all three is not allowed to shrink over time. In addition, the marketing buffer capacity (which serves as a surrogate for understanding demand variability within each region) can be changed. Manufacturing buffer capacity for each product and each site can be varied as well. The service level at regional demand points can be changed in order to view fluctuations in inventory costs. Both the percentage of product shipped by air or surface and the duties can be varied. Finally, the tax differential for each manufacturing site and each product can be changed.

Once again, these sensitivities allow much more flexibility for users than was necessary for this analysis. Shipping might be expected to shift from air to surface over time, as demand becomes more readily predictable. And duties could be assumed to be static. But we wanted to be prepared for the eventuality that a manufacturing manager might want to see yet another scenario modeled.

5.6 Form of Output.

Once again, the *Overview* sheet is where a user can view the outputs for a particular year. These outputs are derived from all of the other sheets, which dump their information back out. No calculations are made on the Overview sheet itself.

The first output that is given is the amount of production at each of the five sites, by site and by product. Recall that two stages of manufacturing are modeled within the analysis - second stage (or intermediate assembly) and third stage (or final assembly). The output is arranged by stage of manufacturing, with both the actual amount of production and the manufacturing capacity buffered amount of production.

The second output is the cost of manufacturing at each site. This overall cost is broken down into the following areas:

- Capital cost of second stage equipment.
- Capital cost of third stage equipment.
- New space needed, in build cost and in square feet.
- Occupancy, in cost and in square feet.

- Labor, by category (operators, technicians, supervisors, engineers, managers), in headcount and in cost.
- Pretax and post-tax manufacturing costs.
- Inventory carrying cost after first stage manufacturing.
- Inventory carrying cost after second stage manufacturing.

The third output is of the inventory carrying cost at each of the regional demand sites. The fourth output is of worldwide duty costs and shipping costs.

5.7 Sub-Models for each Factor.

Now that the user-defined inputs and outputs have been addressed and have been viewed on the Overview sheet, it may be of interest to know how the calculations were made. This section follows the model's inner workings quite closely; again, the reader will find his understanding enhanced by concurrently running the model in Excel.

The reader should ensure that the auditing toolbar is visible. This toolbar allows one to trace formulas, as well as attach notes to particular cells. We used the note system to document sources for each data and formula, as well as to note assumptions. Since the above information was typically proprietary in form, the model packaged with this thesis has been scrubbed of notes. We encourage the reader to save the model as a new file, and to incorporate his own notes into it in order to clarify it for personal use.

Some important notes that are also listed in the *Master* sheet:

- **Black** text entries are where data is entered.
- **Blue** text entries are calculated numbers or are numbers which were entered elsewhere.
- **Green** text entries are test entries, not yet confirmed data.
- **Purple** text entries are error checks.

- **Salmon** backgrounds indicate a fixed entry that is referenced somewhere else in a calculation. If it is moved, the calculation may not pick it up.
- **Gray** backgrounds indicate data that will most probably change from year to year, e.g. equipment yield.

5.7.1 Site Production.

The sub-model used to calculate site production is largely contained in the *Demand* sheet within the model. Inputs include the following factors:

- Monthly demand at each region (or host manufacturing site). This data is static, and is assumed to be averaged over the year in question. Note that since the data is black, it is an input at this stage.
- The "Oops" factor: marketing forecast is above or below in terms of percentage, e.g. demand for Product 1 is 80% of projected demand. Note that this input comes from the *Overview* sheet; that's why it's a blue entry. This factor allows the user to look at the changes in manufacturing costs due to a demand surplus or shortfall.
- The marketing buffer capacity, again in terms of a percentage of demand, and from the *Overview* sheet. Marketing buffer capacity is defined by the company and is based upon the marketing intelligence team's understanding of the variability of demand around its forecast. A buffer then represents the upper end of the variability; for Product 1, which is much more mature, the buffer might be 115%, whereas for Product 6, which is not yet released, the buffer might be 150%.
- The manufacturing buffer capacity, again in terms of a percentage over demand and from the *Overview* sheet. Manufacturing buffer capacity is defined by the manufacturing strategy team; it is based on the comfort level that the manufacturing groups have for the marketing team's projections. As is the case with marketing buffer capacity, buffer percentages might be expected to be lower with more mature products than with the newest releases.

These four inputs are used to calculate the following:

- How many intermediate assemblies for each product are made at each site.
- How much manufacturing capacity needs to exist for the intermediate assembly stage for each product at each site.
- How many final assemblies for each product are made at each site.
- How much manufacturing capacity needs to exist for the final assembly stage for each product at each site.
- How many intermediate assemblies are sent from Site A to Site B, etc.
- How many final assemblies are sent from Site A to Region A, etc.

The logic of the calculations is as follows:

1. Actual product demand is calculated by multiplying static demand by oops marketing factor and marketing capacity upside. For example, if Product 1's demand is 1,000 units/month, its marketing buffer capacity upside is 115%, and the oops marketing factor is 80%, then the actual product demand is: 1,000 x 1.15 x 0.80 = 920 units.
2. Site production for each product is calculated by taking actual product demand from (1) and multiplying it by the allocation matrix imported from the *Overview* sheet. For example, if 80% of this demand is supplied by Site A, then Site A needs to produce: 920 x 0.80 = 736 units.
3. Site production from (2) is multiplied by the manufacturing buffer capacity percentage from the *Overview* sheet. For example, if Site A needs a manufacturing buffer capacity of 135% for Product 1, then there needs to be production equipment available to make: 736 x 1.35 = 994 units.
4. The above three operations are performed for each of the seven products and for both the second (intermediate assembly) stage and the third (final assembly) stage of manufacturing.

The output is listed in several forms within the *Demand* sheet, the most useful being a matrix for each site which lists the amount of each product made at each manufacturing stage, along with its manufacturing capacity buffer.

5.7.2 Manufacturing Processes.

The goal of the *Manufacturing Processes* sheet is to calculate the amount of equipment of both second (intermediate) and third (final) stage process equipment, as well as the space and labor needed to accompany it. In order to calculate these intermediate outputs, two inputs are needed: first, information about the equipment itself, and second, the production volume requirements from the *Demand* worksheet.

- If the reader starts with the input matrix at the top of the sheet, he will see capacity information for final assembly equipment, by products. This daily capacity assumes four shifts/week and an up time of 75%. The careful reader will note that at the final assembly stage, all equipment is dedicated to a single product, e.g. FA4 makes Product 3. This capacity is also assumed to be independent of manufacturing site. The first table also includes the space needed for each piece of equipment and the number of operators, technicians, and engineers per unit output.
- The number of days available for this equipment to be used may well vary from site to site and is included in the table directly below.
- The table below and to the left summarizes final assembly product yields by product (and, since equipment is dedicated at this stage, by equipment).
- The next table, Intermediate Assembly Conversion Assumptions, contains two critical pieces of information. First, it reveals which process steps are needed for each product. Second, it shows that for a given process, there is a different effective capacity for each product. For example, note that Process 1 makes Products 1 - 5. But each wafer made in Process 1 contains 348 pieces if Product 1 is made, whereas it contains 190 pieces if Product 5 is made.

- The next table is Percentage of Product Using; it contains an approximation for Process 3 which Products 1 - 4 use in varying proportions. For example, half of Product 1 uses the Ni process, while the other half uses the Au process.
- The next table is called Labor - Intermediate Assembly. Operators, technicians, and engineers per unit output (in the units relevant to each substage of production) are entered here. Note that processes are not, by and large, dedicated in this manufacturing stage.
- Space - Intermediate Assembly is the next table. It is a very rough cut at the amount of space needed for a certain amount of production of each product at this stage.
- The next few tables are Intermediate Assembly Capacity tables for each process. Note that each process is comprised of several pieces of equipment, e.g. M9 is a substep in the Process 2 step needed to make Products 1 - 4. For each of these pieces of equipment there is a certain capacity associated with whichever product is run on it; for example, M17's daily capacity for Product 1 is 312 sheets and for Product 3 is 305 sheets.
- Intermediate Assembly Yields is the next table: it shows the percentage yield of each product in each of the processes, including yields expected from the upstream first stage manufacturing process.

With this hard data and the calculated production volume needed at each site from the *Demand* sheet, it is now possible to calculate how much equipment is needed, by site. The following description is of the calculations for Site 1; all other sites use the same logical expressions, however.

The first data calculation table is called Intermediate Assembly Capacity Needed. In this table, the amount of manufacturing capacity for each process in the Intermediate Assembly stage is calculated, using demand information and yield information. For example, for Product 1, at Process 6: 2.0, the capacity needed is the number of Intermediate Assemblies needed at Site 1 (from the *Demand* sheet) divided by the yield at that stage. Then as Product 1 is moved upstream through the Intermediate Assembly processes, the yield at each stage is taken into account. Capacity needed at any process is the demand at the successive process divided by the yield. For example, capacity needed for Process 2: 2.0 is calculated from demand at Process 4: 2.0 (the succeeding process) divided by yield for Process 2:2.0 and divided by the number of units per wafer at that stage (from the Conversion Assumptions Table). The conversion needs to be made because at Process 4:2.0, needed capacity is expressed in final units, not wafers. And Process 3 is bypassed because it runs in parallel to the Process 1 and 2 and is added on at Process 4.

The next data calculation table is called Intermediate Assembly Actual Production. Note that its logic in calculations is similar to the previous table. However, the demand for Intermediate Assemblies is for actual production, rather than for manufacturing capacity. The reason for the duplication of calculations is that the company wishes to have the equipment in place to cover the manufacturing capacity buffer described in the *Demand* sheet, but it does not wish to hire any more labor than is needed to make actual production. As a result, Actual Production is needed to drive labor, and Assembly Capacity is needed to drive equipment purchases.

Now that capacity needs are calculated for each process in the Intermediate Assembly stage, the next table calculates the number of pieces of equipment needed to meet that capacity. For Process 1, Machine M1, for instance, all of the capacity needed to make all products made on that machine is summed up and divided by the daily output for the machine and the number of days available to run it at that site. This calculation is offered as the number of sets needed and is repeated for each process.

Note, however, that this model is calculating what equipment is needed each year. If the site already has equipment purchased in previous years, then the table takes it into account in the following line, Existing sets. The existing sets can be entered manually by the user; in this case, they are calculated from the Manufacturing Costs sheet, which is explained in the next section. The table then determines which number is larger - existing sets or needed sets - and enters that in the following line in order to calculate equipment utilization figures.

The next table calculates labor needed for each process and space needed for the Intermediate Assembly operations. Note once again that labor is driven by unit output per operator, technician, and engineer and actual production (as opposed to needed equipment capacity). For space calculations, the logic is to take total needed capacity for each product, divide it by the number of units needed for a certain number of square feet, and round it up to multiply it by the number of square feet. This operation is divided into two parts: slotted (Products 1 - 4) and edge feed (Products 5 - 7).

For the Final Assembly Stage, the calculations of needed capacity are markedly easier; each product is made on one dedicated piece of equipment. The next table calculates the actual production and capacity needed at Site 1, using the data from the *Demand* sheet and the yield table for Final Assembly equipment.

The next table then calculates how many pieces of equipment are needed to accommodate this amount of capacity for each product. As is the case with the Intermediate Assembly calculations, the number of sets of needed equipment are compared to how many sets exist (again, from the *Manufacturing Costs* sheet), in order to get a sense of capacity utilization. Space needed is simply a multiple of the number of sets needed, and labor for each category is driven by the actual production numbers calculated in the previous table.

The above calculations are repeated for the other four sites, and are summed up in the final tables for a worldwide inventory of manufacturing equipment and capacity utilization. Note that capacity utilization can be calculated any number of ways; it can be the average of each site's capacity utilization for a particular machine, or it can simply be worldwide production divided by worldwide capacity available on those machines.

5.7.3 Manufacturing Costs.

Now that the equipment, space, and labor needs are known for each site, it is possible to calculate how much money must be spent on them. In order to do so, more data entry particular to finance is entered on the *Manufacturing Costs* sheet. As in the previous section, the reader is asked to toggle through each input table on the sheet in order to understand the provenance of cost calculations in the output tables.

The first tables simply are lists of the costs of each piece of equipment for both the Intermediate and Final Assembly stages. These costs are assumed to be in today's dollars; the would-be analyst is urged to make sure that all costs are consistently quoted in real or nominal terms. In addition, note that equipment costs are assumed to be independent of site location. This assumption is realistic given the global sourcing (and hence, pricing) techniques which characterize equipment purchases within the company.

The next two tables deal with labor costs. Each labor category costs a different amount, and there is an enormous discrepancy in these costs among the five sites. Note as well the gray background, indicating expected changes in labor costs over time. As before, the costs are listed in current dollars. For supervisors and managers, there is a ratio driver: there are a certain number of operators per supervisor and a certain number of supervisors per manager, depending on the site.

The next table simply tallies up total headcount from the *Manufacturing Processes* sheet, so that total labor costs can be calculated. That's just what happens in the Monthly Personnel Costs per Site table. Note once again that there are many peripheral personnel who do not figure into these calculations; it is assumed that because all of the sites are already in operation that janitors, for instance, are already in place and would figure into headcount drivers as a marginal chit.

The next two tables are data entry points for the cost of space, both in occupancy and in new build rates. While occupancy costs might be expected to change from site to site, build costs for new space are fixed among the sites. Given the space needed for Intermediate and Final Assembly, the occupancy costs for each site can be calculated here given inputs from the *Manufacturing Processes* sheet and the occupancy rates.

The next two tables are listings of depreciation. If the model is simply expected to calculate total manufacturing costs over time, then depreciation could be avoided; each piece of equipment could simply be paid for up front. But if a breakdown of costs over time is of interest, then the depreciation of the capital costs is a more realistic way of looking at manufacturing cost. Note that Intermediate Assembly equipment is typically depreciated over five years, whereas Final Assembly is depreciated over three years.

Given these data inputs, the capital equipment costs can be calculated for each site. The costs are calculated for each machine; costs are apportioned to machines depending on their age. Such a calculus involves byzantine references to the previous year's model; hence the links in each of the cells. A more casual user might manually update the stock of equipment for each year of interest, or do an aggregate capital cost calculation over all the years.

One example may suffice. For Process 1, Machine M1, depreciation is over five years. For "More than 5 years old," the entry is simply the sum of the previous year's entry in that category and the previous year's entry in the "4-5 years old" category. For "1 - 2 years old" the entry is the previous year's new, or "First year" equipment. The "First Year" entry is a bit more complex: it compares the total number of M1's already listed in the column to the number of equipment sets needed from the Manufacturing Processes sheet calculations. If the number of M1's is larger than that needed, then no new equipment is purchased and the entry is "0." If, however, more M1's are needed, the entry is the positive difference between the number needed and the number already owned at that site. The final calculation of the table is simply a multiplication of the depreciation rates times the number of M1's in each age group times the capital cost, in order to get that year's total capital cost for that machine.

A similar calculation is made for the new build space needed at each site. In essence, the model calculates how much space is already in place, and whether the addition of new machines would use additional space. The new space already in place comes from links to the previous year's model; recall that none of the sites under discussion could be considered a greenfield site. The table compares needed space to available space and calculates a cost of new build space for both clean rooms and regular assembly if necessary.

We urge would-be analysts to determine whether or not simplifying assumptions can be made that would obviate the need for such complicated linkages. If not, the analyst should be extremely cautious about the order in which he runs successive years' models. If they are not run in order, the links will simply not work correctly. Determination of the audience to whom the analyst must sell his results figures in the concluding chapter, which should be read carefully before launching willy nilly into a comparable analysis.

5.7.4 Inventory Costs.

The calculations used to estimate inventory costs are done on two sheets: the *Inventory* sheet and the *SSMacro* sheet. What the *SSMacro* sheet does is a simple calculation of the safety stock needed, based on a continuous review, re-order point, re-order quantity model of inventory management. The description of the programming needed to resurrect this calculation can be found in Nahmias (1993); due to the proprietary nature of the macro we used, however, the current model can not include the actual program.

The first three tables calculate the amount of finished goods inventory needed to fulfill service level goals of each of the three regions. In addition, the second five tables calculate the amount of finished goods inventory that must be delivered to the five host manufacturing sites for Products 6 and 7. The third set of tables calculates the amount of Intermediate Assembly inventory needed at each of the five Final Assembly sites. The fourth set of tables calculates the amount of Upstream Components inventory needed at each of the five Intermediate Assembly sites. All of these tables follow the same logic in calculations; a walk through the first table calculating inventory costs for finished goods inventory to Region A will serve to illustrate.

The first entry for this table is unit value for each product; note that the value is expected to change over time, but does not change from site to site. The second entry is desired service level, which is a user-defined entry from the *Overview* sheet. Review Period and Delivery Frequency are the next two entries; they are both expressed in fractions of weeks and are rough cut estimates. The next three entries are demand, first monthly, then weekly, and finally in standard deviation units. Note that standard deviation is a bit of a misnomer in this case; the weekly demand is simply multiplied by a percentage which is expected to change (one hopes, lessen), over time. A similar estimate is made for Supplier Lead Times, and the standard deviation.

The next column, in-transit times, deserves a bit of explanation. Note that the table calculates inventory flows for all finished goods reaching Region A; but these finished goods could come from any of the five manufacturing sites, all of which might be expected to have different delivery times. The calculation references tables that describe the allocation of product, along with expected in-transit times calculated on the *Logistics* sheet, and takes a proportional slice of each to come up with an average in-transit time. Standard Deviation of in-transit times is again a multiplier of the in-transit time that might be expected to change over time. The Replenishment Time is then a sum of the in-transit times and the supplier lead times. The standard deviation for Replenishment Time is then the square root of the sum of the squares of in-transit and supplier standard deviations.

The macro uses the previously discussed entries and calculations to come up with an estimate of the volume of safety stock. The volume is listed in terms of both weeks of inventory (by dividing safety stock by weekly demand) and dollars (by multiplying safety stock by unit value). Cycle stock is then calculated in unit volumes by dividing weekly demand by twice times delivery frequency. Cycle stock and Safety stock are added to get average inventory. In-transit inventory is then calculated by multiplying weekly demand by average in-transit time; once again, this figure can be translated into weeks of inventory or dollars of inventory. Finally, total inventory costs can be calculated, in terms of volume, weeks, and dollars.

5.7.5 Duties.

The amount of duties incurred is calculated on the *Duties* sheet within the model. This sheet makes use of duty percentage inputs from the *Overview* sheet, product volumes calculated in the *Demand* sheet, and dutiable value data entered in the *Product Info* Sheet. Calculations are done by product family, at both the intermediate assembly component stage and the final assembly component stage.

The actual calculations done are simple matrix multiplication. For example, for Product 1, there is a certain percentage duty levied on intermediate assemblies made in Site 2 and sent to Site 3. The table describing these duties is imported from the *Overview* sheet. For Product 1, the actual total dutiable amount for intermediate assemblies made in Site 2 and shipped to Site 3 is calculated by multiplying the number of units sent by the dutiable value of each unit. This table is then multiplied by the duty percentages to obtain intermediate assembly duty charges for Product 1.

These calculations are repeated for final assembly and for all the sites, as well as regional distribution centers. The results are then summed in a Worldwide Duties table at the bottom of the sheet.

5.7.6 Logistics.

The shipping costs calculated in the model are done in the *Logistics* sheet and require inputs from the *Overview* sheet on what percentage of products are shipped air or surface, product weights from the *Product Info* sheet, the number of units shipped from the *Demand* sheet, and shipping costs. As is the case with the duties calculations, logistics are relatively easy to calculate. Once the number of units shipped from one point to another point are determined, all that remains is to determine what percentage of them are shipped air and surface, how much they weigh, and how much it costs to ship it by each method.

The first tables on the sheet are data entry points for point-to-point shipping costs by both air and surface. Note that these costs have a gray background and are expected to change over time. The next tables, which are used for calculating in-transit inventory, are tables of estimated in-transit times from point to point. Shipping costs are calculated by product; an example of how the Product 1 shipping costs are arrived at should suffice.

Note that the first table for Product 1 is for the percentage of intermediate assemblies shipped by air. Intermediate assemblies have a much shorter shelf life, and are quite easily compacted for shipping savings. As a result, the company has decided to ship them all by air in order to shorten the work in process feedback loops and maintain their quality. The second table calculates total weight shipped by air, by multiplying Product 1 intermediate assembly weight, percentage air shipped, and actual number shipped. This table is then multiplied by air shipping costs to obtain the total cost of air shipments for Product 1. The steps are repeated for the total cost of surface shipments.

Each of these steps is repeated for the seven products made by the company, and the totals are calculated at the bottom of the sheet. In addition to these totals, a weighted average in-transit time is calculated for both surface and air shipments by multiplying the relative percentages of products traveling by each manner by the in-transit times. This final calculation is necessary for the inventory calculations explained in section 5.7.4.

5.7.7 Taxes.

The *Taxes* sheet shows tax calculations, which draw heavily from the *Overview* sheet. Note that taxes are a tricky calculation to make, especially in a model which focuses on estimating manufacturing costs. Perhaps a more rigorous approach would attempt to estimate profits made on each product, and assign those profits proportionately to the sites where the products were made. This model uses the hazy notion of a tax differential, calculated by the finance team, which is subject to interpretation. To explain the tax differential as simply as possible: a product can cost a certain amount to make in each of the five locations. But the profits made on its sale are subject to different rates of taxation, depending on both where the product is made and where it is sold. Generally, Sites A and B face the highest rates of taxation, and Sites C, D, and E face somewhat lower rates. The differential seeks to multiply variable costs of manufacturing by a percentage (tax-neutral being 100%), in order to capture some sense of the tax savings of manufacturing products in the latter three sites.

Calculations are done by site, and a walk through of the calculations done for Site A may suffice to show how a tax differential is estimated. The first table is a simple importation of the monthly volumes made at both manufacturing stages, for each product, at Site A. The second table estimates what percentage of the total manufacturing activity at Site A can be attributed to each product. Operating costs for Site A are then imported from the *Overview* sheet; the costs include occupancy, capital depreciation, and labor. Labor is broken down into that which can be attributed to intermediate assembly and that which can be attributed to final assembly.

The next table is a listing of tax differentials which have been defined by the user on the *Overview* sheet. It should be noted that different products can be taxed at different rates; if, for instance, a site gives tax breaks to encourage the siting of newer technology production, then this nuance can be captured here. The final table does a post tax calculation of the manufacturing costs for each factor. For intermediate assembly occupancy, for instance, the calculation multiplies the percentage of each product made at this site by the tax rate for each product and by the total pre-tax cost. It is thus a weighted average of the products and their respective tax rates times the cost before taxes. The calculations are repeated for final assembly occupancy, labor, and capital depreciation.

Each site repeats these calculations, and the results end up on the *Overview* sheet. We urge the would-be analyst to approach this sort of analysis with extreme caution. It will not be at all clear to managers who have predicated their manufacturing strategies on maximizing tax havens that these calculations are rigorous enough.

5.8 Capability to do Sensitivity Analyses.

The model contains the flexibility to test results against changes in certain factors. Among these, the most prominent factor that is open to question is product demand. But other factors, such as shipping methods, duties, service levels and tax differentials, might be of interest as well. The method used by the model to adjust these factors is crude, but both easy to understand and relatively effective. All adjustments are made on the *Overview* sheet, and are entered for each year so that increasing deviations from the initially assumed values can be modeled.

First, and most importantly, demand for the product may deviate substantially over time. There are three points of entry for adjustments that a user may want to make to the demand forecasts he has been given. The first one is the "Oops" matrix; for each product's demand in each region, a user can enter a percentage of demand. Default is 100%; if 100% is entered, then if the forecast is 1,000 units/month, the user expects to see that amount. If 120% is entered, then the user wants to know what the manufacturing costs will be if demand is 1,200 units/month. The power of this matrix is that it allows the user to incorporate into his analysis a sense of how the demand might slip over time, and what consumers might consider as substitutions. For example, the introduction date of Product 6 might slip three years, which would shift the demand curve displayed in Chapter 2. As a result, the company might push sales of Products 4 or 5, thus increasing their demands beyond current forecasts.

The second table that deals with demand is the Marketing Buffer Capacity matrix, which attempts to capture some sense of the variability that surrounds the predicted demand itself. The marketing intelligence team estimates buffer capacities for each of the products, but the user can play around with the upside amount for each product. For Product 1, for instance, the marketing buffer capacity upside might be estimated at 115% of the forecast demand. But a user can input 135% to see by how much costs might increase. It is to be expected that over time the variability around demand forecasts would be expected to diminish, for at least two reasons. First, the marketing forecasting process might be expected to improve, and second, as products become more mature, demand is more stable and hence more predictable.

The third table is the Manufacturing Buffer Capacity table, which reveals an underlying level of disjunction between the marketing group and the manufacturing group at this company. The manufacturing group has decided to set what-if upper limits on their capacity needs when determining equipment purchases, if not labor requirements. A certain percentage of this buffer can be attributed to the manufacturing group's understanding of its own production variability; but a large percentage of it appears to reflect a level of distrust of the marketing group's forecasts. To further complicate matters, the senior management of the company has decreed that the manufacturing group simply have the capacity in place to make whatever is sold, creating an incentive to inflate the needed manufacturing capacity buffer.

User-specified inputs from these tables are incorporated into the *Demand* sheet, which calculates how many products are made in each site.

Shipping methods and duties were addressed in the above sections describing their relevant cost drivers. Briefly, however, the company expects shipping costs to go down through increased reliance on surface as opposed to air shipments over time. It is not at all clear that the need for quick feedback loops, clarity on demand, and shelf life will allow this shift to the proverbial slow boat from China. Users can thus specify what percentage of products will be shipped by air from point to point for each year. Duties are also expected to remain minimal over the next ten years; it is our belief, however, that duties may well increase if only temporarily as trading regions become more clearly defined. Users can thus specify what duty percentages they expect to see for each point-to-point shipment each year.

Service levels for final products affect the inventory levels needed at regional distribution centers; the lower the level, the lower the inventory needed as a buffer in each location. The company has defined its service level at a default value of 98% (for all practical purposes, 100%), indicating that it always wants to have product available for shipment in each region. But this number may be reduced over time if the company decides that increased risk of stocking out is worth the savings in inventory costs. The service level estimates are incorporated into the macro that runs in the *Inventory* sheet.

Finally, tax classifications can be expected to change over time. The model simply allows users to adjust this value by product; note that the default value is 100%. The adjustments are incorporated into calculations made on the *Taxes* sheet.

CHAPTER SIX - COMPARISON OF STRATEGIES.

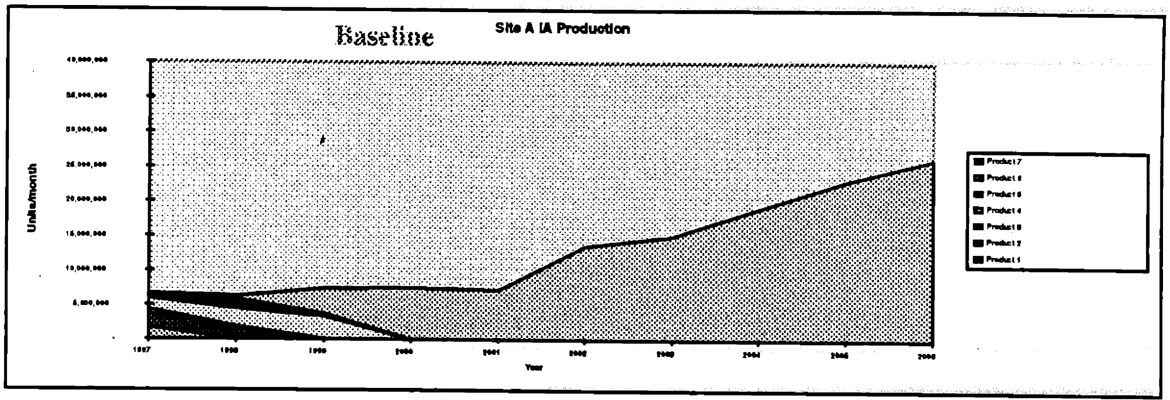
This chapter is comprised of two broad elements: a description of the two manufacturing strategies that the company is considering pursuing over the next ten years, and the results of having run the two strategies through the model. The first section defines a continuation of the company's current strategy, taking into account the sea changes brought about by increases in demand forecast for yet to be released products. The second section looks at a modified regionalization strategy, where the final assembly stage of manufacturing is regionally matched to demand. The third section describes a completely regionalized strategy, where both second and third stages of manufacturing are moved to supply each of the three regions' demand profiles. The fourth section provides the results of a cost comparison of the current strategy and the completely regionalized strategy, including a sensitivity analysis for each.

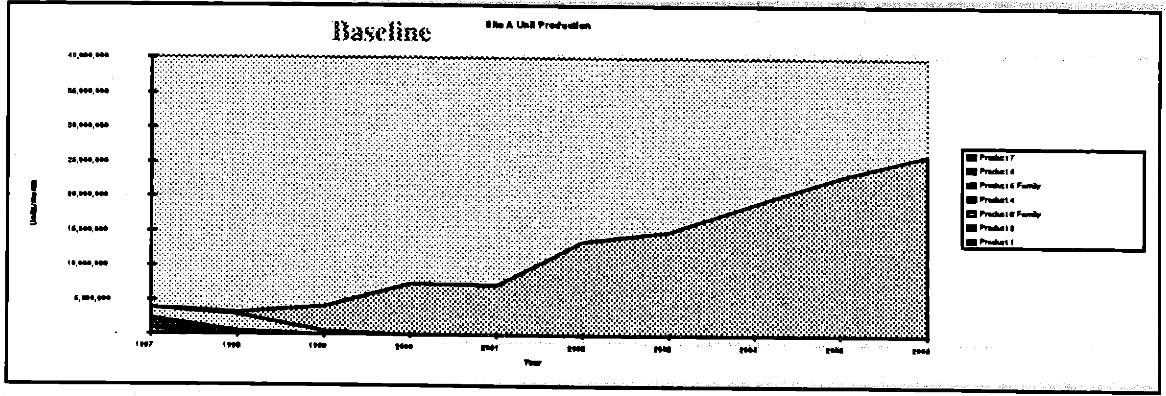
6.1 Conventional Strategy.

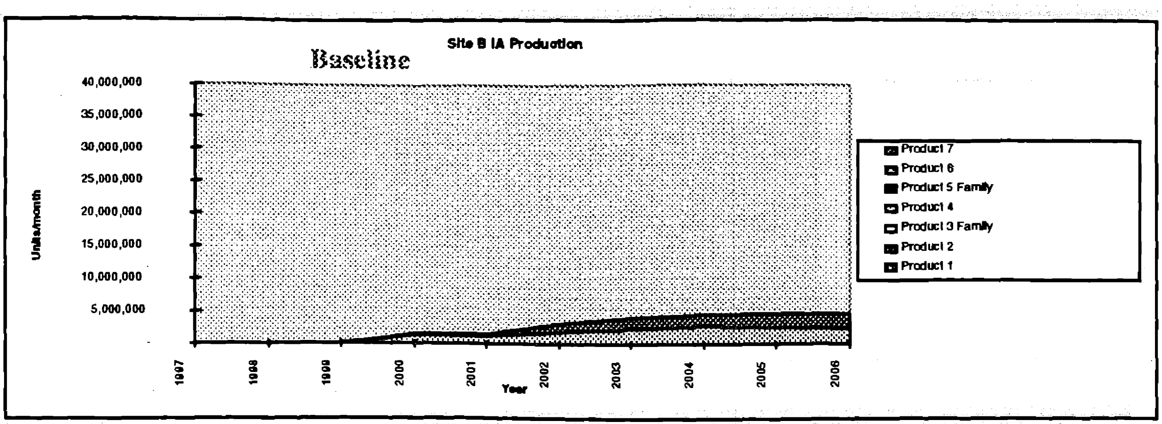
The company's current manufacturing strategy is a natural outgrowth of its humble beginnings in Site A. Since 1984, when the product was first commercialized, both Site A and Site B have served as the research and development centers for the company's products. As a result, particularly in Site A, the development of manufacturing processes needed to make its newest products has closely followed suit. While Site A is, as a result, the largest site in the company's realm, Site B has been kept small.

Sites C, D, and E have come about through a combination of the company's sharing of common real estate placement through its corporate parents and an understanding of which locations might offer the lowest cost manufacturing. Not coincidentally, the conception of lowest cost manufacturing includes a sophisticated manipulation of tax havens; Sites C, D, and E have lower taxes on profits, so higher margin production is typically situated there.

Note that the analysis assumes that a strategy will be implemented gradually. The following graphs show the growth of production volumes over time for each of the five sites. Graphs are shown with all of the seven products separated and with distinctions made between second (intermediate) stage assembly and third (final) stage assembly. While some sites develop what might be considered vertical integration in their manufacturing, other sites, e.g. Site D, become large scale producers of either stage of assembly. Such site growth in product volumes follows the company's current strategy of moving its larger scale operations (and higher margin products) to the lowest cost manufacturing centers. Low cost does not, however, take into account such factors as labor costs, shipping costs, or duties.



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Site B IA Production
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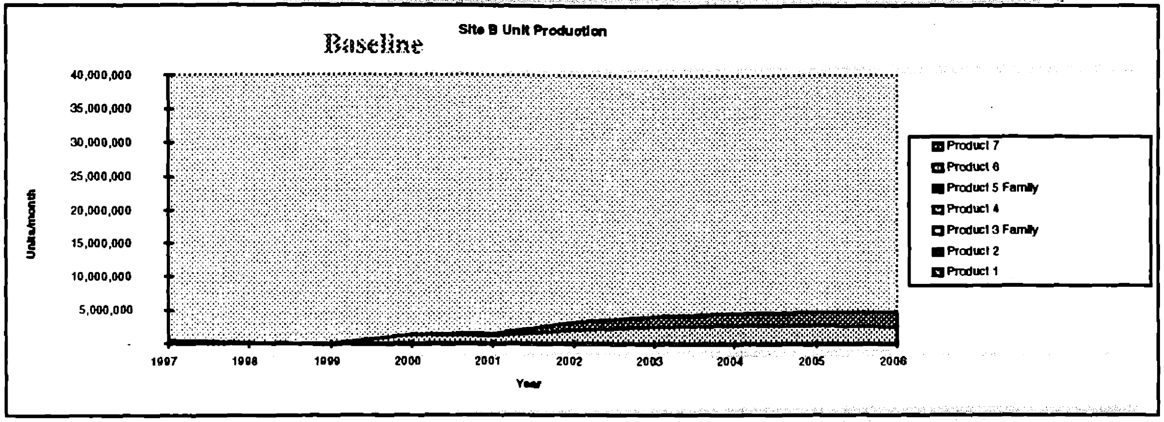
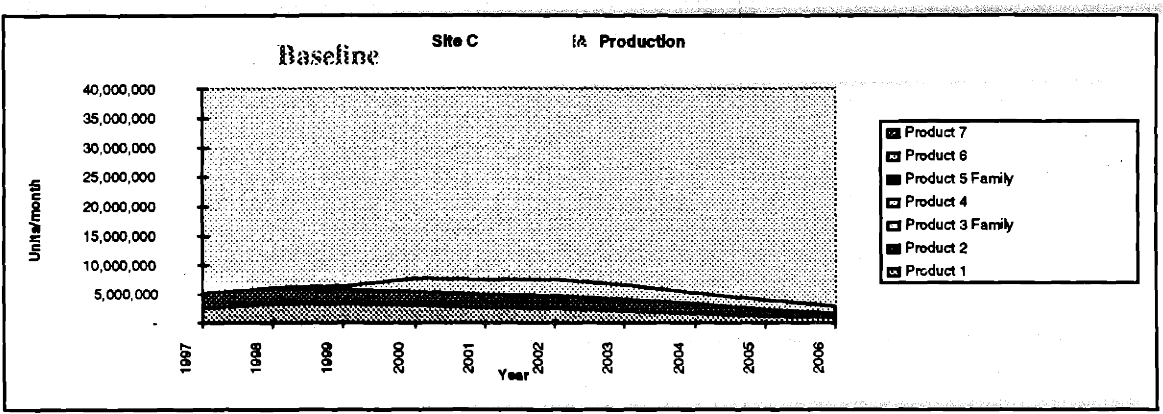
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Product 7
Product 6
Product 5 Family
Product 4
Product 3 Family
Product 2
Product 1


Baseline
Site B Unit Production
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Product 7
Product 6
Product 5 Family
Product 4
Product 3 Family
Product 2
Product 1


Baseline
Site C
IA Production
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
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1998
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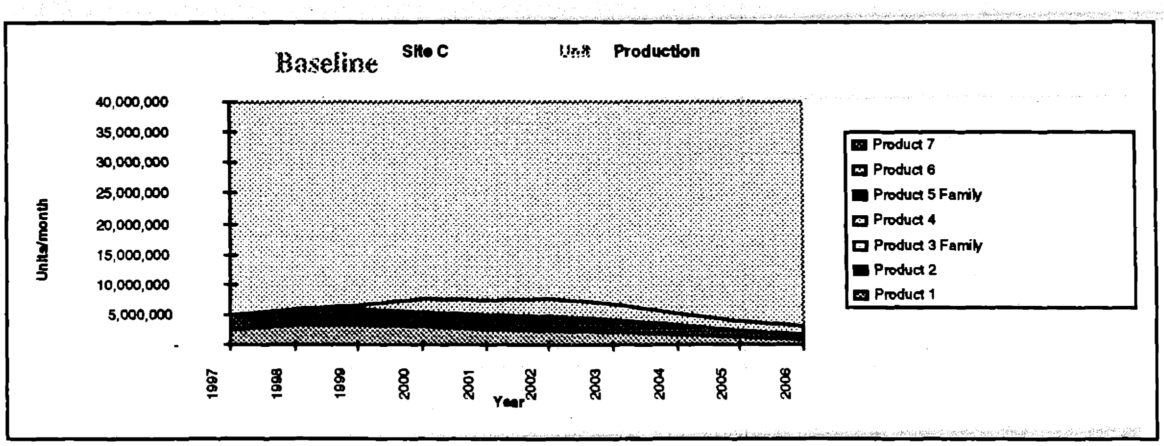
Year
Product 7
Product 6
Product 5 Family
Product 4
Product 3 Family
Product 2
Product 1


Baseline
Site C
Unit
Production
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
1997
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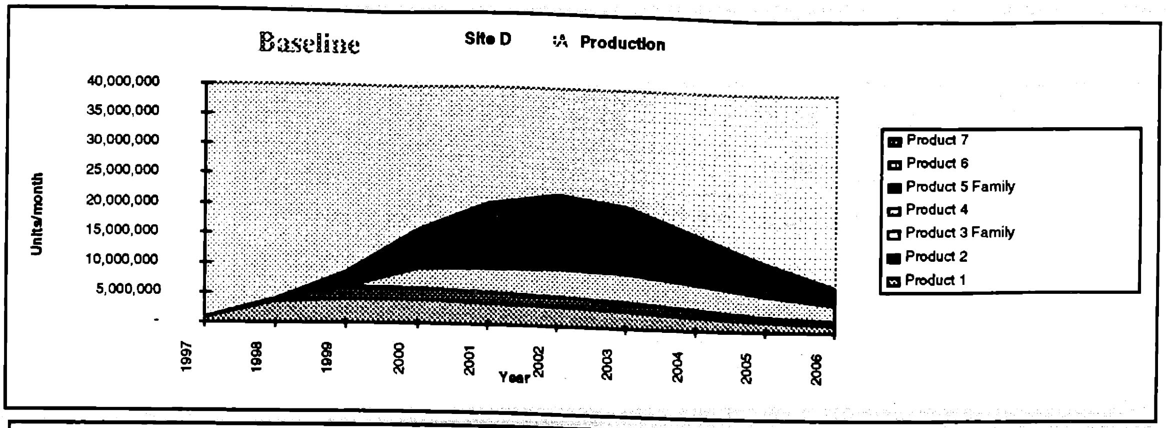
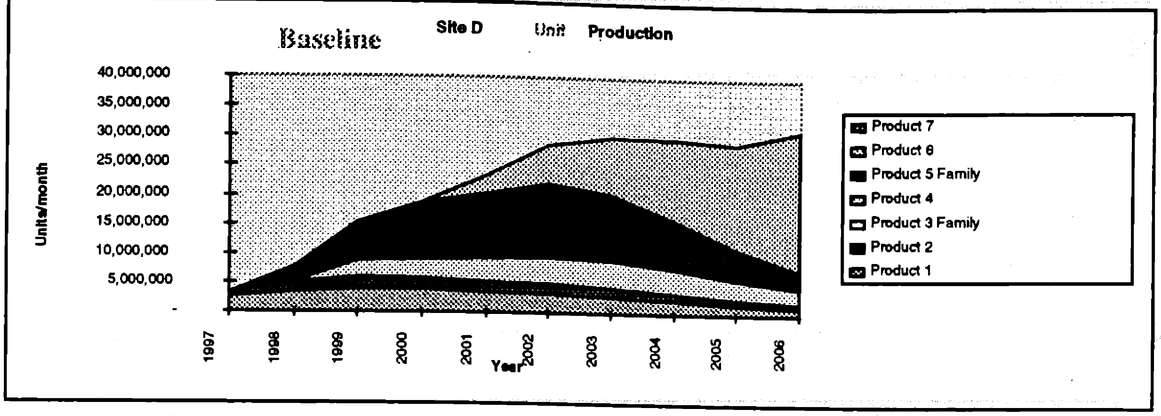
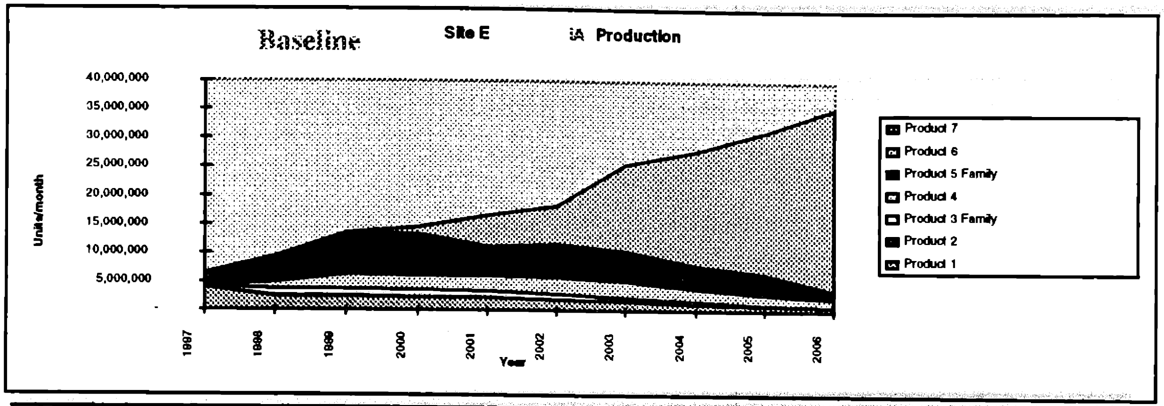
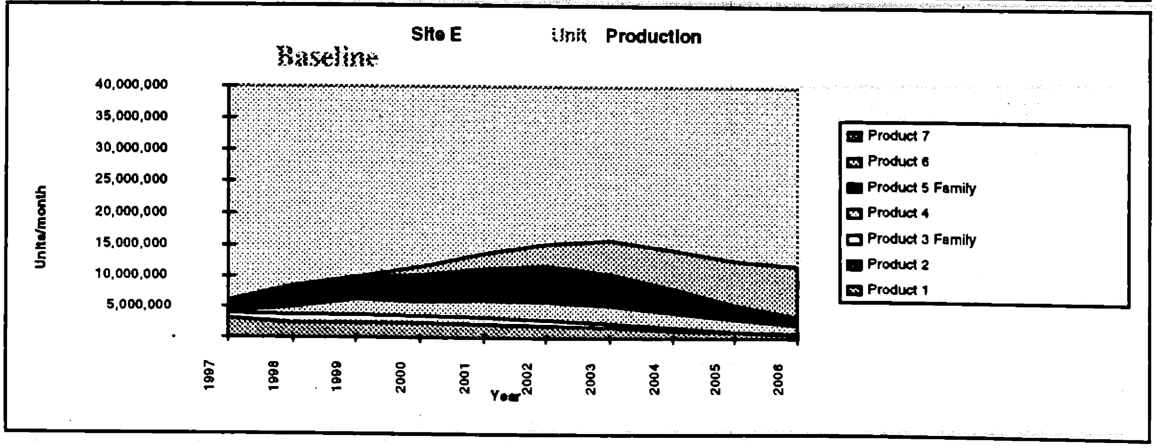
Product 4
Product 3 Family
Product 2
Product 1


Baseline
Site D
IA Production
Units/month
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Product 7
Product 6
Product 5 Family
Product 4
Product 3 Family
Product 2
Product 1


Baseline
Site D
Unit Production
Units/month
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Product 7
Product 6
Product 5 Family
Product 4
Product 3 Family
Product 2
Product 1


Baseline
Site E
IA Production
Units/month
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Product 7
Product 6
Product 5 Family
Product 4
Product 3 Family
Product 2
Product 1


Site E
Unit Production
Baseline
Units/month
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Product 7
Product 6
Product 5 Family
Product 4
Product 3 Family
Product 2
Product 1

6.2 Regionalizing the Third Stage of Manufacturing.

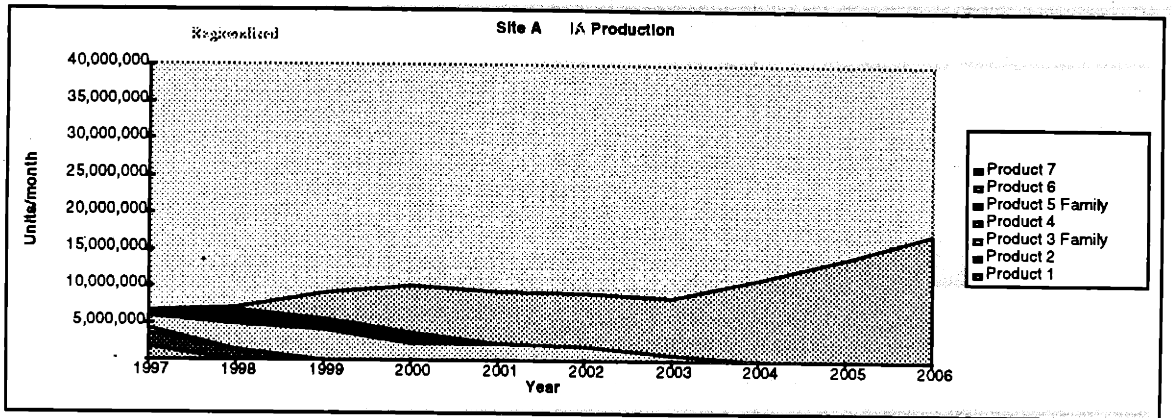
Reference to the depiction of the company's manufacturing process may be helpful here. Note that the company's current strategy is to use its packaging postponement and distribution centers (which fall outside of the scope of this analysis) as regionalized demand nodes. Thus all of Region 2's demand flows through a packaging center located in that region. Fortunately, each of the three regions have manufacturing sites located relatively close; so some vertical integration of the regionalization concept could be implemented without having to build a greenfield site.

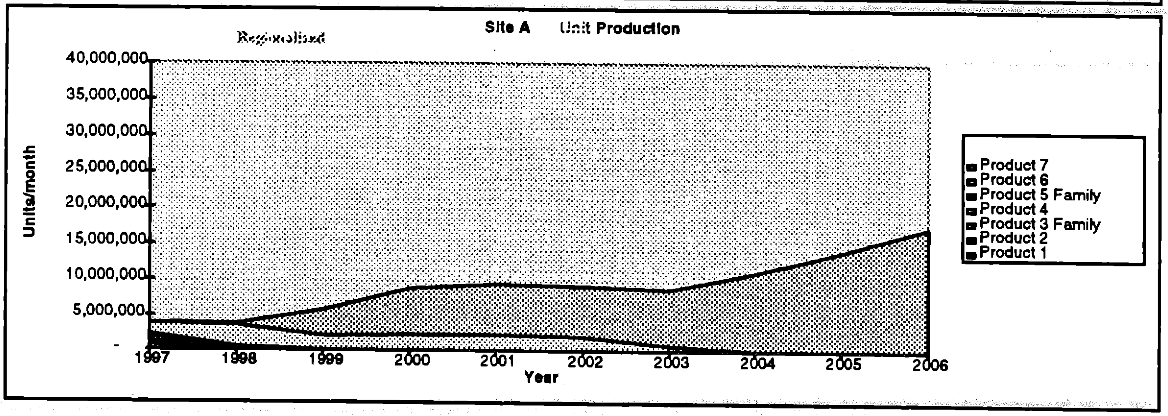
A partial regionalization scheme would then move all the third stage manufacturing needed for that region to whichever sites serve that region. For Region 1, Sites A, B, and C could all serve as final assembly sites. For Region 2, Site D could supply final assembly, and for Region 3, Site E could supply final assembly. A move to this partial regionalization would necessarily take time; currently, for instance, Site E has much more final assembly capacity than it needs to supply its own regional demand. But the company is not interested in actually shrinking any one of the sites, merely constraining its growth.

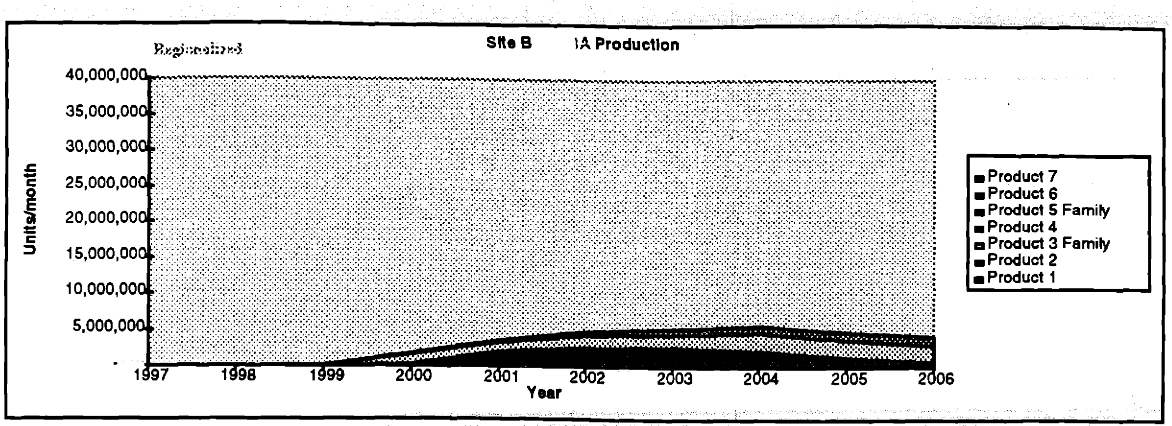
This analysis focuses on the more dramatic approach of moving towards complete regionalization, including integration of the second and third stages of manufacturing. The costs of a partial regionalization might thus be expected to fall somewhere within the spectrum ranged by the company's current manufacturing strategy and the complete regionalization strategy. Given the fact that the difference in manufacturing costs between the baseline strategy currently being followed and the regionalized strategy described in the next section is insignificant, a partial regionalization scheme would not appear to have any appreciable cost difference.

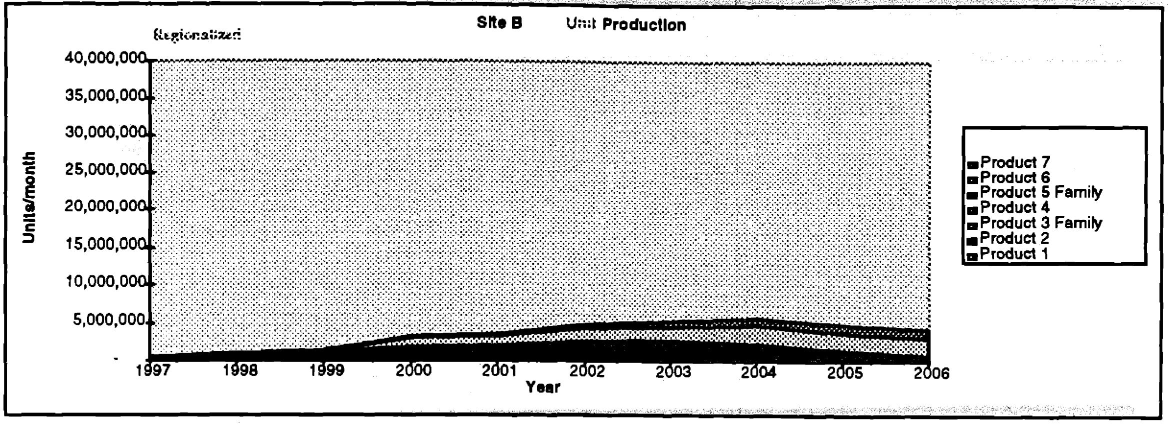
6.3 Regionalizing both Second and Third Stages.

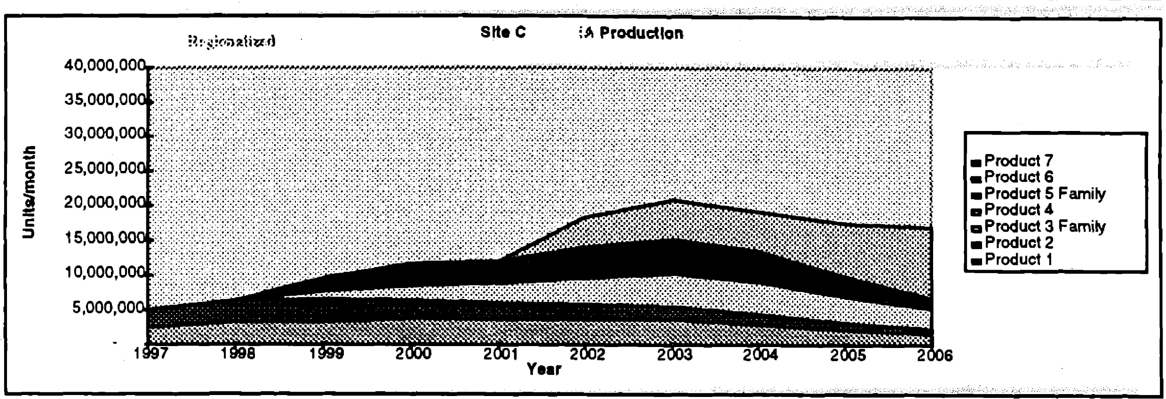
This strategy's basic goal is to completely regionalize both the second (intermediate) and third (final) assembly stages as a continuation of the regionalization of the company's packaging centers. Such a strategy means that both manufacturing stages will be completely vertically integrated over time. Once again, Sites A, B, and C would serve Region 1. Site D (and potentially a Site F) would serve Region 2. And Site E (and potentially a Site G) would serve Region 3. The projected growth of each of the five sites is depicted in the graphs below; as in section 6.1, growth is broken up by product and by stage of production, although the perceptive reader will note a move towards matching volumes of second and third stage production over time.

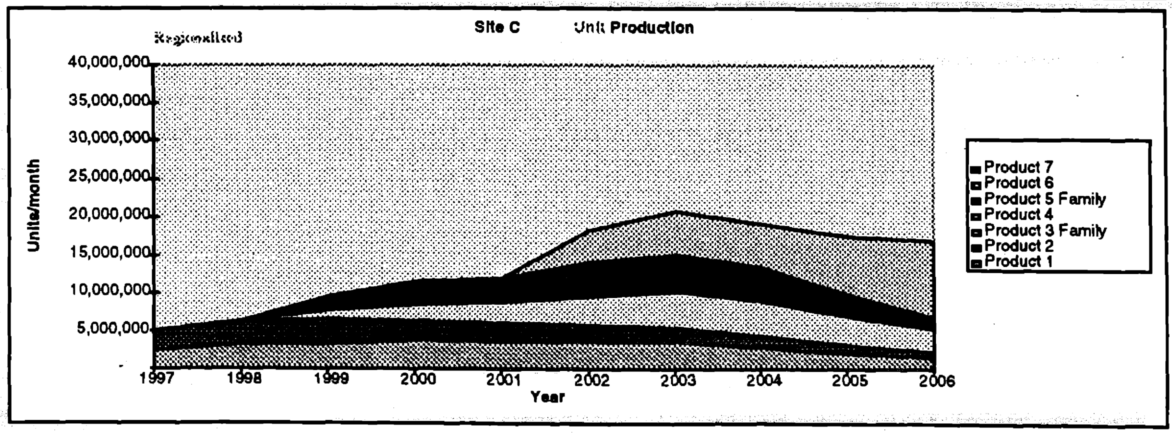


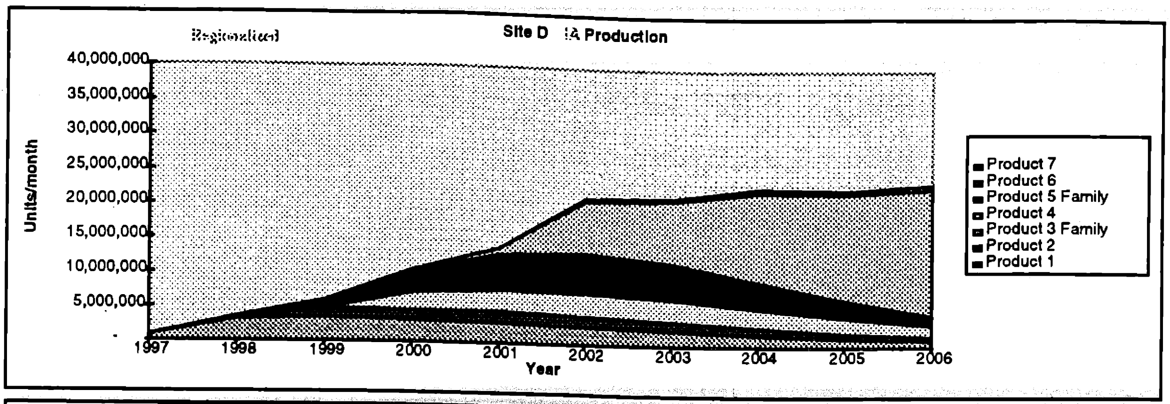


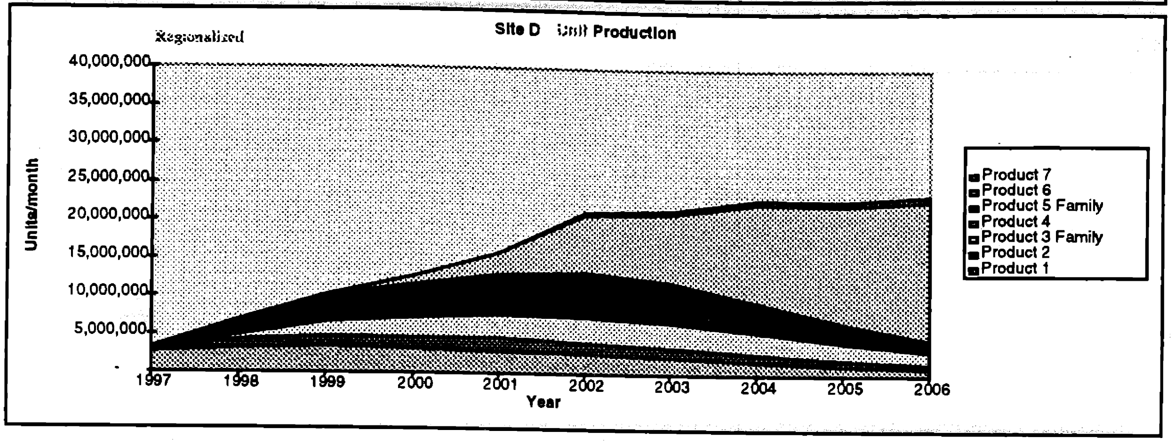

Regionalized
Site B A Production
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Product 7
Product 6
Product 5 Family
Product 4
Product 3 Family
Product 2
Product 1

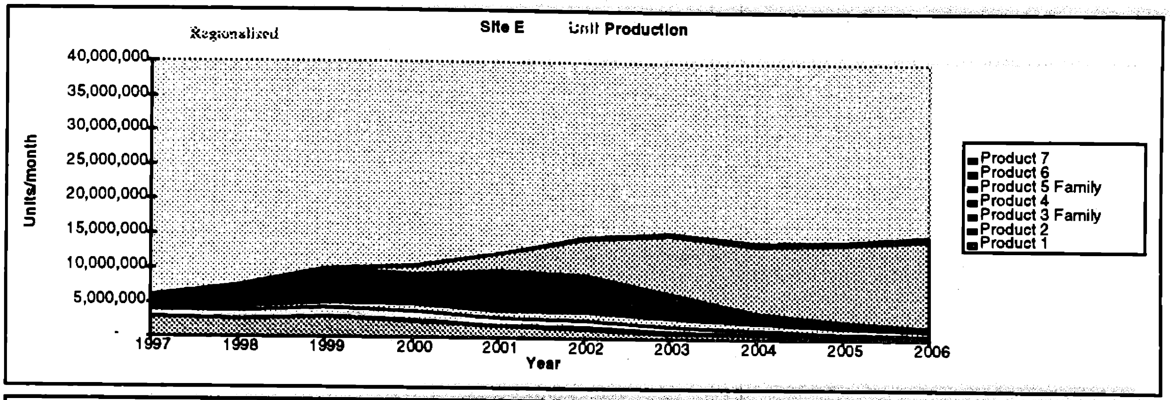

Regionalized
Site B Unit Production
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Product 7
Product 6
Product 5 Family
Product 4
Product 3 Family
Product 2
Product 1

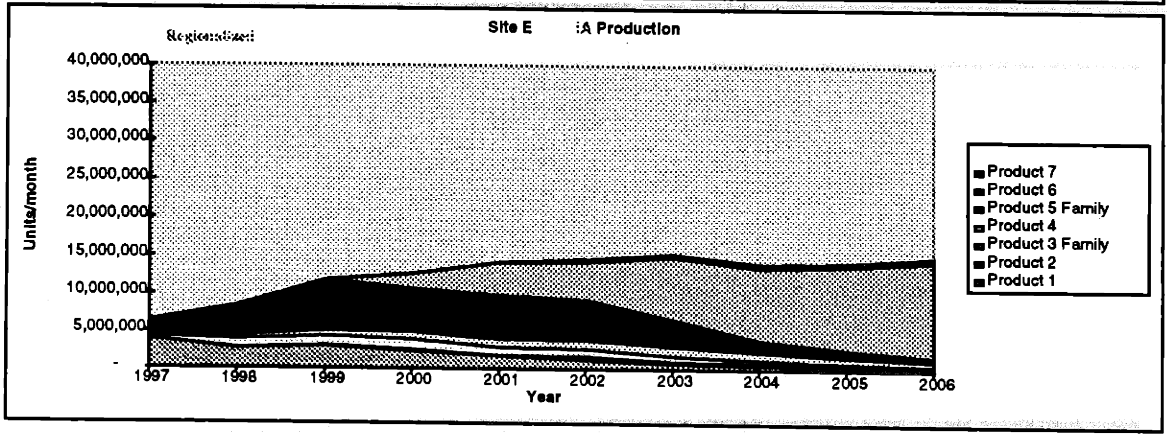

Regionalized
Site C A Production
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Product 7
Product 6
Product 5 Family
Product 4
Product 3 Family
Product 2
Product 1


Regionalized
Site C Unit Production
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Product 7
Product 6
Product 5 Family
Product 4
Product 3 Family
Product 2
Product 1


Regionalized
Site D :A Production
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
■ Product 7
■ Product 6
■ Product 5 Family
■ Product 4
■ Product 3 Family
■ Product 2
■ Product 1


Regionalized
Site D Unit Production
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
■ Product 7
■ Product 6
■ Product 5 Family
■ Product 4
■ Product 3 Family
■ Product 2
■ Product 1


Regionalized
Site E Unit Production
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
■ Product 7
■ Product 6
■ Product 5 Family
■ Product 4
■ Product 3 Family
■ Product 2
■ Product 1


Regionalized
Site E :A Production
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
-
Units/month
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
■ Product 7
■ Product 6
■ Product 5 Family
■ Product 4
■ Product 3 Family
■ Product 2
■ Product 1

It is worth noting that Site B, even in the regionalized strategy, continues to be much smaller than its brethren Sites A and B serving Region 1's demand. This constraint takes stock of the fact that the company simply does not see that site as expandable; the other sites must then take up the slack. In addition, Site A's production eventually concentrates on Product 7, whereas Site C makes the full suite of products demanded in Region 1. Again, note that Site A continues to be the research and development site for the company's products; new products not represented within this analysis might in fact be developed there. Sites D and E, as the sole regional sites for Regions 2 and 3, respectively, must carry a full suite of products and grow with regional demand.

6.4 Results of Analysis.

Both the conventional and full regionalization strategies were analyzed using the model described in Chapter 5. As a reminder of the evolution of the two strategies, the following table sums up what each strategy looks like ten years out.

Models and Sensitivities

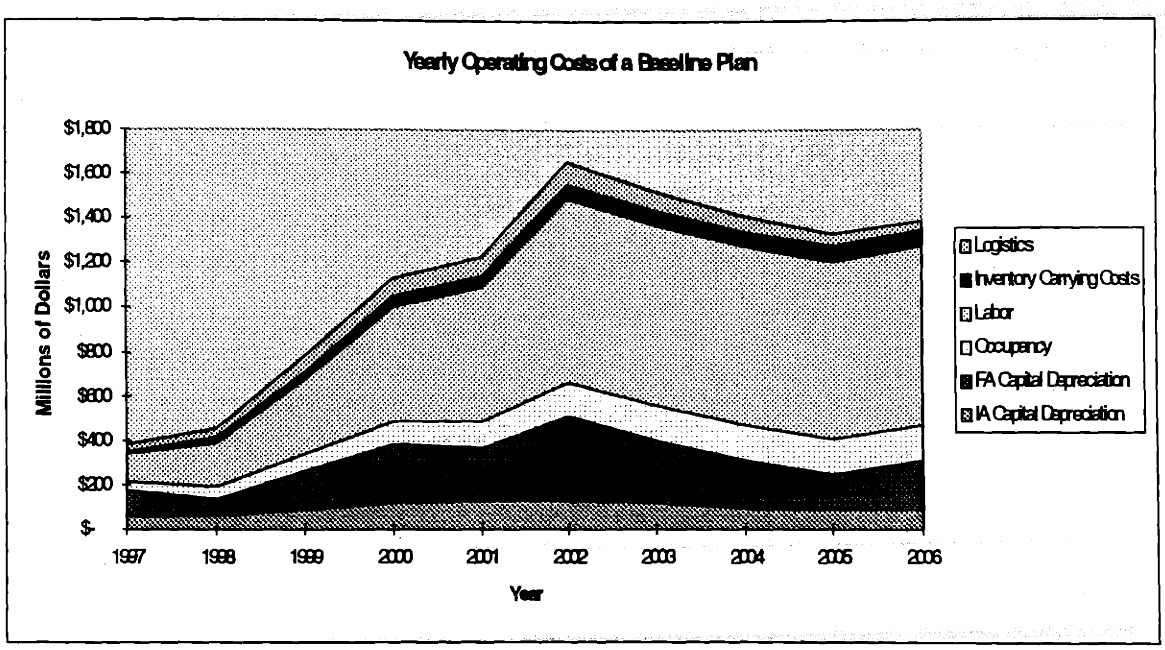
Product Families	**Baseline Model**	**Regional Model**
Product 1	Site C, D, E - all vertically integrated	no change.
Product 2	Site C, D - both vertically integrated.	add Site E production - vertically integrated.
Product 3	Site E - vertically integrated	no change.
Product 4	Site C, D, E - all vertically integrated	no change.
Product 5	Site D, E - both vertically integrated.	add Site B, C - vertically integrated.
Product 6	Site A, B, E - all vertically integrated. Site D has some final assembly	Adds Site C and Site D IA - all 5 sites now vertically integrated.
Product 7	Site B - vertically integrated.	Adds Site D and Site E - both vertically integrated.

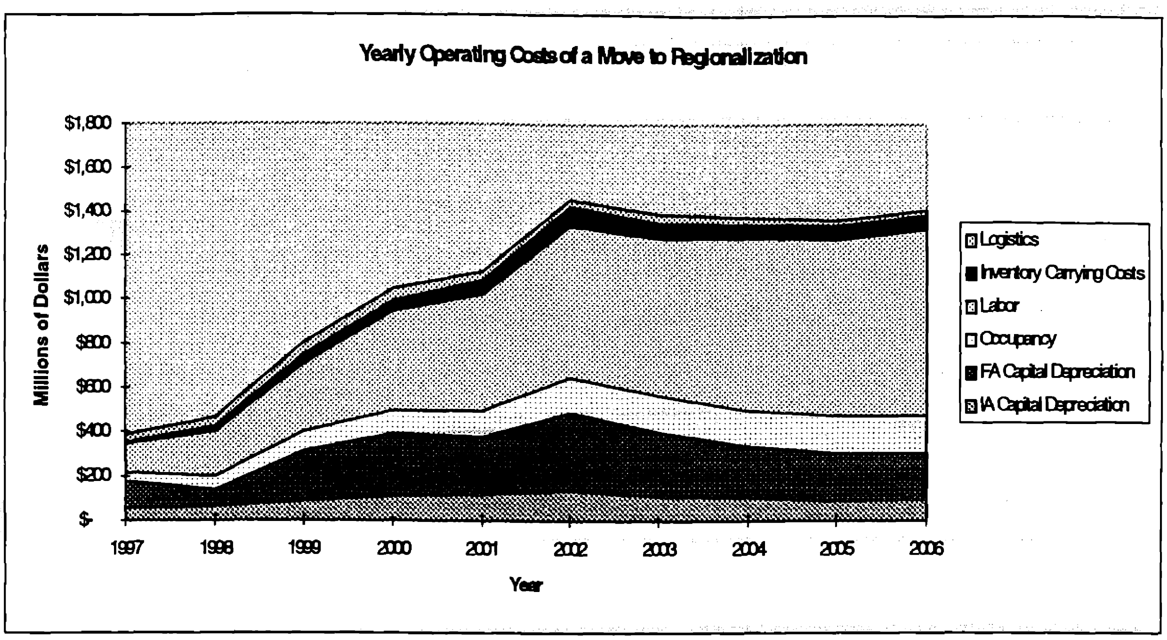
Sensitivities: vary market demand, shipping costs, duties, service level, tax status.

Sensitivity Analysis

Sensitivity Applied	Baseline Model	Regional Model
Shift to FGI shipped surface (70% after year 2000).	Marginal differences between two models.	
Duties go from 0% to 5%.	Dramatically affected: costs $215 m. more year 2006.	Initially affected, then surcharge falls to $10 m.
Overall Market Demand is 80% of forecast.	Marginal differences between two models.	
Product 6 Trade Volumes drop to 50% of forecast.	Marginal differences between two models.	

Results are depicted in the following two graphs showing the evolution of manufacturing costs over the next ten years.





If the total costs are looked at over the ten years, by cost factor, it becomes even more apparent that in terms of overall costs, the difference between the two strategies is insignificant. And the following table reveals that even with costs broken down, there is not a significant difference between the two strategies over time.

BASELINE

	IA Capital Depreciation		FA Capital Depreciation		Occupancy		Labor		Inventory Carrying Costs		Logistics	
1997	$	53	$	120	$	43	$	123	$	14	$	30
1998	$	61	$	75	$	59	$	198	$	24	$	41
1999	$	89	$	172	$	79	$	337	$	34	$	67
2000	$	119	$	282	$	103	$	522	$	44	$	81
2001	$	125	$	242	$	117	$	610	$	48	$	86
2002	$	131	$	380	$	153	$	624	$	65	$	101
2003	$	117	$	280	$	163	$	610	$	65	$	89
2004	$	98	$	210	$	158	$	609	$	66	$	72
2005	$	87	$	161	$	159	$	799	$	65	$	57
2006	$	87	$	221	$	162	$	803	$	70	$	46
Total:	$	967	$	2,143	$	1,196	$	5,235	$	495	$	670

REGIONAL

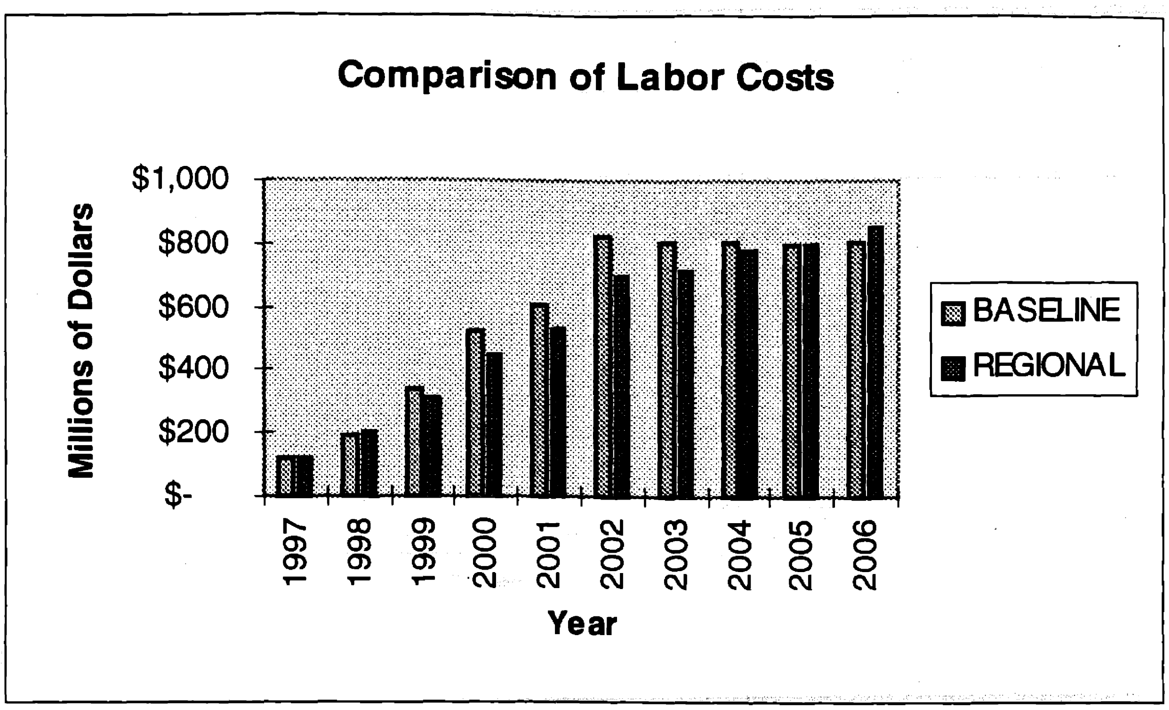
	IA Capital Depreciation		FA Capital Depreciation		Occupancy		Labor		Inventory Carrying Costs		Logistics	
1997	$	53	$	120	$	43	$	123	$	14	$	30
1998	$	62	$	75	$	59	$	203	$	23	$	39
1999	$	91	$	217	$	89	$	315	$	34	$	56
2000	$	113	$	274	$	109	$	453	$	43	$	59
2001	$	116	$	255	$	122	$	530	$	69	$	64
2002	$	132	$	352	$	162	$	694	$	82	$	70
2003	$	115	$	284	$	167	$	715	$	74	$	65
2004	$	102	$	230	$	168	$	781	$	66	$	52
2005	$	92	$	212	$	167	$	802	$	61	$	43
2006	$	92	$	208	$	169	$	854	$	64	$	37
Total:	$	967	$	2,228	$	1,255	$	5,471	$	530	$	515

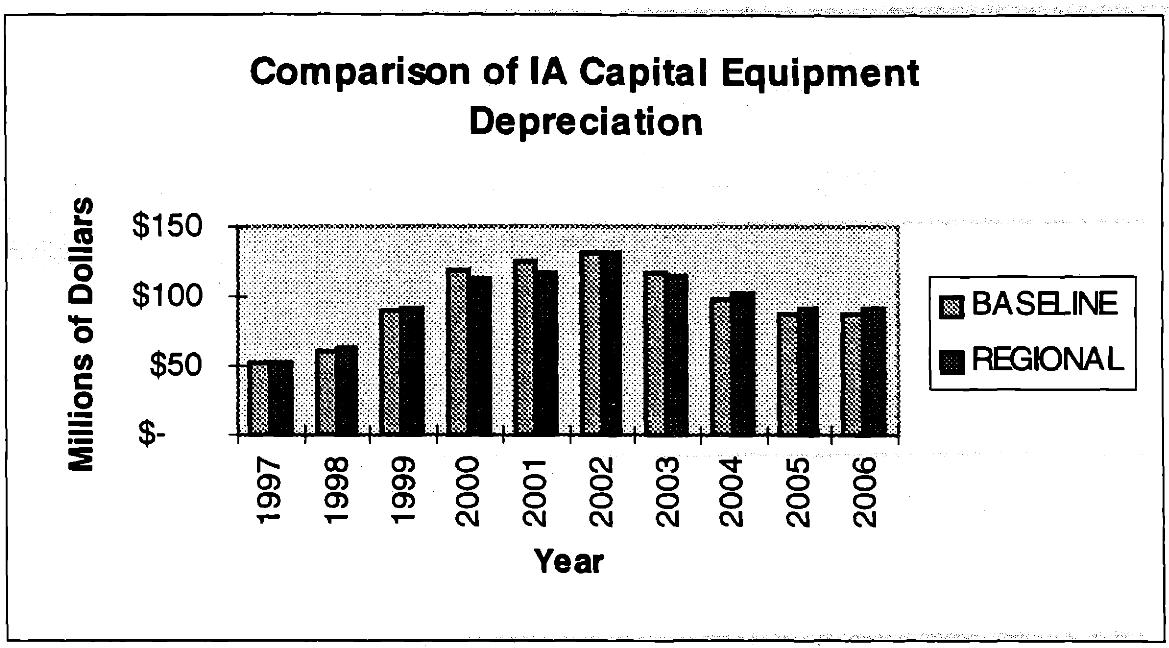
Two issues then become of interest. First, how do the costs of each factor compare to the other? In other words, are logistics costs greater than labor costs? And second, when each cost factor is broken out, how do they compare between the two strategies? In other words, how does capital depreciation compare between the two strategies over time?

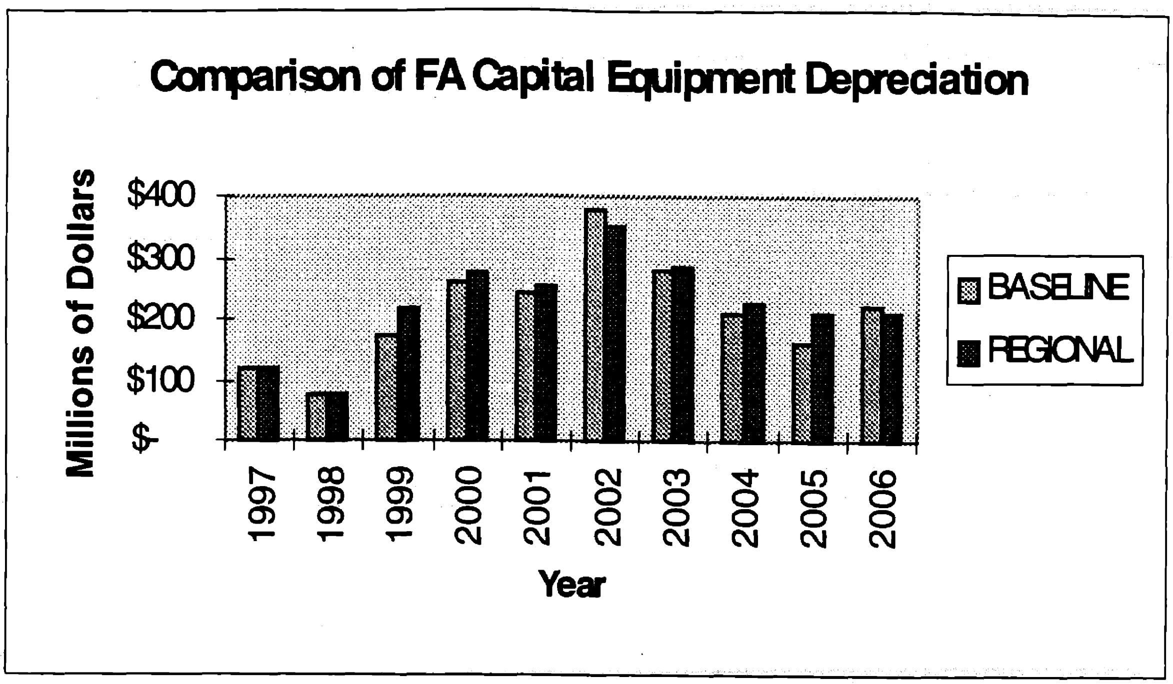
The first question may reveal some surprising conclusions to the casual observer. First, although the company describes itself as participating in a capital-intensive, high technology industry, labor costs grow dramatically in proportion to other costs over time. This factor is visible in both manufacturing strategies; in fact, it constitutes well over half the cost of manufacture. The growth of the proportion of costs attributable to labor can be ascribed to the fact that the equipment needed to make products quickly depreciates away but continues to be useful. Note that new products in addition to the seven under analysis would continue to be introduced; to the extent that this cycle continues, the company should expect to see capital costs as a significant part of its structure.

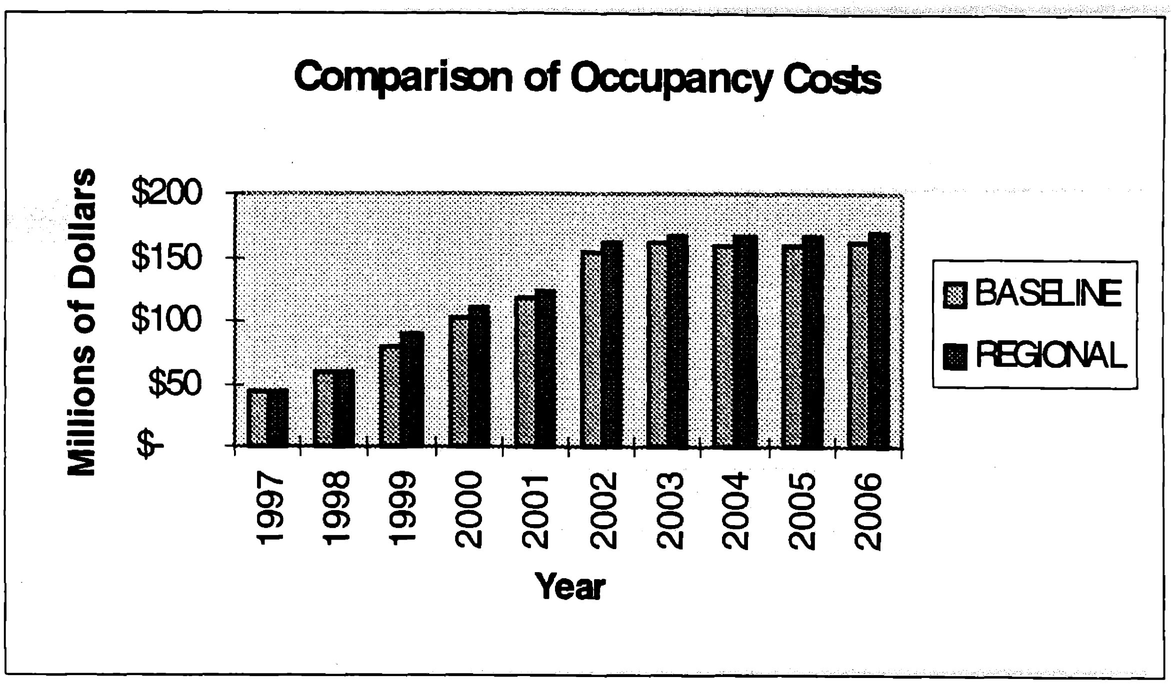
On the other hand, it is important to note that the company expects a sea change in the demand profile for its products that involves a shift towards high volume manufacturing; unless the process is more fully automated or labor's productivity increases more dramatically than what is assumed within the model, labor will continue to trump other costs as consumers demand any of the seven products.

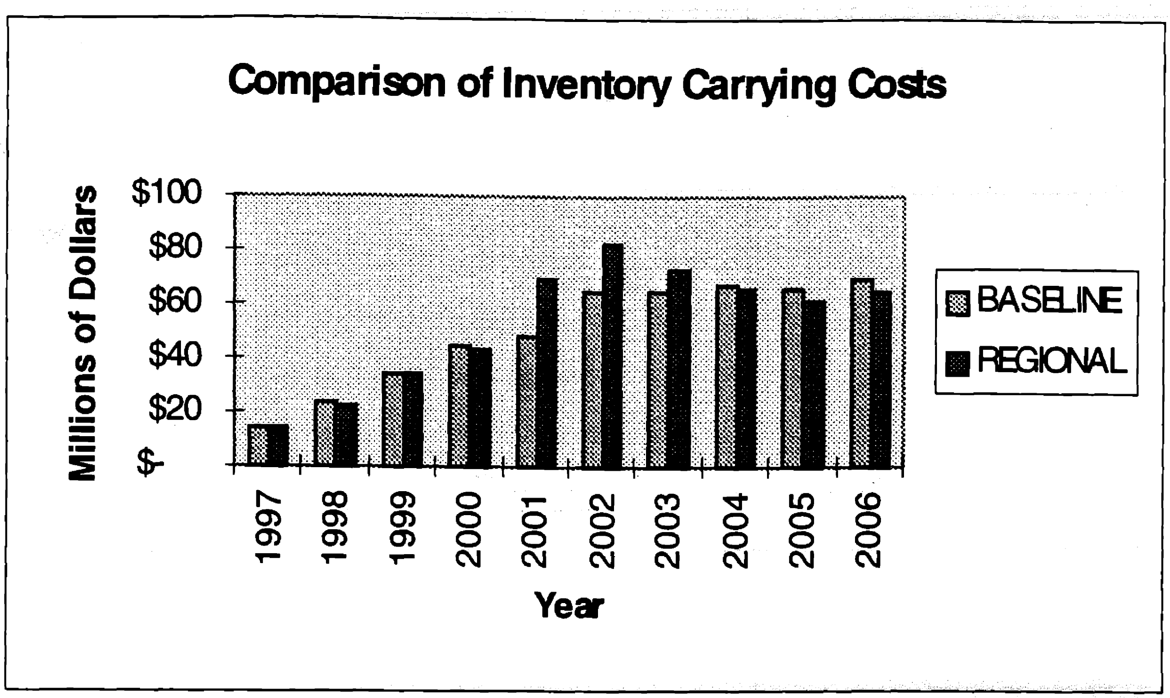
The next six graphs allow the reader to more closely compare separate cost factors:

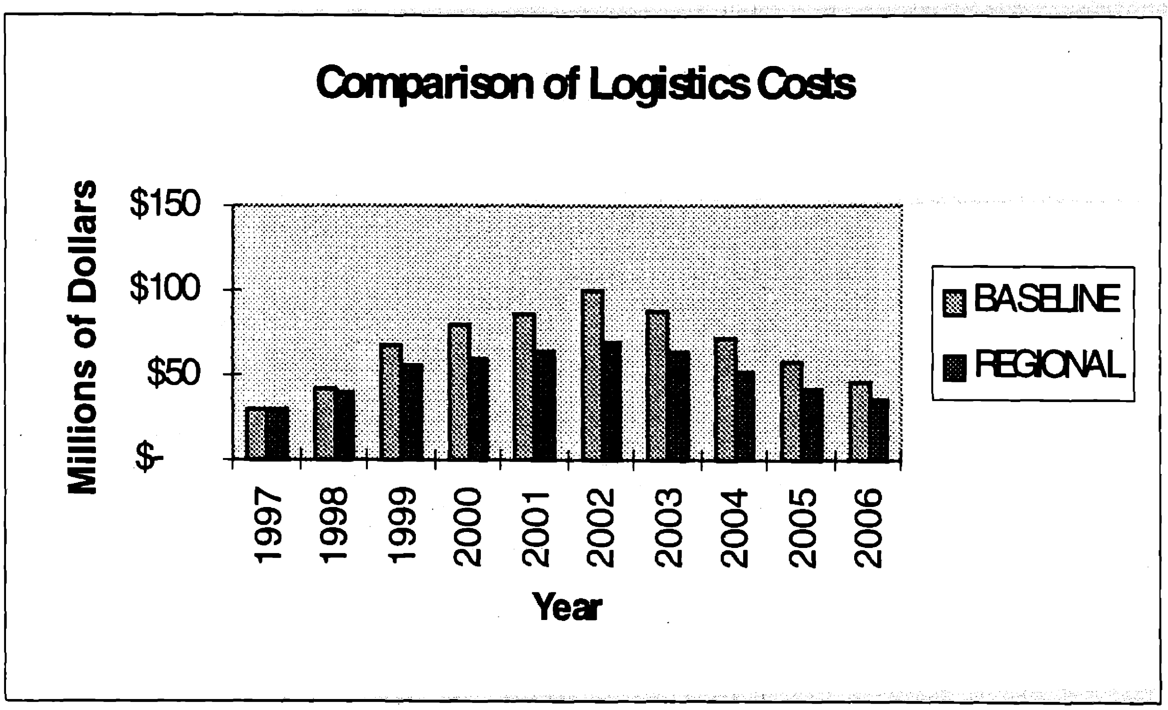

Comparison of Labor Costs
Millions of Dollars
$1,000
$800
$600
$400
$200
$-
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
▨ BASELINE
■ REGIONAL


Comparison of IA Capital Equipment Depreciation
Millions of Dollars
$150
$100
$50
$-
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
▨ BASELINE
■ REGIONAL


Comparison of FA Capital Equipment Depreciation
Millions of Dollars
$400
$300
$200
$100
$-
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
BASELINE
REGIONAL


Comparison of Occupancy Costs
Millions of Dollars
$200
$150
$100
$50
$-
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
BASELINE
REGIONAL





First, labor costs in the baseline strategy grow more significantly in the baseline strategy than they do in the regionalized strategy; but over time, the difference in costs narrows. The difference in growth can largely be attributed to the rate of change in allocation strategies for each strategy; note that labor costs are significantly higher in Sites A, B, and D than they are in Sites C and E.

Second, capital depreciation for both manufacturing stages does not vary significantly at any point in time between the two strategies. Whereas the conventional wisdom is that manufacturing any given product in multiple locations is more costly in terms of required equipment than a centralized economies of scale type manufacturing, the volumes that are projected a few years out completely sidestep this issue. At a certain volume, multiple manufacturing sites can take advantages of economies of scale in equipment.

Third, occupancy costs hardly vary over time between the two strategies. To the extent that occupancy serves as a surrogate for used space, it might appear at first glance that both manufacturing strategies simply have the same site growth over time. It is worth noting, however, that the sites are growing in very different directions in the two strategies; if a site becomes the primary supplier of intermediate assembly components, for instance, it has a higher per foot cost of occupancy than it would if it were more vertically integrated.

Fourth, inventory costs are closely linked in both strategies, although four or five years out there is a surcharge in the shift towards a regionalized manufacturing structure. The amount of this difference, and its timing, depend largely on when the shifts in vertical integration and regionalization are made. But in any case the difference is real and matches expectations of carrying higher inventory costs if each region must have buffers for its own demand as opposed to a slightly more centralized buffer.

Fifth, logistics costs are substantially more expensive over a long period of time for the baseline model than they are for the regional model. Again, this difference meets expectations; if product must be shipped halfway around the world as opposed to being made in one region, then it will most probably cost more to do so. It is interesting to note, however, that even the baseline model includes a move towards more localized manufacturing, the main reason being that volumes are sufficiently large to warrant multiple manufacturing sites for the newest products.

In conclusion, then, the company is well situated to make use of its current sites to build up capability for a regionalized manufacturing structure without a severe manufacturing cost penalty. It remains to be seen, however, whether or not the company has a sufficient comfort level with the fact that it might have to restructure its organization in order to more effectively manage a decentralized empire.

A note on current sites here: the company has a severe discomfort with managing large sites; indeed, Site A is considered already to be too large, although it is situated in the company's largest market. As a result, the company intends to build a sixth and seventh site in the next few years. This analysis does not include these potential sites for two reasons: first, it is not at all clear where they might be situated, and second, an analysis allowing unconstrained growth in any one site spurs valuable discussions regarding the strategic impact of where such an additional site might be located. One example: if Site D supplies all of Region 2's demand, and as a result grows to be much too large in the model, then it reveals a need for an additional site in Region 2 to fulfill the spirit of regionalization.

CHAPTER 7 - CONCLUSION.

7.1 Strengths and Weaknesses of Approach Used.

Throughout this thesis we have made notes about the assumptions made in building a model-based analysis, as well as some of the pitfalls that such an approach might encounter. In this concluding section, the strengths and weaknesses of the approach used are summarized at the risk of repetition.

First, the strengths. The original problem statement contained a broad challenge to find and recommend the optimal manufacturing strategy for the company for the next ten years, given its background and expectations of demand growth. This thesis has focused on the much narrower and more modest goal of building a solid foundation of quantifiable manufacturing costs to spur discussion among the company's management. The thesis's focus on measuring and modeling quantifiable costs made the project manageable in a six month time frame, and fulfilled the technical requirements needed to complete a master's degree in MIT's engineering department.

In order to focus on these costs we found it necessary to both gain highly accurate data for those factors determined to be most important, and to build a model that would have sufficient horsepower to calculate manufacturing costs and perform sensitivity analyses. The end result of asking for detailed data, and building a model that captured a relatively complex manufacturing process was that the analysis was able to withstand potential challenges to its credibility. Industrial engineers who were in a position to contribute information were critical of the strategy group's traditional superficial treatment of the nuances inherent in machine capacity and flexibility; in order to convince them to contribute to the thesis, the manufacturing process calculations are a bit more complex than necessary. By working to understand how the finance group understood manufacturing costs, and incorporating these understandings into the model as it was being built, we were able to build support among this group for the model's outputs.

Another strength of the model lay in the realistic depiction of alternate manufacturing scenarios. A vast difference in manufacturing costs could be envisioned were one to compare a single site to multiple sites, for instance; but in the case of this company, there were already multiple sites that would continue to be used. The fact that the baseline strategy did not differ appreciably from the regionalized strategy in terms of manufacturing costs does not in any way call into question the ability of the model. Since manufacturing managers contributed to the depiction of both strategies, they had already bought into the premise that both were realistic options. Painting extreme strategies may have been more satisfying from an academic point of view, but would have done little to convince the decision makers within the company to go beyond the easily identifiable costs and ask themselves what type of organization they wanted.

In building the model, we wavered between seeing it as a means to an end and seeing it as part of the end in itself. From the company's point of view, the model was initially simply a temporary tool to be used in a six month internship. But the sophistication of the model and its flexibility of use lend it to other uses, both within this company and in others. The model's complexity is thus a strength in the sense that it can be used again, with minor modifications; hence, its inclusion in the thesis.

On the other hand, the time needed to build a model represented a necessary opportunity cost for us; we were not able to tackle the rich question of qualitative costs. In addition, there are some limitations to the model itself, in terms of its assumptions about demand and about external suppliers. While these limitations can be fixed, there is no doubt that some time would have to be spent repairing what could best be described as a work in process. Finally, as is the case with any project of limited duration, we were ourselves on a learning curve with respect to model building - one that forced long hours to be worked towards the end of the six month internship. Indeed, we hope that a similar time sink can be avoided by a would-be analyst if the current model can be adapted.

Most notably, in spite of the strengths inherent in narrowing the scope of the thesis, we would have liked to participate more fully in the subsequent analysis which inevitably must follow a depiction of the manufacturing costs. Once it is determined that the costs are not the driver in a company's decision to regionalize its manufacturing, then the question becomes, which factors are? How does a company determine its comfort level with a shift in manufacturing strategy? And how might a move from low volume manufacturing in a capital intensive manufacturing environment to high volume manufacturing in a labor intensive environment affect the company's culture?

7.2 Presentation of Results.

This section is included in the conclusion because it is of particular interest to us, but may seem to be peripheral to the thesis. Yet we would argue that proper presentation of the results is at least as important as the results themselves. And if we were to take away anything from our internship beyond a more sophisticated understanding of how to model manufacturing costs, we would argue that building a support coalition within the key groups of the company is instrumental to the success of an analysis.

Part of the project involved lengthy discussions with manufacturing managers, industrial engineers, financial analysts, marketing analysts, and capacity planners. Perhaps it goes without saying that any person involved in contributing information, either in recommendations for modeling, data, or strategy, is by definition a stakeholder in that analysis. We were careful to make notes of all sources for both assumptions and data within the model, although these notes had to be scrubbed from the included model. And each of these contributors was then concerned with the results of the analysis; for their names were attached to it. By acknowledging these individuals both in casual conversation and in a formal presentation, we hoped to forestall any attacks on our results and a more gracious acceptance of their implications. Within the meeting in which the results were presented, we did indeed find this acceptance to be the case; manufacturing managers defended the results of the analysis in front of the general manager of the site.

In general, we did not win conclusive acceptance within the company; but in hindsight, the results were accepted at the levels of management which mattered most for decision making.

7.3 Recommendations for Further Research.

It should come as no surprise to the careful reader that this thesis concludes with some strong recommendations for further research that go beyond quantitative measures. Some of the company's managers are convinced that the company must go beyond the immediate costs of manufacturing and try to understand how the structure of managing a global organization affects its ability to make money.

Within the company this issue is called cost of complexity; the question hinges on whether or not it is more expensive to have a regional manufacturing site autonomously act on that region's demand and decide its own production, or to continue to have a centralized manufacturing scheme. Some consulting companies have attempted to attach measures such as numbers of contacts made before a certain level decision is acted on; but this area appears at first glance to be an undeveloped field of interest.

Another area which might prove to be interesting is how a company's culture which allows it to introduce innovative technological solutions might hamper its ability to manage the growth of the market it spawns. This company is currently the undisputed leader in the field that it has created; but the growth projects are so high that one wonders if the company can continue to manage it with its constrained site growth and historical emphasis on high technology as opposed to efficiency in manufacturing. A related question centers on the interaction between a company's decision to pursue a growing market and the ability of that market to transform the company's culture. To the extent that this company is successful in managing the market, will it remain the same company? Or will it cede a large portion of the market to competitors and concentrate on high technology niches?

Finally, the interaction between marketing and manufacturing is of particular interest to us. In this analysis marketing was taken to be a static input. But in reality, one might imagine scenarios where a company's manufacturing ability and location both serve to enable and constrain marketing channels. Localized manufacturing, particularly in the downstream activities, might allow a company to respond more quickly to a brand tie-in or coloring fad. On the other hand, it might constrain a company's ability to gear up quickly for a big jump in demand if the product moves from being sold mail order to being sold in convenience stores. While these issues fell outside of the scope of this analysis, we can envision a more nuanced understanding of the interaction between a company's marketing success and its manufacturing operations.

References

Nahmias, S., *Production and Operations Analysis, 2nd. Ed.* Richard D. Irwin Incorporated, Boston, Massachusetts, 1993.