Management of the Supply Chain in a Rapid Product Development Environment

by

Bryan Clark Gilpin

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Submitted to the Department of Electrical Engineering and Computer Science
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Abstract

Ethicon Endo-Surgery (EES), a Johnson & Johnson company, has experienced consistent supply problems when introducing new products. On several occasions, demand for a new endoscopic surgical instrument has outstripped EES's ability to supply the instrument. (Demand in this sense refers to the volume of product ordered by distributors.) Depleted finished goods inventories have translated into several months of continuous stockouts. In response, production has been forced to quickly ramp up its output in an effort to restore consistent supply to distributors and, consequently, to end-customers (hospitals).

Ethicon Endo-Surgery's strategy of rapidly developing innovative products and of servicing hospitals through new sales channels has earned it tremendous success in the market for endoscopic surgical instruments. In keeping with EES's product development strategy, the original research problem focused on forecasting demand for new products. Having consistently experienced supply shortages for new products, EES felt that being able to better predict distributor demand could help alleviate the supply problems. In other words, EES wanted to understand the extrinsic factors associated with new product introductions.

Interestingly, the extrinsic factors did not turn out to be nearly as important as the intrinsic factors. Distributor demand was found to be surprisingly predictable and stable relative to production. Variations in production rates from week to week and from month to month often exceeded the corresponding variations in incoming demand. And despite the relatively stable demand, finished goods inventory levels were found to be well in excess of corporate objectives (on the order of $10 million). The real issue, therefore, was not in predicting distributor ordering patterns, but in the way that EES converted the orders into actual production plans and inventory policies.

In this thesis, I provide the research path that began with an extrinsic view of new product introductions and ended with a focus on processes within EES. I will demonstrate that distributor demand patterns are relatively predictable, even during new product introductions. I will then show how month-to-month changes in production exceeded month-to-month changes in demand for both new products and stable products. An analysis of finished goods inventory levels uncovered inventory well in excess of corporate objectives. Why was the leverage for improving product supply initially believed to exist in understanding extrinsic factors? I argue that the organizational structure, incentives, planning processes, and information systems were largely responsible for the organization's external focus. No single group or person had the ability or the incentives to tie together the key pieces of the puzzle. Lack of readily available information made the task even more difficult.

Lastly, I present a new production system that, in light of the research findings, should help improve EES's internal operations. This new system, in contrast to the current monthly forecasting and planning system, uses simple concepts of "demand-pull" to schedule production. Simulation modeling efforts demonstrate that, even with the most extreme demand patterns, variation in demand can actually be reduced in production. Reduced variation results in reduced inventory with improved delivery service. From an organizational standpoint, the system naturally emphasizes cycle time reduction, inventory reduction, and increased flexibility. I will show how these benefits complement, rather than conflict, with each other, resulting in the ability to align incentives throughout the manufacturing function.

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I would like to thank Professor Steve Graves for often going beyond the call of duty to help provide analytical support for my findings. This support often came with awkwardly short notice. Additionally, my thesis supervisors deserve special recognition. To Al Drake, who helped provide me with the confidence to keep pushing forward; and to Rebecca Henderson, whose sincere enthusiasm for the project continually inspired my research, I am extremely grateful.

Finally, I dedicate this thesis to my classmates in the Leaders for Manufacturing Program. Thank you for making the past two years the some of the most personally enlightening and influential years of my life.

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Executive Summary

With rapid product development central to Ethicon Endo-Surgery's business strategy, the ability to introduce new products smoothly into the market has been of critical importance for success. Introducing products smoothly requires having finished product consistently available to supply to distributors and hospitals. Unfortunately, the past several years have brought new product introductions that were not always smooth. Orders coming into Ethicon Endo-Surgery (EES) often outstripped production capacity, depleting inventories and sending the product into back order[1]. This defined the basis of the research as understanding hospital and distributor[2] ordering behavior for new products. The intention was to develop forecasting techniques to predict the incoming demand and to offer a strategy for planning for introductions based on those predictions. By understanding the ordering behavior of hospitals and distributors, EES could build up an appropriate level of finished goods inventory prior to the introduction.

The first several months of the research were spent investigating distributor and hospital ordering and inventory policies, particularly in relation to new products. Three important findings emerged (refer to Chapter 3 in the thesis):

1. Distributors typically build inventory during the first few weeks of an introduction, resulting in an ordering "spike." The spike is immediately followed by steady demand;
2. The demand "spike" can be easily predicted;
3. No evidence could be found that distributor demand increases due to "panic ordering" or due to increasing safety stock policies.

The initial spike in demand occurring during the first few weeks of the introduction was found to be largely responsible for demand outstripping supply and, consequently, for new

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[1]"Back order" in this case refers to the condition when there are more orders for a product than can be immediately supplied from finished goods inventory.
[2]Ethicon Endo-Surgery uses domestic dealers to distribute product within the United States and Johnson & Johnson affiliates to distribute product internationally. The term "distributor" will be used at this point to refer to both dealers and affiliates.

products falling into back order. I originally held a belief that distributors would increase their ordering in response to a product falling into back order. This has since been disproved. The belief stemmed from various reports that distributors "panic order" (i.e., game with the EES order filling policies in an effort to increase the probability of receiving product) and, as a result of increased delivery lead times, increase safety stock levels.

Variation in Production Exceeds Variation in Demand

After discovering a consistent, predictable pattern for new product demand, I investigated how EES reacted internally to the demand (see Chapter 4 of the thesis). All examined products revealed that the initial "spike" was under-forecast, forcing the production processes to quickly ramp up to meet the incoming demand. The reaction from a production standpoint was found to be rather extreme -- production output would literally double from one month to the next. Even more surprising, the production processes, designed largely to shield specific operations from variations in demand, were found to vary significantly more from month to month than the incoming demand. The monthly changes in production rate often exceeded the monthly changes in demand by a factor of two.

Products other than new products were also found to demonstrate a similar pattern. In one particular case, the assembly production rate nearly quadrupled within a five week period. Changes in demand for the product were not nearly as significant.

As a side but related issue, finished goods inventory levels were found to significantly exceed the corporate inventory objective (see Chapter 6 of the thesis). The current inventory policy, stated in terms of weeks of inventory, translated into a higher service level than the corporate service level objective. Alternatively, the corporate objective translated into a significantly lower inventory level than the current policy. The magnitude of the difference has been calculated to be on the order of $10 million.

Why Was the Leverage Believed to Exist with Extrinsic Factors?

Given that distributor demand turned out to be predictable for new product introductions; and given that the demand was relatively stable for all products (see Chapter 9 of the thesis), the question that should immediately come to mind is, Why was the leverage for improvement initially believed to exist with extrinsic factors? The ability to recognize the internal factors of the analysis hinged on combining three critical pieces of data -- demand, inventory, and production (see Chapter 8). By examining production rates relative to demand, the fact that demand is relatively stable and that production varies considerably more becomes immediately evident. Bv adding inventory to the graph, the timing of back order with production responses becomes clear. Additionally, placing inventory and demand on the same graph helps demonstrate how high the inventory levels really are. Finally, a graphical view of the demand data over an extended period of time demonstrates the steady trends of most of EES's products.

The research found that no one single group or person had immediate incentives to combine separate pieces of the puzzle. One part of the organization, the central planning group, was responsible for developing forecasts and monthly production "plans." The "plans" were actually the volume of product that needed to be transferred into finished goods inventory to satisfy the forecast demand. Therefore, they did not provide insight into the actual production schedules (see Chapter 2 of the thesis for an explanation of the current monthly planning process). Additionally, the central planning group's "view" of demand was limited to monthly snapshots taken only over the preceding few months. With another group, the primary responsibility was in scheduling production and ordering component parts from suppliers. Creating the schedules based off forecasts from the central planning group did not require significant knowledge of product demand. With yet another group, management of inventory was the primary responsibility. This group, however, did not have responsibility for creating the production schedules or for interpreting demand data.

The other important factor to consider is that the demand, inventory, and production data was difficult to obtain. Data concerning the assembly schedules could not be obtained for most plants. In the case of one particular plant, it had to be pulled from a local spreadsheet. And once obtained, the information often had to be converted into comparable units. For example, much of the monthly information was based on quarterly financial calendar months. The financial quarter is composed of three months of four weeks, four weeks, and five weeks in length. The five week months had to be converted into equivalent four week months.

How Can EES's Production System Be Improved?

The fortunate part of demand being relatively stable is that the production system can potentially be greatly simplified. In particular, a simple Order Point / Order Quantity (OP/OQ) "Pull" policy can be used to schedule production (see Chapter 10 of the thesis). This policy simply states that when inventory drops below a certain point, a new batch of product should be initiated through the production process. No forecasting is necessary, so inaccurate forecasts can no longer be an excuse for not providing a high level of customer service. Aside from the potential to reduce variation in converting demand into production, the policy emphasizes cycle time reduction, inventory reduction, and increased flexibility. It also very simply allows demand, inventory, and production to be controlled within one manageable group.

Final Remarks Before Proceeding Forward

In summary, this thesis will show that in EES's case the ability to cope with external complexity depends critically on the ability to reduce complexity internally. An important distinction should be made between the tendency to find ways of accommodating complexity and the need to find ways of reducing it. This idea is presented clearly in chapter 7 of Dynamic Manufacturing by Hayes, Clark, and Wheelwright[3], and in Reengineering the Corporation by Hammer and Champy[4]. (This will also be discussed briefly in Chapter 1 of the thesis). As EES moves to improve its product supply to hospitals, I advocate finding ways of reducing rather than accommodating complexity throughout its production and business processes. Anyone reading this thesis will find that this theme consistently arises in several chapters. So that my conclusions will be best understood, I ask that the reader keep this in mind as he or she proceeds forward.

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[3]Hayes, R., S. Wheelwright, K. Clark, Dynamic Manufacturing: Creating the Learning Organization, New York: Free Press, 1988.
[4]Hammer, M., J. Champy, Reengineering the Corporation: A Manifesto for Business Revolution, New York: HarperCollins Publishers, Inc., 1993.

Chapter 1 Introduction

1.1 Background

Johnson & Johnson is the world's largest and most diversified health care company, boasting revenues of $15.7 billion in 1994[5]. Johnson & Johnson's products range from consumer goods to professional equipment, and from BAND-AID™ brand adhesive bandages to surgical instruments. Baby powder, Tylenol™ brand pain relief products, sutures, contact lenses, scalpels, dialysis machines, CO_2 surgical laser systems, and pharmaceuticals are just a sample of offerings. Equally as diverse are Johnson & Johnson's customers -- an aching high-school student and a highly-specialized surgeon are equally likely to use its products. Having such a diverse set of products and customers places unique demands on an organization. To compensate, Johnson & Johnson approaches these demands with an emphasis on decentralization. Comprised of over 160 individual companies, Johnson & Johnson is actually an established network of autonomous business units that each determine their own mission and are responsible for quarterly and annual financial reporting to the parent company[6].

The research in this thesis focuses on a recently formed Johnson & Johnson company, Ethicon Endo-Surgery. Ethicon Endo-Surgery (EES) was spun-off from its parent, Ethicon Inc., in 1992 to address the unique needs of the endoscopic and mechanical surgical instrument businesses[7]. The research itself is a result of my internship conducted under the auspices of the Leaders for Manufacturing (LFM) program at the Massachusetts Institute of Technology. The LFM program is sponsored by Johnson &

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[5]Johnson & Johnson 1994 Annual Report

[6]For further information on Johnson & Johnson's individual companies, refer to: Aguilar, Francis J. and Arvind Bhambri. *Johnson & Johnson (A)*, Harvard Business School Case Services, Case Study #384-053, 1983.

[7]Endoscopic surgery is a rapidly emerging surgical technique characterized as minimally invasive. With this technique, the surgeon essentially performs the surgery on a video screen. Surgical instruments along with an optical device are inserted into the body through small incisions. The surgeon then guides the instruments' actions by watching the screen. Once the necessary actions have been completed, the instruments and scope are removed from the body and the small incisions are closed. The small size of the incisions often results in a shortened patient recovery time.

Johnson along with twelve other industrial companies[8]. Through Johnson & Johnson's participation in LFM and as an opportunity presented to LFM Fellows, I conducted the research efforts at Ethicon Endo-Surgery's main site in Cincinnati, Ohio. The internship itself ran six-and-a-half months, from June through mid-December of 1994, with two initial site visits conducted in April and May of the same year. Two company supervisors and two M.I.T. advisors provided guidance. After returning to M.I.T. in January of the following year (1995), I proceeded to write up my findings and conclusions in this thesis.

1.2 Internship Project Background

Ethicon Endo-Surgery has grown rapidly during its short existence. Its chief competitor, U.S. Surgical Corporation, maintained almost complete control of the minimally invasive surgery market as recently as 1989. Now, as of late-1994, Ethicon Endo-Surgery claims to have captured the market share lead[9]. This tremendous market success has required a large emphasis on marketing, sales, and rapid product development. With its main customers being hospital materials managers and surgeons (as opposed to household consumers), EES has had to rely on a sales force that could establish important relationships and reliably deliver quality products. Being a relatively new company, EES has also had to concentrate on rapidly developing products to fill out product line offerings. A complete product line increases the company's attractiveness to potential new hospital customers -- a direct result of hospitals that typically purchase through second-party vendors (specifically, group purchasing organizations or GPOs[10]) and need a sufficient volume of product to justify a re-writing of purchasing contracts.

Now that Ethicon Endo-Surgery has established itself in the market, it faces the task of establishing solid business processes and finding ways of reducing operating costs (i.e., inventory and cost of goods sold). Yet, the ability to rapidly develop new products continues as part of the company's mission, presenting challenges unique to its parent's 80-year old suture business. One of these challenges, understanding supply chain reactions (principally, distributor and hospital reactions) to new product introductions, forms the

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[8]The other sponsoring companies include Alcoa, Boeing, Chrysler, Digital Equipment Corporation (DEC), Ford, General Motors, Hewlett-Packard, Kodak, Motorola, Polaroid, and United Technologies Corporation (UTC).

[9]Smart, T., "Can U.S. Surgical Make a Full Recovery?," Business Week, Dec. 5, 1994. It should also be noted that Ethicon Endo-Surgery's market share leadership claim has been disputed by the CEO of U.S. Surgical. The fact that a controversy even exists provides enough evidence of EES's remarkable growth.

[10]For a better understanding of group purchasing organizations (GPOs), see for example, Scott, L., "Group Purchasing Evolution," Modern Healthcare, Sept. 27, 1993.

initial focus of the research. As will be described, the focus shifted slightly as the internship progressed.

After arriving at the site last June, I worked with several people at Ethicon Endo-Surgery to create a well-defined project proposal. The drafted proposal described the need to "find the lever" that would improve EES's supply and distribution process. Original discussions with EES representatives (back in April and May) hinted at the need to develop an improved forecasting methodology for new products. The initial direction to understand distributor and hospital behavior *outside of* EES, as will be discussed in the forthcoming chapters, unexpectedly evolved into an analysis of the planning, inventory, and forecasting processes *within* EES. From the research, I found that improvements to *internal* processes for <u>all</u> products would have a significantly greater impact than improvements in predicting *external* behavior for <u>new</u> products. In other words, the "lever" turned out to exist within the company. This immediately drew into question, Why was the problem defined throughout the organization as a forecasting problem? With the problem defined as forecasting, I will argue that the organization did not recognize substantial opportunities to improve internal operations. The internal improvements found to be possible include reductions in finished goods inventory and reducing large production swings. (Finished goods inventories were found to be high relative to desired service levels[11,12], and production rates, following a brief period of unexpectedly high demand, would at times double or triple from one month to the next.)

1.3 Thesis Summary

Divided into four parts, this thesis presents the findings of my six-and-a-half month internship at Ethicon Endo-Surgery, offering some explanations of what was observed and proposing a few fixes and enhancements to the internal operations.

Part I of the thesis provides the background necessary for understanding the remainder of the thesis. It describes the entire supply chain from raw materials to the hospitals' shelves. For clarity, I will refer to the portion of the supply chain that moves finished goods onto hospital shelves as the "external supply chain." This portion includes

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[11]Service level here is defined as the percentage of customer orders arriving at EES that are immediately filled from finished goods inventory. An order that cannot be immediately filled from finished goods inventory is commmonly refered to as a "stockout."

[12]By "high inventory levels" I refer to the fact that the actual inventory levels for most products support a substantially higher service level than the company's target service level. By "substantially" I mean that the target probability of a stockout occuring (i.e., 1 / target service level) is two orders of magnitude greater than the actual probability of a stockout occuring (i.e., 1 / actual service level). This will be discussed in detail in Chapter 6.

hospitals, domestic dealers, international Johnson & Johnson affiliate companies, and Ethicon Endo-Surgery's distribution center. The "internal supply chain" will refer to the portion that resides entirely *within* EES. Included in this portion are the main processes that convert component parts into finished goods. The production planning processes, inventory policies, and organizational structures also fall under the internal supply chain topic. It may be noticed that I do not provide a particular name for the portion of the supply chain that delivers component parts to Ethicon Endo-Surgery. Raw material providers and component parts suppliers were not specifically investigated as part of the internship research.

Part II, in supporting the initial project proposal to model the external supply chain, presents an analysis of distributor and hospital ordering patterns for new products. I show that hospital orders to distributors build quickly to a steady level, rarely reaching a peak level within the first few months. Distributors, on the other hand, need to build up inventories when a product is first released. Distributor orders reach a high peak (or "spike") during the first two weeks of the introduction as distributors build inventory; the orders then typically drop off to a steady level. For products that fall into back order[13], I initially hypothesized an additional event. I believed, based on discussions with EES, dealer, and affiliate representatives, that increased ordering would result for products that fell into back order. The increased ordering would result from larger safety stock levels (due to longer waiting periods for delivery of the product) and/or "panic ordering." The perceived response is similar to the "production-distribution system" model results presented by Forrester[14] and to the "beer game" description presented by Senge[15] where an increased period of ordering within the supply chain is followed by a period of reduced ordering. The data, however, demonstrates otherwise -- no increases in ordering are evident even for even the most severe cases of back order. Finally, I will present a simple technique (actually, more of a heuristic or "rule-of-thumb") for forecasting the initial distributor ordering peak. Proper preparation for the peak in distributor demand will help eliminate the occurrence of back order in new product introductions.

In Part III, I will demonstrate how the organization reacts *internally* to back order during new product introductions. This analysis will put together distributor demand data, finished goods inventory, and assembly rates to show how fluctuations in demand are

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[13]Back order here and throughout this thesis refers to a period of time when a particular product is "stocked out" (there is not enough product in finished goods to immediately fill all customer orders).
[14]Forrester, J. W., Industrial Dynamics, Cambridge: Productivity Press, 1961.
[15]Senge, P. M., The Fifth Discipline: The Art & Practice of the Learning Organization, New York: Doubleday/Currency, 1990.

followed by amplified internal reactions -- i.e., the magnitude of the production reaction exceeds the magnitude of any demand fluctuation. It will then be shown that the amplified reactions occur with any product that falls into back order, independent of new product introductions. Additionally, I will show that the finished goods inventory levels are excessive when compared to desired inventory levels when examined using statistical methods.

After demonstrating the reactions to back order and the high levels of inventory, I will explain why these findings occur. In particular, the original emphasis on marketing and sales that led to much of EES's marketplace success resulted in strong incentives to avoid back order. The back order incentive emphasized the expense of high inventories over benefits of maintaining low inventories, and emphasized the costs associated with rapid reactions in production over restoring product supply gradually. Additionally, I will show how the organizational structure, incentives, information systems, and current business processes did not allow the organization to perceive the "lever" as residing within its own operations. The problem was originally believed to be a forecasting issue, but the research uncovered the larger inventory and back order reaction problems. This will address why the organization framed the problems as *external* rather than *internal*. I will provide an explanation as to how the original business emphasis that made the organization successful -- marketing, sales, and product development -- resulted in the organization's own view of its problems.

In Part IV of the thesis, I present a relatively simple production planning, scheduling, and inventory management system that I believe will resolve many of EES's operations problems. The system's design takes into account the product demand patterns and the flexibility of the current production process. I will show how the system provides the correct incentives, organizational structure, and flexibility to address EES's major objectives (inventory reduction, cycle time reduction, and improved service levels). Finally, I will demonstrate a simple statistical forecasting technique that improves EES's current "annual forecast / market intelligence" methodology. Understanding the nature of product demand was important in redesigning the planning and inventory management system.

In the final concluding chapter, I discuss my final recommendations, as presented to Ethicon Endo-Surgery *prior* to leaving the internship, and offer some additional issues not addressed in the thesis but worth pursuing.

1.4 Literature Review

Several aspects of this thesis have been discussed in other texts. The system dynamics work of Forrester[16] demonstrates the effects of delays in a simple production-distribution model. The model considers a typical supply chain consisting of a retailer, a distributor, a factory warehouse, and a factory. The retailer receives orders for product from, and ships product directly to, customers; the distributor receives orders from and ships product to the retailer; the warehouse receives orders from and ships product to the distributor; and lastly, the factory orders from and ships to the warehouse. During relatively stable periods of demand, the ordering and shipping delays do not have much of an influence on production rates and inventory levels. When the level of customer demand suddenly increases by 10%, however, the delays have a tremendous impact throughout the chain. The 10% increase gets amplified from retailer to factory, reaching a peak order at the factory 51% higher than the original order level.

Although this amplifying effect was not clearly evident in comparing order levels from hospitals to order levels at EES, it did exist with comparisons of dealer demand (demand into EES) to EES production levels. Much of the thesis will be devoted to explaining this finding, both organizationally and from a systemic viewpoint. From the systemic side, Alonso and Frasier discuss the impact of management delays on the lifetime profitability of a product[17]. They found that delays in planning can have a significant impact on how well an organization reacts to changing product demand. In particular, they compare a JIT system (low planning delays) with an MRP-type system. The impact of altering the planning delay for Ethicon Endo-Surgery's production system will be discussed later in this thesis. Further discussion of what has been termed the "Bullwhip" effect (amplified variation in the supply chain) can be found in the paper by Lee, Padmanabhan, and Whang[18].

From the organizational side, Hayes, Wheelwright, and Clark[19] discuss how an organization's structure can influence its ability to react to change. Many typical and successful manufacturing organizations have established incentive structures that naturally resist change. Under steady conditions when changes are incremental, the incentive structures can gradually give way to new policies and business processes. The structures

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[16]Forrester, J. W., Industrial Dynamics, Cambridge: Productivity Press, 1961.
[17]Alonso, R. L., and C. W. Frasier, "JIT Hits Home: A Case Study in Reducing Management Delays," Sloan Management Review, Summer, 1991.
[18]Lee, H., P. Padmanabhan, S. Whang, "Information Distortion in a Supply Chain: The Bullwhip Effect," Working Paper, Stanford University, 1995.
[19]Hayes, R. H., S. C. Wheelwright, K. B. Clark, Dynamic Manufacturing: Creating the Learning Organization, New York: Free Press, 1988.

are not as forgiving when the change is dramatic, however. For example, the typical manufacturing organization contains several product line managers, each having responsibility for meeting a regular production schedule. The organization may also have an inventory manager responsible for controlling inventories across the product lines. Conflict results if an objective is set to drastically reduce inventories. The inventory manager's job is to reduce inventory, but reducing inventory may result in a stockout of critical component parts. Without component parts, the product line manager cannot meet her schedule. The objective of the inventory manager therefore directly clashes with the objective of the product line manager. A similar conflict was found to exist at Ethicon Endo-Surgery. This may at least partially explain the difference between current inventory policy and corporate inventory objectives. (It will be shown that Current policy, stated in terms of a service level, exceeds the equivalent corporate service level objective.) Other conflicts will be discussed.

Hayes, Wheelwright, and Clark also discuss how a factory's production system can influence its performance. Two example factories are discussed. The first factory's operations are divided up by process, with each process having several specialists. A sophisticated MRP system controls the daily flow of material. Complaints abound of too much inventory and inaccurate sales forecasts, and operations are hectic and wrought with complicated problems. Factory B, on the other hand, uses a simple layout with operations divided along product lines. A simple order point / order quantity replenishing system is used to determine production schedules. An MRP system is used, but only to plan longer-term. The amount of inventory, while considered a problem within the factory, is only a fraction of what is found in Factory A. Complaints from workers center around the constant change taking place. The two factories participate in similar industrial markets, have essentially the same suppliers, and utilize the same processing equipment. So, why do they differ? One explanation offered by Hayes, Wheelwright, and Clark lies in the way the two factories deal with complexity. In factory A, complexity is <u>accommodated</u> by building more sophisticated systems and product flows. Factory B, on the other hand, seeks to <u>reduce</u> complexity by simplifying systems and product flows. This concept along with other ideas from Hayes, Wheelwright, and Clark provide much of the inspiration for the "Pull System" discussed in the second to last chapter. I will argue that this proposed system simplifies Ethicon Endo-Surgery's production processes and will potentially produce better operational results than their current system.

1.5 Thesis Organization

This section outlines the key points presented in each chapter of the thesis.

Part I -- Thesis Introduction and Background

Chapter 1 Introduction

Chapter 2 Overview of the Supply Chain

This chapter briefly describes the supply chain that converts raw materials into finished goods and delivers finished goods into the hands of surgeons. The various entities involved with the entire supply chain, including suppliers, Ethicon Endo-Surgery itself, distributors (dealers), international affiliates, and hospitals, are discussed. Divided into two major sections, the chapter addresses the external supply chain and the internal supply chain separately. An explanation of the production planning processes, inventory policies, and organizational structure within Ethicon Endo-Surgery is provided. Readers already familiar with the supply chain may skip this chapter and proceed to Chapter 3.

Part II -- The External Supply Chain

Chapter 3 Supply Chain Demand for New Products

This chapter discusses hospital, dealer, and international affiliate ordering patterns for new products. The initial ordering "spike" resulting from dealer/affiliate stocking is demonstrated and contrasted with the underlying hospital demand. I demonstrate how to predict the magnitude of the demand spike with a simple rule-of-thumb. The dealer order patterns will be overlaid with actual hospital demand. This will demonstrate that, in contrast to dealer orders, hospital orders don't experience an initial spike. It will be argued that this difference in ordering patterns demonstrates that the initial dealer demand is largely a result of building up inventory. Lastly, I show that dealers and affiliates actually do not increase ordering when a new product falls into back order. On the contrary, there is no noticeable difference between dealer orders for a new product that falls deeply into back order and dealer orders for a product that does not.

Part III -- The Internal Supply Chain

Chapter 4 Internal Supply Chain Reactions

This chapter first presents how Ethicon Endo-Surgery's production system responds to the new product "spike." The spike often forces the company into back order. The back order condition is often met with a rapid ramp-up of production output. Once product supply has been restored and finished goods inventory reaches its desired level, production levels quickly drop back to steady levels. Interestingly, the magnitude of the production reaction often exceeds the magnitude of the spike in dealer/affiliate demand. This comes as a surprise considering that the production system was designed to shield the assembly process from swings in demand. Further evidence reveals that this reaction occurs not only for new products but for many products that fall into back order.

Chapter 5 Production Planning and Supply Chain Reactions

Having demonstrated that the production system tends to amplify large swings in demand, I demonstrate in this chapter the effect of production planning intervals on the production reactions. Previous literature has discussed the effect that production lead times have on reactions; therefore, the advantages of shortened lead times will not be addressed here. Instead, I will present how the reactions change when the production planning interval decreases from monthly to weekly and from weekly to daily. The results of three computer simulation models will demonstrate that the large swings are reduced in moving from monthly planning to weekly, but that the smaller, weekly variations are increased. The daily production planning system model actually simulates a "demand pull-type" system. This latter system was found to dampen both the smaller, weekly variations and the larger demand swings.

Chapter 6 Inventory and Cost of Reactions

The next part of the chapter demonstrates that, based on the organization's customer service objective, actual finished goods inventory levels far exceed desired levels. The analysis utilizes both statistics and a simple, graphical argument. The calculated difference between objective and actual levels is of the magnitude of $10 million[20], resulting in additional inventory carrying costs on the order of over $1 million. Discrepancies between the statistical models and actual operations are discussed. It will be argued that the discrepancies do not change the analysis significantly.

The final part of this chapter presents a framework to understand the costs associated with quick production reactions. The organization has a choice in how to react to the sudden increases in demand. The framework presented will outline the cost/benefit tradeoffs associated with the decision.

[20]Note that I present only the magnitude of the value of the inventory. Precise dollar values are proprietary in nature and are therefore not presented.

Chapter 7 The Emphasis on Back Order Protection and Reaction

In this chapter, I present some rationale behind the back order reactions and the high levels of inventory (protection from back order). I argue that both the reactions to back order and the protection from back order are a direct result from EES's original successful market growth strategy -- a strategy that emphasized always having product available for sale at all times. Now that the organization has established itself in the marketplace and is turning its focus on reducing costs, it must consider the tradeoffs between the benefits and the costs of reacting quickly versus reacting gradually, and between the benefits and costs of maintaining high levels of inventory versus maintaining low levels.

Chapter 8 Identifying and Addressing Back Order Reactions and Inventory Levels

In this chapter, I discuss why the organization defined its problems as *external* rather than *internal*, failing to fully recognize the back order reactions and the cost of high inventory levels. Clearly, no one person within the organization is exposed to the same data in the same format as presented throughout this thesis. Putting the information together and analyzing it required substantial effort on my part. The key to the entire analysis came from tying together demand, production, and inventory data. I argue that, due to the existing organizational structure, incentives, information systems, and business processes, no part of the organization (1) could readily obtain the necessary information; (2) had incentives to pursue obtaining the information; and (3) could recognize the issues without having the same time and resources as available to an M.I.T. intern.

In the final part of the chapter, I propose that the existing organizational structure, incentives, information systems, and business processes are a direct result of four key influences:

1. Market growth emphasis
2. Rapid product development
3. The need for consistent supply of product
4. Parent business processes

The discussion centers around the ways in which these influence manifest themselves.

Part IV -- Improving the Production System

Chapter 9 Improving Monthly Forecasting

This chapter demonstrates a new monthly forecasting methodology. I show that this methodology, based only on historical data, produces more accurate forecasts on average than the current market intelligence-based procedure. The procedure demonstrates that dealer/affiliate demand generally follows a linear trend that slopes moderately upward.

This information will prove important in determining the new planning and inventory management system described in Chapter 10.

Chapter 10 An Alternative Production System -- the "Pull" System

This chapter presents an alternative to the current monthly planning process used by Ethicon Endo-Surgery to plan production, forecast demand, and manage inventories. The "Pull" system utilizes a simple order point / order quantity (OP/OQ) methodology to tie together the production stages. I present the advantages of this system over the current monthly planning system with respect to EES's key operations objectives (inventory reduction, cycle time reduction, and delivery service level). The factors that make this system ideal -- low demand variability and high process flexibility -- are discussed. Finally, a deterministic model is presented that helps substantiate the claim that the system functions well. To account for the limits of using a deterministic model, the analysis utilizes demand data from dozens of different products and tests for parameter sensitivity (i.e., a sensitivity analysis demonstrates that the results are independent of constant lead time assumptions).

Chapter 11 Conclusion

In this chapter, I discuss my final recommendations presented to Ethicon Endo-Surgery prior to my departure in mid-December. I additionally discuss some additional areas of interest not pursued within the thesis. Lastly, I present a summary of the key points presented throughout the thesis.

Chapter 2 The Supply and Distribution Chain

2.1 Introduction

In this chapter, I describe the entire supply and distribution chain[21] for endoscopic surgical instruments -- from raw materials to finished instruments (supply chain) and from finished instruments into the hands of surgeons (distribution chain). The information presented here provides the base for the rest of the thesis. Readers already familiar with the supply chain, the distribution chain, the monthly production planning process, and the Operations organization may choose to skip this chapter and proceed on to Chapter 3.

The chapter first presents the supply and distribution chain in total. All distribution chain entities relevant to this thesis are presented -- Ethicon Endo Surgery, domestic dealers, international Johnson & Johnson affiliates, and hospitals. Secondly, I describe the "internal supply chain" (i.e., the movement of material within EES beginning with the assembly of components into instruments and ending with finished goods inventory). As opposed to treating EES essentially as a "black box" entity as in the preceding section, the second section describes the process steps and the in-process inventory locations involved in manufacturing a medical instrument. In the last part of the chapter, I describe how the supply chain is actually run. The key business processes of planning, production scheduling, and forecasting are presented, and a brief explanation of the various organizational roles carried out within the Operations Division is provided.

2.2 The Complete Supply and Distribution Chain

Figure 2.1 displays a simplified version of Ethicon Endo-Surgery's supply and distribution chain. Beginning with raw material suppliers and ending with the hospital, each entity receives orders from and delivers product to the "downstream" entity that it immediately precedes. Raw material suppliers deliver raw materials to, and receive orders from,

[21]Throughout this thesis and contrary to some other definitions, the term "supply chain" here refers to process of supplying finished goods inventory with product. In other words, it is the entities and policies involved in converting raw materials into finished instruments. The term "distribution chain" refers to the entities and policies involved in moving instruments from finished goods inventory and into the final customer's hands.

component parts suppliers; component parts suppliers deliver parts to, and receive orders from, EES; and so on down the chain.

Figure 2.1 demonstrates two types of flows: material flow and order flow. Material flows move in one direction from raw materials to the surgeon -- raw materials are shipped to component suppliers; component parts are shipped to EES; and so on until a completed instrument arrives in a surgeons hands. Orders flow in the exact opposite direction; hospitals order from dealers; dealers order from EES; and so on down the line. This section discusses both the material and the order flows as they relate to the remainder of the thesis. Of particular importance is how orders and delivery of material are tied together. This involves an understanding of the inventory policies of the various entities involved with the supply and distribution chain and will be discussed in greater detail below.

The Material Flow

The formation of the surgical instruments begins with raw materials such as plastics and metals. These materials are converted into component parts by suppliers, which are in turn assembled into surgical instruments by EES. EES packages the instruments, sterilizes them, and stores them in finished goods inventory at a Johnson & Johnson Hospital Services (JJHS) distribution center. This portion of the supply chain, the "internal supply chain," will be discussed in more detail later in this chapter. For now, details of the processes within Ethicon Endo-Surgery will be withheld.

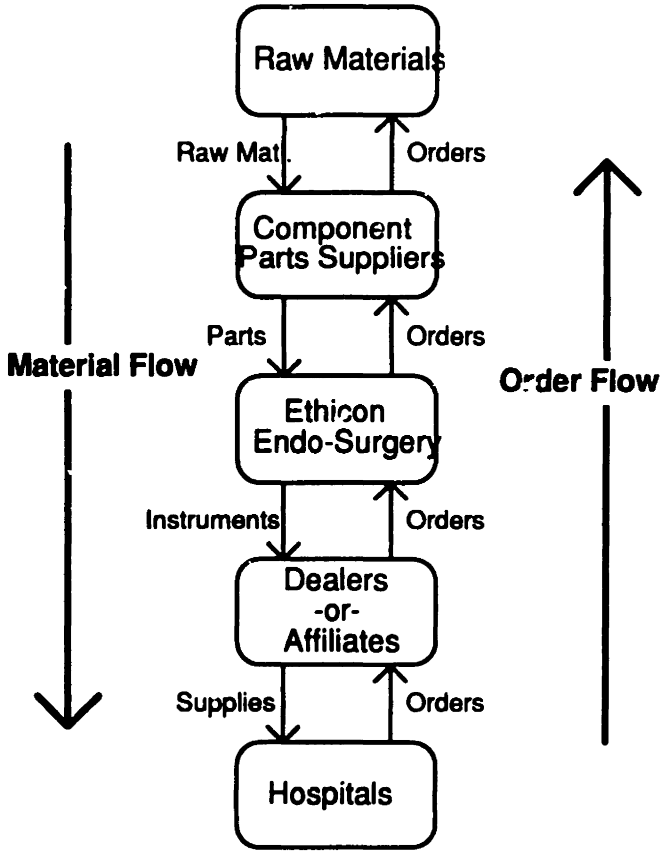


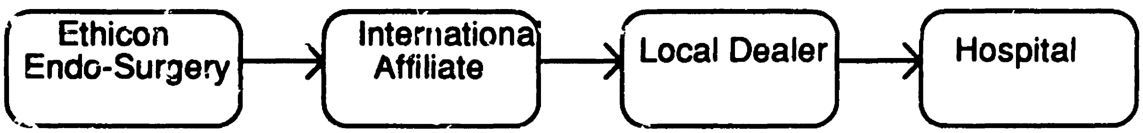
Figure 2.1 A simplified version of Ethicon Endo-Surgery's entire Supply and Distribution Chain demonstrating the direction of material flow versus order flow.

The completed instruments at Ethicon Endo-Surgery can move in one of several directions depending on whether the product's destination is domestic (within the United States) or international. Domestically, the products typically ship to dealers (Figure 2.2a) which then supply product to hospitals. Dealers typically reside a close distance from the hospitals that they service, allowing them to quickly deliver product when needed. Being able to deliver product quickly consequently requires maintaining a certain level of inventory. Therefore, dealers stock the product received from EES before passing it on to hospitals.

Internationally, the products are first shipped to a Johnson & Johnson international affiliate company (Figures 2.2b and 2.2c). The affiliates act as dealers to international customers, supplying products either to hospitals within their own country, to hospitals in neighboring countries, or to local dealers. As with domestic dealers, international affiliates maintain inventories to ensure consistent supply to customers. Product is therefore stocked at an affiliate before being passed on to either an international hospital or a local dealer. Local dealers act similarly to domestic dealers. They exist to provide quick, reliable service to their local hospitals and therefore maintain a stock of the product.

(a) Delivery of product to a domestic customer.

(b) Delivery of product to an international customer.



(c) Delivery of product to an international customer through a local dealer.

Figure 2.2 (a), (b), and (c) Flow of product from Ethicon Endo-Surgery to domestic and international hospitals.

When examining the entire supply and distribution chain diagrams, it is important to remember, first, that the view is taken from the perspective of Ethicon Endo-Surgery as the primary manufacturer and, secondly, that it does not demonstrate the many raw material suppliers, component suppliers, dealers, affiliates, and hospitals that exist in the actual chain. Raw material suppliers typically ship to many customers, some of which may be EES component suppliers. EES component suppliers may also supply components to several manufacturers. Equally as important is the understanding of the distribution chain. Numerous dealers and international affiliates order product from Ethicon Endo-Surgery and dealers, and international affiliates may service many hospitals. Alternatively, hospitals typically purchase products from at least two separate dealers; dealers carry products from several different manufacturers; EES purchases components from several different suppliers; and so on. The understanding that this many-to-many relationship exists throughout the chain contrasts with the one-to-one relationships assumed in the models described by Forrester[22] and in the "beer game" described by Senge[23]. This issue will be addressed further in Chapter 3.

2.3 The Internal Supply Chain

In this section, we open the "black box" around Ethicon Endo Surgery and describe the flow of material and orders within the organization. The *Internal Supply Chain* that will be discussed throughout this chapter consists of the portion of the chain that resides within EES -- namely, the bulk instrument assembly process, packaging/sterilization, and warehousing of finished goods to JJHS. The internal supply chain and its relationship to the overall chain is depicted in Figure 2.3.

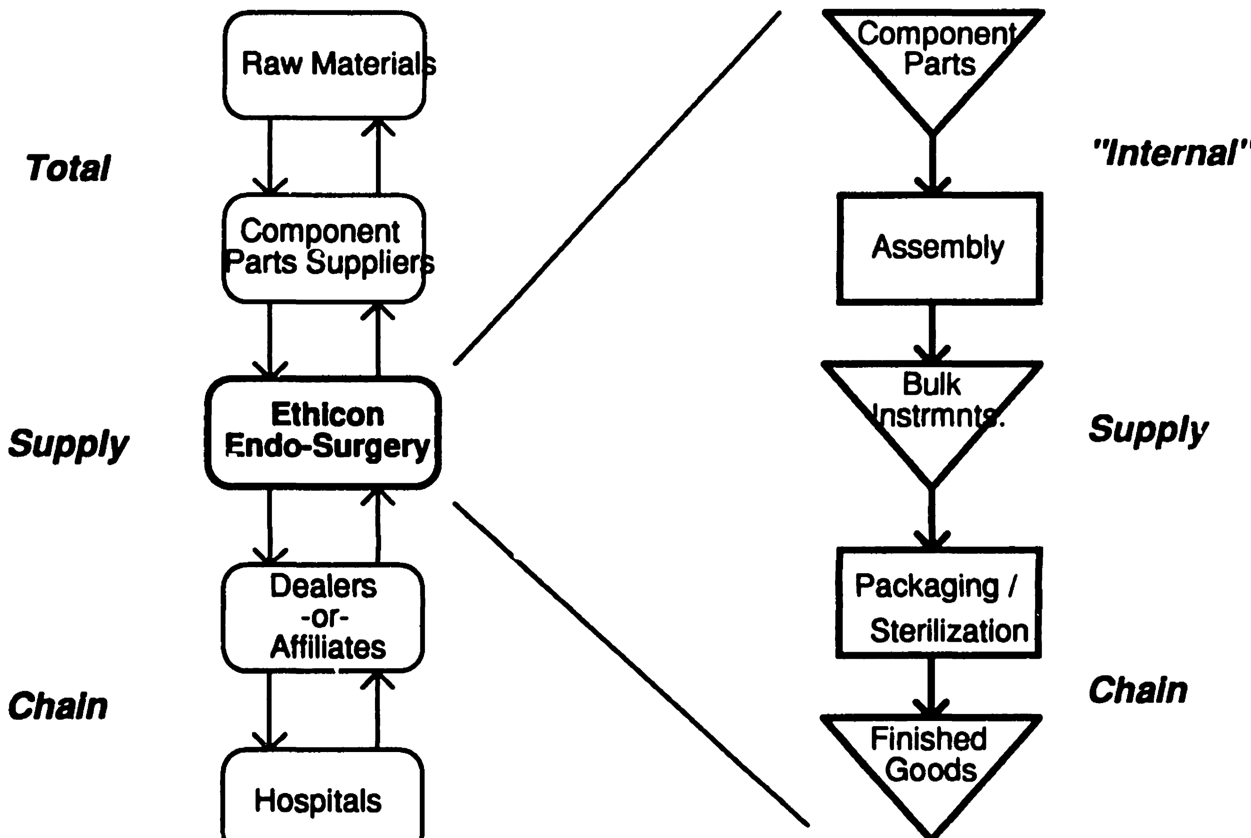


Figure 2.3 The Internal Supply Chain and its relationship to the entire Supply and Distribution Chain.

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[22]Forrester, J. W., Industrial Dynamics, Cambridge: Productivity Press, 1961.
[23]Senge, P. M., The Fifth Discipline: The Art & Practice of the Learning Organization, New York: Doubleday/Currency, 1990.

Inventory Positioning

In order to isolate the two main functions of the chain (instrument assembly and packaging/sterilization) from differing levels of flexibility and from varying mixtures of inputs and outputs, three main inventory stocking locations are maintained strategically within the internal supply chain (see Figure 2.3). The function of each inventory location is described below:

> **Finished Goods Inventory at JJHS** - isolates shipment of product from the lead time of the packaging/sterilization operation and allows fulfillment of customer orders directly from stock.
>
> **Bulk Instrument Inventory** - isolates the daily "pull" operation of packaging and sterilization from the less-flexible "push" operation of assembly. Additionally, assembled bulk instruments may be packaged into one of several configurations. The bulk inventory allows the flexibility to determine which packaging configuration the instrument is packaged into immediately before the configuration is actually packaged and sterilized.
>
> **Parts Inventory** - isolates the assembly process from the long lead times of parts suppliers. Additionally, a single part may be assembled into one of several instruments. The parts inventory allows the flexibility to determine which instrument a particular part is assembled into immediately before the instrument is actually assembled.

Finished goods at Johnson & Johnson Hospital Services (JJHS)

Finished goods are held, along with products from other J&J companies, at JJHS. They are responsible for receiving orders, picking the appropriate products from the shelves, packing the products together, and shipping to either domestic dealers, hospitals, or international affiliates. All systems that track finished goods inventory levels, incoming orders, and tracking the fulfillment of the orders are handled by JJHS, as are billing operations.

The Packaging and Sterilization "Demand-Pull" Operation

The packaging / sterilization operation draws assembled instruments from bulk inventory, configures the instruments into the required package type, sterilizes the configuration, and delivers the finished product to the JJHS warehouse. Although both the packaging and sterilization steps require capital-intensive equipment that are inherently subject to capacity constraints, the entire operation has remained highly flexible with the ability to react to large daily fluctuations in demands. Even the degree of flexibility between the packaging and the sterilization steps remains great enough that batches are considered to "flow through" without significant in-process stocking.

Batch sizes are predominately determined on a product-by-product basis through EOQ-type calculations[24] and remain relatively small due to the high degree of flexibility within the operation (low changeover costs result in small batch sizes). Packaging / Sterilization orders are initiated based on a "pull"-type system -- when finished goods inventory for a particular product at JJHS drops below a predetermined order point, a new batch of that product is initiated through the process. Schedules are determined on a daily basis, and finished goods inventory levels are monitored with the same high frequency.

The Assembly "Forecast-Push" Operation

Contrary to the capital-intensive operation of packaging/sterilization, the process of assembling parts into bulk instruments is predominately labor-intensive. Capacities are limited to the speed at which the workers operate and to the availability of parts. The time required for scheduling the work force and the supply of incoming parts are the greatest limiting factors in terms of flexibility. Additionally, several different instruments within a product family may be assembled on a single production line. This further complicates the assembly scheduling process due to the need to incorporate line changeovers.

To accommodate the previously mentioned difficulties, weekly assembly schedules and orders for parts are planned on a monthly basis using monthly forecasts. The forecasts, which stretch out several periods into the future, are broken down by an MRP-type system[25] into weekly assembly and parts requirements, resulting in a "push" of product through assembly. The break down of requirements takes into account parts, bulk, and finished goods inventory levels as well as assembly and parts-ordering lead times.

Parts Supply

As discussed in the preceding paragraph, orders for parts are determined based on the monthly planning process and, consequently, on the monthly forecasts. Lead times are typically on the order of 4-6 weeks, but lead times longer than 10 weeks are not uncommon. In general, the order size for major parts equals 3-4 weeks worth of demand.

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[24]for an explanation of basic EOQ models, refer to Chapter 4 of: Nahmias, S., Production and Operations Analysis, Second Edition, Homewood, IL: Irwin, 1993.
[25]for a detailed explanation of MRP techniques for production scheduling, refer to Chapter 6 of: Nahmias, S., Production and Operations Analysis, Second Edition, Homewood, IL: Irwin, 1993.

2.4 Running the Internal Supply Chain

This section shifts the focus away from the structure of the internal supply chain to concentrate on how the chain actually operates. The ordering of component parts from suppliers, the scheduling of assembly, and the scheduling of the packaging/sterilization operation must somehow be coordinated with each other as well as with demands from the market. In EES's case, this process takes place once each month for the ordering of parts and the scheduling of assembly. I have termed this entire process as the "monthly planning process." The packaging/sterilization operation operates somewhat differently, monitoring finished goods inventory on a daily basis and initiating batches of product as needed. Both of these scheduling processes are discussed below.

In this section, I will also present the market forecasting methodology used to predict demand for each product. The forecasts from this process are utilized by the monthly planning process to determine assembly requirements and supplier orders. Lastly, I conclude with a brief discussion on the organization and the various roles within the organization responsible for running the supply chain.

The Monthly Planning Process

This section describes the *monthly planning process* used to convert market forecasts into weekly production requirements. At the beginning of each month, information is gathered for each individual product. This information includes the number of orders that were received in the previous month, inventory levels in finished goods, monthly forecasts, and desired finished goods safety stock. By combining this information, the monthly planning process generates two outputs -- the aggregate production requirement for the entire month and revised extended forecasts (Figure 2.4). This information is further broken down into orders for parts and weekly assembly schedules, with weekly assembly schedules being broken down still further into daily assembly schedules.

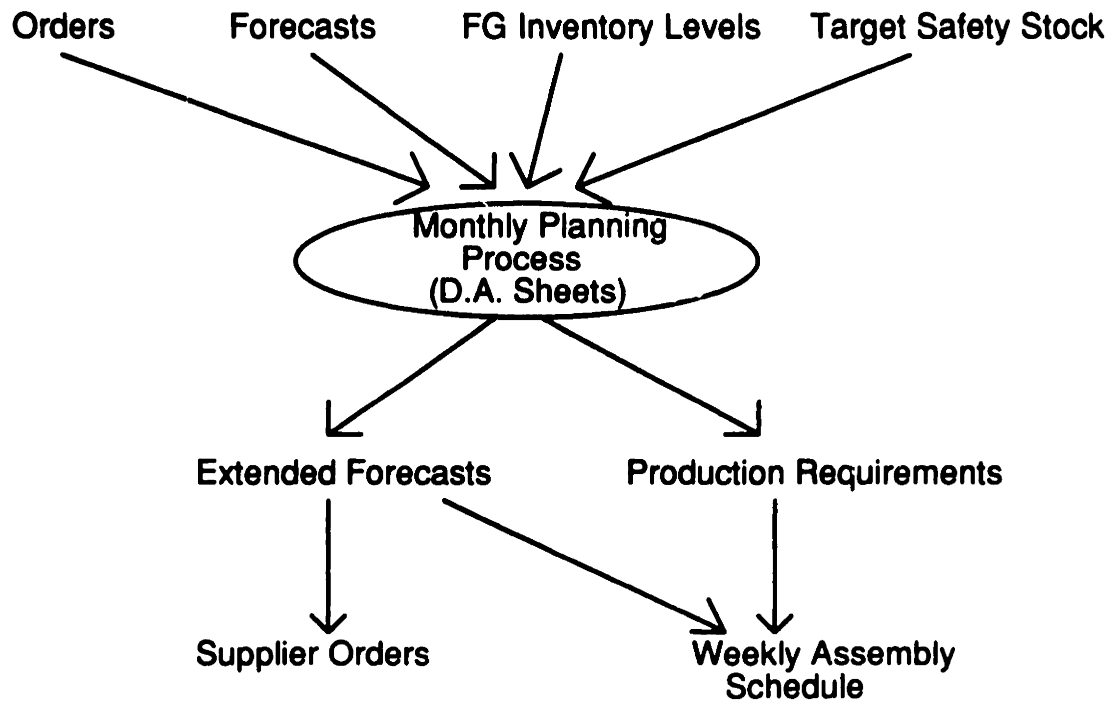

Figure 2.4 The monthly process of converting market forecasts into weekly production schedules and orders for parts from suppliers.

Central to the monthly planning process is the use of a planning tool called the "Demand Analysis (DA) sheet." Containing all data necessary to determine production requirements, the DA sheets (one sheet is generated for each finished product code) effectively facilitate information exchange between Marketing, the central planning group, and the production areas. The DA Sheet and the DA Sheet planning process are discussed in detail below.

The Demand Analysis (DA) Sheets

The DA Sheets are generated as part of the central planning process each month, with one DA sheet being generated for each product code. They contain information concerning the aggregate production plan -- extended forecasts, the quantity of finished goods required to be transferred into the JJHS warehouse to meet the forecast demand, and the target safety stock in finished goods (determined as a function of the extended forecasts). They additionally contain results from the past several planning months -- information such as demand over the previous several months, forecasts for the current month (i.e. the forecast given for November in November, the forecast given for October in October, etc.), finished goods inventory at each month's end, and variances from forecast and target finished goods inventory.

The Demand Analysis (DA) Sheets serve three main functions within the organization: to communicate, for approval purposes, the extended monthly forecasts to the functions with market knowledge (marketing and customer service), to alert plant management of the production requirements for the month, and to pass forecasts down to the Buyers/Planners. As discussed previously, the Buyers/Planners use monthly forecasts, as found on the DA Sheets, to determine parts ordering and assembly schedules. It is important to note that the DA Sheets are only partially used by Packaging / Sterilization for which they are only used to ensure that sufficient equipment capacity and packaging materials are in place. In general, Marketing, Customer Service, Plant Managers, and Buyers/Planners are the principal areas concerned with DA Sheet information.

The DA Sheet Planning Process

At the beginning of each month, the resulting previous month's demand (Net Orders), finished goods inventory, and actual finished goods transfers from the previous month are input into the appropriate location of each product's DA Sheet. Once the DA Sheets have been updated, the Master Planners, in conjunction with Marketing, determine whether modifications need to be made to the next periods' forecasts, inputting any changes directly onto the sheet[26]. Based on target finished goods inventory levels, actual inventory levels, and the current month's forecast, the quantity of finished goods required (Planned Transfers) to meet the forecast are calculated and entered into the sheet. A simplified sample DA Sheet as viewed from the start of the month of October is provided in Figure 2.5. The same DA Sheet as viewed after the forecasts have been modified and the new Planned Transfers have been recorded is shown in Figure 2.6.

Once completed for a particular month, all of the DA Sheets are routed through the organization for signatures. Marketing, Master Planning Management, and Customer Service must all examine the information to ensure validity and recommend modifications if necessary. Plant Management examines the information to ensure that the assembly operation can produce enough instruments to meet the DA Sheet's Planned Transfers number. When all functions are in agreement that the DA Sheet seems reasonable and its proposed plan (as determined through Planned Transfers) can be met, each area signs-off and the sheet moves on to the Buying/Planning function, for use in determining assembly

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[26]Note that when forecast changes are input into the DA Sheet, all information concerning the prior month's forecasts beyond the current-month forecast is lost. As explained earlier in the chapter, the current-month forecast is simply the forecast provided in the month that the DA Sheet is being evaluated. In other words, August's current-month forecast is determined in August, September's current-month forecast is determined in September, etc. In September, any forecast changes on the DA Sheet overwrite August's forecasts for September, October, November, and December. Only August's forecast for August is retained. This issue will be addressed again in Chapter 5.

schedules and parts ordering, and to the Packaging/Sterilization function for determining capacity requirements.

Product: ABC10

	Total 1993	July	Aug	Sept	Oct	Nov	Dec	Total 1994
Forecast	2200	100	120	130	130	140	130	1500
Actual Orders Received	2300	110	100	135*				
Variance	*100*	*10*	*-20*	*5**				
Planned Transfers	2200	120	140	90				
Actual Transfers	2400	110	160	90*				
Variance	*200*	*-10*	*20*	*0**				
Target FG Inventory	200	200	200	200	200	200	200	
Actual FG Inventory	180	180	240	195*				
Variance	*-20*	*-20*	*40*	*-5**				

Figure 2.5 Sample DA Sheet for October after the results from September have been entered but prior to any modifications to the forecast or to Planned Transfers. (* = information on September's results updated the first day of October).

Product: ABC10

	Total 1993	July	Aug	Sept	Oct	Nov	Dec	Total 1994
Forecast	2200	100	120	130	120*	130*	120*	1470*
Actual Orders Received	2300	110	100	135				
Variance	*100*	*10*	*-20*	*5*				
Planned Transfers	2200	120	140	90	125*			
Actual Transfers	2400	110	160	90				
Variance	*200*	*-10*	*20*	*0*				
Target FG Inventory	200	200	200	200	200	200	200	
Actual FG Inventory	180	180	240	195				
Variance	*-20*	*-20*	*40*	*-5*				

Figure 2.6 Sample DA Sheet for October after modifications to the forecasts and with the new Planned Transfers already entered. (* = information updated during the first or second week of October.)

The completion of the DA Sheets, including approval by management in all required areas, usually occurs for all products at the end of the second week of the month. It is not until after this point that the Buyers/Planners receive the information, update the MRP system, and determine assembly schedules and supplier orders for the following month. Occasionally changes will be made after the hand-off to the Buyers/Planners, but flexibility at this point is limited to parts availability and capacity constraints. Figure 2.7 demonstrates the typical timeline of the DA Sheet process.

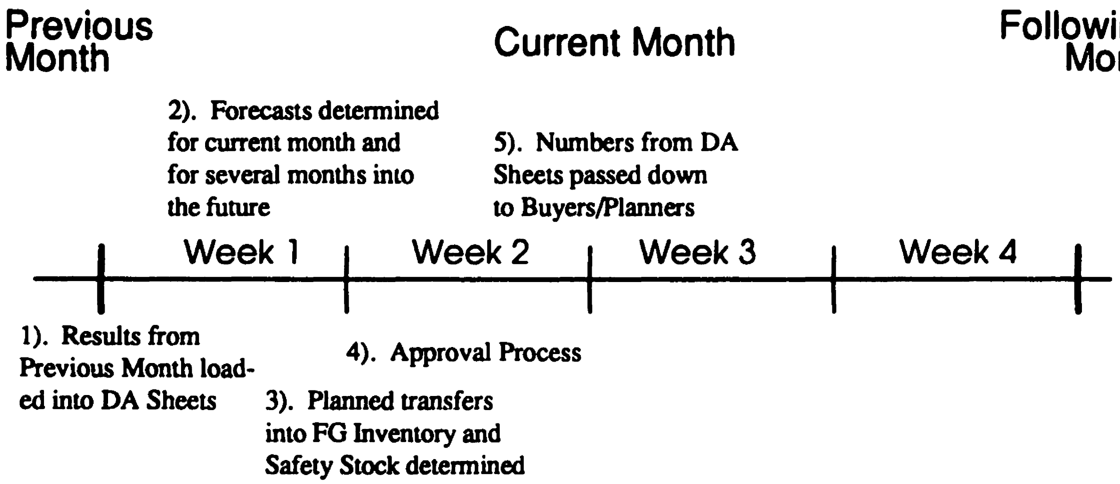

Figure 2.7 Timeline of events required for the DA Sheet Process

Converting the Monthly Production Requirements into a Daily Production Schedule

After the second week of the month, the completed and signed DA Sheet is passed down to the production area. For each product, a production planner takes the forecast for the current month, as well as for several months into the future (far enough to cover procurement of long lead-time parts), and enters them into their systems. Although several systems are used by planners to determine their weekly production requirements and parts orders, the process in general breaks down the DA Sheet's monthly forecasts into weekly forecasts and, consequently, into weekly demands. From these demands, the number of instruments to assemble each week and when to order new batches of parts are determined. The exact details of the systems are purposefully omitted here since they vary somewhat from planner to planner, but it is important to note that the planners do have considerable flexibility in selecting the methods and systems to use.

To determine the weekly demands from the monthly forecasts, the planner simply divides each month's forecast by the number of weeks in the month. Weekly production schedules are then determined, regardless of the actual system used, based on lead time offsets from each week's projected demand. The production numbers then typically do not change until the planning process is completed again for the following month. The long lead times that are required to procure parts and to assemble instruments disallow much flexibility for changes[27].

Packaging and Sterilization

As discussed earlier in this chapter, the Packaging / Sterilization process operates essentially on a pure demand-pull type system that does not rely on forecasts to determine packaging / sterilization schedules, effectively eliminating the need for DA Sheet information for daily and weekly scheduling. The results of the DA Sheets are, however, passed through the Packaging / Sterilization organization for the purposes of recognizing potential equipment capacity constraints or packaging material procurement constraints. In the typical case, neither capacity nor packaging materials are an issue.

The Operations Division

The Operations Division contains the principal planning and production functions as required to manufacture finished products and deliver those products to customers. All high-level planning, parts procurement, production planning, assembly, packaging, and sterilization operations, and customer service functions report under the Operations Division. The particular departments involved include Master Planning, Buying/Planning, Business Units, Packaging / Sterilization, and Customer Service and Distribution. Along the process pipeline of turning forecasts into the actual production of instruments, Master Planning resides on the front-end, generating the monthly forecasts and determining production plans in aggregate. They are closely linked to the marketing area of the business and act as the connection between market knowledge and production. Business Units and Packaging / Sterilization reside on the opposite end of the pipeline converting raw components into finished goods inventory. A single business unit controls all activities associated with the assembly process for a particular product line. Packaging / Sterilization has responsibility for maintaining adequate finished goods inventory for <u>all</u> products. Fitting somewhere in the middle are Buyers / Planners who determine weekly assembly plans and generate orders to suppliers for parts. The Customer Service and

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[27]The actual flexibility of the assembly and the parts procurement processes will be challenged later in the thesis as this issue is important to the determination of alternate, potentially more robust planning processes.

Distribution area is concerned primarily with movement of finished goods to domestic dealers, hospitals, and international affiliates.

The corresponding responsibilities of all areas in the Operations Division are outlined and summarized in Table 2.1. Their roles in the planning/production pipeline are diagrammed in Figure 2.8.

Functional Area	Primary Responsibilities to the Supply Chain
Master Planning	- Link between Marketing and Production - Monthly requirements for Finished Goods - Monthly forecasts for each product
Buying/Planning	- Orders to suppliers for parts - Weekly production schedule
Business Units	- Assembly of instruments for a single product line - Daily production schedule
Packaging / Sterilization	- Packaging and sterilization of instruments - Initiation of Packaging / Sterilization batches
Customer Service and Distribution	- Product supply-related relationships with hospitals, domestic dealers, and international affiliates - Handling of special instances of supply problems

Table 2.1 Summary and outline of functional areas involved with the planning/production pipeline.

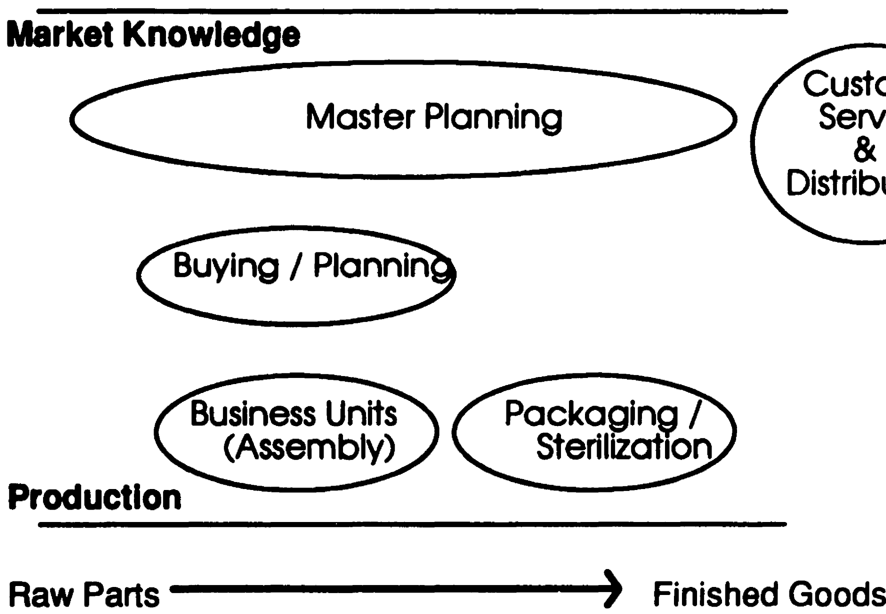

Figure 2.8 The roles involved with the planning/production pipeline and their relationships to the internal supply chain.

The Importance of Forecasts

Forecasting plays a critical role in the monthly planning process. Forecasts are produced each month for anticipated demand one month, two months, three months, and four months into the future. All assembly scheduling and parts procurement are based on the forecasts that extend several months into the future. Due to long lead times for procuring parts, typically on the order of 4-16 weeks, the accuracy of extended forecasts beyond one month becomes critical. Additionally, the monthly planning process requires time to complete due to the large number of product codes (over 200 in total). As a result, functioning forecasts are not delivered to the production area until two weeks into the current month. The first month's forecast, already two weeks old, is only valid for the last two weeks of the month. This places further importance on the forecasts beyond a one month horizon.

The process involved in generating forecasts deserves some mentioning here; although, the detailed process will not be presented until Chapter 9. The monthly forecasts are derived from an annual financial forecast, where the annual financial forecast is determined at the beginning of each year. As the year progresses, monthly forecasts may be adjusted up or down as dictated by market intelligence. In general, the monthly forecasts should be thought of as a combination of the annual financial forecasting and market intelligence.

2.5 Conclusion

The entire supply and distribution chain for Ethicon Endo-Surgery was discussed in this chapter. In review, the distribution chain refers to the portion of the overall chain that moves product from finished goods inventory into a hospital. Domestically, product passes through a local before being passed on to the hospital. The dealer maintains a certain level of inventory to ensure consistent supply to its customers, the hospitals. International Johnson & Johnson affiliates operate in much the same way, but instead of delivering product to domestic customers, they deliver to international locations.

The "internal" supply chain refers to the portion of the overall chain that resides entirely within EES. It consists of two major processing steps -- assembly and packaging / sterilization -- and three major inventory positions -- component parts, bulk instruments, and finished goods. Scheduling of the packaging / sterilization process is done on a "pull"-type basis, and scheduling of the assembly process and of component parts orders is done MRP-style, based on extended monthly forecasts. The generation of the monthly forecasts and the monthly production plan revolve around the Demand Analysis (D.A.) sheet analysis. D.A. sheets are completed by the Master Planners for all products 1-2 weeks after the beginning of each month. From the forecasts on the D.A. sheets, Buyers / Planners determine weekly and daily assembly schedules and component parts orders.

Now that the basic aspects of the supply and distribution chain have been discussed, we are ready to move on to Chapter 3 to discuss demand for new products.

Chapter 3 Supply Chain Demand for New Products

3.1 Introduction

This chapter demonstrates how dealers, international affiliates, and hospitals react to the introduction of a new product. In particular, it examines dealer and affiliate order patterns to determine the volume of orders that Ethicon Endo-Surgery should expect to see immediately following the introduction. The research demonstrated that a consistent pattern emerged with the introductions -- an initial demand "spike" occurring within the first few weeks. The analysis will demonstrate that the spike is relatively predictable, and a "rule of thumb" is provided for building inventory in preparation for the spike. By comparing domestic hospital sales information with domestic dealer orders, I will demonstrate that this "spike" is attributable to dealers and affiliates building up inventory. The final part of the chapter will discuss the issue of "panic ordering" on the part of dealers and affiliates. Strong evidence will be provided that panic ordering does not actually occur, emphasizing the fact that dealers and affiliates behave in rational, predictable ways.

3.2 The Recurring Demand Pattern

As mentioned in the introduction, the research uncovered a consistent dealer and affiliate demand pattern associated with new product introductions. Throughout this chapter, new product introductions refer to the introduction of a new product into the market where the product is a replacement for a preceding product. In other words, the market for the product has already been established and a relatively reliable customer base already exists. The new product itself replaces an older, potentially outdated product. The demand pattern that recurs is shown in Figure 3.1 for one sample product. A demand "spike" at the outset of the introduction is followed by a relatively stable level of demand. The spike occurs within the first few weeks of the introduction.

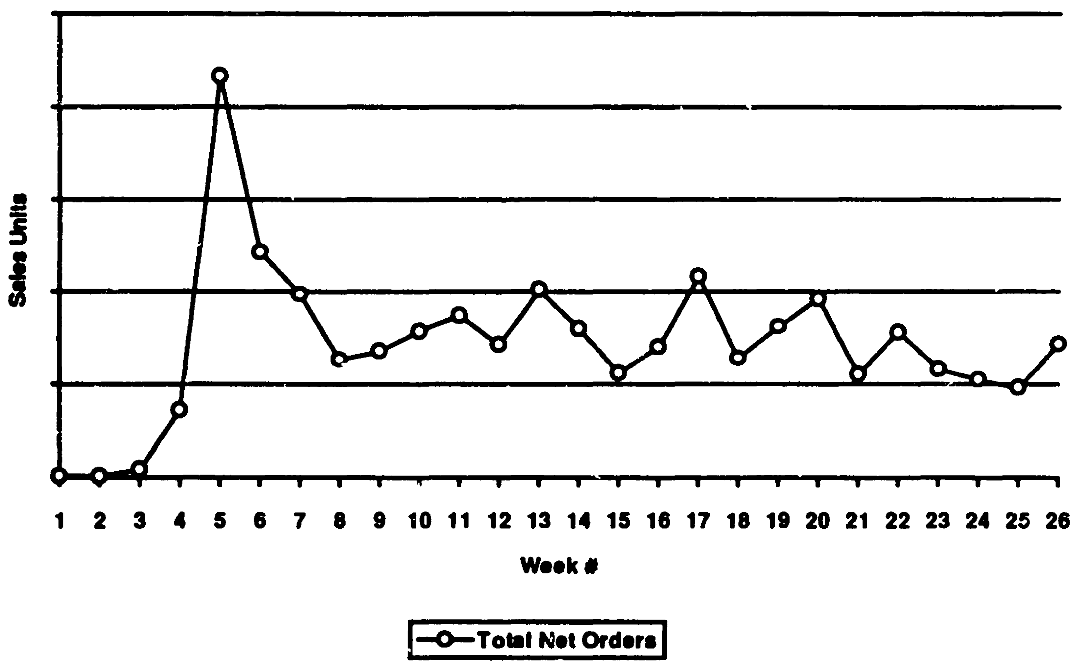

Figure 3.1 Total dealer and affiliate weekly orders for a new product introduction. The demand spike occurs in Week 5 and Week 6.

Predicting the Demand Peak

We will now attempt to characterize the initial demand peak in a way useful for forecasting. The measurement that will be used is "weeks of additional demand" -- in other words, the number of weeks worth of demand in excess of average demand, determined during the first few weeks of the introduction. The equation for this measurement is:

Additional Demand During Peak / Average Weekly Demand

This equation may seem somewhat vague. The definition of *Additional Demand During Peak* has been purposely left unclear. The demand peaks occur for differing lengths of time depending on each product's particular situation. The determination of when the peak actually occurs for the purpose of this study is therefore left to the discretion of the author. Typically, the peak will be the first two weeks of demand immediately following the introduction. *Additional Demand During Peak* is determined by taking the total demand during the peak period and subtracting off the average weekly demand over an equivalent length of time. If the peak period lasts for 3 weeks, the demand during that period is 1500 units and the average weekly demand is 250 units, *Additional Demand*

During Peak is 1500 - (3 × 250) = 750 units. *Weeks of Additional Demand* is then calculated by dividing *Additional Demand During Peak* by the average demand, 750 / 250 = 3 weeks.

Average weekly demand for the product in steady state can be readily forecast with reasonable accuracy. Being predominantly single-use disposable, Ethicon Endo-Surgery's products do not exhibit life cycle effects (i.e., rapid initial growth, market saturation, and replacement-only sales). Additionally, changes in market share are gradual[28]. As a result, demand is relatively stable, and demand for the preceding product can be used to predict steady state demand for the replacement product. It will be assumed that this prediction is accurate enough that we can simply use the actual average steady state demand and still obtain useful results.

Table 3.1 displays the information and results for the products used in the analysis. Eight products in all were used, consisting only of eligible products with significant sales volume. To determine eligible products with significant sales volume, all product codes released over a one year time period (the time period over which data was available) were gathered. Only products with a significant percentage of Ethicon Endo-Surgery's total sales volume[29] were considered further. Of the products with significant sales volume, fourteen in total, six outliers were identified and removed. A product would be considered an outlier if any unique forces were found to influence the demand from dealers. For example, one particular outlier was part of a family of recently introduced products that all had problems with back order. The outlier was introduced after the other products had gone into back order and was therefore well controlled in its release. The demand from dealers and affiliates, therefore, was influenced heavily by the controls placed on the release. In another case, significant market dependencies unexpectedly developed between two products in the sample. One of the products was therefore declared as an outlier and removed from the analysis.

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[28]More information on the characteristics of the products and the effects that the characteristics have on demand patterns will be discussed in Chapter 9.

[29]The cut-off point for considering a product as having significant sales volume has been purposely omitted due to proprietary concerns.

Product	Number of Weeks of Peak Period	Total Demand During Peak Period	Average Demand	Additional Demand During Peak	Weeks of Additional Demand
1	2	522	84	354	4.2
2	1	735	181	554	3.1
3	1	511	134	377	2.8
4	2	814	182	450	2.5
5	1	374	187	187	1.0
6	3	4366	705	2251	3.2
7	7	19,198	1831	6381	3.5
8	2	5163	1269	2271	2.1

Table 3.1 Determining the magnitude in terms of weeks of demand for the initial demand peak. (Actual values for Total Demand During Peak Period and Average Demand have been disguised.)

From the organization's standpoint, just knowing how much additional demand to expect during the first few weeks of introduction will allow it to prepare accordingly by building up finished goods inventory beforehand. When the product is introduced and the demand peak hits, Ethicon Endo-Surgery will then be able to avoid back order. To determine how much additional finished goods inventory to have in place, we can use the data in Table 3.1 to calculate an average of Weeks of Additional Demand. The calculated average, with some slight adjustments, may serve as a policy for the additional finished goods inventory. If we were to just use the average alone as the inventory policy, approximately one half of future introductions would experience demand peaks above the average, and one half will experience peaks below. We therefore provide 95% confidence intervals[30] around the average. (For the upper bounds using 90% and other confidence intervals, see Table 3.2.) By stocking at the upper bound of the 90% confidence interval, Ethicon Endo-Surgery would expect that in 90% of all introductions, they will have enough additional inventory to cover the additional demand during the peak.

[30]For a description of calculating confidence intervals for means using a Student's t-distribution, see for example: Hogg, R. V., J. Ledolter, Applied Statistics for Engineers and Physical Scientists, New York: Macmillan Publishing Company, 1992, chapter 4.

Average (n=8 Samples)	90% Confidence	95% Confidence	97.5% Confidence
2.8 weeks	3.3 weeks	6.0 weeks	8.3 weeks

Table 3.2 Upper confidence intervals for *Weeks of Additional Demand* data.

Of course, the preceding calculations assume that the sample data in Table 3.1 is representative of the *Weeks of Additional Demand* that would be determined for all products. Given the small sample size, this probably is not the case. Therefore, a word of caution is provided. The numbers in their current state provide a reasonable "rule of thumb" for determining the quantity of inventory needed to have in place prior to the introduction. For a more rigorous calculation, more samples would need to be examined. On the other hand, the 2.8 weeks of inventory required on average and the 90% confidence value of 3.3 weeks exceeds all other previous forecasts researched. This alone should provide substantial guidance for future product releases.

3.3 Dealer and Affiliate Stocking in New Product Introductions

This section will compare domestic sales information with domestic dealer orders to show that the initial spikes in demand are indeed a result of dealer and affiliate stocking. Figure 3.2 shows monthly domestic dealer orders for two products. The first product is the same product displayed in Figure 3.1. The second product is the "extreme back order" case that will be discussed in Section 3.4. In addition to the dealer orders, domestic hospital orders are plotted on both graphs. For both products, the introduction occurred during Month 1; and for both products a demand spike occurred at that time. (Since Product B was introduced near the middle of Month 1, the peak for Product B does not appear nearly as significant as for Product A.)

As shown in the figure, the hospital orders do not exhibit a demand spike. Instead, the hospital orders either start at a level close to the eventual steady state level, as with Product A, or increase gradually over several months, as with Product B. Additionally, the area between the dealer and hospital orders represents the approximate volume of product delivered to dealers that has not yet been ordered by hospitals. In other words, this volume must reside at the dealer. To determine the total dealer inventory, we only need to find the area. Since finding the area gives the number of sales units stocked at the dealer at the end of the period, we must convert *sales units of inventory* into *weeks of inventory*, where one week of inventory represents the volume of product inventory expected to be sold each week. To do this, we divide the area between the curves by the average weekly demand. As a result, the dealer stocking levels turn out to be 4.2 weeks for Product A and 4.5 weeks for Product B. In conversation with several dealers, these numbers are indeed consistent with most dealers' policies.

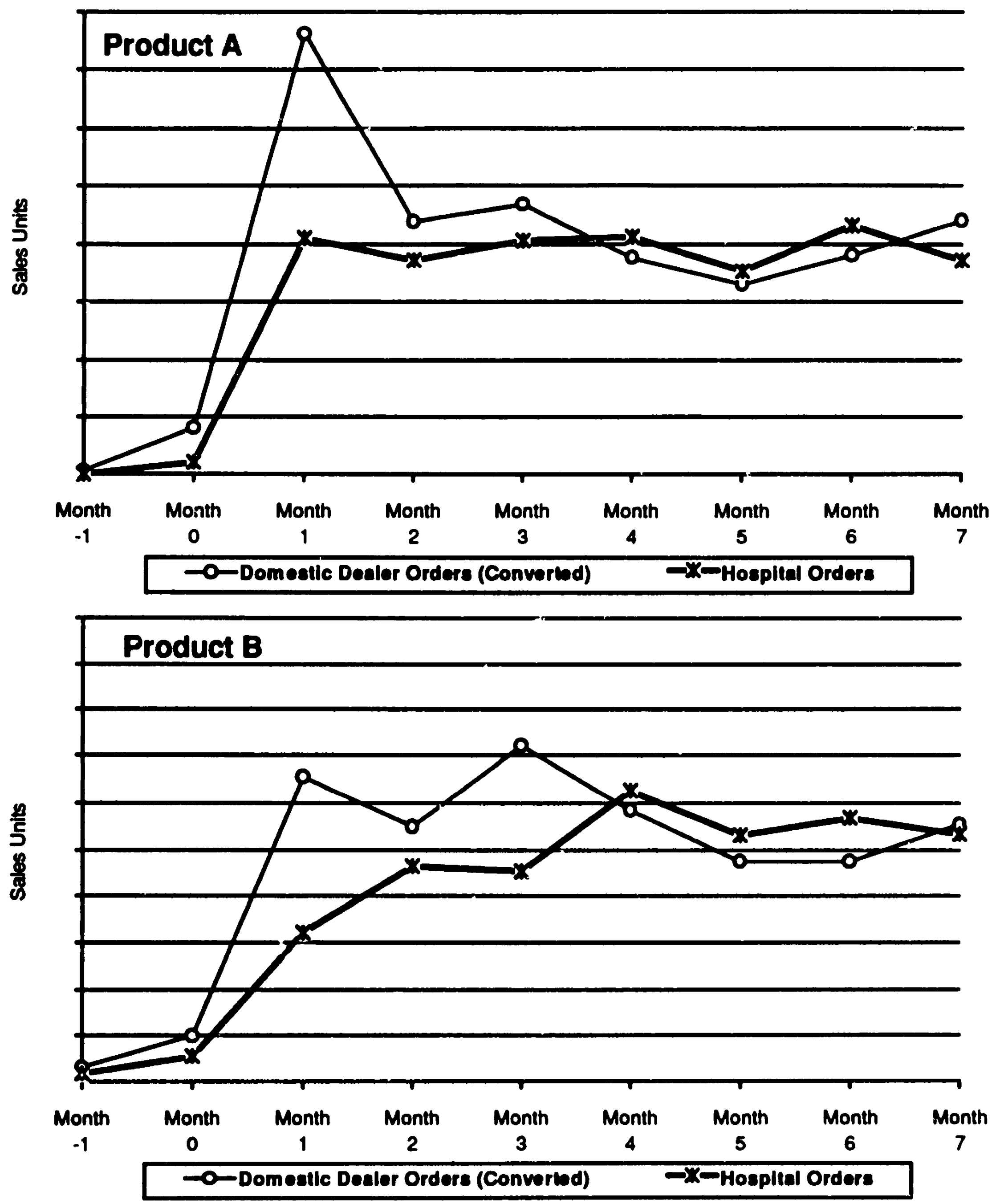

Figure 3.2 Hospital orders domestic dealer orders for two new product introductions.

3.4 Misperceptions About Panic Ordering

In this section, I will refute many of the perceptions throughout the supply chain concerning "panic ordering" with dealers and affiliates. Panic ordering as used throughout this section is defined as ordering by dealers and affiliates in excess of what is actually needed. Dealers and affiliates may panic order when they believe that the products they need will soon be in short supply. When demand outstrips supply, the manufacturer must use an allocation system to determine who will receive the product and how much will be received. The dealers or affiliates may believe that increasing orders influences the allocation system to send them a greater portion of the available product. Another perceived cause of panic order is based on dealer and affiliate inventory systems. Safety stock at dealers and affiliates is typically based on lead time for delivery of a product. When product falls into back order and delivery time for the product shoots up from 3 days to 3 weeks, the safety stock levels also shoot up. This further increases the orders as incoming product must be used to increase safety stocks as well as meet hospital demand.

Several people within Ethicon Endo-Surgery had revealed concerns that panic ordering was artificially driving up demand for back ordered products. This concern had been made with regard to a few recently introduced products. Surveys and discussions with several representatives from domestic dealers and international affiliates revealed a belief that both sources of "panic ordering" could be evident. Several dealers described their ordering systems as using lead times to determine safety stocks. In many cases the calculations were completed automatically. Both dealers and affiliates indicated that increased orders to "game" with Ethicon Endo-Surgery's allocation system were plausible. No explicit data, however, were provided to validate these statements.

Refuting the "Panic Ordering" Perceptions

To determine the extent of panic ordering, I took three new products from the same product family that were introduced within a few weeks of each other. One of the products fell into deep back order, outstanding orders equaling three weeks worth of demand at the lowest point. Another of the products fell into a moderate back order of about one week's worth of demand. The final product did not fall into back order at all. These three products, coming from the same product family and providing similar functionality, should experience similar patterns of demand throughout the year. By comparing the dealer and affiliate orders between the products, any pattern of panic ordering should be evident. If panic ordering is present, we will expect to see that the product that went into severe back order receives a greater portion of orders while in back order. Once out of back order, the product's demand should drop off as dealers and affiliates receive all of their excess panic-ordered product. Ordering should remain at the lower state until dealers and affiliates sell all of their excess inventory. In contrast, the product that did not fall into back order should not experience the same fluctuations in demand. Supply in that case was never in jeopardy, so dealers and affiliates would not have a reason to panic order. Somewhere in the middle we would expect to find the moderate back ordered product.

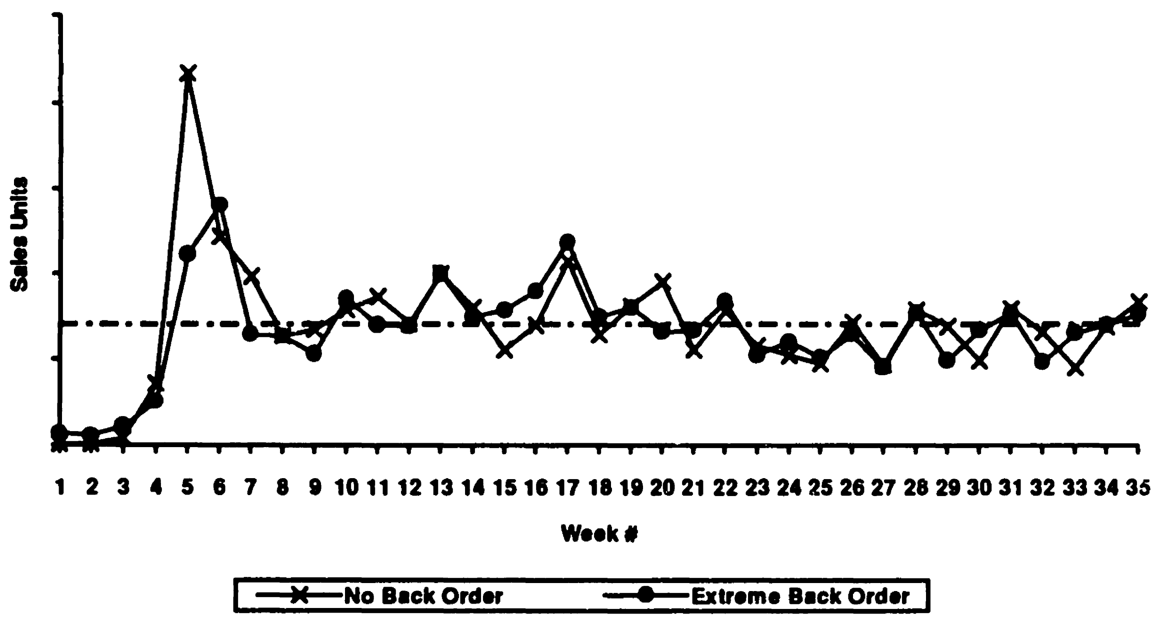

Figure 3.3 Dealer and affiliate weekly orders for two products introduced at about the same time. One product fell into back order, and the other did not. Order quantities have been normalized based on average demand to facilitate the comparison. Interestingly, the patterns look almost indistinguishable.

To compare the ordering patterns, we can first examine weekly ordering data between the No Back Order and the Extreme Back Order cases. This comparison is made in Figure 3.3. Note that aside from the demand during the introduction of each product, the patterns look almost identical. The product was in back order between Week 10 and Week 19. During this time, there appears to be a light increase in demand for the Extreme Back Order product; however, in the weeks following Week 19, there is no evidence of demand dropping off relative to the No Back Order product. Instead both seem to drop slightly, indicating a market-dependent rather than a product-dependent trend.

Figure 3.4 demonstrates the same concepts, adding a third product and using monthly instead of weekly data. The third product was introduced a few weeks after the previous two, explaining the delayed demand peak during Month 2. Back order for both products began in Month 2 and continued through Month 3. Once again, a slight positive difference in ordering for the back ordered products is evident at the time of the back order. After Month 3, the three products follow in lock-step. This seems to negate the panic order theory, since panic ordering should lead to a decrease in orders after the products come out of back order. Additionally, aside from differences during the introduction months, the back ordered products' demands almost exactly match beginning with Month 3. This occurred irrespective of the differences in the severity of the back order.

On a final note and as a point of interest, the cumulative monthly demand for the three products have been plotted in Figure 3.5. Amazingly, the cumulative results follow closely for all three. Except at the beginning, the total volumes of the products are almost identical. This seems to indicate that the slight increase in demand for the back ordered products is actually a continuation of the peak period described in the previous section. Instead of ordering all at once in the first few weeks, some dealers may hold off for several weeks. Consequently, the orders are eventually placed.

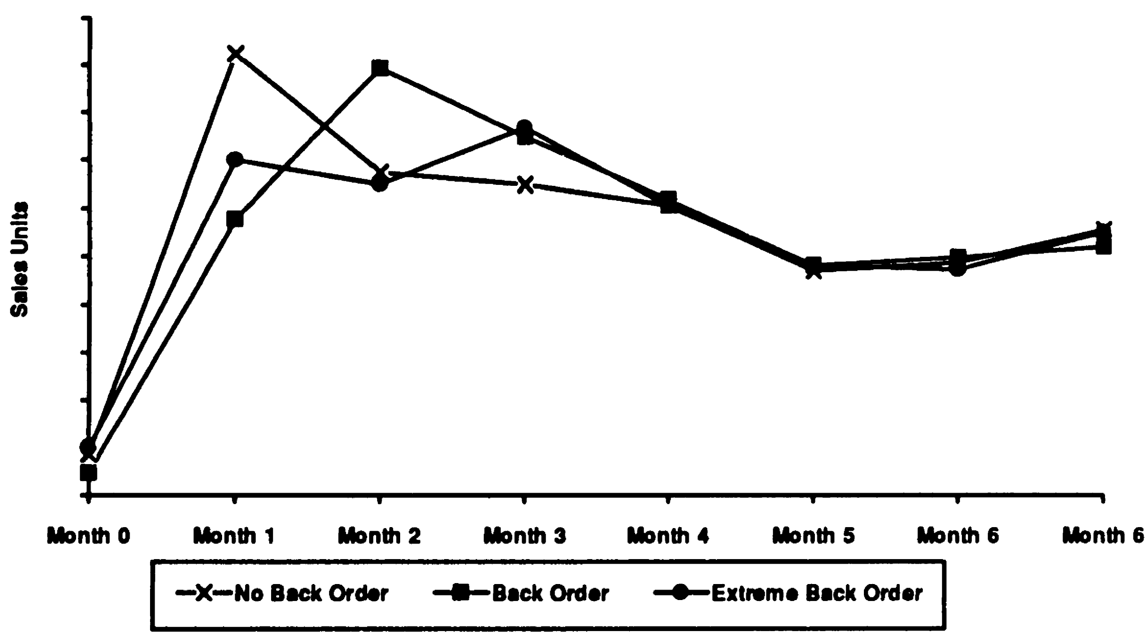

Figure 3.4 Dealer and affiliate monthly orders for three products introduced within a few weeks of each other. Two of the products, No Back Order and Extreme Back Order, are also shown with weekly orders in Figure 3.2. The two back-ordered products fell into back order during Month 2 and Month 3. Although ordering increased in Month 3, the expected drop-off in ordering with respect to the No Back Order product did not occur.

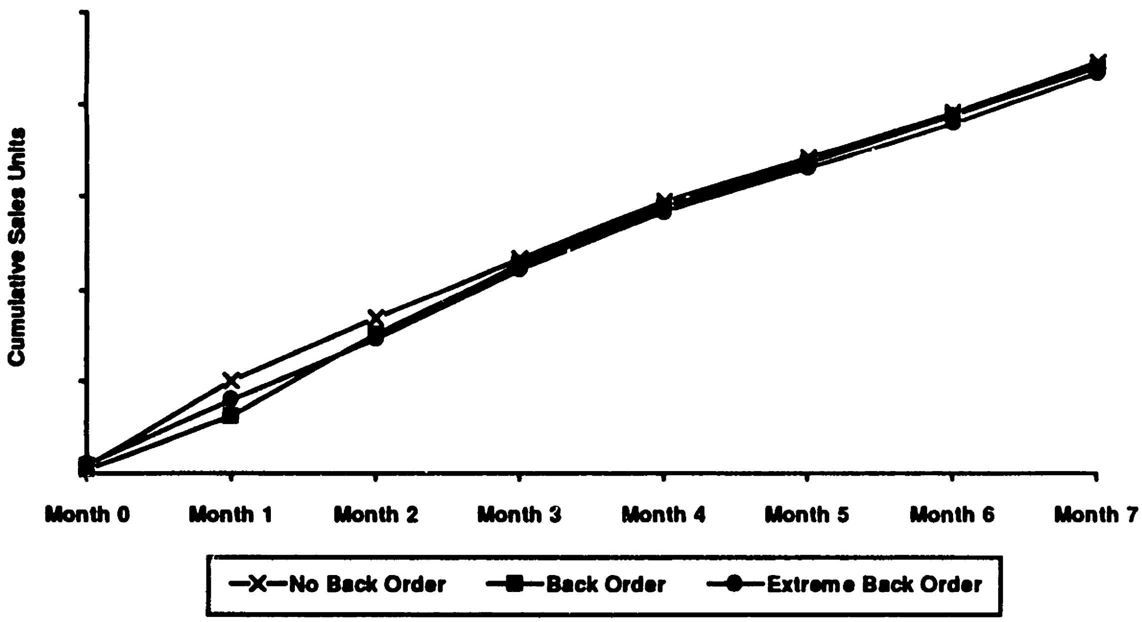

Figure 3.5 Cumulative dealer and affiliate monthly orders. This graph demonstrates that the total volume ordered for each product moves in lock-step.

3.5 Conclusion

In this chapter, demand for new products was shown to be relatively predictable. In the first few weeks of the introduction, dealers and affiliates increase ordering in order to build inventory. The additional demand during that period should be expected to equal approximately 3 weeks worth of expected average demand. Immediately following the peak ordering, demand can be expected to follow a relatively stable pattern. This pattern, as will be shown in Chapter 9, tends to follow a steady trend line. By comparing two recently introduced products, one that fell deeply into back order and one that did not, I demonstrated that dealers and affiliates do not increase orders for new products that fall into back order. This refuted my early research assumptions that dealer and affiliate demand increases due to panic ordering and increased levels of safety stock.

The next chapter will discuss how EES reacted to the new product demand patterns.

Chapter 4 Internal Supply Chain Reactions

4.1 Introduction

The previous chapter identified a consistent demand pattern unique to new product introductions. The initial surge (or "spike") in orders occurring in the first few weeks of the introduction often forces Ethicon Endo-Surgery into back order. As discussed in the preceding chapter, the spike is attributable to dealer and affiliates "stocking up" on new products to both fill their inventories <u>and</u> meet the incoming hospital demand. But understanding the cause and the extent of the demand spike is only one part of the puzzle. The other part is understanding how Ethicon Endo-Surgery, in its efforts to maintain a consistent supply of product, prepares for, and reacts to, the spike.

In this chapter, I demonstrate the "internal" reactions to new product introductions. By "internal," I refer to the production system within Ethicon Endo-Surgery that allows it to deliver product to dealers, international affiliates, and, ultimately, to hospitals. I will show that the initial demand spike results in surprisingly dramatic reactions in production -- surprisingly dramatic in that the production system was designed largely to "shield" the assembly process from variation in demand; however, the data will show that demand variation is actually amplified in the assembly process. In one particular case presented below, production output doubled from one month to the next; yet, the only large preceding increase in demand occurred during the product's introduction four months earlier. I continue this chapter by demonstrating that the new-product-introduction-type reactions occur anytime a product falls into back order. This finding altered my initial interpretations that new product introductions alone were at the center of Ethicon Endo-Surgery's supply problems. Instead, it shifted the focus toward back order as a root cause, with new product introductions being a subset of that root cause.

This chapter will present the internal reactions to new product introductions and, more generally, the reactions to products that fall into back order. I will demonstrate that, in many cases, any sudden increases in demand are met with at least equally dramatic reactions from production, suggesting that demand variation is actually amplified by the production system. The following chapter, Chapter 5, will demonstrate some reasons why the reactions occur as a result of the current monthly planning process, and Chapter 7 will describe how the organizational incentives contribute to the reactions.

4.2 Reactions to New Product Introductions

In many of the new product introductions examined, a consistent reaction was found. The sequence of events that occur are as follows (see Figure 4.1)[31]:

1. Increased demand causes back order - the unexpectedly high level of demand depletes inventory, often sending the organization into back order.

2. Production increases output - the production process must increase its output to match both the increased orders and the depletion of inventory. This increase oftentimes is delayed one or more months due to difficulties in obtaining adequate parts supply.

3. FG Inventory levels shoot up - the increase in production output continues to drive FG inventory levels up above normal stocking levels.

4. Production decreases output - the increased levels of inventory result in a reduced need to produce; therefore, production decreases temporarily.

5. Production output and FG inventory levels settle at a steady state - the system finally reaches a steady state several months after the unexpected occurrence.

[31]Throughout this chapter, all monthly production, demand, and forecast data has been converted from a single monthly number into a 4-week monthly rate. In other words, the number of units produced in one particular month has been converted into an equivalent number units produced had the month been a 4-week month. This conversion was necessary to maintain consistent comparisons from one month to the next in light of the company's varying duration of a month.

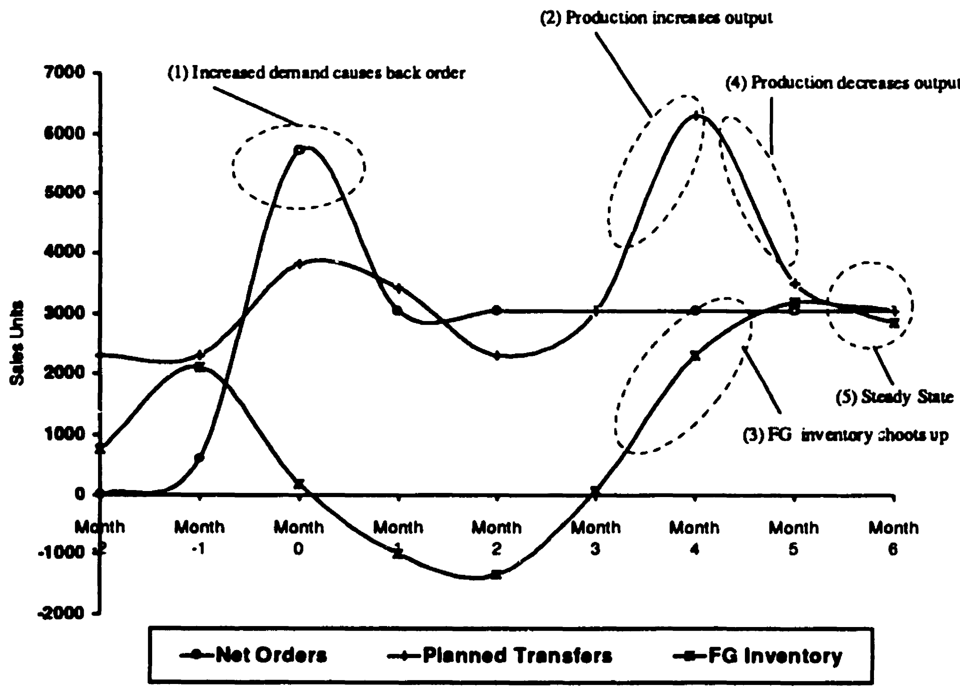

Figure 4.1 Sample Reaction. A reaction to a new product introduction demonstrating how production (planned transfers) responds to the initial drop in FG inventory. This follows the standard sequence of steps outlined in the text: (1) Increased demand causes back order; (2) Production increases its output; (3) FG inventory levels shoot up; (4) Production decreases output; and (5) Production output and inventory levels reach steady state. In this particular case, the steady state has just been reached in Month 6.

The following section examines two particular examples of the reaction sequence -- one involved with a new product introduction and the other with an unexpected supply interruption.

4.3 New Product Introduction Example

This first example demonstrates the supply chain reactions in a new product introduction as derived from the information on DA Sheets. The key components of understanding the reactions are examined -- forecast (Current-month Forecast) versus demand (Net Orders), production (Planned Transfers) versus demand (Net Orders), and production (Planned Transfers) versus finished goods inventory (FG Inventory). If the meanings of any of these components is unclear, it is recommended that the reader briefly read back through Chapter 2. An important point unique to the new product introduction demonstrated below is worth mentioning here. Actual assembly data, either daily, weekly, or monthly, was not available. Instead, a different representation, Planned Transfers from the DA Sheets, had to be used. Although Planned Transfers does not actually represent the production rates for a particular month, it offers a reasonable approximation in the case of the following product introduction. This issue is explained further in the following section. In a later section of this chapter, the example back-ordered product utilizes actual assembly data. In that case, the use of Planned Transfers therefore will not be an issue.

Importance of Using "Planned Transfers" in Place of Actual Assembly Rates

Although it can be argued that Planned Transfers does not necessarily represent what was either assembled or packaged /sterilized, it does represent what was believed to be required in finished goods to meet the month's forecast demand. In the case of this particular new product introduction, it represents what the plants believed they could produce given constraints on capacity and parts supply. This number is of value in a slightly different way. Actual assembly or packaging/sterilization volume represents the results *after the month has ended.* These actual volume numbers are subject to parts availability, quality problems, and other unforeseen issues that were not known at the beginning of the month when the plan was approved. They therefore represent the *actual* outcome rather than what was intended. By providing a number, Planned Transfers, that is directly calculated from available inventory and forecast demand, the *intentions* of the organization are captured.

Bear in mind, though, that this analysis does not apply in the same way with situations other than the new product introduction presented below. Only in this new product introduction, and other more recent introductions, is availability of parts closely examined prior to determining Planned Transfers. As a result, only in this introduction, and other more recent introductions, does the Planned Transfers number represent the true intentions of the organization.

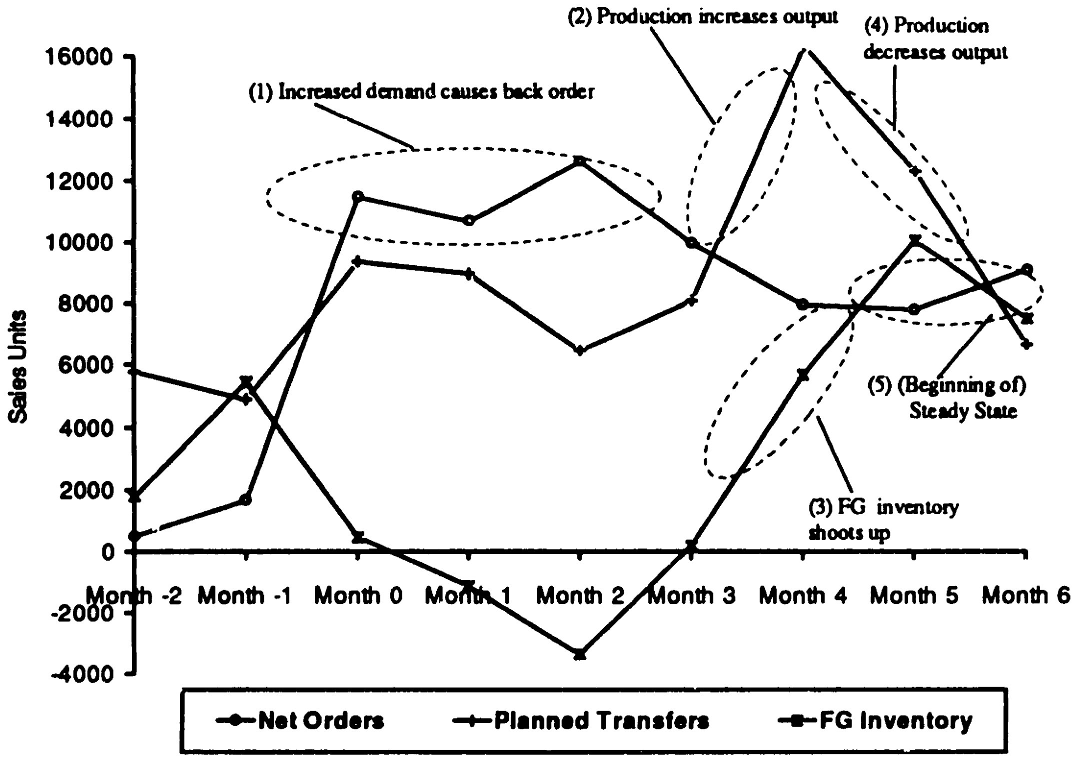

Figure 4.2 Actual new product introduction. (Actual sales unit values for net orders, planned transfers, and FG inventory disguised)

Figure 4.2 demonstrates three of four key variables for understanding the internal reactions -- demand, inventory, and production. The graphs in Figure 4.3 include the additional variable, current-month forecast[32], and demonstrate the relationships of the four key variables (demand, inventory, production, and forecast) presented two-at-a-time. The forecasts provided for the first several months of the introduction (Month 0 and Month 1) were well below the actual product demand. Note that the dealer and affiliate inventory stocking was not adequately accounted for in the forecast. More important, however, is the reaction to the missed forecast. As expected, the high levels of ordering immediately put finished goods inventory into back order. We would expect production to increase substantially in Month 1 to make up for the back order from the previous month, as well

[32]Note that this "forecast" represents the forecast produced for the current month. As stated in Chapter 2, the current month forecast is not delivered to the production area until two weeks into the month. As a result, forecasts for one month, two months, and three months into the future are of more importance for assembly and parts orders. The current month forecast is therefore an approximate representation of the extended forecasts.

as make up for Month 1's forecast demand, but instead, due to capacity constraints at the suppliers, the assembly process could not procure sufficient parts to assemble a large enough quantity of instruments. Since this parts shortage problem was known ahead of time, a lower quantity of instruments were planned for transfer into finished goods, and production (Planned Transfers) fell well below the level of demand.

The demand far exceeded the forecast for a second month (Month 1), and the company plunged further into back order. When parts supply increased around Month 3, production consequently increased to levels well above demand, and inventory levels began to rise. Right about the time that demand started to drop off in Month 4, the planned production from prior months began to arrive into finished goods inventory pushing finished goods inventory up to a full months' worth of demand (double the target inventory level of 1/2 month of demand). Lastly, this jump in inventory triggered a drop in production during Month 6.

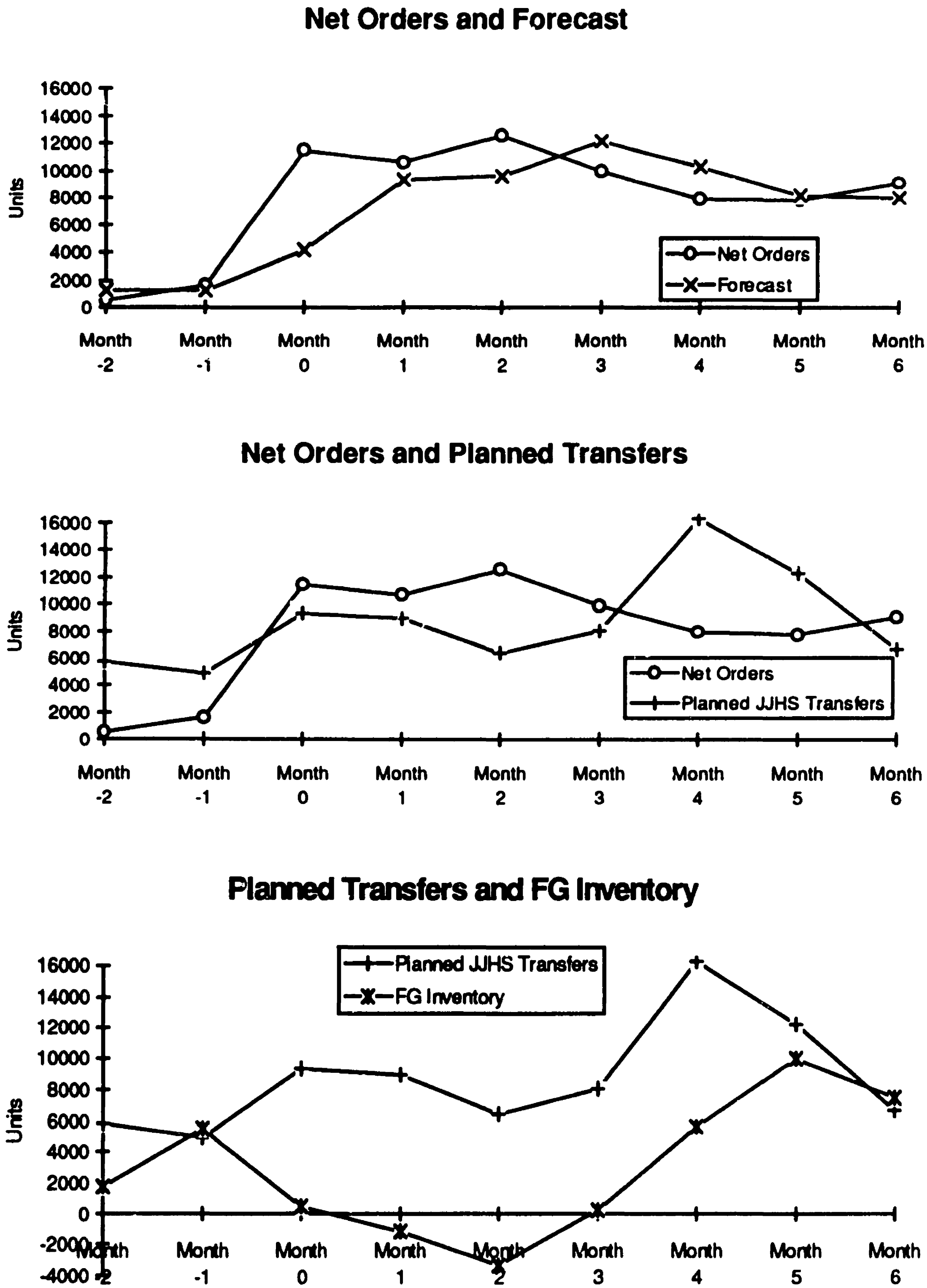

Figure 4.3 *New Product Introduction* example outcome showing Net Orders (demand), Forecast (current-month), Planned Transfers, and Finished Goods Inventory. This product was released to the open market in Month 0. (Actual sales unit values for net orders, planned transfers, and FG inventory disguised.)

Changes in Demand versus Changes in Production

One method to better understand how the variation in demand translates into variation in production levels is to take a look at how much demand and production change from month-to-month. If the average change in demand from month-to-month exceeds the average change in production, it is reasonable to conclude that monthly production varies more than monthly demand. Table 4.1 presents the average demand and production changes for the four most recently products that were studied. The results presented in the table are intended to augment the graphical analysis just presented. The changes in demand and production were taken for the first six months of the respective introduction. Five observations, one observation for each change from one month to the next, were considered in the averages.

Product	Average Δ in Monthly Demand (std. dev.)	Average Δ in Monthly Production (std. dev.)
1	920 (566)	2150 (679)
2	447 (445)	966 (1058)
3	1164 (838)	2395 (1204)
4	977 (1010)	716 (467)
Average of all 4 products (Ave. standard dev.)	877 (714)	1556 (852)

Table 4.1 Average change in demand and production for four recently introduced products. Data was taken for the six months following the introduction for a total of five observations (five "changes" occur between the six months). (Actual demand and production values are disguised.)

The table demonstrates that for three of the four products studied, the average change in monthly production exceeded the average change in monthly demand by approximately 100%. In the case that did not experience a greater average change in production, a single significant drop in demand drove up the average change in demand. Since the change was a drop in demand, production was able to maintain a relatively stable level of output and still meet the demand.

4.4 Back-Ordered Product Example

In this next section, I show that the typical sequence of events found with new product introductions also occurs for other products that fall into back order. The example below demonstrates a product that fell into back order due, in part, to a shortage of component parts and, in part, to an unexpectedly high level of demand (Figure 4.4). In this case, the unexpected demand was a result of a functionally similar product being temporarily pulled from the market. Since customers could not order that functionally similar instrument, they instead ordered the example product. Other sources of unexpected demand might include short-term incentives provided to the sales force and periodic price increases announced a short time prior to the date of the increase.

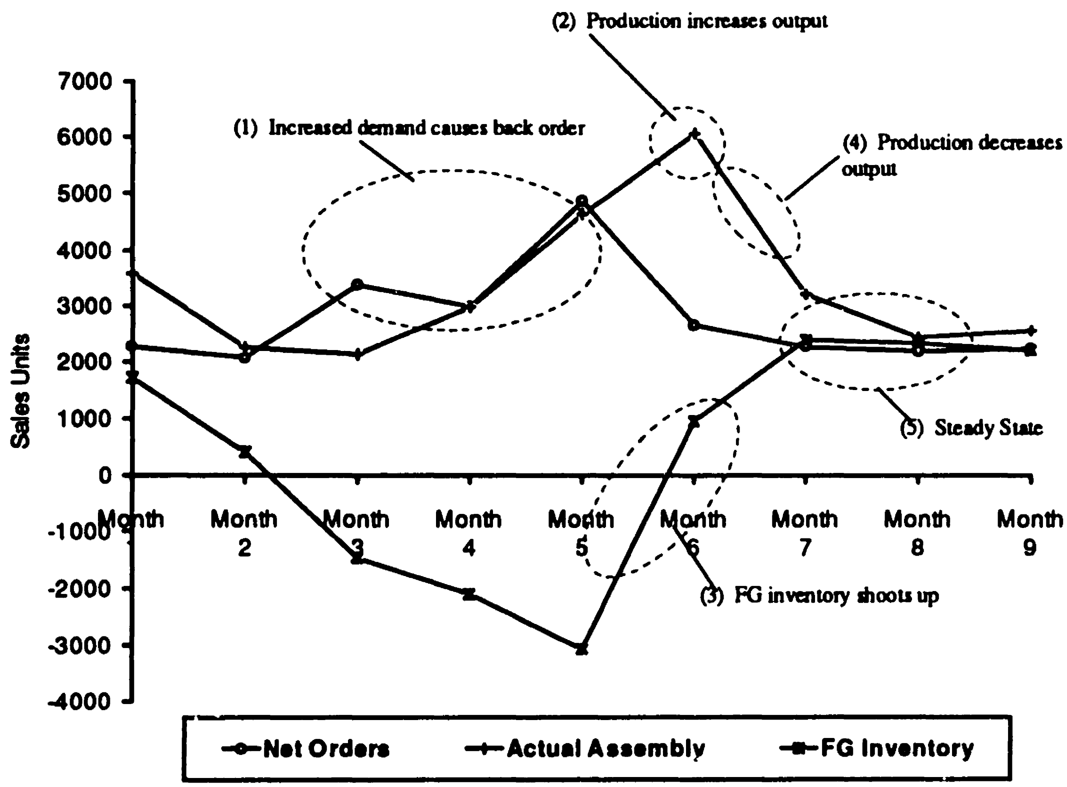

Figure 4.4 Product that fell into back order due to unexpected increase in demand. (Actual sales unit values for net orders, planned transfers, and FG inventory are disguised.)

Once again taking information directly from the DA Sheets, this next example looks at a product that first had problems with supply of component parts in Month 1. It was then under-forecast for three consecutive months -- Month 3, Month 4, and Month 5 -- due to an unanticipated temporary change in the marketplace. The under-predicted demand during those months resulted in immediate back order in Month 3. Shortly afterward, in Month 6, the monthly production rate[33] was increased to four times the steady level of demand. In Months 7, 8, and 9, finished goods inventory rose significantly, almost double the original steady state level, to around one month's worth of demand. The reaction was just starting to settle down in Month 12.

[33]As opposed to the new product introduction example, actual daily, weekly, and monthly assembly volumes were available for this product. Therefore, Actual Assembly will be used in place of Planned Transfers.

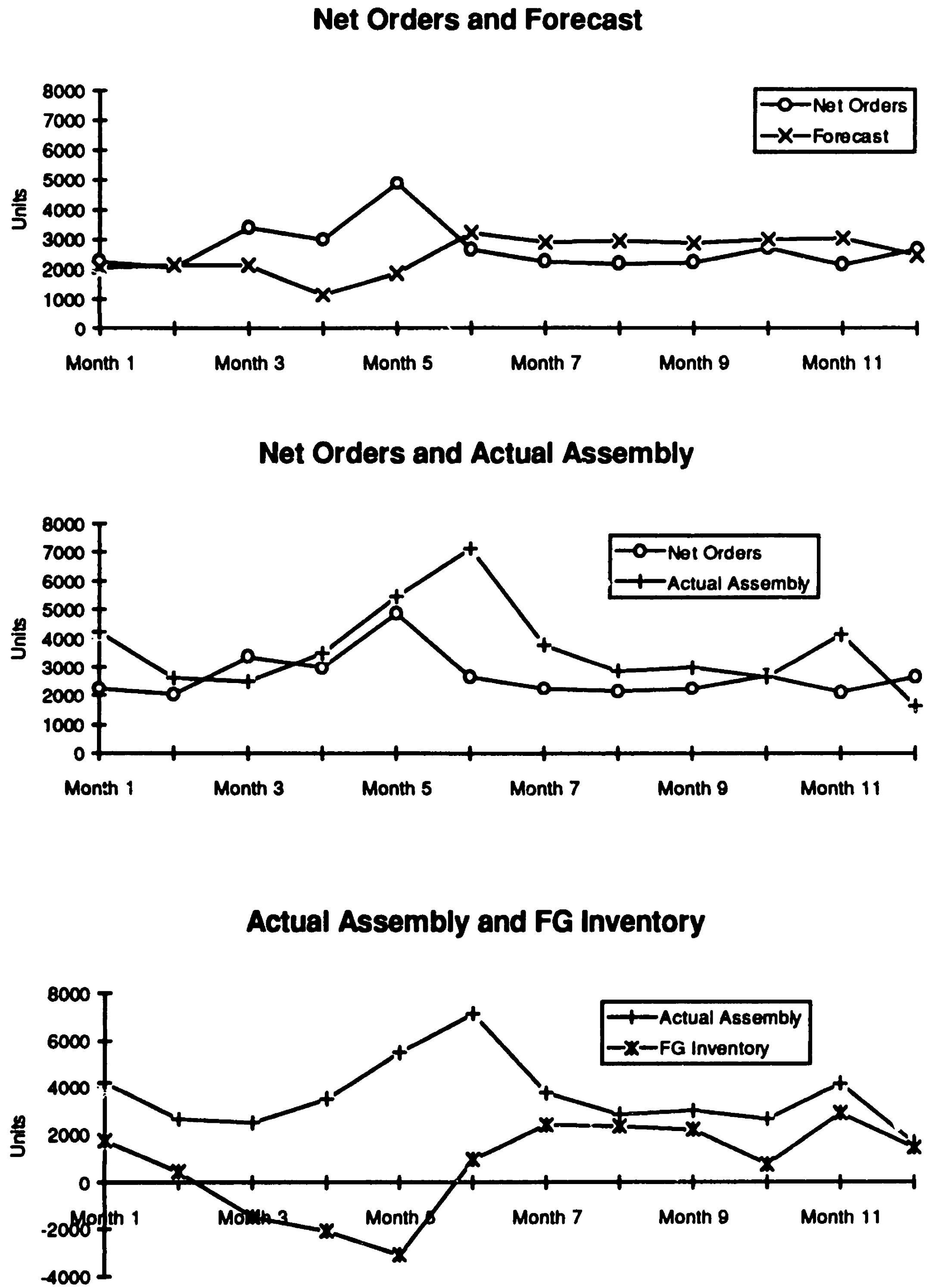

Figure 4.5 *Back-Ordered Product* example outcome showing Net Orders (demand), Forecast (current-month), Actual Assembly (production), and Finished Goods Inventory. The interruption, a sudden increase in dealer demand, occurred in Month 3, Month 4 and Month 5. (Actual sales unit values for net orders, planned transfers, and FG inventory disguised.)

While the preceding example presents the internal reactions to back order for a certain product under fairly unusual circumstances (a shortage in component parts and an unexpectedly high level of demand), I want to stress that similar reactions occur for most products examined that fall into back order for significant periods of time. The level of back order in this case was severe, three weeks worth of demand at its peak, as was the three-month duration of the back order. But as a result of the severity, the example clearly demonstrates the reactions that take place.

4.5 Conclusion

This chapter demonstrated the internal reactions to new product introductions and unexpectedly high levels of demand. In both cases presented, high levels of demand sent the product into back order, forcing production to ramp up and restore product supply. The reactions show how sudden changes in demand are amplified by the production system. In the next chapter, I will show how one particular attribute, the production planning interval, influences the timing and extent of the production response. By moving from a monthly planning system to a daily, demand-pull system, the magnitude of the reaction can be reduced. Future chapters will discuss why EES failed to recognize the extent of the reactions and the potential for improvement.

Chapter 5 Production Planning and Internal Supply Chain Reactions

5.1 Introduction

In the upcoming chapters, I will argue that two main categories of factors contribute to the internal reactions demonstrated in Chapter 4. The two categories are systemic (e.g., lead times, inventory policies, planning processes, etc.) and organizational (e.g., organizational structure, incentives, information systems, etc.) In this chapter, I will demonstrate some of the systemic driving forces. Other literature has addressed the effect that lead time has on supply chain reactions. This topic, therefore, will not be re-addressed. Rather, I will show that one force, the time interval between each production planning period, plays a significant role in determining the extent and the timing of the reactions. The planning time interval for Ethicon Endo-Surgery is essentially one month. By decreasing the planning interval from one month to one week to one day, the extent of the production reactions will also be shown to decrease. As a consequence of the decreased planning intervals, I will show that production must react faster to, and to smaller changes in, demand.

Three simulation models will be presented in this chapter. The first one will demonstrate the production system's reaction to monthly planning. In this case, monthly forecasts are broken down into a monthly assembly schedule. The monthly assembly schedule is further broken down into a weekly production schedule, such that a constant volume of product will be scheduled for assembly each week. The second model, planning on a weekly basis, breaks monthly forecasts into weekly forecasts, and then each week the model determines a new schedule. As opposed to the first model where production schedules may not reflect changes in demand or parts supply shortages until the following month, the second model will adjust its schedules within one week. The final model presented goes one step further to daily planning. In this case, the model of using forecasts to determine production schedules will change; the assembly process will be scheduled only as needed to replenish Bulk Instruments inventory. The scheduling algorithm that will be used is a simple Order Point / Order Quantity, resulting in a basic "demand pull-type" system. This daily planning system will be discussed in further detail in Chapter 10 (An Alternative Production System).

5.2 The Spreadsheet Simulation Models

The reactions to forecast error presented in the previous section are attributable to two broad main causes -- systemic reasons (lead times and intervals between successive production plans) and organizational reasons (incentives to alleviate to back order as quickly as possible). The systemic reasons stem from the long lead times associated with acquiring parts, planning lead times (the delay in getting the plan down to the production areas), and the planning interval (either monthly, weekly, or daily). Both the effects of long material lead times and effects of planning/management delays on supply chains are well documented in the literature[34].

The purpose for the three models presented below is to capture the effects of planning in monthly intervals versus weekly or daily intervals. Through the models it will be shown that the planning interval has a significant effect on the reactions to back order. It is important to realize that the interval between planning periods in particular will be analyzed. Other delays in the production system, such as supplier lead times, assembly lead times, packaging / sterilization lead times, and planning lead times, will only be discussed. The reason is that the effects of reducing planning intervals are almost immediately realizable. As will be shown with the "demand-pull system" used in the final model and as will be discussed in Chapter 10, the planning interval can be reduced from one month to one day without increasing planning effort. While continuous improvements in production and planning lead times were clearly evident, significant improvements require a detailed understanding of the underlying processes. This detailed understanding would have to cut across all of Ethicon Endo-Surgery's product lines to be realized on a broad scale. Changing the planning process would not require the same detailed understanding. Changes to planning could therefore be implemented across dozens of product lines. Benefits could be realized with minimal effort[35]. Additionally, the benefits of reducing the lead times were fairly well understood within the organization. At the time of this writing, several groups were addressing the issue of lead time reduction. Decreasing the planning interval, however, was not an evident emphasis, most likely reflecting the fact that the benefits were not well understood.

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[34]Refer to the literature review section of Chapter 1 for further details.

[35]A word of caution: Ignorance of the underlying production processes when implementing a change in the planning process could lead to disaster. As will be shown with the simulation models, changing the planning interval also changes the flexibility required of the production processes. If the planning process is altered and the production processes are not flexible enough to support the change, the benefits of the new planning process will not be realized.

The Monthly, Weekly, and Daily Planning Models

To understand the effects of reducing the time interval between planning periods, three models were created -- one model that simulates a monthly planning process, another that simulates a weekly planning process, and another that simulates a daily planning process. The first two models attempt to simulate the same supply chain as described in Chapter 2 (see Figure 5.1 for a diagram of Ethicon Endo-Surgery's internal supply chain). Component parts and assembly are determined based on future forecasts. Orders for packaging/sterilization are initiated as needed to replenish finished goods. In other words, the models simulate a supply chain with component parts "forecast-pushed" into assembly, instruments "forecast-pushed" through assembly into bulk inventory, and bulk instruments "demand-pulled" through packaging/sterilization into finished goods inventory. The key difference between the two is in the way in which the monthly forecasts are used to plan assembly and order parts. This difference is outlined below and is presented in Table 5.1.

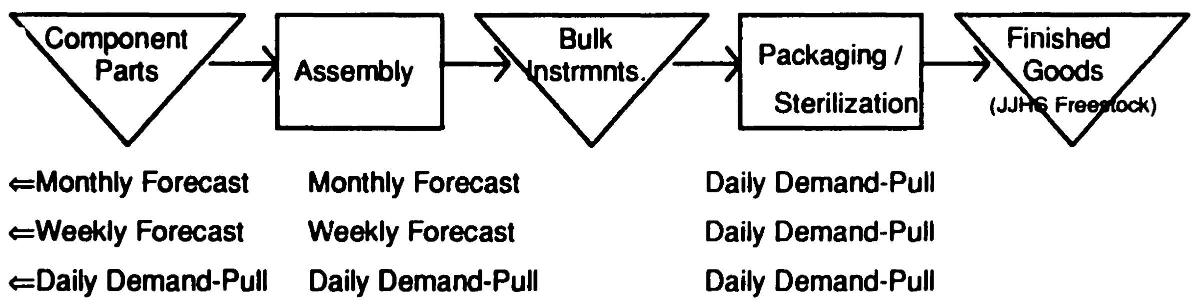

Figure 5.1. The internal supply chain, showing how each process -- parts ordering, assembly, and packaging/sterilization -- are scheduled for the Monthly Planning, Weekly Planning, and Daily Planning models.

Process	Model	Scheduling Basis	Description
Packaging / Sterilization	Monthly	- Daily Order point / Order quantity	Demand-Pull - Order Point determined for FG inventory. When FG inventory drops below the order point, a new batch of instruments are initiated through packaging / sterilization.
	Weekly	- Same	Demand-Pull - (same as Monthly Planning).
	Daily	- Same	Demand-Pull - (same as Monthly Planning).
Assembly	Monthly	- Monthly forecast determines Monthly assembly plan	Forecast-Push - Monthly forecast and inventory levels determine the number of instruments required to be assembled for the month. The monthly assembly requirements are divided evenly across each week of the month.
	Weekly	- Weekly forecasts, determined from the Monthly forecast, determines Weekly assembly plan.	Forecast-Push - Weekly forecast is determined from the Monthly forecast. Weekly forecast and inventory levels determine the number of instruments required to be assembled for the week.
	Daily	- Daily Order point / Order quantity	Demand-Pull - Order Point determined for Bulk inventory. When Bulk inventory drops below the order point, a new batch of instruments are initiated through assembly.
Component Parts Orders	Monthly	- Ordered to arrive when needed. Order schedule updated each month.	Forecast-Push - Monthly forecast, Parts inventory levels, and weekly assembly plans are used to project when the Parts inventory level will drop below the safety stock level. One lead time prior to that projected point, an order is sent to the supplier.
	Weekly	- Ordered to arrive when needed. Order schedule updated each week.	Forecast-Push - Weekly forecasts, Parts inventory levels, and weekly assembly plans are used to project when the Parts inventory level will drop below the safety stock level. One lead time prior to that projected point, an order is sent to the supplier.
	Daily	- Daily Order point / Order quantity	Demand-Pull - Order Point determined for Parts inventory. When Parts inventory drops below the order point, an replenishment order is sent to the supplier.

Table 5.1. Scheduling Summary. Summary of how Packaging / Sterilization, Assembly, and Component Parts Orders are scheduled for each model.

The Monthly Planning Model: In the monthly planning model, the weekly production plans and component parts orders are determined at the beginning of the month and do not change until the start of the following month. Data concerning actual orders and final inventory levels are gathered on the first day, Monday, of the new month. By the following Monday, exactly one week later, the new monthly forecasts have been generated and a new monthly production plan has been determined. This monthly production plan is broken down evenly into the weekly assembly plan. The resulting assembly plan schedules the same volume of instruments to be assembled each week during the month. The weekly plan does not change until a new monthly plan is generated the following month.

Immediately after the weekly assembly plan is determined, the component parts orders are determined. Based on the weekly assembly plans and the inventory level of component parts at the beginning of the month, the model determines when the component parts inventory will drop below a predetermined safety stock level. Exactly one delivery lead time prior to that point, the model initiates a new order for component parts. The parts are then expected to arrive exactly in time to prevent the inventory from dipping below the safety stock level.

The Weekly Planning Model: In the weekly planning model, the weekly production plans and component parts orders are determined each week. On Monday morning, information concerning Friday's inventory levels in conjunction with the monthly forecasts determines that week's plan. As with the monthly planning model, forecasts are generated monthly and are not available for planning purposes until the second Monday of each month. Unlike the monthly planning model, the monthly forecasts are broken down into weekly forecasts rather than into a monthly production schedule. The weekly forecasts are determined by dividing the monthly forecast by the number of weeks in the month. The weekly forecasts are then used each week to determine a new assembly schedule.

Component parts orders are determined using the same method as used in the monthly planning model -- the current component parts inventory level in conjunction with the weekly assembly plan determines when a new order should be initiated. The weekly model, however, determines each week whether or not it needs to initiate a new order for component parts.

The Daily Planning Model: As opposed to the monthly planning and weekly planning models, the daily planning model utilizes a "demand-pull" policy for scheduling assembly and for determining orders for parts. An order point / order quantity system is used to create a "build-to-stock" system through assembly. In other words, when the Bulk Instrument inventory level drops below the predetermined order point, the assembly process initiates assembly of a new batch, or order quantity, of instruments. As for component parts, when the inventory level for a particular part drops below the predetermined order point, an order for more component parts is sent to the supplier. Order points are determined from a combination of replenishment lead times and variability in demand[36]. Order quantities depend on the flexibility of either the assembly process or the supplier's production process. The more flexibility in the process, the smaller the order quantity. The reader should observe that the order point / order quantity system is already in place for scheduling packaging / sterilization.

The reason for switching to a demand-pull system for the daily planning model is that it provides a simple process for scheduling on a daily basis. It is relatively easy to understand, relying only on replenishing the appropriate inventory position as necessary. It is also simple to implement in a simulation model since decisions at each point in time depend only on the current state of the system; it does not determine current actions by predicting what the future will look like and then planning according to that prediction.

As mentioned previously, the models assume a deterministic world with no deviation from the set planning process, no uncertainty in lead times or parts deliveries, and perfectly flexible resources. They use actual weekly order data and actual monthly forecasts from prior D.A. sheets as inputs. Outputs from the models include graphs of parts, bulk, and finished goods inventory, assembly and packaging/sterilization rates, daily service levels, and inventory investments. The objective of these simulations was not so much to determine how the system would behave differently had uncertainties not existed, but to understand how the system would behave differently under a different planning scenario -- specifically weekly adjustments to production plans instead of monthly.

For the models, three basic assumptions govern the simulations:

<u>Constant lead times</u> - lead times are constant for parts orders, assembly, and packaging/sterilization. This assumption holds regardless of the order size and batch sizes.

<u>Infinite capacity</u> - no capacity restrictions exist within the supply chain including within suppliers.

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[36]For detailed information on determining order points and order quantities, see for example: Nahmias, S., <u>Production and Operations Analysis</u>, Second Edition. Homewood, IL: Irwin, 1993.

Infinite flexibility - all parts of the supply chain can change their production rates from week to week to whatever rate is necessary uphold the constant lead time assumption.

The assumption of infinite capacity deserves further attention. The models will demonstrate that despite the more favorable assumption that capacity restrictions do not exist, the amplified reactions still occur. Without the assumption, we would expect the reactions to be even further amplified. Interestingly, the models will show that the daily planning system requires the least production capacity (a factor of two less than the monthly planning model) to keep up with incoming demand.

5.3 The Simulation Spreadsheet

This section describes the details of the simulation models. The method used to create the simulation model on spreadsheet software is discussed briefly. The bulk of the section presents a more detailed discussion of the variables used by the model. Readers not interested in the technical details should skip this section, as the details are not necessary for understanding the findings from the models.

Spreadsheet Simulation Modeling: The simulation models were implemented on a Microsoft Excel[37] spreadsheet on an IBM PS/2[38] personal computer. Implementation of a simulation model on a spreadsheet deserves some more discussion. Each row of the spreadsheet represents one day of the simulation. The values of the model variables are held in the spreadsheet columns (see Table 5.2). For each day in the simulation, the column variables are recalculated based on data from the previous day or row. The values of all variables for a particular day are represented by a single row in the spreadsheet. The values of a single variable for all days of the simulation are presented by a single column in the spreadsheet. As an example, determining what the Bulk Inventory level was on July 7 requires finding the row that represents July 7 and then crossing it with the column that represents Bulk Inventory. To determine the Bulk Inventory level for July 8, simply look one row down but in the same Bulk Inventory column. An additional section of the spreadsheet maintains the MRP-style calculations used for breaking the forecasts down into parts and assembly requirements for each month/week. The monthly forecasts are converted into weekly forecasts and used to determine finished goods requirements for

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[37]Excel is a registered trademark of Microsoft Corporation, Redmond, WA.
[38]PS/2 is a registered trademark of IBM Corporation, Armonk, NY.

each week. Lead time offsets for packaging/sterilization, assembly, and parts orders in conjunction with current inventory levels determine production plans and orders for parts. In the monthly planning model, this procedure is completed once per month on the second Monday of the month. The weekly planning model completes the procedure on Monday of every week.

Date	Bulk Inventory	Pack/Ster Order	Pack/Ster WIP	FG Inventory
3/7/94	1200	0	500	1000
3/8/94	1200	0	500	800
3/9/94	1200	0	500	600
3/10/94	1100	100	500	400
3/11/94	1100	0	200	700
3/14/94	1000	100	200	550

Table 5.2 Sample section from a simulation spreadsheet. Variables are represented in columns. Dates are represented by rows. The value of any particular variable at any given time can be determined by aligning the appropriate variable column with the appropriate date row. In the sample, Bulk Inventory, Pack/Ster WIP, and FG Inventory are state variables. Pack/Ster Order is an event variable indicating the moment that the model initiates a new batch of instruments through packaging / sterilization.

State Variables versus Event Variables: There are two basic kinds of variables in the model -- state variables and event variables. State variables track levels of parts, instruments, and finished product at each point in the system. These variables include Parts Inventory, Outstanding Parts Orders, Outstanding Assembly Orders, Assembly WIP, Bulk Inventory, Outstanding Pack/Ster Orders, Pack/Ster WIP, and Finished Goods Inventory. Event variables represent the orders throughout the system that cause state variables to change. Event variables include Parts Order, Assembly Order, Pack/Ster Order, and Distributor Order. All quantities for the variables are normalized to represent one sales unit where one sales unit may consist of several instruments of a given product code and one instrument may be composed of several different parts. For a discussion of the variables and how they are determined, the interested reader should refer to Appendix A at the end of the thesis.

5.4 Results of the Simulations

In this section, I present results of the simulation of one particular product. This product happens to be the same product demonstrated in Chapter 4. It was chosen for the simulations because of its unexpectedly high demand during three consecutive months (see Figure 5.2). The system's reactions to the three consecutive months of high demand provide an excellent demonstration of the effects of changing planning intervals.

The results from the models are presented in Figures 5.3a-c and Figures 5.4a-c. Figures present the resulting finished goods and bulk instrument inventory levels.

The monthly planning model demonstrated the greatest swing in production rate following the unexpected demand peaks; but it also demonstrated relatively steady production during the remainder of the simulation. The weekly planning model also demonstrated a large swing in production, but the swing was not as large as that found with monthly planning (remember that the production rates are approximate and would be smoothed out in a real sense). In contrast, the daily planning model exhibited a relatively small swing in production in order to meet the increased demand. It additionally demonstrated a relatively stable production rate throughout the simulation.

Looking at FG inventory levels, the monthly planning model exhibits considerable variation while the daily planning model's inventory remains remarkably stable. The weekly planning model falls somewhere in the middle.

5.5 Conclusion

This chapter presented the effect of changing the planning interval on the production system. In particular, in moving from a monthly planning model to daily, pull-type planning model, unexpectedly high demand is dampened rather than amplified. Additionally, inventory levels tended to flatten out as the planning interval got smaller. This has major implications concerning the ability to reduce inventory and still maintain a high level of delivery service.

The daily, pull-type system will be revisited in Chapter 10 as a potential alternative to Ethicon Endo-Surgery's existing planning and production process. As will be discussed in that chapter, the daily system has many organizational advantages in addition to being able to reduce variation in production and stabilize inventory levels.

Figure 5.2 Weekly Customer Orders

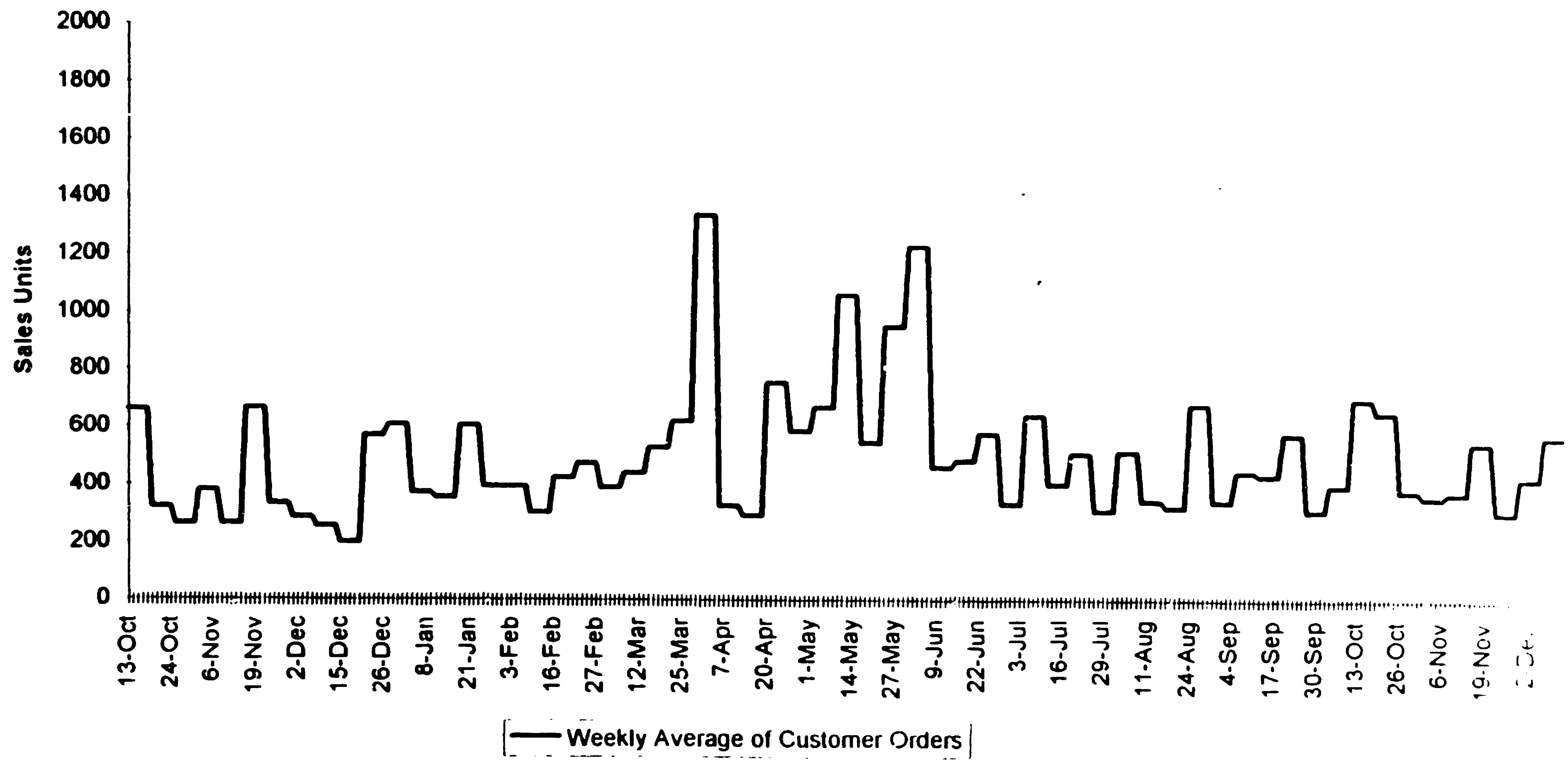


Figure 5.2a Inventory (Monthly Planning)

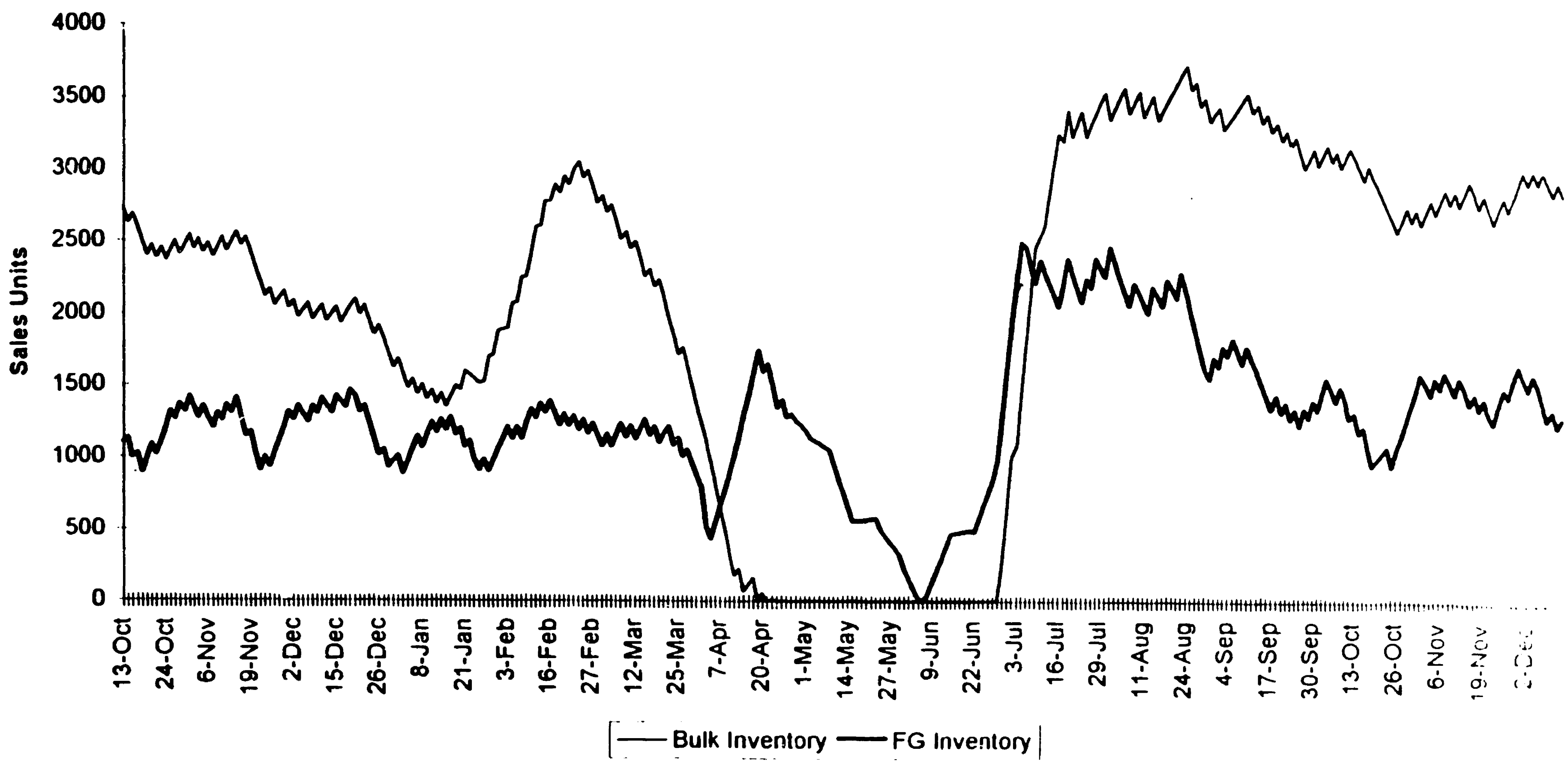


Figure 5.2b Inventory (Weekly Planning)

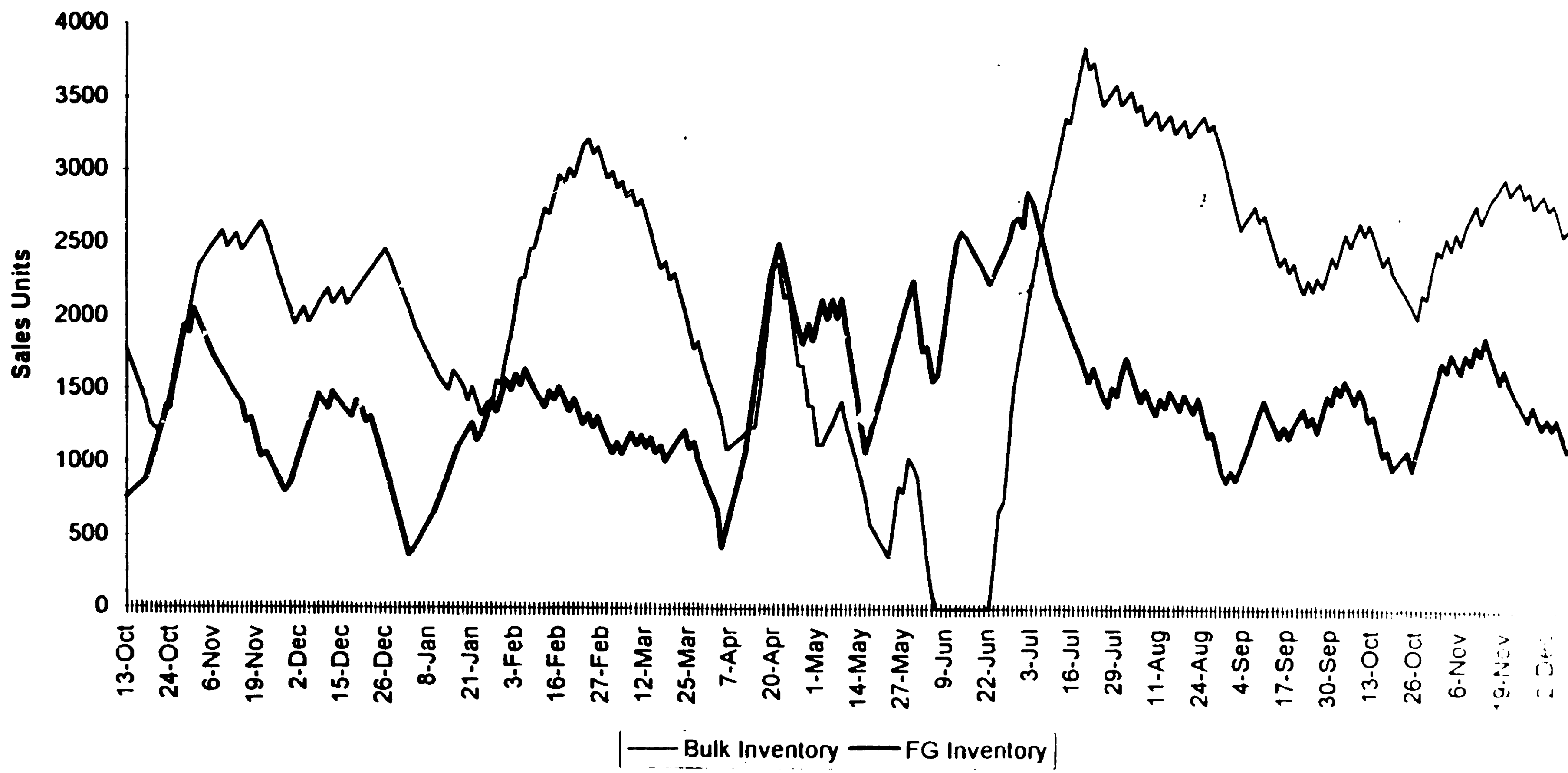


Figure 5.2c Inventory (Demand-Pull, Daily Model)

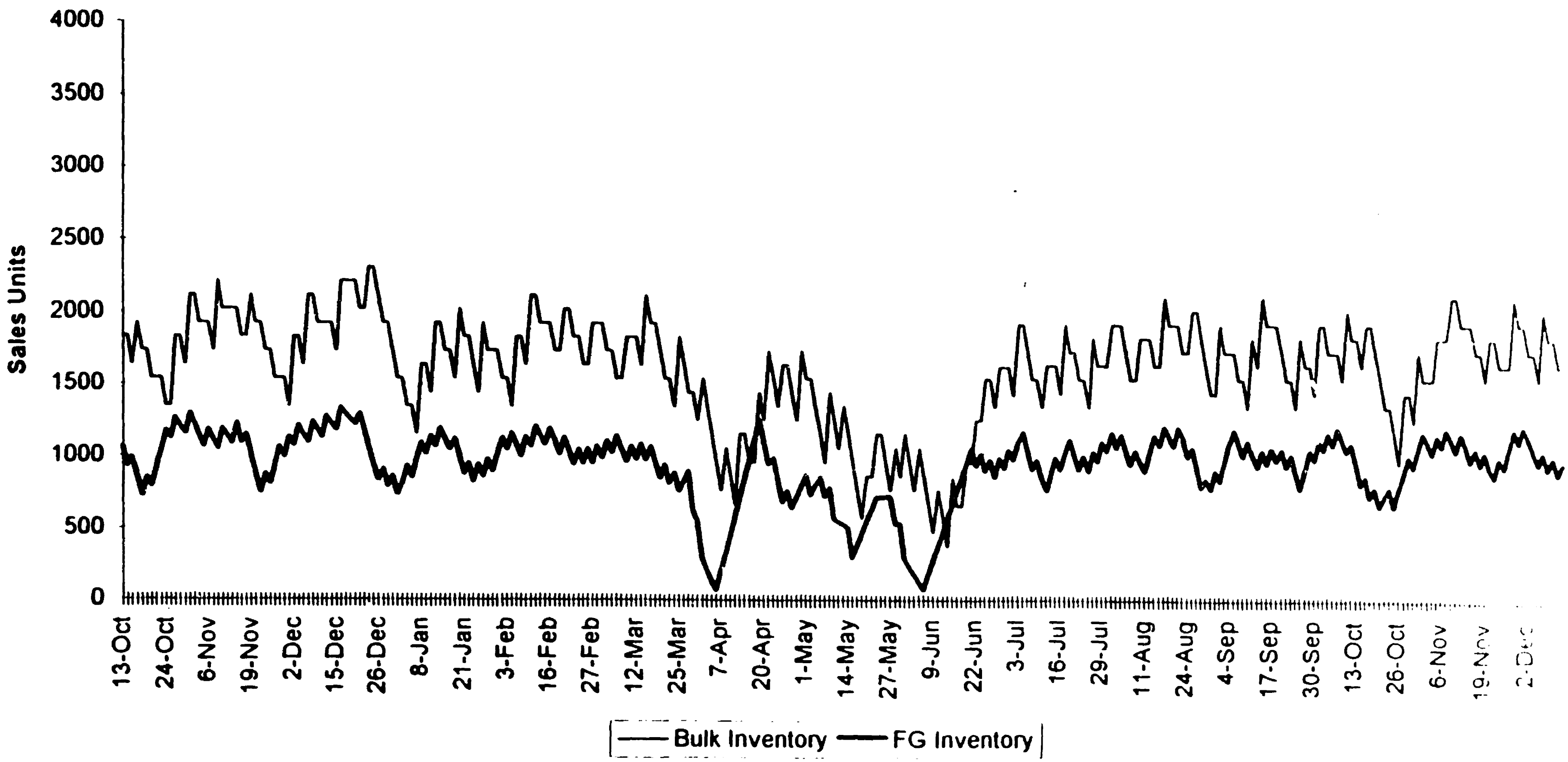


Figure 5.3a Assembly Rates (Monthly Planning)

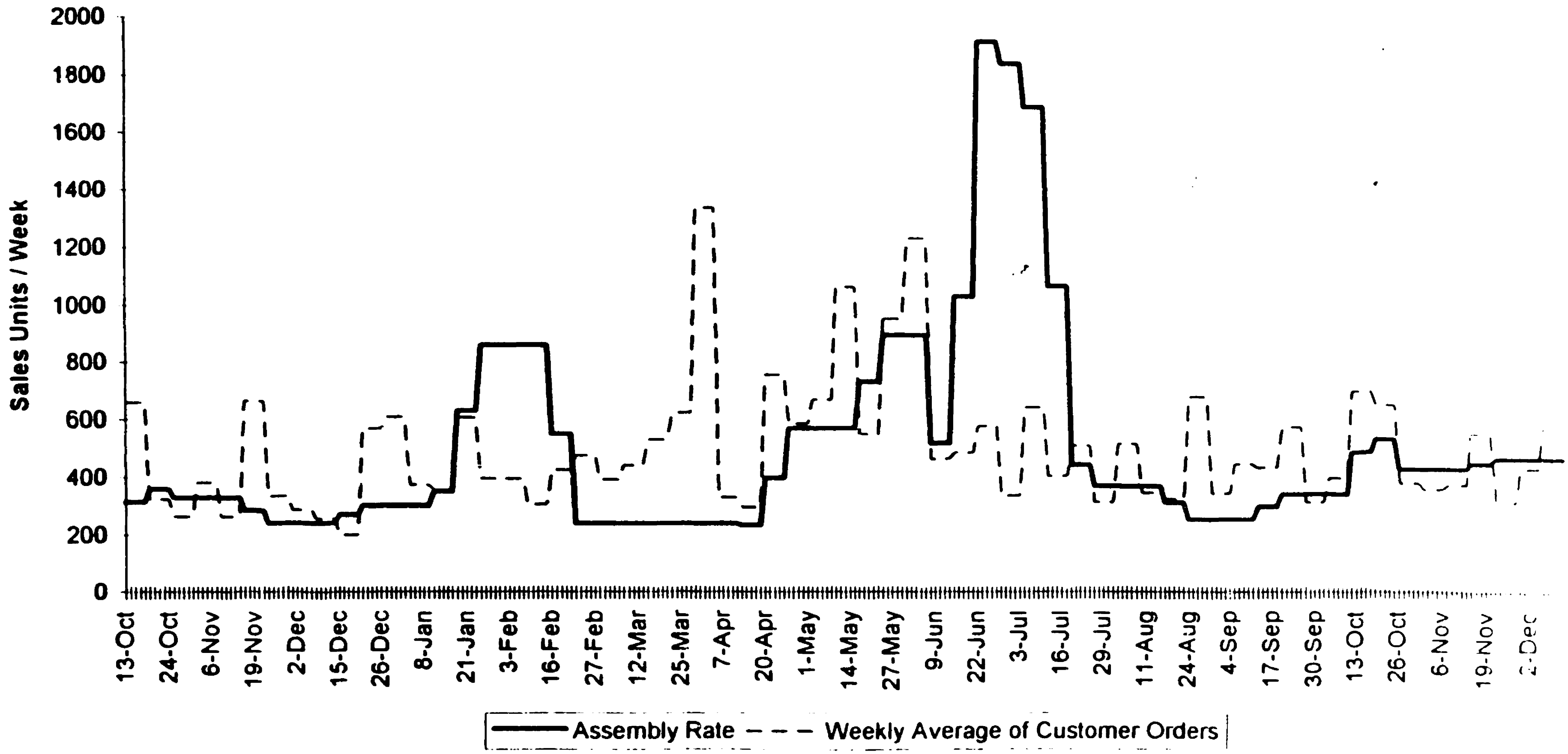


Figure 5.3b Assembly Rates (Weekly Model)

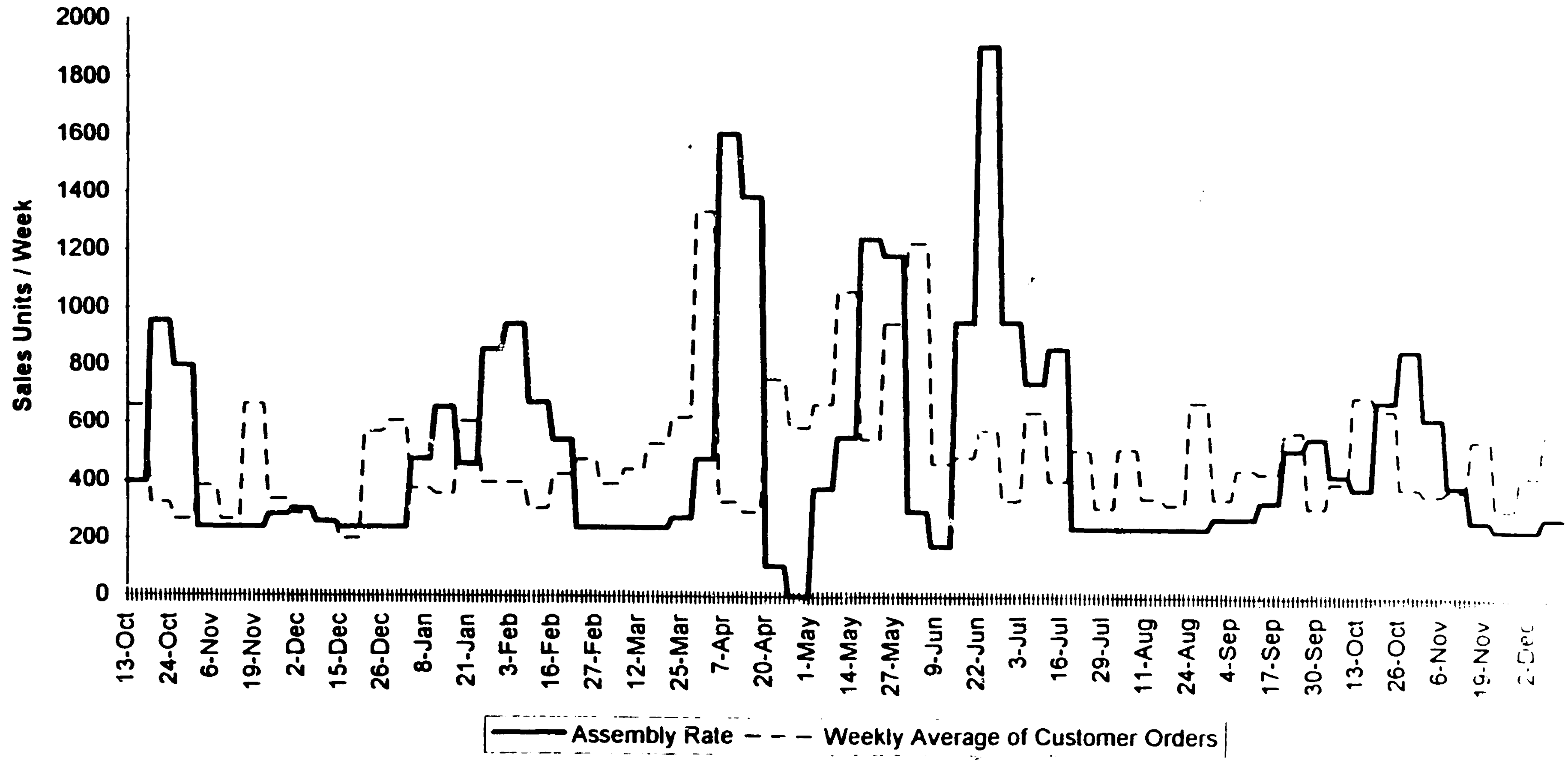
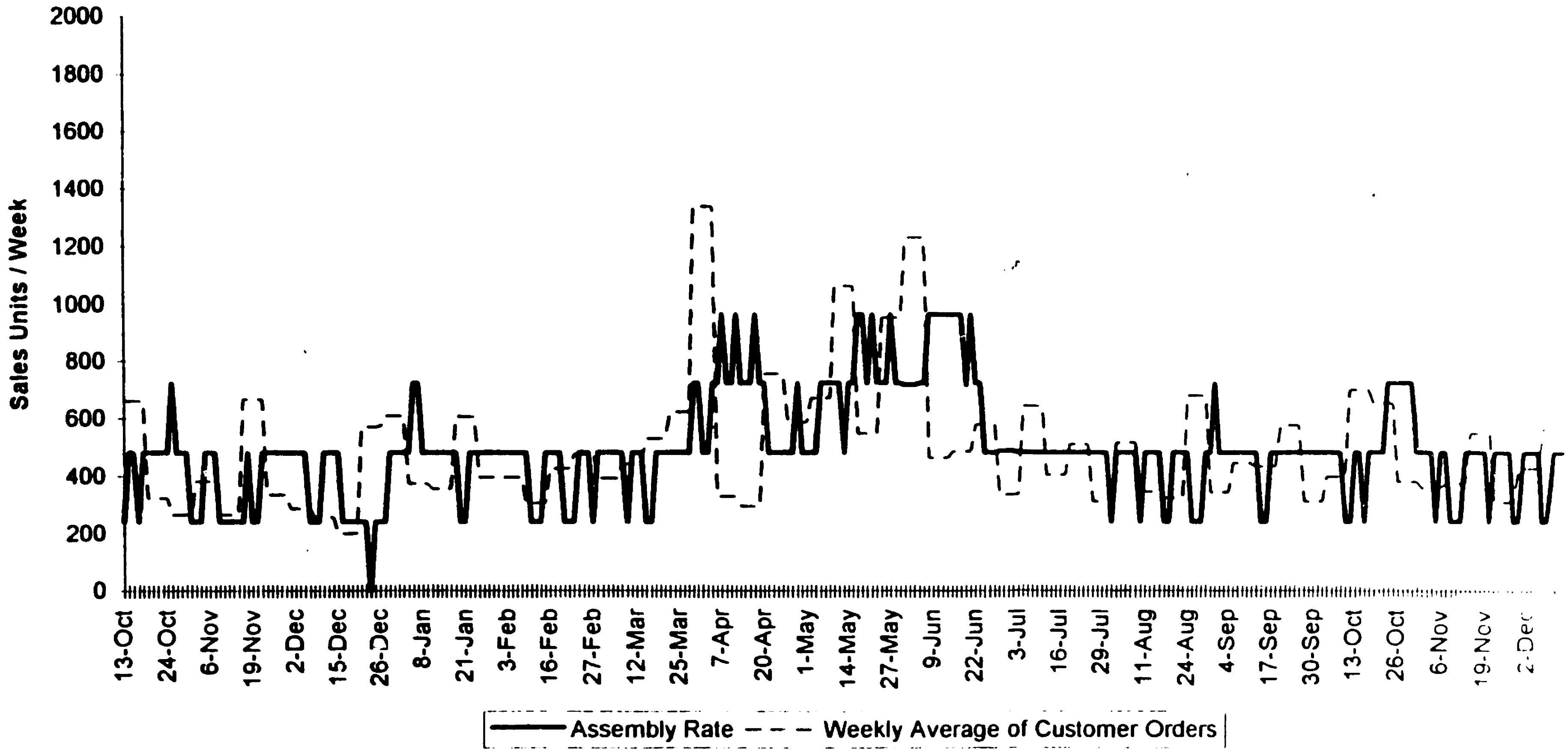


Figure 5.3c Assembly Rates (Demand-Pull, Daily Planning)



Chapter 6 Inventory and Cost of Reactions

6.1 Introduction

Up to this point in the thesis, inventory has remained on the sidelines. Production rates and demand levels were used to demonstrate how the production system amplifies unexpected jumps in demand. Inventory levels were only presented to add perspective to the reactions -- to show when the product fell into back order, when it came out of back order, and how much time was required to bring inventory levels back to their normal levels. In this chapter, I turn attention to the levels of inventory throughout the internal supply chain. As a natural extension of my research on demand and production, I analyzed the current inventory levels and the current inventory policy. I found that the current policy, stated as weeks of inventory and relatively consistent across all products, does not match the corporate service objective. I will show that the inventory levels dictated by the current policy greatly exceed the inventory levels dictated by the corporate service objective. In other words, the current inventory level can be reduced without jeopardizing the ability to meet the corporate objective. This potential for inventory reduction has been valued at millions of dollars.

The first part of this chapter is devoted to the inventory analysis, demonstrating statistically and conceptually why the inventory levels exceed corporate objectives. The remainder of the chapter will concentrate on costs of the supply chain. In particular, it will demonstrate the difference in inventory value between the current policy and the corporate objective. It will also return back to internal supply chain reactions. A model will be presented for analyzing the costs associated with the reactions.

6.2 Inventory Analysis

In this section, I will demonstrate why the finished goods inventory levels are high in terms of the corporate service level objectives. The current "inventory policy" for finished goods is stated in terms of demand-weeks of inventory, where one demand-week of inventory represents the volume of product expected to be sold in one week. (The reorder point used to replenish finished goods is the same as the "inventory policy" referred to throughout this thesis. This definition is used to remain consistent with EES.) On the other hand, the corporate objective is stated as a line service level[39]. The line service level represents the number of times a product was available in finished goods when an order arrived divided by the number of orders for a given product:

$$\text{Line Service Level} = \frac{\text{\# of Order Lines Filled from FG Inventory}}{\text{Total \# of Order Lines}}$$

If, for example, Ethicon Endo-Surgery's corporate service level objective is 95%[40], then 95 out of every 100 orders for a particular product should be filled completely from finished goods inventory.

Given the current policy and the corporate objective, the inventory levels will be examined in three different ways. The first analysis examines inventory levels graphically compared to actual demand data. Using conservative assumptions, this simple, graphical analysis should demonstrate clearly the potential for inventory reduction. The other two, more rigorous analyses utilize standard service level models to, first, translate the corporate service level objective into a weeks of inventory objective and, secondly, translate the current weeks of inventory policy into a corresponding service level policy. These translations will allow direct comparison of the demand-weeks policy and the corporate service level objective.

A Graphical Approach to Understanding the FG Inventory Level

The simple approach demonstrates graphically the relationship between demand and FG inventory levels. Figure 6.1 shows a product that has a fairly representative variation in demand (standard deviation equals 25% of average demand) and a fairly representative inventory policy (3 weeks of demand). In the graph. the jagged line shows the incoming demand for the product over a four month period. The dashed line drawn through the middle of the demand line is the average demand for the period. Note that the highest peak in demand occurs on July 2 with a demand of about 1750 sales units. Immediately above the average demand, a line has been constructed to pass just above that demand

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[39]The term "line" refers to the line on an order sheet. Customers may specify several different products on a single order sheet, and each distinct product receives its own line on the sheet. For a discussion on service level concepts, see for example: Nahmias, S., Production and Operations Analysis, Second Edition, Homewood, IL: Irwin, 1993.

[40]The actual line service level objective is witheld as proprietary information. The upcoming inventory level calculations that compare the corporate objective to current policy will utilize the actual service level objective, but will not disclose the particular number.

peak. This line, by passing through the peak demand of 1750 sales units, represents the inventory required to avoid falling into back order. In other words, since demand never exceeded 1750 sales units, as long as just over 1750 sales units (1 $^1/_3$ demand-weeks) of inventory are present in finished goods at the beginning of each week, the product would not fall into back order.

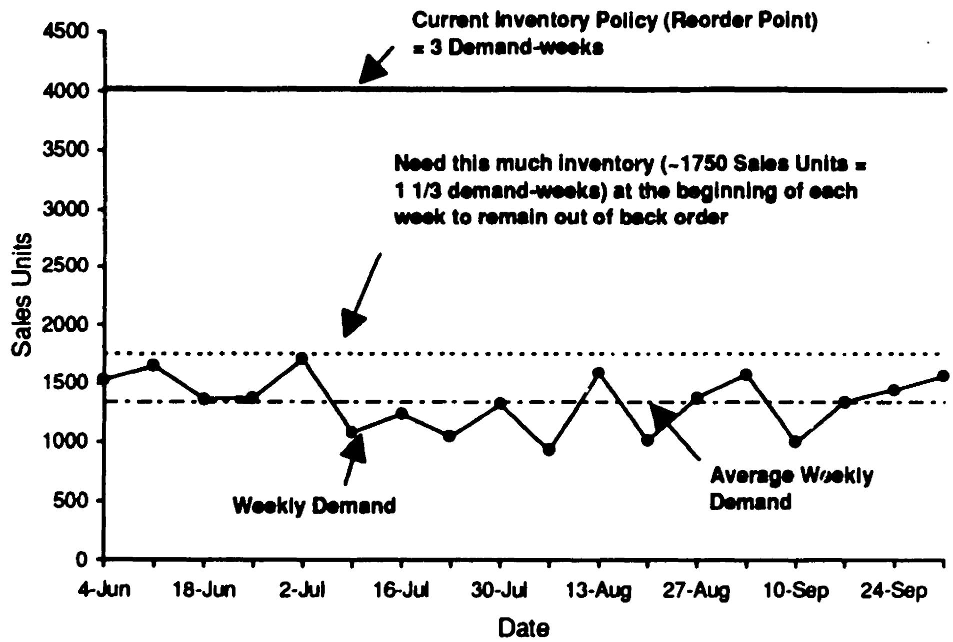

Figure 6.1 Weekly demand relative to the finished goods inventory policy for a representative product. As show in the graph, peak demand over the four month period occurs on July 2 with a demand of 1750 sales units. As long as 1750 sales units (about 1 1/3 demand-weeks) of product are present in finished goods inventory at the beginning of each week, the product would not fall into back order.

As discussed in Chapter 2, the packaging / sterilization process replenishes FG inventory on an Order Point / Order Quantity basis. We can assume conservatively that the packaging / sterilization process examines the FG inventory level once per week with a replenishment lead time of one week. (In actuality, FG inventory is examined every day.) In this case and under the assumption that FG inventory can be replenished to 1750 sales units (1 $^1/_3$ demand-weeks) each week[41,42], the absolute maximum inventory level would

[41]As discussed in Chapter 2, the packaging / sterilization process is highly flexible. Packaging / sterilization of $^1/_3$ higher volume for one particular product that represents less than 5% of the total volume should conservatively not pose a problem

be 1750 sales units. This maximum would be present at the beginning of the week and would be depleted to a lower level by the end of the week. This maximum should be contrasted with the current inventory policy of 3 demand-weeks. In figure 6.1, this policy is represented by the highest horizontal line drawn through 3900 sales units.

As a final point, it should be noted how the line service level would change had there been slightly less than 1750 sales units of inventory available for shipment each week. The graph is composed of one data point for each week of the four-month period. This results in a total of 18 data points. For discussion's sake, suppose that FG inventory can only be replenished to 1500 sales units. As a result, for every week with a demand greater than 1500 sales units, some orders will not be filled from FG inventory. During those weeks, the number of orders filled from FG will simply be 1500. Taking this into account, we can determine the total number of orders that would be filled from FG inventory and consequently determine the line service level. The resulting service level, calculated separately from this discussion, would be 97.4%. In other words, if the packaging / sterilization operation can only replenish FG inventory up to 1500 sales units each week, the resulting service level would still be 97.4%.

Detailed Analysis of the Inventory Policy

The service level concept found at EES exactly matches the Type 2 Service model of a (Q, R) system described in serveral operations management texts[43]. For details of the calculations, I refer the reader to those other texts. The reorder point and the replenishment batch size found in the model deserve some further discussion. The reorder point represents the point at which a new replenishment batch is initiated. When the finished goods inventory level drops below the reorder point, a new batch of product is initiated through the packaging and sterilization process. The size of this batch will always be the order quantity. With this in mind, the reorder point is equivalent to EES's concept of finished goods safety stock. When finished goods inventory drops below the safety

[42]The inventory replenishment policy may not actually be clear here. In order to replenish up to 1 1/3 weeks physically residing in finished goods at the beginning of each week, the policy would be to order up to 1 (to account for cycle stock) plus 1 1/3 weeks. This will result in an average inventory level on the first day of the week of 1 1/3 weeks. Also note that this policy will fail with two or more consecutive weeks of high demand. To be thorough, we would need to replenish up to 2 x 1 1/3 = 2 2/3 weeks. This will result in an average weekly inventory level of 2 2/3 - 1 = 1 2/3 weeks. 1 2/3 weeks is still far short of the current 3-week policy.

[43]See for example: Nahmias, S., Production and Operations Analysis, Second Edition, Homewood, IL: Irwin, 1993.

stock level, a new batch is initiated through packaging / sterilization. Additionally, the replenishment batch size is equivalent to EES's packaging / sterilization batch size.

This analysis will involve two calculations -- one that converts the current inventory policy into an expected service level and one that converts the service level objective into a demand-weeks inventory policy.

Converting the Current Inventory Policy into an Expected Service Level

I will first demonstrate the mechanics of the calculation with a sample product. The product selected is one of EES's high volume instruments, representing approximately 5% of the total EES sales volume. The policy for this product is to carry three weeks of safety stock. The average weekly demand over the past six months has been 1450 sales units with a standard deviation of 346 sales units. Since the replenishment lead time is approximately one week, the average demand over the replenishment lead time is simply the average *weekly* demand. Using the same logic, the standard deviation of demand over the replenishment lead time is simply the *weekly* standard deviation. The three week inventory policy translates into a reorder point of 1450*3 = 4350 sales units. As for the final piece of information, the batch replenishment size is one week's worth of demand, or 1450 sales units[44].

Given the information for this product, the expected service level comes out to be greater than 99.9%. This suggests that a significant investment has been made in inventory to ensure that all but 0.1% of the incoming orders are filled directly from finished goods inventory.

[44]A batch size of 1450 sales units is actually larger than the batch size actually used. The actual number is not used here for two reasons. First, the batch size was still being debated at the time of this writing. Enough flexibility existed in the process that the ECQ (Economic Order Quantity) was smaller than one typical week's worth of demand. The question of batch size therefore rested more with what quanitity was reasonable for operators to handle. Secondly, the calculations have been completed with batch sizes ranging from 145 sales units to 2900 sales units. Even with a batch size of 145 sales units, the resulting service level was still above 99.98%.

Product	Average Weekly Demand	Standard Deviation of Demand	Service Level (with Current Inventory Policy of 3 Demand-Weeks)
A	1749	541	99.9%
B	1503	264	99.9%
C	440	141	99.9%
D	1275	304	99.9%
E	1600	422	99.9%
F	646	110	99.9%
G	861	141	100.0%
H	615	145	99.9%
I	132	55	99.9%
J	598	105	99.9%
K	598	185	100.0%
L	536	110	99.9%
M	1011	207	100.0%

Table 6.1. Converting the Current Inventory Policy into Expected Service Level. Expected Service levels for the top thirteen selling product codes (top 50% of sales dollar volume) based on the current inventory policy of 3 demand-weeks. All thirteen codes have expected service levels greater than 99.9%. When this analysis is expanded to the top 80% of sales dollar volume, 43 of the 45 product codes should expect a service level greater than 99.9%.

Was this chosen product code simply a random exception? Going through the same calculations with the top thirteen selling product codes, all thirteen codes should expect a 99.9% service level under the current inventory policy (see Table 6.1). Expanding this analysis further to the top 45 product codes, 43 of the 45 should expect a service level of 99.9% or better[45].

[45]Once again, the service levels were calculated assuming a batch size of one week's worth of demand. In changing the batch size from one week to a half day, 40 of the 45 product codes have a service of 99.9% or greater.

Converting the Corporate Service Level Objective into an Inventory Policy:
For the second calculation, determining the expected inventory level, the process just described will be reversed. In this case, the service level is already known, so we work backward to determine the corresponding reorder point. The calculated reorder point will be compared to the current inventory policy. Once again, the corporate service level objective will be kept proprietary.

Results: Considering the first code examined (average demand and standard deviation are 1450 and 346 sales units respectively and the batch size is one week's worth of demand, or1450 sales units) and reversing the calculations, the corporate service level results in a reorder point of 1790 sales units or 1.2 weeks. This is less than half the current policy of 4350 sales units and 3 weeks[46].

Problems With the Inventory Analysis:
Two major issues may be brought up in examining the presented analysis. First of all, the calculations did not take into account variability in supply. Having an unsteady supply of assembled components into the packaging / sterilization process would necessitate additional inventory. Several times in the past, supplier disruptions have resulted in extended periods of back order. When a supply disruption occurs at a stage upstream from packaging / sterilization, the additional inventory allows a certain amount of time to pass before the finished goods inventory drops to dangerously low levels. The supply disruption, it would be hoped, could be resolved within the given time. However, in defense of the analysis, supply disruptions are certainly not a consistent occurance across any particular product line. So the question is, why should high levels of inventory be maintained with all products when a problem is not likely to occur with any one product in particular?

The other major issue involves variation in lead times. In this case, the assumed lead time was one week. Due to competitive reasons, the accuracy of this lead time cannot be divulged. But this number errs on the conservative side (i.e., less than the lead time used by the calculations); and the lead time used by the calculations accounts for a significant portion of the actual lead time range. Variability in lead time, therefore, should not change the results of the analysis significantly.

[46]Once again, the batch sizes were varied to determine the influence on the calculated reorder point. Reducing the batch size to 1/2 day's worth of demand, the reorder point only increases from 1.2 weeks to 1.4 weeks. Therefore, the conclusions presented concerning the reorder point are nearly independent of the batch size.

6.3 Inventory Valuation

Now that we have determined a significant difference exists between current inventory policy and the corporate service level objective, we can determine the value of the excess inventory. After calculating that value, we can determine the additional annual costs incurred based on Ethicon Endo-Surgery's carrying cost of inventory. The calculated dollar value will represent the annual additional costs incurred for maintaining excess FG inventory.

As a word of caution before proceeding forward, the previous section mentioned that there may be many reasons for the organization to hold onto the excess inventory. Problems such as uncertain supply or uncertain production processes may necessitate holding the excess inventory. With this view, however, the annual costs that will be calculated no longer simply represent the cost associated with holding excess inventory. Instead, they represent the cost associated with having uncertain supply and uncertain production processes. After all, without the problems that necessitate the excess inventory, the excess inventory is no longer needed. The costs associated with holding that excess inventory are no longer incurred.

Carrying Cost of Inventory

Carrying inventory incurs certain costs to the organization. Inventory takes up floor space for storage, requires labor and equipment for handling, and ties up working capital. The cost of holding inventory can be broken down into three major categories: carrying cost, cost of capital, and efficiency costs. Carrying cost refers to the cost of physically storing and moving the inventory. For example, floor space, material handling equipment and labor, and information systems for tracking inventory are all examples of carrying costs. The cost of capital refers to the opportunity cost associated with investing working capital in inventory. In other words, the money that an organization invests in inventory could instead be invested somewhere else, such as in a mutual fund or a bond portfolio, that produces some rate of return on the investment. Finally, the efficiency cost of inventory refers to the often qualitative impact that inventory has on a production process. The common analogy used to express this cost is the proverbial "rocks in the stream[47]."

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[47]The "rocks in the stream" analogy goes something like this: The level of water in the stream represents the level of inventory; rocks represent quality problems, poor process capability, variability in lead times, or anything else that can negatively impact a production process. When the water level is high, the rocks are unexposed. Any floating object can move with the current uninhibited by the obstructions below the

Quantifying these costs can become difficult and cumbersome, particularly when accounting for all of the carrying costs and quantifying some of the efficiency costs. To compensate, Ethicon Endo-Surgery and many other organizations approximate all of the costs into one straight percentage of the inventory's value. Knowing this percentage and the value of the inventory leads to a close approximation of the cost of holding the inventory. Both of these numbers are readily available within EES.

Rough Cut Calculations for Inventory Savings:

In this section, I provide a rough-cut method for calculating the inventory savings. To perform this rough-cut calculation, we return to the product used in the previous section. In that section we specified and/or determined the following information:

- the average weekly demand for the product is 1450 sales units;
- the current inventory policy (reorder point) is 4350 sales units (3 demand-weeks);
- the inventory policy (reorder point) using the objective service level is 1790 sales units.

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water's surface. But as the water level begins to drop, rocks become exposed and must be removed. If the water level in the stream is kept at a high level, the rocks are never exposed and removed. If on the other hand the water level is low, the rocks are not only visible but must be remove to avoid obstructing flow. To complete the analog, production processes that maintain high levels of inventory are uninhibited by the underlying production problems. Since the problems do not inhibit the process, they are allowed to persist unresolved and often undetected.

Each sales unit of inventory for this product is valued at, say for example, \$150. The total value of the reorder point inventory under the current policy is \$652,500 (4350 × \$150); the total value under the corporate service level policy is \$268,500 (1790 × \$150)[48]. The difference between the two is \$384,000. We can now get a very rough estimate of the total potential inventory difference. By using the following equation, we can linearly extrapolate the savings of \$384,000, representing 5% of the sales volume, to the total savings across all products.

$$x/_{100\%} = \$384,000/_{5\%}$$

The total value of the inventory difference comes out to \$7.68 million:

$$\Rightarrow \quad x = \$7.68 million$$

With a cost of carrying inventory at 15%, the annual cost of the inventory is:

$$\Rightarrow \quad \$7.68 million \times 15\% = \$1.15 million$$

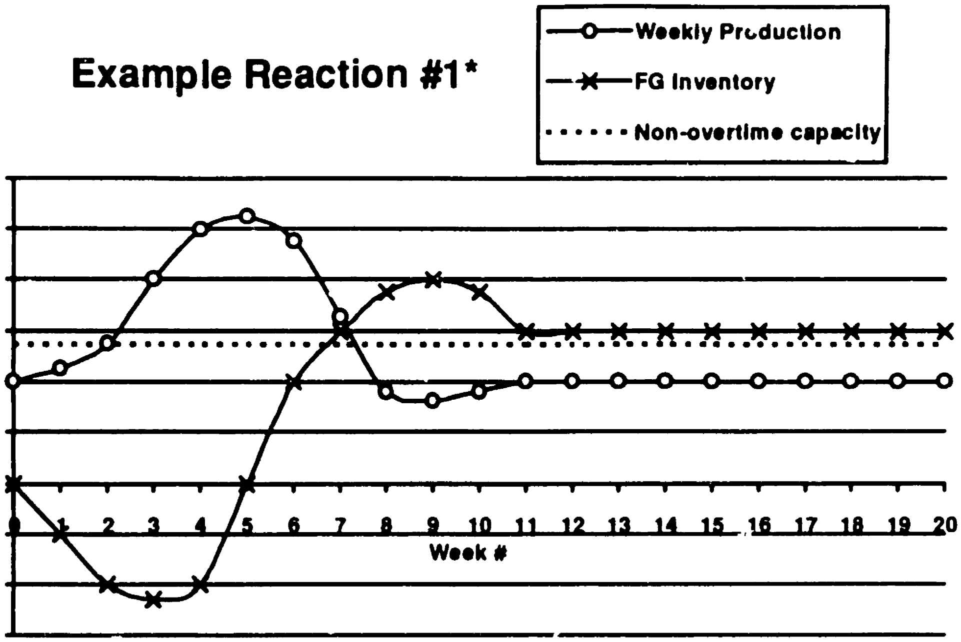
How accurate is this rough-cut approach? As part of the research, total potential inventory savings were calculated using a more exhaustive approach. The exhaustive approach considered current inventory levels for <u>all</u> products (some products had higher inventory policies than others). It additionally used a new policy for all products that could still be considered as conservative. The calculated savings in FG inventory value was on the same order of magnitude of the above calculations.

6.4 Cost of Reactions

Continuing along the lines of determining costs in the internal supply chain, I now present the costs associated with reactions to back order. The reactions presented in Chapter 4 demonstrate that, in response to back order, the organization rapidly ramps up

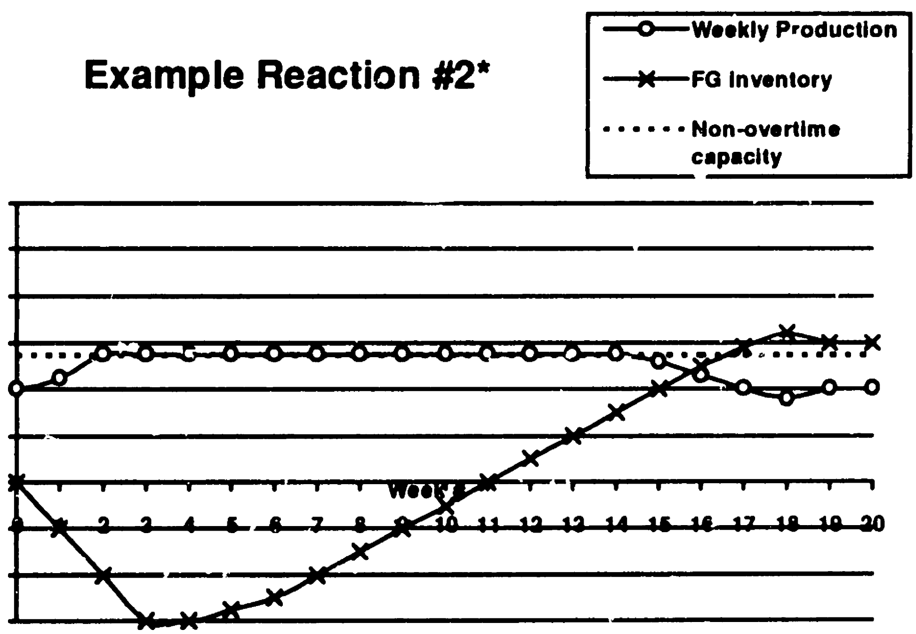
[48]The reader may question determining the difference in inventory value by taking the difference in the reorder points. The (approximate) average inventory in either case is $Q/2 + R - \mu$, where Q is the batch size, R is the reorder point and μ is the average demand over the lead-time. The two policies have the same values for Q and for μ. Therefore, taking the difference between the two policies results in an inventory level of $(Q/2 + R_1 - \mu) - (Q/2 + R_2 - \mu) = R_1 - R_2$.

production to quickly restore finished goods inventory levels. Alternatively, the organization could choose to react in a different way -- it could raise its production level slightly and restore finished goods inventory gradually over time. By restoring inventory gradually over time, the manufacturing organization may take advantage of any existing excess capacity. This latter approach represents the lowest-cost alternative. Using already available excess capacity incurs no additional labor overtime. There is also no need to incur the cost of expediting orders from suppliers to hasten the delivery of incoming components. Using overnight and two-day delivery to customers would not be necessary. On the other hand, the current demonstrated approach, reacting quickly to restore finished goods inventory levels, may incur significant costs. These costs are in the form of labor overtime, expediting supplier orders, and using expensive overnight and two-day delivery.



***Not based on actual data.**

Figure 6.1(a). Rapid ramp-up of production in response to back order, restoring finished goods inventory levels as quickly as possible.



***Not based on actual data.**

Figure 6.1(b). Gradual reaction to back order that uses readily available excess capacity to restore finished goods inventory.

The purpose of the model is not to specifically determine the optimal way for the organization to react to back order. Instead, the model should provide a framework for examining the cost/benefit tradeoffs as demanded by each specific case. For products that have fallen deeply into back order to the point where surgeons may not be receiving needed product, the decision is most likely clear without the aid of the model. The organization will need to ramp up production as quickly as possible regardless of expediting and shipping costs. For products that have only slightly fallen behind the market demand, the slow approach might be best. Again, this decision may not require use of the model. Use of the model is most appropriate with inbetween cases where the decision is not clear-cut.

As a final note before continuing, the costs specified by the model have not actually been evaluated for any sample products. The numbers were difficult to obtain *post facto* and were therefore not pursued. I present this model as a piece of the research that is complete enough to offer insight. It is open for future refinement, particularly by those who might need to understand the reaction decision further.

Quick versus Slow Ramp-Up -- Cost Model

Table 6.1(a). presents the costs associated with a fast reaction that are not incurred with a slow, steady reaction. Table 6.1(b). presents the benefits versus the drawbacks of each approach. Note that the biggest drawback of the fast approach is cost while the primary benefit is a better service level (restoring finished goods inventory as quickly as possible minimizes impact on service level). Another important consideration is the strain on suppliers versus the strain on dealers and affiliates. Restoring finished goods inventory as quickly as possible will minimize impact on dealers and affiliates but strain suppliers. After all, the suppliers will have to produce the components to correspond with the increase in production. With a gradual response, the reverse is true -- dealers and affiliates will be strained while impact on suppliers will be minimized. The delivery delays resulting from back order potentially result in ill will on the part of dealers and affiliates. Additionally, the increases in lead times force dealers and affiliates to carry higher levels of safety stock. (Safety stock is function of demand variation over lead time. An increase in delivery lead times requires a corresponding increase in dealer safety stock.)

Major Costs Incurred with a Quick Reaction
• Labor Overtime • Expediting Components from Suppliers • Overnight and Two-Day Shipments to Customers • Excess Inventory

Table 6.1(a). The major cost drivers associated with rapidly increasing production output in response to a product going into back order.

	Increase Production Rapidly via Overtime and Expediting Supplier Orders	*Increase Production via Slowly Ramping Up Capacity*
Benefits	• Maximize service level • 100% product supply restored as quickly as possible • Minimize strain on dealers and affiliates	• Low cost • Minimize strain on suppliers
Drawbacks	• High cost • Strained relationships with suppliers	• Poor service level • 100% product supply may not be restored for several months • Potentially strained relationships with dealers and affiliates
Unknown	• Number and percentage of orders that are delivered after expected delivery dates • Dealers' and affiliates' inventory	

Table 6.1(b). Tradeoffs of increasing production quickly through overtime and expediting supplier orders versus increasing production only through excess capacity.

Also, note that the impact on other customer-driven measures of delivery service can not adequately be determined -- for example, delivery within an expected delivery time. Even though a particular product is in back order, delivery of product to customers may still occur within the desired timeframe. To see this, consider twenty customers who order product on Day One and expect that their orders be delivered within seven days. Also assume that the manufacturer does not have the product in stock on warehouse shelves. When the orders arrive at the manufacturer's warehouse, they cannot be immediately filled; the manufacturer falls into back order. If on the following day, Day Two, twenty units of the product arrive at the warehouse, the orders from Day One are immediately filled and delivered within the desired timeframe. Assuming that twenty new customers order on Day Two, the manufacturer is still in back order. But these new orders may be met with product arriving at the warehouse on Day Three. Customer expectations of delivery in seven days are still met, and may continue to be met, even though the manufacturer remains in back order and the service level is a lousy 0%. Additionally, no measures are provided of dealer and affiliate inventories. When Ethicon Endo-Surgery does not have product immediately available for dealers and affiliates, this does not indicate that dealers and affiliates have no product available for hospitals. After all, dealers and affiliates also maintain safety stock to avoid going into back order. Only when their safety stocks are depleted is there a danger that hospitals don't get the product they need right away. Needless to say, hospitals also carry safety stocks that must be depleted before the surgeon is actually impacted[49].

One particular case examined during the internship demonstrated this effect. The particular product had been in back order for several weeks, accumulating a total outstanding demand of over $250,000. Domestic dealers and major international affiliates were surveyed to determine their inventory positions. The survey revealed that dealers had, on average, 30 days worth of inventory. International affiliates were even better off, maintaining between 4-16 weeks of inventory. The resulting conclusion was that the back order posed little threat to hospitals' orders.

6.5 Conclusion

In this chapter, I showed that the finished goods inventory levels were significantly higher than the intended level as determined by the corporate service level objective. Proof was provided in three ways. First, I demonstrated the level of inventory graphically

[49]This discussion in no way advocates getting rid of service level as a measure of performance to customer needs. Nor does it advocate only being concerned about supply of product when dealers and affiliates are in danger of falling into back order. If it is falsely assumed that dealer inventories will always cover shortages at the manufacturer and the manufacturer chooses not to be concerned about back order, the dealer will run out of inventory at some point and service to hospitals will be impacted. The important point is that several factors should be considered before incurring the costs of rapidly ramping up production.

with respect to weekly demand. Assuming weekly replenishment, an appropriate level of inventory could be determined by constructing a line the peak demand. As long as finished goods inventory could be replenished each week up to the level of the line, the product would remain out of back order. This line was found to be substantially lower than the existing inventory policy. Another of the methods took current information and converted it into comparable values. The existing inventory policy of three weeks was converted into a service level number. For most of the products examined, this service level turned out to be greater than 99.9%.

In the last part of the chapter, the costs associated with a quick reaction to back order were examined. This discussion established that reacting as quickly as possible to a back order situation does indeed incur costs and that an alternative, slower reaction may be considered.

The next chapter will discuss why the organization has implicitly chosen to react quickly and to maintain high levels of inventory.

Chapter 7 The Emphasis on Back Order Reaction and Protection

7.1 Introduction

Previous chapters have demonstrated both the organization's reactions when a product goes into back order and the organization's high levels of inventory. The reaction consists of production quickly ramping up its output and producing at an increased rate for a period of several weeks. Once finished goods inventory has been restored, production slows down to steady levels and resumes normal operations. With each back order reaction, the organization makes an implicit decision to ramp production up quickly. A quick response in production incurs additional costs not found with a gradual response. Due to dealer and affiliate stocking, a gradual response does not necessarily impact delivery to end-customers. In such an instance, there would be no need to ramp production up quickly to alleviate the back order.

As opposed to the reaction to back order, the high levels of inventory can be considered as protection from going into back order in the first place. As inventory levels increase, the likelihood of depleting the inventory and going into back order diminishes. It was shown in the preceding chapter that FG inventory levels exceed the corporate inventory objectives. In other words, the organization has made an implicit decision to incur the costs of additional protection from back order.

This chapter presents some rationale behind these implicit decisions. Given the original emphasis on market growth, an emphasis that contributed greatly to the company's overwhelming success, I will argue that the resulting incentives naturally support the decisions.

7.2 Marketing Focus and Delivery Reliability

Ethicon Endo-Surgery was spun off from its parent company in the suture business, Ethicon, Inc., to address the specific needs of its own young markets. At the time, few competitors existed in the market, and one company, U.S. Surgical Corporation, owned the majority of market share. Ethicon Endo-Surgery surpassed its chief competitor in 1994 to capture a greater portion of the U.S. market[50]. But this rapid growth did not

[50]Johnson & Johnson 1994 annual report.

come without a carefully orchestrated strategy. The successful strategy involved emphasis on market growth and product development and required that a consistent supply of product be available to the sales force. The three key components, market growth, product development, and consistent supply, are discussed further below. Of the three, product development seemed to have only minor impact on the researched portion of the manufacturing organization (i.e., organizational structure, incentives, and information systems); therefore product development is not considered beyond this section. Market growth and consistent product supply, on the other hand, were instrumental in establishing the importance of back order.

Market Growth and Product Development Emphasis

To save on costs, hospitals typically purchase through contracts with purchasing organizations. Purchasing organizations typically represent several hospitals in a given area and therefore have greater purchasing power than a single hospital. Greater purchasing power translates into lower prices for products. The purchasing organizations, in turn, develop contracts with dealers to supply the product. Dealers, of course, order and receive product from manufacturers.

This arrangement of contracts and relationships makes life difficult for a new manufacturer trying to enter the market. When a hospital wants to start purchasing products from a new manufacturer, it must first assert that it will purchase enough volume from the manufacturer to warrant supply from the purchasing organization. If the purchasing organization does not supply the manufacturer's product, the volume must be significant enough to pursue updating the contract with the corresponding dealer. If the purchasing organization already supplies the product, the contract with the hospital must be updated.

Although this process may seem complex, the critical point is that a hospital typically cannot look on a dealer's shelves and purchase any product from any manufacturer. Instead, the hospital must determine that it has significant need for a product and then work with the purchasing organization to supply it. Convincing a hospital that it should purchase a new manufacturer's product requires significant sales effort. A salesperson must first convince the surgeons in the hospital that they should start using their company's products; he or she must also convince the hospital materials manager that there is some advantage or need to bring the product in. To EES sales people, this process is referred to as "converting" a hospital. Therefore, to get its instruments into hospitals and accepted by surgeons, Ethicon Endo-Surgery had to concentrate heavily on its sales force. Tremendous marketing effort also was required to direct the sales force and determine the sales strategies.

In order to develop products that surgeons would want to use, Ethicon Endo-Surgery also concentrated heavily on product development. Upon being spun off from Ethicon, Inc. in January, 1992, EES was far behind its chief competitor, U.S. Surgical Corporation, in product offerings. In addition to having great products, having a broad range of products was critical for converting a hospital; therefore EES had to expand its existing surgical instrument line rapidly without compromising quality. The success of this effort can be gauged by the number of new product offerings introduced to the market in each of the following years.

The rapid growth, largely at the expense of the principal competitor, exceeded expectations within the company itself as well as within the parent corporation. By year-end, 1994, Ethicon Endo-Surgery became the dominant player in the U.S. endosurgical instrument market.

Ensuring Consistent Supply

Having product available at all times is critical to growing market share in the surgical instrument business. The reason for this goes beyond simply satisfying customers (hospitals and surgeons) by delivering products when they're expected. Having product ready to deliver at all times to an ongoing account is certainly a selling point; but having product ready to sell immediately to a brand new account is critical. Product must be available, or new potential customers can not even be approached. As one salesperson put it, "we can't even walk in the door unless we have product to sell." Additionally, the process of converting a hospital is a lengthy process, but the conversion is unlikely to take place if no product is available for the new customer. Otherwise, why would they convert?

Having the products available to sell when a new customer wanted to purchase them was critical to winning the customer over. This emphasis further increased the already high costs associated with stocking out of a surgical product. The resulting risk associated with introducing innovations into the production process was weighted toward the high costs associated with failure (not being able to deliver product and convert the hospital) rather than the less significant rewards for success (reductions in variable and fixed costs).

The ability to market and sell products was obviously a tremendous asset in Ethicon Endo-Surgery's drive to grab market share. This effort required rapid expansion of the product line and a consistent supply of product to the sales force. The requirement of having consistent supply emphasized the fact that back order could not be tolerated. Given the already high cost associated with stocking out (i.e., that a surgeon may not get an instrument when needed for surgery), the need for consistent supply further increased the costs.

This emphasis helps explain the quick reactions in response to a product in back order and the willingness to tolerate high inventory levels. The original need -- always have product available -- was translated into a slightly different operational need -- always have product available to fill orders from finished goods inventory. If product is not available in finished goods inventory, the customer and sale are potentially impacted. Under this view, the organization must fill depleted inventories as quickly as possible. The sooner inventory is restored to its desired level, the fewer the number of customers that are potentially impacted. When inventories are not at their desired levels, a danger exists of not filling an order from finished goods, i.e., going into back order.

At present, the initial market share expansion has largely slowed down and the product line is essentially complete; the company can now focus its efforts more on improving operations and reducing costs. Manufacturing process capabilities and customer behavior are now better known, helping to reduce uncertainty and risks associated with production process innovations. As mentioned previously, there's much evidence that the original emphasis on providing product at all times still exists. This is clearly evident in the reactions associated with back order and with the high levels of inventory, particularly finished goods inventory.

Additionally, it is important to consider the impact that the strategic emphasis on market growth and having product available at all times has had on the manufacturing organization, its incentives, the existing information systems, and important business processes. While the influences on the overall organization are difficult to discern, many may be readily implied. Figure 7.1 shows some of the connections that can be implied. The impact of the original strategic emphases will be addressed further in Chapter 8. At that point, an additional influence, parent business (Ethicon, Inc.) processes and structure, will be introduced and explained further.

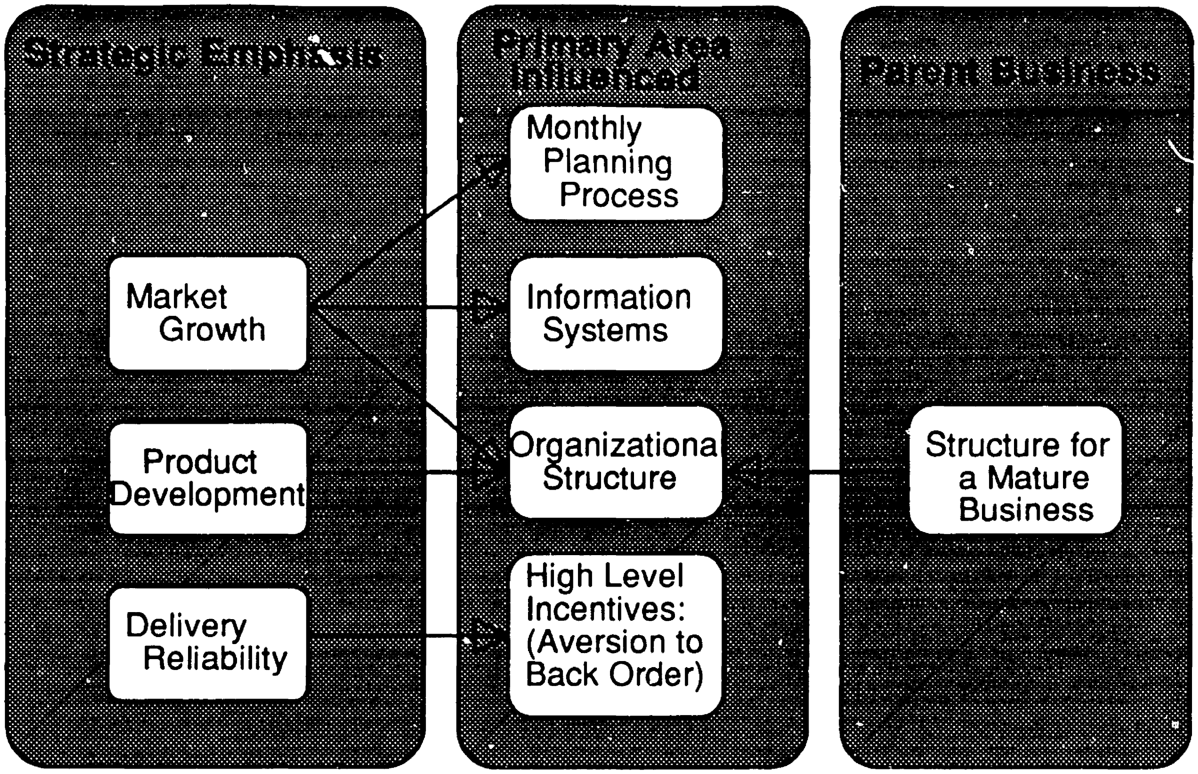


Figure 7.1. The influences exerted on the development of key pieces of the business -- the monthly planning process, organizational structure, formal and informal information systems, and high level incentives (back order / inventory tradeoffs

7.3 Conclusion

Ethicon Endo-Surgery's original successful emphasis on growth has naturally led to two key implicit decisions -- reacting quickly rather than gradually and adding additional back order protection through inventory The sales force had to have a study supply of product in order to "convert" hospitals. This further increased the already high stockout costs associated with surgical instruments in general. The high costs of stockout resulted in an emphasis on back order throughout the organization. The impact that the back order emphasis has had manifests itself in two ways -- through reactions to being in back order and through protection from back order using high levels of inventory. The decision to react quickly to get out of back order does not come without costs, however. Realizing that there are cost/benefit tradeoffs involved identifies that back order reactions as a decision that can and should be analyzed. The decision to hold high levels of inventory incurs reasonably quantifiable costs. The next question, which will be addressed in Chapter 8, is, why has the organization largely failed to identify the reaction tradeoffs and the high levels of inventory?

Chapter 8 Identifying and Addressing Back Order Reactions and Inventory Levels

8.1 Introduction

The previous chapter described how the emphasis on back order developed -- through the high cost associated with stocking out and a need to constantly have product available in order to grow market share. The costs of rapidly increasing production output and maintaining high levels of inventory were implicitly overshadowed by the benefits of restoring product supply as quickly as possible and of emphasizing protection against back order.

Now that the business has reached a maturing stage in its development, pressures to reduce costs have increased. As a result, the cost/benefit tradeoffs of inventory and rapid reactions gain added importance. Given that production can ramp up gradually (rather than rapidly) without impacting end-customer service, and given the magnitude of potential inventory savings, the organization would undoubtedly benefit from examining the tradeoffs. On the contrary, no analysis was ever completed to determine the best approach to recovering from back order. At the time of this writing, a determination had been made of the appropriate inventory levels, but the determination failed to incorporate the cost/benefit tradeoffs of holding inventory. Of more importance, evidence suggests that the organization did not fully recognize the magnitude of the reactions or of the inventory levels. Two considerations arise from this last statement:

1. Conducting a cost/benefit analysis each time a product falls into back order would certainly be unnecessary, but the fact that the extent of the reactions went largely unrecognized is in itself revealing.

2. There seemed to be some internal strife over whether or not the inventory levels were appropriate at their current state. While several individuals recognized that inventory levels were high, the organization as a whole had not come to the same conclusion.

This chapter addresses the issue of why the organization did not fully recognize the extent of the reactions and the potential for inventory reduction. As an outsider looking in, the extent of the back order reactions and the high levels of inventory may seem clear, particularly when presented in the context of this thesis. But an individual working in the company is subject to the existing organizational environment and therefore witnesses the issues in a different light than presented here. Understanding the influence of organizational structure, incentives, information systems, and business processes within the company is necessary for understanding how the organization identifies and defines its problems. A discussion on how these existing influences failed to lead to identification and definition of the problems is presented in this chapter. Also presented are some observations on how the organizational structure, incentives, information systems, and business process might have developed.

8.2 Recognizing the Back Order Reactions and Inventory

Understanding why the organization did not recognize the magnitude of the back order reactions and the high levels of inventory requires a look inside the organization. In this particular case, the organizational structure, the incentives, the monthly planning and forecasting process, and the information systems were found to be predominately responsible for the view of the organization's problems from within.

Recognizing the extent of the reactions requires three key pieces of information to come together -- demand, production, and inventory. The previous chapters demonstrated the reactions clearly by combining all three pieces into one single graph. When the pieces are viewed in isolation, little information is conveyed; but by placing even two of the pieces together, the picture becomes clearer. Production output coupled with demand demonstrates how much the level of production exceeds the level of demand. Place inventory on the same graph, and the timing of the reaction with the back order becomes instantly visible. But this information -- demand, production, and inventory -- resides partially with the master planners and partially with the buyer/planners. Organizational separation, lack of overlapping incentives, and lack of supporting information systems do not allow the critical information to readily come together. A major connection between master planners and buyer/planners does exist in the monthly planning process. But this process, as will be explained shortly, still falls short for putting together the key pieces of the demand-production-inventory puzzle.

The problem of recognizing the high levels of inventory revolves around the same situation. Demand coupled with inventory demonstrates the level of inventory versus the variation in the incoming demand -- a critical connection for determining appropriate inventory levels[51]. But as recently stated, the organizational structure, incentives,

[51] As demonstrated in Chapter 6 and in: Nahmias, S., Production and Operations Analysis, Second Edition, Homewood, IL: Irwin, 1993.

information systems, and monthly planning process do not support the connection well. The problem, therefore, remains relatively unnoticed to the organization as a whole.

More detail on how the organizational structure, incentives, information systems, and business processes hinder identification of the problems is presented below. An additional factor, growing pains, is first considered. This factor validly states that the organization has been concentrating heavily, and appropriately, on growth. The organization consequently has not had the opportunity or the resources to address some important issues that might otherwise have been addressed.

Growing Pains

A valid argument to why the organization has not fully addressed the problems is that it has only been in existence for a few years, concentrating almost exclusively on growth during that time. Therefore, it has not yet had the opportunity to identify and resolve many problems; reactions to back order and high levels of inventory may arguably be such problems. Under this perception, given enough time and resources, the organization would have put someone in charge of investigating and resolving the problems; but since everyone already has their hands full, this has not been practical.

While this view has much validity, it misses the fact that the organization in general had not clearly understood the reaction problems. It must be said that a group did exist in part to address the problems -- a group was charged with redeveloping the monthly planning process and incentives to improve operating efficiency[52]. Clearly one of the problems this group has had has been getting the rest of the organization to understand clearly why a redevelopment need even occur. Much of the research presented here was utilized by the group in their efforts. Interestingly, the charts presented in Chapter 4 -- demonstrating overreactions to back order and tying together demand, production, and inventory data -- represented, to the best of anyone's knowledge in the group, the first analysis clearly tying together all three variables.

In the case of inventory, demands to reduce inventory were clearly mandated. Approximately one year prior to the time of this writing, two people were positioned within the central planning group to address inventory reduction full time. Considerable progress had been made, particularly with the process of getting rid of obsolete inventory. The general sense of the organization, however, was mixed. Some groups did not recognize the need to reduce inventory at all. Others felt that inventory was too high, but

[52]The work of this group coincided closely with my research and was ongoing at the time of this writing. Much of their effort contributed to the development of the thoughts presented throughout the thesis; and my research often provided the hard data required for their analysis.

had no feel for how high. This uncertainty is surprising considering the data presented in Chapter 6. For the particular product investigated, finished goods inventory could be cut in half and still support the objective corporate service level. Additionally, the high levels of inventory are consistent with the current inventory *policy*. The problem therefore is not in bringing inventory levels down to their intended level but in recognizing that the intended level itself is high. With the magnitude of reductions possible, it seems unlikely that the youth of the company alone would drive the confusion. It is equally unlikely that maturity alone would lead to the potential inventory reductions.

Organizational Structure

It was explained earlier that the master planners and the buyer/planners have visibility into separate pieces of the demand-production-inventory puzzle. The particular viewpoints of each function can be largely attributed to the location of the function within the organizational structure. Their actions are then directed by formal and informal incentive structures. Figure 8.1 shows the organization chart of the operations organization. This particular discussion will focus on the master planning group and the buyers/planners since their responsibilities have the greatest overlap between market demand, production, and inventory.

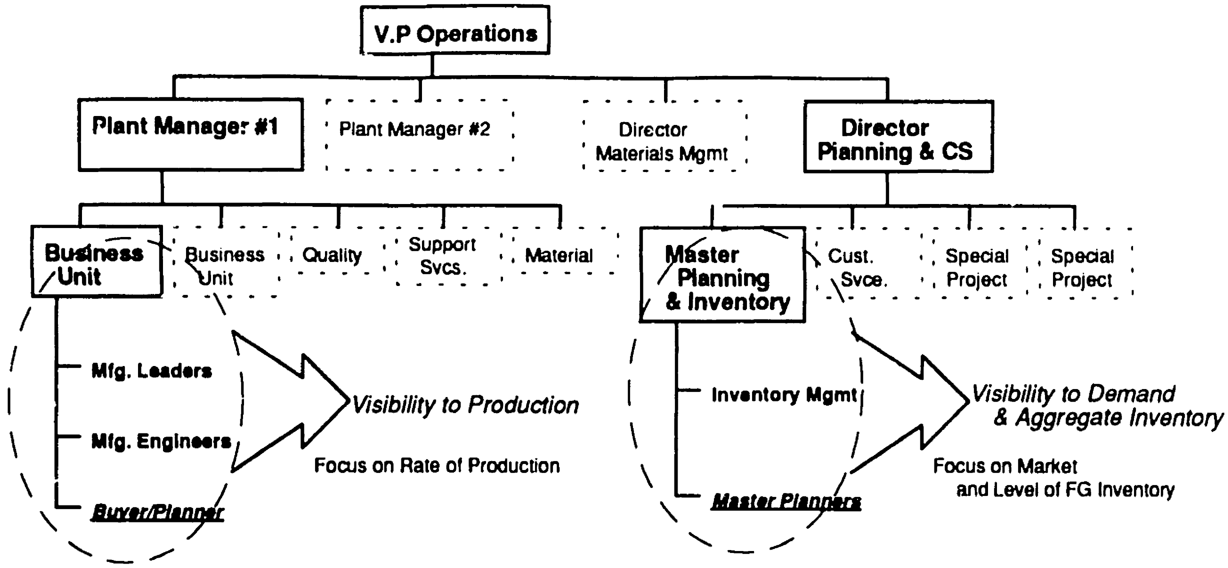


Figure 8.1. Operations organization chart showing orientation of buyer/planners versus master planners.

The master planners reside in the central operations group and are chiefly responsible for interpreting the market demands into monthly production plans. They must work closely with marketing to produce monthly demand forecasts and translate the forecasts into finished goods requirements. (A finished goods requirement refers to the volume of finished goods that must be transferred into finished goods inventory each month. The volume must meet the forecast demand *and* maintain a set level of safety stock. For more detail on this process, refer to the descriptions provided in Chapter 2.) Once the forecasts have been determined, the finished goods requirements are essentially locked in as a function of the following equation:

$$\text{Finished Goods Requirement}_t = \text{Forecast}_t + \text{Target Safety Stock}_t - \text{FG Inventory}_{t-1} \qquad \text{(Eqn. 8.1)}$$

In other words, since Target Safety Stock and FG Inventory are already determined, the month's finished goods requirement depends only on the month's forecast. Producing the monthly forecasts and the plan, therefore, requires a strong understanding of the market. The finished goods requirement is only changed if review by the plant manager determines that the plan cannot be met, a fairly rare occurrence.

It should also be noted that the master planners do not deal with the actual production requirements for the month. The finished goods requirement only loosely translates into the month's production level. Since the overall production process consists of two main steps, assembly and packaging/sterilization, substantial inventory may reside between the two steps. If enough inventory exists in-between, for example, no assembly may be necessary. Packaging/sterilization will simply utilize the in-between inventory to meet the finished goods requirement. If no inventory exists in-between assembly and packaging/sterilization, assembly needs to build inventory between the two steps *and* supply enough product to meet the finished goods requirement. The assembly output would therefore be greater than the finished goods requirement.

The use of a finished goods requirement therefore clouds the picture even further for the master planners. It's possible that the master planners provide a steady finished goods requirement each month, but assembly rates vary substantially. Alternatively, the master planners may provide highly variable finished goods requirements each month, but assembly rates remain steady.

On the opposite side of the organization chart, the buyers/planners must concentrate on the production process. Their principal responsibilities are to take the monthly production plans, produce weekly and daily production plans, and schedule component orders for suppliers. When breaking down the monthly plan, an attempt is made to smooth (maintain a steady level of) production. In contrast to the market and finished goods focus required of the master planners, buyer/planners must understand the production process and the suppliers. *Rate* (of production) becomes more of an issue than *level* (of finished goods inventory). In terms of the reactions to back order, buyers/planners are impacted directly when the production process must schedule overtime and orders to suppliers must be expedited. In terms of finished goods inventory, the level is not of direct concern to the buyer/planner until the product falls into back order. In this event, the production process must step up production to restore product flow.

Incentives

Understanding the incentives of the master planners and the buyer/planners also helps demonstrate why the organization did not identify the tradeoffs. Interestingly, neither group has a direct incentive to reduce inventory. While arguably both have an interest in reducing inventory due to the overall operations objectives, only the inventory management group is directly evaluated on inventory reduction. This will be discussed further below.

The master planners must produce forecasts and determine monthly plans. Their incentives are for generating plans that marketing, customer service, and plant management agree to. As argued in the previous discussion, this activity naturally tends to fall toward understanding the market. It should also be noted that the master planners have incentives to stay out of back order[53], extending from their planning responsibilities and visibility to finished goods inventory.

The buyer/planners have a slightly different focus. They must ensure consistent supply of components to the assembly line and schedule production to avoid back order further downstream in finished goods. The emphasis on their part is heavily weighted toward keeping the line running and staying out of back order downstream.

The incentives for both groups coincide with their positions within the organizational structure. Master planners must understand the market and finished goods inventory levels. Buyer/planners must keep the line going and ensure that production plans are met. Both are responsible for ensuring a continuous flow of product, and both are responsible for back order. Lowering inventory levels, however, decreases any protection from back order. Any reductions in inventory result in an increased probability of going into back order. The master planners and buyer/planners therefore actually have underlying *disincentives* to reduce inventory.

Formal and Informal Information Systems

The information that people use and make decisions with depends on the availability of the information. In this case, the pieces of information were difficult to put together, requiring considerable effort in the forms of data entry, finding the right person to talk to, and translating from one data format to another. The customer demand information required the least effort to obtain. A customer ordering system kept track of all orders on a centralized database over the last several years. Obtaining aggregate weekly order quantities required logging into the mainframe system, running the right database query, and uploading the information from the mainframe to the desktop computer. Since several people throughout the organization frequently requested this information, one person took on the responsibility for running the query and uploading the data each week. Obtaining the information required a phone call to that person. The data could be translated into almost any format -- spreadsheet, local database, etc.

Finished goods inventory proved a particularly difficult task. No finished goods inventory tracking systems were in place. The only method of obtaining the information

[53]Not mentioned previously is the fact that the master planning group was responsible for weekly back order reports. These reports served to inform the entire organization, including senior level management, of the products that were in back order. This tended to put the master planners near the center of back order problems.

was to either pull the data from a Data Analysis (D.A.) sheet (the sheet used for planning each month -- see Chapter 2) or to pull the information from the weekly backup files of the customer order database. The first method required obtaining the appropriate D.A. sheet electronically from the appropriate master planner and reformatting the information as required. The problem with this method was that only the inventory level at the beginning of each month was available. Tracking in time increments of one week or smaller was not possible. The second method, pulling information from backed up database files, required pulling one file for each week needed. For example, to track inventory over the course of the past year, data would have to be manually extracted from fifty-two separate files. Additionally, the database backups were not always completed on the same day of each week. Data points might be five days apart or eight days apart, depending on when the database was backed up. Once again, tracking in small time increments of less than one week was not possible.

As for inventory of components, the difficulty was in separating inventory by final product code. EES maintained supply of hundreds of different components. Some components were unique to a specific final product code and others were used by several different final product codes. The data itself, however, was not available throughout the organization; it resided on an EES local database requiring specific access. More importantly, this database is separate from the customer order database. Manual intervention was required to combine information from the two sources.

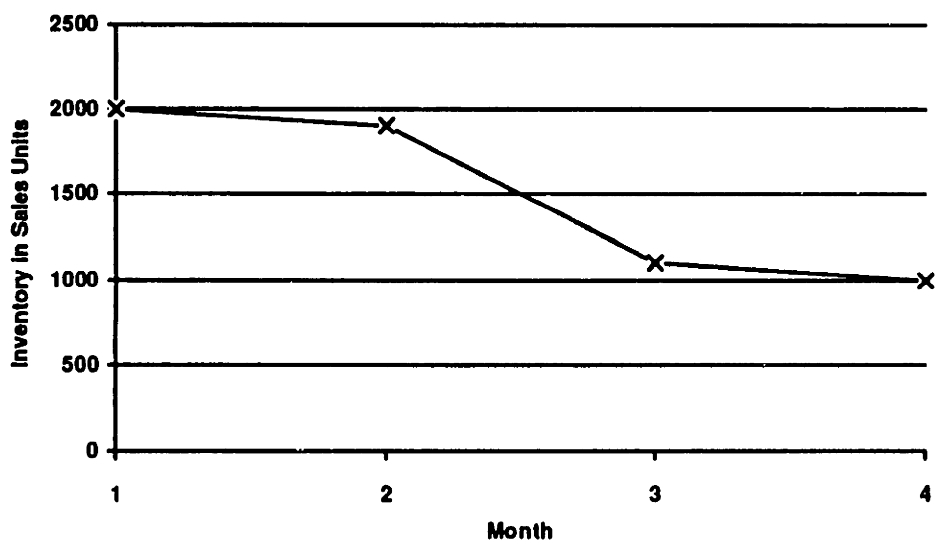
The final piece of the puzzle, production, was also elusive. Actual daily assembly volume was summed by product code on one single spreadsheet. This spreadsheet, generated each new business month, contained information for all product codes produced in a given plant. The daily information was summed into weekly totals, and the weekly totals were summed into monthly. Once again, this information resided in a format that was difficult to manipulate. Getting the data into another spreadsheet or into a database required significant manual intervention.

The Monthly Planning and Forecasting Process

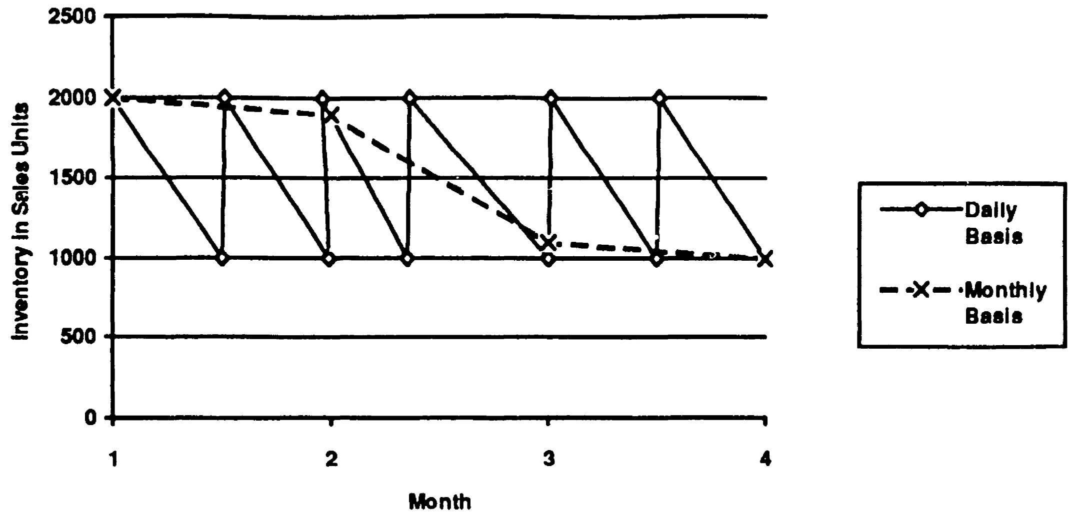
The monthly planning process is the one business process that ties together marketing, production, customer service, and master planning. Through one single planning sheet (Demand Analysis sheet) for each product, demand, finished goods inventory, monthly forecasts, and production (or, at least, transfers to finished goods) are represented and visible to all groups. The question is then, why didn't this allow the reactions and inventory levels to be identified?

The monthly planning process did shed some light on the reactions, but allowed limited visibility to whether or not the inventory levels were appropriate. Through the Demand Analysis (D.A.) sheets and through communication with the buyer/planner, master planners could determine when production levels were high. Additionally, the master planners generally know production capacity limits for their products and therefore know when assembly will be strained. Therefore, the extent of the reactions could be at least partially understood. However, if master planners only base their perceptions from the numbers on the D.A. sheets, the picture is not so clear. The limited connection between Finished Goods Transfers on the D.A. sheets and actual assembly was discussed earlier in this section. It is conceivable that assembly would be strained for capacity without the master planners knowing the extent of the strain.

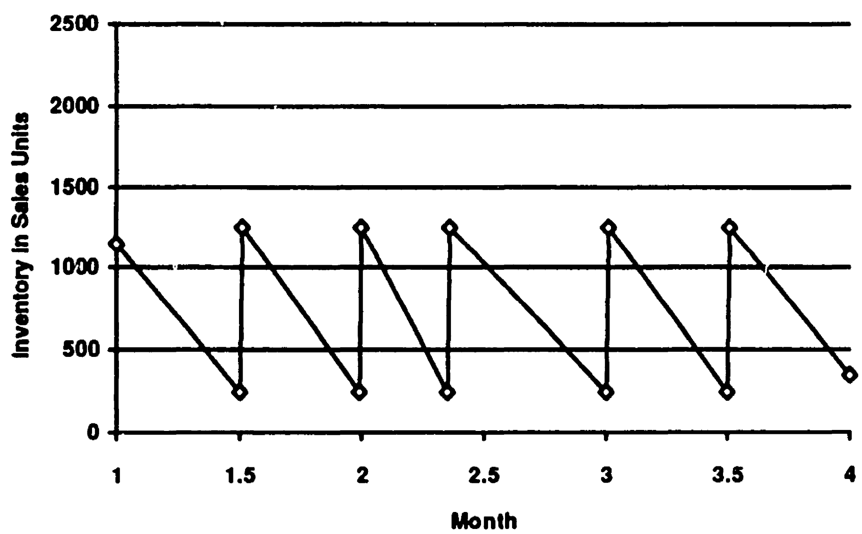
It is also important to remember that the D.A. sheets provide only a monthly snapshot of the production process; but the ordering of parts, assembly of instruments, and packaging/sterilization occur on a daily basis. The monthly snapshot, while sufficient for monthly planning activities, does not provide an accurate view of daily activity. This is particularly relevant regarding inventory. This can be seen through the following example. A monthly view of the inventory level for one product may look like the following:



In this case, it appears that the inventory level has been cut in half in months 3 and 4. Depending on how the situation's viewed, either the operation is nearing danger of going into back order and inventory therefore needs to be raised, or the operation is OK and the inventory can be kept safely at the low level. When the inventory is examined on a daily basis rather than a monthly basis, it might look like the following:



Looking at the daily view would indicate that inventory is not too low at all. As a matter of fact, it may be reduced from its current average of about 1500 units to about 750 units -- a reduction of 50%:



By viewing the inventory on a monthly basis, this reduction in inventory would not have been as easily recognized. Of course, it may also be the case that inventory is in fact too low and needs to be raised. Once again, the monthly picture would not provide enough information to discern this fact.

To understand these effects further, we can examine actual monthly inventory levels taken from the DA Sheets. Figure 8.2(a) shows sample data extracted from a DA Sheet. By only examining the data in the figure, we cannot determine whether the inventory level should be increased or reduced. Even by looking at a plot of the data

(Figure 8.2(b)), the solution is not obvious. Knowing that the replenishment lead time is approximately one week and that the batch size is approximately 200 sales units helps interpret the picture. But once again, a clear determination cannot be made.

	August	September	October	November
Demand	2049	2497	2489	2298
FG Inventory	1569	2081	2409	1792

Figure 8.2(a). Sample information from DA Sheet. The product had just gotten out of back order in June. Judging from the July, August, and September FG inventory results, the appropriate inventory levels are difficult to discern.

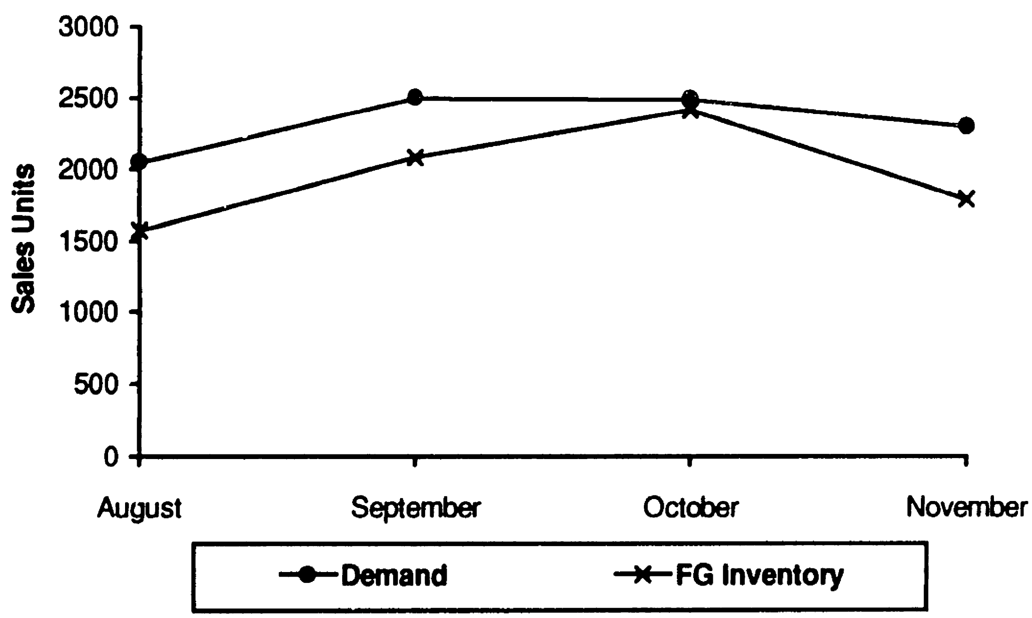


Figure 8.2(b). Monthly Demand and FG Inventory plot from the data presented in Figure 8.2(a).

As far as the reactions to back order go, the monthly snapshots may also obscure weekly production levels. In the one case from Chapter 4, assembly output nearly quadrupled within a five week time frame. The *monthly* information presented in the chapter demonstrated a tripling of output. While the tripling in monthly output is undoubtedly quite dramatic, it does not convey the severity that quadrupling weekly output within a five week time frame conveys.

As a final note, the forecasting process may also contribute to the high levels of inventory. Chapter 9 will demonstrate that the forecasting process currently in place is not as accurate as using a linear regression model based on past data. The inaccuracies of the current process may even make demand seem quite erratic in some cases[54]. In such instances, the greater uncertainty would help justify the higher levels of finished goods inventory (i.e. more uncertainty translates into a need for more inventory). A more accurate forecast could then expose the need for lower inventory levels.

8.3 Development of the Organization

The previous section demonstrated many of the ways that the current organizational structure, incentives, information systems, and key business processes inhibited the identification and resolution of the back order reactions and the high levels of inventory. In particular, the key pieces of information -- demand, production, and inventory -- were not readily available for any single group to tie together, nor were there incentives for any group to seek all of the information. This next section presents some ideas on how the structure, incentives, information systems and business processes themselves developed. While exact origins are difficult to discern, a look at the early business influences (i.e. how the business developed and the key strategic emphases in that development) reveals some insight into the origins (see Figure 8.3).

The dominant early influences -- market growth, product availability, product development, and parent business structures -- manifest themselves in many ways. For example, Ethicon Endo-Surgery's manufacturing organization structure seems to follow closely with what Clark, Hayes, and Wheelwright refer to as a "representative plant organization[55]." This structure, the authors argue, works well with a stable business that follows a path of incremental, as opposed to radical, improvements. This coincides with many aspects of Ethicon Endo-Surgery's parent suture business -- a business that has been in existence for over 100 years[56]. Alternatively, EES's modifications to the Clark, Hayes,

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[54]For one particular product, the average monthly forecast error under the current process was 28%. Using the linear regression, a forecast error of only 7% could be achieved. For a product with average sales of 1000 units per month, this error translates into ±280 sales units for the current process (a range of 720-1280) and ±70 for the linear regression (a range of 930-1070). This example product represents an extreme in the data studied. In most cases, the differences between the two forecasting procedures was much less.

[55]Hayes, R. H., S. C. Wheelwright, K. B. Clark, Dynamic Manufacturing: Creating the Learning Organization, New York: Free Press, 1988, chapter 4.

[56]Source: Johnson & Johnson 1994 Annual Report

and Wheelwright structure appear to support product-focused manufacturing, following EES's strategic emphasis on product development.

The remainder of this chapter takes a look at each business area -- organizational structure and incentives, information systems, and monthly planning process -- and describes how they support the original influences from the parent business, the emphasis on market growth, the need to have consistent product supply, and rapid product development.

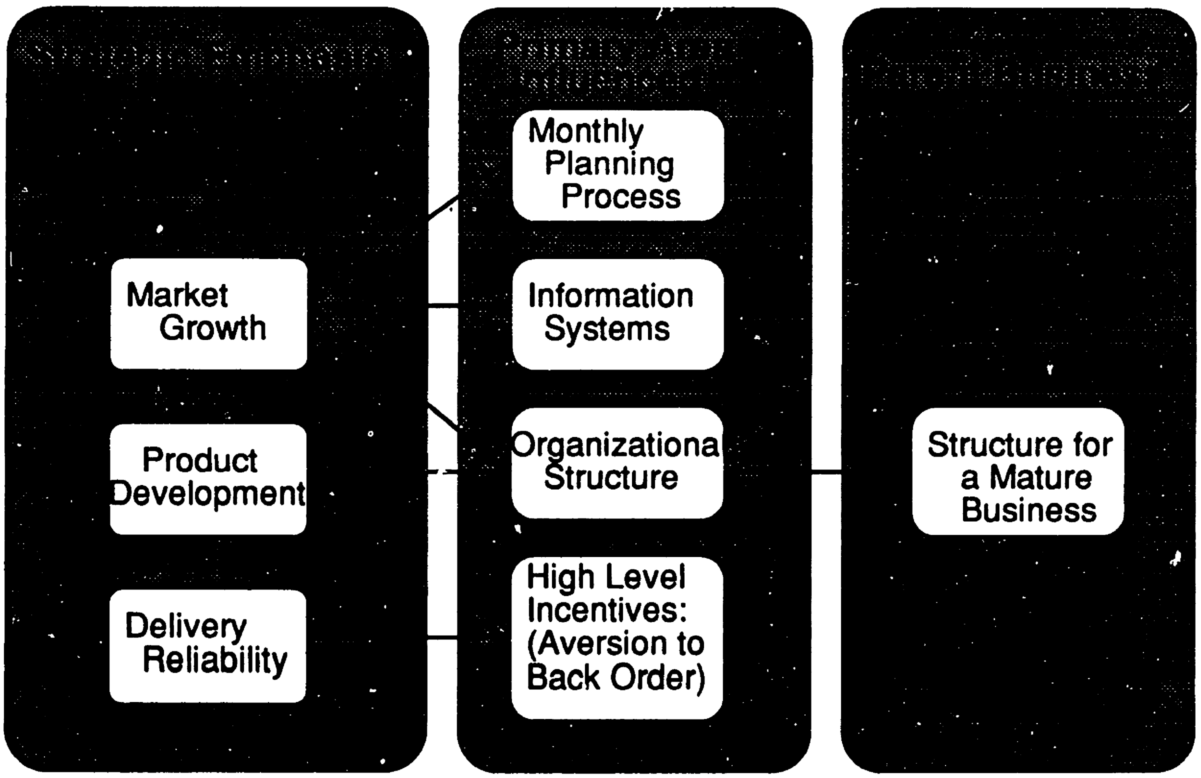


Figure 8.3. The observed influences exerted on the development of key pieces of the business -- the monthly planning process, organizational structure, formal and informal information systems, and high level incentives (back order / inventory tradeoffs).

Organizational Structure and Incentives

As already mentioned, Ethicon Endo-Surgery's organizational structure and incentives closely match what Clark, Hayes, and Wheelwright refer to as a "representative plant organization." A diagram of their sample organization is presented in Figure 8.4. The authors argue that this structure works well as long as the organization does not need to undergo significant change or improvement. When major improvements must take place, incentives within the structure start to conflict. For example, the materials management group may have a requirement to reduce inventory by 50%. The group may find this goal obtainable only by reducing inventories of parts and partially completed units (i.e., WIP). The production group, however, might be using those inventories to ensure that production schedules are met. Without the inventories of parts and partially completed units, production schedules may not meet the schedule consistently. The objectives of the two groups, therefore, are in direct conflict.

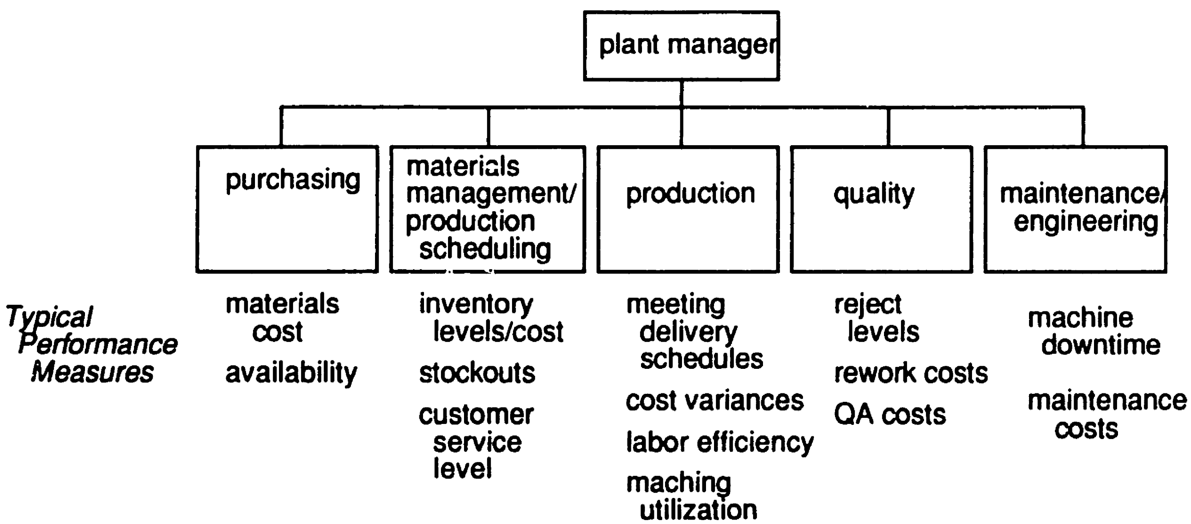


Figure 8.4. A representative plant organization as presented in Chapter 4 of <u>Dynamic Manufacturing</u> by Hayes, Wheelwright, and Clark.

The parent business of Ethicon Endo-Surgery, sutures (produced by Ethicon, Inc.), is a relatively stable business, particularly when compared to the young, expanding markets of endoscopic surgery. Sutures have been a staple product in the medical industry for the past 100 years. Ethicon Inc. has also held a dominant market share for many years and consequently has reached a mature state in its business lifetime. This helps explain how the Clark, Hayes, and Wheelwright structure fits in with the past business, Ethicon, Inc., suggesting that much of EES's structure has potentially been adopted from Ethicon, Inc.

Some important distinctions exist between the organizational structure presented in Figure 8.4 and EES's structure (see Figure 8.5). The product development emphasis is particularly prevalent. EES's structure, for example, breaks production down by product line, or business unit. In looking at EES's structure when compared to Clark, Hayes, and

Wheelwright's "representative plant organization." the product orientation becomes immediately evident. The business unit structures undoubtedly help to bring products from development into manufacturing. In addition, the planning and customer service department reporting directly to the vice president of operations acts as a connection to customers and to marketing -- areas critical to EES's rapid growth.

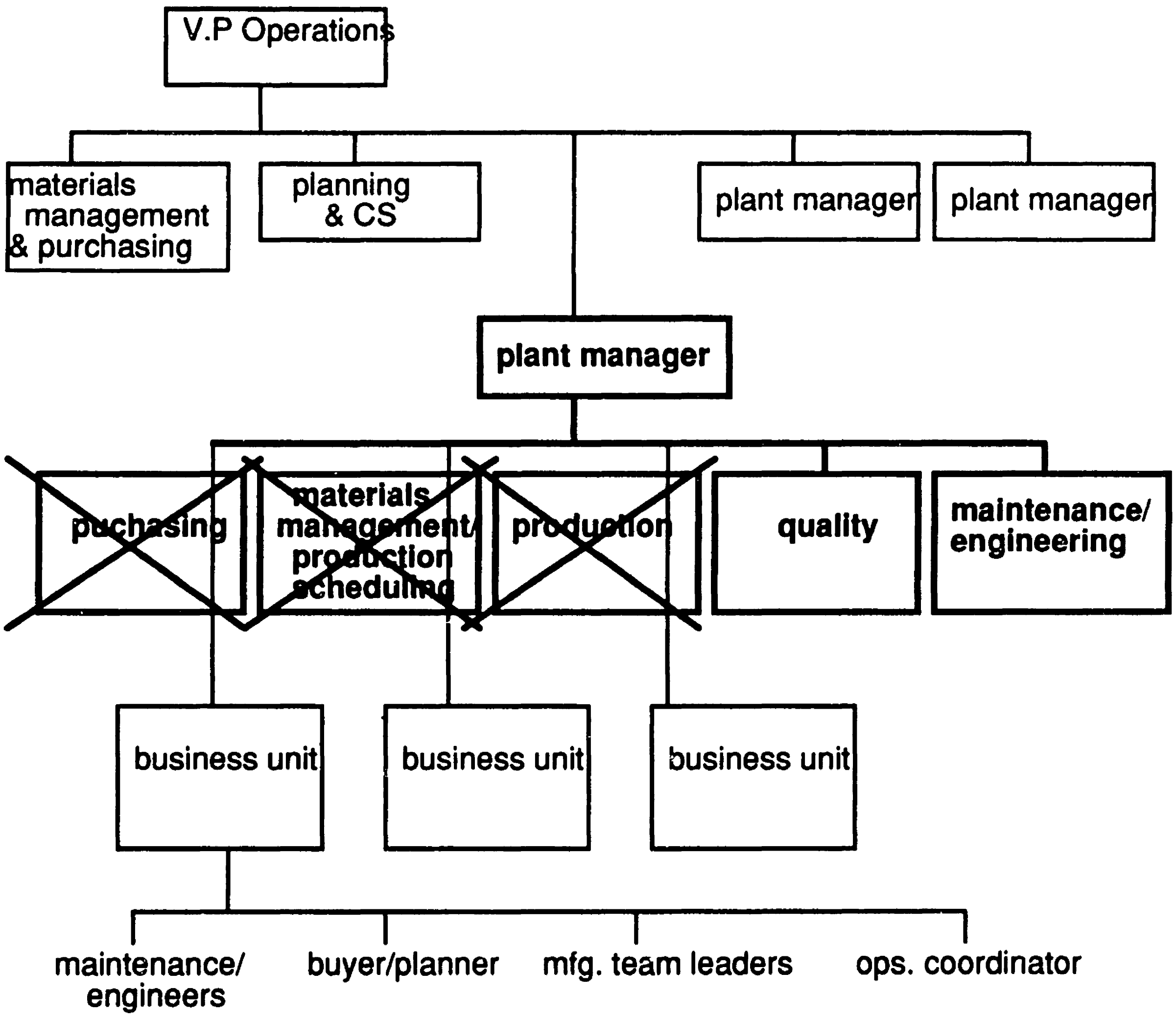


Figure 8.5. Ethicon Endo-Surgery operations organization showing alterations from Figure 8.4 that support product development focus.

Information Systems

The D.A. sheets played the major communications role in connecting market demands and production. As discussed earlier, no other information systems readily tied together demand, production, and inventory. The formation of the D.A. sheets as a major communications device can be seen by examining the development of the monthly planning process. When the company was attacking unfamiliar markets with its strong sales force, forecasting was understandably difficult. The sales force was spending considerable time converting hospitals, and new products were constantly being introduced. Variability in demand was tremendous. Marketing was closest to the sales force and to understanding the volume of product that would be required each month. Marketing therefore had to determine the monthly market needs and relay them to production. Production would then have to verify whether or not it could "meet the plan."

This monthly process of determining market needs and turning them into production plans evolved into the current monthly planning process. A communications channel developed from the monthly planning process in the form of the current D.A. sheet. The D.A. sheet allowed all groups to communicate what needed to be communicated each month. Marketing could relay market needs to production, and production could verify its ability to meet the market needs.

In general, the other dominant information systems grew out of three key areas: customer order fulfillment, finance, and operations. Hardware and software platforms separated the three areas, giving an indication that development had occurred in each area independently. This again seemingly reflects the lack of organizational overlap in terms of structure and incentives.

Monthly Planning Process

The previous discussion on information systems also outlined the development of the monthly planning process. The same factors that led to the D.A. sheets playing an important communications role were driven by the development of the monthly planning process. Early market demands were highly variable and required marketing to dictate what each month's needs would be. The monthly planning process evolved to allow marketing to communicate those needs and for production to verify that the needs could be met.

8.4 Conclusion

In this chapter, the question of why the organization had not fully recognized and addressed the issues with back order reactions and inventory policy. The analysis of cost/benefit tradeoffs thus far has hinged on the combination of three critical pieces of information -- demand, production and inventory. Without this information, the fact that a tradeoff even exists may not be evident, let alone having enough information to evaluate, explicitly or implicitly, appropriate costs and benefits. The information was not readily available, nor was it sought after. The reason for this lies with the organizational structure, incentives, information systems, and one key business process. Organizational structure and incentives separated the critical parts of the organization that would have been able to combine the data. Information systems inhibited any one group from having ready access to the information. Finally, while the monthly planning process did actually combine all necessary information, it did so in a context that was not useful for recognizing the problems.

Interestingly, many of the business structures that inhibited recognition of the problems apparently were put in place to support rapid market growth and product development. Other of these structures seemed to develop from Ethicon Endo-Surgery's parent suture business -- a business that is well established and relatively stable compared to endoscopic surgical instruments. In close of this chapter, these observations cannot pass without emphasizing EES's tremendous success in both market growth and product development.

Chapter 9 Improving Monthly Forecasting

9.1 Introduction

In this chapter, I will demonstrate that Ethicon Endo-Surgery's monthly forecast accuracy can be improved using a statistical method. Specifically, the improved method is a linear regression made through past data using time as the only dependent variable. In contrast to the current forecasting method which predominantly relies on market intelligence, the linear regressions depend only on historical information. As a result, forecasts may be calculated automatically using a computer spreadsheet. More importantly, however, the calculations can be performed as soon as the new demand information becomes available each month. This automation can significantly reduce the time required to complete the planning process each month.

In this chapter, I detail the forecasting process used by Ethicon Endo-Surgery to predict monthly demand. I will then describe how a linear regression can be used to replace the current methodology. Using historical information, I demonstrate the improved accuracy attainable with the statistical technique. The chapter closes with a brief discussion on the implications of automating the monthly forecasting process.

9.2 The Current Forecasting Method

In a general sense, the monthly forecasts on the DA sheet are derived from annual forecasts, as determined by the marketing and finance organizations. As the year progresses, the annual forecasts are then adjusted month-by-month as necessary (see Figure 9.1). The marketing and finance forecasts originate as a forecast for each product family. Product family forecasts are then broken down into forecasts for each end-product code. These forecasts, both by product family and by end-product units, are determined in the fourth quarter of each year for the following year. They are immediately entered into the DA Sheets. The DA Sheets automatically break the annual figure down into forecasts for each month throughout the entire year based on the number of weeks in the month (either four or five) and taking into account any predetermined quarterly seasonality. As the year progresses and each month's DA Sheet is determined, the forecasts may be either increased or decreased as predicated by the Marketing organization and from judgment on the part of the responsible Master Planner. Any changes to a forecast on one month's DA Sheet often result in a corresponding change to the product's overall annual forecast.

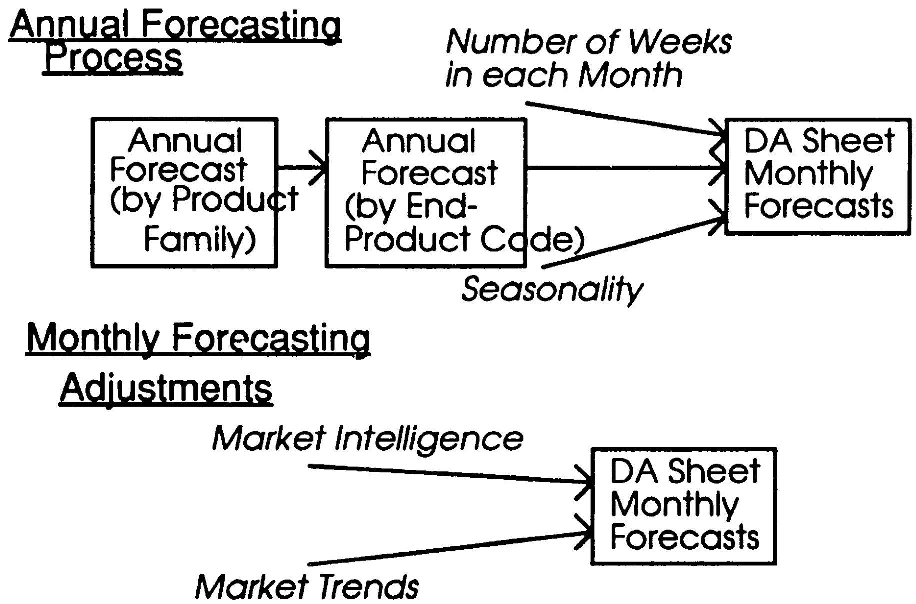


Figure 9.1. Annual forecasting process and monthly adjustments.

As an example of determining monthly forecasts from the annual forecast, suppose that the annual forecast for a particular product is 100,000 units and that the June forecast is needed. Assume that the product typically sells 30% of its annual volume in the first quarter, 25% in the second, 25% in the third, and 20% in the fourth. The DA Sheet will then calculate a first-quarter forecast of 30,000 units (30% x 100,000), a second-quarter forecast of 25,000 units (25% x 100,000), a third-quarter forecast of 25,000, and a fourth-quarter forecast of 20,000. The second quarter happens to contain a total of 13 corporate calendar weeks -- April and May contain four corporate calendar weeks and June contains five weeks. The forecast for April then becomes 4/13 x 25,000 = 7692 units, the forecast for May then becomes 4/13 x 25,000 = 7692 units, and the forecast for our desired month, June, is 5/13 x 25,000 = 9615 units.

The same calculations are completed for all twelve months of the calendar and form the basis for the DA Sheet forecasts for the entire year. As the year progresses, the original forecasts are adjusted, either up or down, based on information from Marketing and from any noticeable trends over the past couple of months. The actual adjustments are subject to the impressions of the responsible Master Planner, but any changes must be approved by the responsible marketing manager and by the Master Planning Manager.

Overall the methodology can be thought of as utilizing an annual forecast to determine monthly forecasts and making periodic adjustments to the monthly forecasts based on market intelligence. This technique of breaking down an annual forecast and making adjustments as necessary contrasts sharply with the history-based forecasting technique that will be discussed in the next section. Interestingly, it will be shown that past history alone is almost always a better predictor of monthly demand.

9.3 Improving Forecasting

In contrast to the annual forecast/monthly adjustment methodology just described, a statistical technique that depends on past history can be used and, consequently, produces forecasts of greater accuracy. More specifically, a linear regression that makes minimal provision for market intelligence has been shown to consistently outperform the current forecasting methodology. This finding tends to state that past history is a better predictor of future demand than is an annual forecast adjusted monthly with market input. The market intelligence used by the regression consists only of events that are well known in advance and are generally quantifiable. An example of such an event is a sales promotion. In this case, the additional anticipated order quantity is added into the linear regression forecast.

The remainder of this section deals with why a linear regression technique works well for forecasting, the method of analysis used to compare the two techniques, the results of the analysis, and lastly implications for the planning process.

Low Seasonality, Gradual Demand Changes, and Single-Use

The reason why the linear regression works well requires an understanding of the basic demand characteristics of the products involved. In particular, three main properties help explain the success of the regression technique -- surgical instruments have low seasonality, experience steady increases or decreases in demand, and are single-use.

Low seasonality - Seasonality in this sense refers to the predictability of the demand based only on the particular time of the year. Many retail goods experience seasonality each year in December due to the increase of demand during the holiday season. Surgeries, however, are performed fairly consistently throughout the year as needed by patients and therefore experience little seasonality. Some seasonality arguably exists for surgical procedures that are less urgent and can be scheduled at the patients' convenience.

Steady growth or decline - The "steadiness" in this context refers to the likelihood that the level of demand will suddenly increase or decrease with only minimal warning. The less likely a sudden change, the steadier the demand. Demand for oil would be considered relatively steady since overall demand is not likely to change quickly (although oil certainly experiences seasonality). Trendy fashions would be considered highly unsteady since demand for the fashion may be high one month but non-existent for the next.

Surgical instruments generally experience steady demand since surgical procedures will consistently be performed and hospitals are not likely to quickly switch between producers. Unlike most consumer goods where the customer can select from a variety of products simply by visiting a local retail outlet, surgical instruments are subject to purchasing contracts between a group purchasing organization (GPO) and the hospital or directly between the hospital and the producer. This greatly reduces the ability and desire for hospitals to switch between different producers. Conversely, taking market share away from competitors is a slow process that requires, on a small scale, altering surgeons preferences and, on a larger scale, "converting" a hospital or related organization (i.e. convincing the hospital or organization to establish purchasing agreements for acquiring the producer's instruments). Therefore, surgical instruments do not typically exhibit substantial jumps or drops in demand due to customer preference. Increases or decreases in demand tend to occur at a relatively steady rate.

Single-use - The importance of the products being single-use is that the products will experience a relatively flat life-cycle demand curve. Customers will buy a new instrument for each individual use rather than purchasing one instrument and using it several times before replacing it, as is the case with durable goods. With durable goods, a portion of the product's life is spent getting the product into customers' hands. Once most of the potential customers have the product, they won't need to buy another one for a period of time. Therefore, sales start to decline and most customers only purchase the product occasionally and only do so to replace their old product. Durable products experience a life-cycle curve with high sales near the beginning of the product's life, when customers are first purchasing the product, followed by a decline in demand as customers only purchase new product to replace old. In contrast with sales of durable goods, single-use goods sales are essentially all replacement sales since the customer purchases the product each time to replace the last one that was used. Demand therefore does not experience a decline once everyone has purchased the product but remains relatively flat throughout most of the product's lifetime.

9.4 Producing the Statistical Forecasts

The statistical forecasting methodology is a simple linear regression using least squares fit[57]. Each month, four forecast numbers are generated -- a forecast of demand for the current month, for one month into the future, for two months into the future, and for three months into the future. The regression uses data from the prior twelve months of demand to determine a best-fit line and, consequently, determine the forecasts of future demand. The details of the regression technique are purposefully omitted here since the importance of the forecasting is not the particular technique that is used, but rather the fact that a simple history-based forecast can perform better than current methods. Different forecasting methodologies also were not investigated in this research due to the fact that the company had already purchased a software package to automatically generate the forecasting using advanced regression, exponential smoothing, and seasonality techniques. Determining that a simple history-based statistical model can outperform current methodologies provides enough support to move toward using the software package for generating forecasts.

The one piece of the linear regression analysis that does need further investigation is the method used to determine the quantities used for the regression. The unconverted raw monthly data alone is not appropriate for performing the regression without some slight modification. There are two modifications to the monthly data that needed to be made -- normalizing each months data to a four-week month and accounting for some simple market intelligence of well-known events. Since the company runs from a calendar based on a combination of four-week and five-week months, some months experience greater demand simply because they are longer. Therefore, all months need to be normalized to a set length prior to performing the regression. The normalization length was arbitrarily chosen as four weeks, so all five-week months were divided by five to determine a weekly order rate and then multiplied by four to normalize to a four-week month (Figure 9.2).

[57]For details on this regression technique, see for example: Hogg, R. V., J. Ledolter, Applied Statistics for Engineers and Physical Scientists, New York: Macmillan Publishing Company, 1992, chapter 9.

Raw Monthly Data	Determining the Normalized Data
Four-week Month's demand:	=> use in the regression "as-is"
Five-week Month's demand:	*Weekly rate* = *Five-week Month Demand* / 5
	Normalized Month = *Weekly rate* x 4
	=> use *Normalized Month* in the regression

Figure 9.2. Normalizing four-week and five-week monthly demands into a four-week month.

Although it was stated earlier that the regression performs well without market intelligence, the business does experience certain demand increases that are known several months in advance and therefore need to be factored into the regression forecasts. For determining the forecast for a month that is known to have an increase or decrease in demand and the change is fairly well known, the increase or decrease is simply added to the original forecast produced by the regression. This technique presents another problem when the event month has passed and the orders from that month need to be used as part of the regression for future forecasts. For example, if August 1994 has a known increase in demand of 1000 units in addition to whatever demand August 1994 would normally have, the August 1994 forecast is determined by performing the regression through normalized data of the twelve months between August 1993 and July 1994. If the regression forecasts a value of 1500 units for August 1994, the overall forecast will be 1000 + 1500 = 2500 units. When August has passed and the actual orders are known, these actual orders are an outlier for future forecasts. In other words, if August's demand turned out to be 2764 units and 1000 of those units are believed to be due to a special one-time event, using 2764 for future forecasts of months that do not have the same one-time event will artificially skew the slope of the regression line upward. To get around the problem, future regressions use the event month's original regression forecast. In the example above, 1500 would be used as the August 1994 data point for forecasts after August 1994.

Figure 9.3 shows a sample portion of a spreadsheet used to determine the linear regression forecasts.

Actual Demand Data

Linear regression forecast for April determined in March

Linear regression forecast for June determined in March

Month	Net Orders	Weeks in Month	Normalized Net Orders	Market Intelligence	Net Orders Used for Regression		Linear Regression Results			Forecasts with Market Intelligence	
							1-Month	3-Month		1-Month	3-Month
Jan-94	3300	4	3300	0	3300		3751	3734		3751	2234
Feb-94	3500	4	3500	0	3500		3430	3326		6287	3326
Mar-94	7000	5	5600	2000	3556		3310	3181		1810	3977
Apr-94	1600	4	1600	-1500	4395		4872	5124		4872	5124
May-94	2700	4	2700	0	2700		3878	3903		4847	3903
Jun-94	4700	5	3760	0	3760		3379	3284		3379	4105
Jul-94	4200	4	4200	0	4200		3759	3748		3759	3748
Aug-94	3700	4	3700	0	3700		3803	3787		4754	3787
Sep-94	4700	5	3760	0	3760		3854	3864		3854	4830
Oct-94	3800	4	3800	0	3800		4284	4398		4284	4398
Nov-94	4100	4	4100	0	4100		4195	4282		5244	4282
Dec-94	4500	5	3600	0	3600		4130	4179		4130	5224

Normalized Demand Data

One-Time Event in March and April

These numbers are a regression over the previous twelve months' data

Non-normalized forecasts with Market Intelligence added in

Figure 9.3. Sample portion of a spreadsheet used to determine linear regression forecasts.

Determination of Test Products

Due to the number of products available for the comparison and the resources required for retrieving past forecast information from old D.A. Sheets, the analysis was limited to carefully selected products. The selection criteria for the products involved a combination of input from the master planners, statistics, and dollar sales volume. From visual examination of almost one hundred plots of weekly demand data and from past experience in the research, eight categories of demand patterns were identified -- general cases, new product introductions, large quarterly increase, large quarterly decrease, noisy, fast growth, and special cases. For each category, one or more specific products were selected based on, as previously mentioned, input from master planners and statistics, with sales dollar volume being used as a final determinant in each category. Sales volume became the deciding factor since the majority of sales revenue comes from a small sample of product codes[58]. It was decided that forecasting accuracy was most critical for those codes and that those codes should be concentrated on in the analysis. A summary of the seven categories, the products that fell into each category, and the method(s) used for selecting the products are summarized in Table 9.1.

[58]Although the exact number of products that make up the majority of the sales volume is considered proprietary information, it is appropriate to say that the 80-20 rule essentially applies here, where 80% of the sales revenue is produced by approximately 20% of the products.

Category #	Category	Category Description	Product Selection Method	Selected Products
1	General Case	"Typical" demand pattern	Feedback from Master Planners	1(a), 1(b), 1(c)
2	New Product Introduction	Introduction of a new product that replaces an old version of the product[59].	Feedback from Master Planners	2(a), 2(b)
3	Large Quarterly Increase	Large increase in quarterly demand above average quarterly demand.	Statistical: > 50% increase in demand in any quarter over average quarterly demand	3(a), 3(b)
4	Large Quarterly Decrease	Large decrease in quarterly demand below average quarterly demand.	Statistical: >50% decrease in demand in any quarter under average quarterly demand	3(a), 3(b) -- same as Category #3
5	Noisy	Weekly data exhibits substantial noise as opposed to consistently following a trend line.	Statistical: Ratio of standard deviation to weekly average > 50%.	5(a), 5(b)
6	Fast Growth	Products with demand increasing at the fastest rate.	Feedback from Master Planners	5(a) -- same as from Category #5
7	Special Cases	Any products that have special circumstances that have made them difficult to forecast.	Feedback from Master Planners	8(a), 8(b)

Table 9.1. Summary of the eight categories used to determine test products and how products were selected into each category.

9.5 Comparison of Methods

The method of comparison between the two forecasting methods was to compare forecasts of 1-month and 3-months into the future -- most assembly scheduling depends

[59]As stated, the new product introductions in this case refer only to those instances where the new product replaces an already existing product. In this case, historical data exists from the predecessor product that can be used to determine demand for the new product. Products that have no predecessor consequently have no source of historical data and therefore cannot be forecast with a linear regression. The majority of product introductions, however, are of the former kind where new product replaces old.

on the 1-month forecast and a significant portion of orders for parts are based on the 3-month forecast -- with *error as a percentage of actual demand* as the measurement basis. For each product code, forecast information was obtainable from the D.A. sheets for the past 10-12 months, resulting in a comparison of between 9-11 data points for the 1-month and 7-9 data points for the 3-month forecasts. Monthly forecast errors were then averaged across the available data points and a final percent error number was generated for the 1-month and the 3-month forecasts for each methodology. This analysis was completed for all considered product codes. Final results are presented in Table 9.2.

	1-Month Forecast Errors		3-Month Forecast Errors	
Product	D.A. Sheet	Regression	D.A. Sheet	Regression
1a	30%	**12%**	27%	**10%**
1b	**8%**	14%	10%	**6%**
1c	28%	**7%**	29%	**7%**
2a	30%	**27%**	43%	**24%**
2b	**29%**	35%	40%	**34%**
3a	23%	**7%**	24%	**12%**
3b	22%	**15%**	20%	**14%**
5a	**13%**	15%	41%	**14%**
5b	22%	**19%**	23%	**19%**
7a	48%	**26%**	40%	**38%**
7b	37%	**22%**	39%	**22%**
AVERAGES	26%	**18%**	31%	**18%**

Table 9.2. Comparison of Average Forecast Error between the methodology use by D.A. Sheets and a linear regression. Numbers in parenthesis represent the standard deviation of the monthly forecast errors. Lowest forecast errors for each product are highlighted.

Results of the Comparison

The comparison of average percent error between the two methods reveals two important observations:

1. Substantially Improved Extended Forecasts: The linear regression not only performs better than the D.A. Sheets on 1-Month forecasts, but performs substantially better with 3-Month forecasts.

2. Consistency with Forecasting: The linear regression experiences much less variation in its forecast accuracy resulting in a more consistent forecast. The D.A.

Sheet forecasts tended to be more hit-and-miss where the forecast would be extremely accurate one month but be completely off the next.

9.6 Benefits of Using a Linear Regression for Forecasting

The importance of finding that past history is a better indicator of future demand and that a simple statistical model can perform well not only lies with the improvements in forecasting accuracy, but also with the improved speed with which the forecasts can be made and turned into weekly production plans. The linear regressions can potentially be completed for all products in minutes using spreadsheet or database software. This is in stark contrast to the current DA sheet process which may require a week or more of meetings between planning and marketing to determine the final forecast. And although the approval process for the DA sheets may still require several days to complete, the forecasts required for the weekly production plans can be made available immediately at the beginning of each month.

9.7 Conclusion

In this chapter, I demonstrated that monthly forecast accuracy could be improved using a simple statistical technique. Of equal importance, this analysis reaffirmed that demand follows a relatively stable trend line and can be predicted with reasonable accuracy. The next chapter will discuss an alternative production system, the "Pull System," that reduces dependency on forecasting to meet incoming demand.

Chapter 10 An Alternative Production System -- the "Pull" System

10.1 Introduction

This chapter presents an alternative production system that I believe could help alleviate many of Ethicon Endo-Surgery's back order, inventory, and cycle time problems. The system uses a simple Order Point / Order Quantity (OP/OQ) policy to initiate production at each stage. When finished goods inventory drops below the finished goods order point, the packaging / sterilization process receives an order for a new batch of finished product. When bulk instrument inventory falls below the bulk instrument reorder point, assembly receives an order for another batch of instruments. Component parts inventory is replenished in a similar fashion. This method of scheduling production directly contrasts with the monthly planning system and MRP-style scheduling currently in place. In this current system, each week's assembly schedule is planned out ahead of time based on lead times through the process and monthly market forecasts.

The OP/OQ system has appropriately been termed the "Pull System" within the organization, recognizing that product is "pulled" through each process step by a need to fill depleted inventory. In contrast, the monthly planning process is predominantly a "push" system, pushing components into assembly based on monthly forecasts. One key advantage of the pull system is that it allows each business unit to have full control over inventory and production, decreasing dependency on forecasting and simplifying the overall scheduling process. It combines demand, production, and inventory responsibilities within one group, minimizeing conflicting organizational incentives and time-consuming business processes. Additionally, the new system places a strong emphasis on inventory control, cycle time reductions, and increased flexibility.

This chapter describes the pull system and the changes that it presents to the current manufacturing structure. Further discussion is provided on why I believe the system will help improved Ethicon Endo-Surgery's operations. A model has been completed -- the same model as the Daily Planning model discussed in Chapter 5 -- to demonstrate that the pull concept not only seems to work but works well for Ethicon Endo-Surgery's internal supply chain.

10.2 The "Pull" System

In contrast to a forecast-push operation, such as in the Monthly Planning and the Weekly Planning models presented earlier in this thesis, the Pull System does not utilize forecasts to determine production volumes. Instead, production batches are only scheduled as needed to replenish inventory levels. The organization sets the size of each batch based on the flexibility of the corresponding production process.

As stated thus far, the Pull System intiates a new batch of material through the production process when the inventory level drops below a predetermined order point. As soon as the inventory level reaches the order point, the replenishing process receives an order to produce another batch of product. I will now expand on this idea a little further. The "inventory level," as used in this case, actually refers to more than just the amount of inventory physically residing at the inventory location. It is composed of the actual inventory itself, plus WIP, plus product that has been ordered but not started by the process. In other words, inventory refers to all product that has been produced, is being produced, or is has an order to be produced. When the <u>total</u> volume of product <u>in the process</u>, including inventory, WIP, and outstanding orders, drops below the order point, a new order is initiated. This distinction will become important in understanding the influence of lead times on inventory levels.

Pull-type scheduling is currently used to replenish finished goods inventory through the packaging / sterilization operation. Finished goods inventory levels (or more specifically, FG inventory, packaging / sterilization WIP, and outstanding packaging / sterilization orders) are monitored on a daily basis. As soon as the inventory level for a particular product falls below the order point, a new batch of instruments are initiated through packaging / sterilization. I now advocate expanding this process throughout the internal supply chain -- scheduling assembly based on bulk instruments inventory and scheduling component parts orders based on component parts inventory.

The principle variables used in the Pull System are the Order Points and Order Quantities determined for each inventory position for each product. Details for calculating these variables are intentionally omitted here but are readily available from many operations management texts (see for example, Nahmias, 1993). The following presents a general discussion, detailed enough to allow the reader to fully understand the Pull System's merits.

The *Order Quantity* for a particular inventory position depends on the flexibility of the replenishing operation. The relationship is an inverse relationship -- the more flexible the process, the lower the order quantity:

Order Quanity ~ -(flexibility)

If the Order Quantity equals one week's worth of demand, the production operation will receive a new order on average once per week. If the Order Quantity equals two days, the operation will on average receive a new order every two days. The smaller the Order Quantity, the more often the operation receives, and must respond to, a new order. The more often the operation receives new orders, the more often it must change its production schedule.

The calculations for the *Order Point* are the same calculations used in Chapter 6 to demonstrate the appropriate inventory levels for a given service level objective. As recently discussed, when inventory drops below the Order Point, a new batch is initiated through the replenishing process. To ensure that inventory does not drop below zero during the replenishment cycle, enough inventory must be in place to cover the incoming demand while awaiting replenishment. In other words, enough inventory must be in place such that, between the time an order for replenishment is sent and the ordered product is received in inventory, inventory does not drop below zero. This inventory, or Order Point, equals the expected demand during the replenishment lead time plus an additional factor to account for uncertainty. The Order Point therefore depends on the lead time for replenishment plus a service factor:

Order Point ~ lead time + service factor

It was stated earlier that the Pull System does not depend on forecasting to determine production schedules; yet, it was just stated that the expected demand during replenishment determines the Order Point. At first glance, since the expected demand over the replenishment period is actually another term for a forecast, it would seem that the Pull System actually does use "forecasts" of a sort. The former statement, that expected demand is actually a forecast, is certainly true. However, the production scheduling is not determined directly from expected demand. Production scheduling, instead, is determined from the order point which is in turn determined using expected demand. This distinction is subtle but important. Using a "forecast" only to determine the order point results in less dependency on the accuracy of the forecast. The Pull System models, presented in Chapter 5 and presented later in this chapter, actually use the same weekly "forecast" throughout the entire 1¼ year simulation. The "forecast," actually an average of the entire period's demand, does not change for 1¼ years!

10.3 Benefits of the "Pull" System

Assuming that the Pull System and the current Monthly Planning System operate equivalently for scheduling and managing inventory (this assumption will be challenged in the following section), why would an organization want to demand-pull rather than forecast-push? In this section, I discuss several of the organizational reasons why the Pull System is a better choice for Ethicon Endo-Surgery, particularly considering EES's performance metrics. The Pull System acts to emphasize inventory, cycle time, and service level improvements in a complementary, rather than conflicting, way. It additionally fits in with EES's current move to push full product responsibility down to the level of the Business Unit Manager.

Emphasis on Cycle Times

Cycle time, or lead time, refers here to the total time required for an operation to process materials and deliver product to the next inventory position in the supply chain. As discussed briefly in Chapter 5, reducing cycle times can provide tremendous benefit to an operation. The Pull System acts to emphasize cycle time reduction by (1) simplifying the defintion of cycle time and (2) by tying it to improvements in other metrics.

By using predetermined batch sizes, cycle time can be defined as the amount of time required to process one batch of material. The start and finish of one batch can be made clear to the people producing it. The definition is simple and unambiguous. Under a monthly planning system where forecasts determine production schedules based on fixed lead times, the definition of cycle time is not as clear. The system determines a schedule for each production day. This schedule may vary from day to day depending on the forecasts and the inventory levels. The cycle time would be considered as one day divided by the number of instruments produced in that day. If the schedule calls for 200 instruments on one day, the cycle time is 1/200 day. If the schedule calls for 250 on the second day, the cycle time is reduced to 1/250 day. But has the cycle time really been reduced? If the schedule changes to 180 instruments, the cycle time increases up to 1/180 day. The cycle time depends more on the day's schedule than on the ability of the operation to consistently produce the product faster.

The Pull System also ties cycle time reduction with improvements in other key operations metrics such as inventory and service level. Under an OP/OQ system, inventory level is a direct function of cycle time, batch size, and demand variation:

$$\textit{Inventory} \sim f(\textit{ cycle time, batch size, demand variation })$$

Therefore, inventory reduction depends in part on reducing cycle times. Alternatively, a reduction in cycle time results directly in a reduction in inventory. As for service level, a shorter cycle time results in quicker response to changes in demand, allowing the operation to respond faster to unexpected demand shifts. The ability to react faster allows the organization to restore supply of product quicker and improve service level:

$$\textit{Fast Cycle Time} \Rightarrow \quad \textit{Ability to React Quickly} \Rightarrow \quad \textit{Improved Service Level}$$

Emphasis on Inventory Reduction

As stated, inventory levels depend only on cycle time, batch size, and demand variation. While the production area has no control over demand variation, it can control cycle time and batch size; and only by changing cycle times and batch sizes can the area change inventory levels. This makes the determination of inventory levels an objective function, calculated based on objective data (cycle time, batch size, and demand variation), eliminating the potential to use inventory as a buffer against underlying problems. The message is again simple and clear -- in order to decrease inventory, the operation must either (1) consistently produce faster or (2) increase flexibility by decreasing batch size. Alternatively, inventory cannot be increased without either an unlikely corresponding increase in cycle time or batch size, or an increase in demand variation.

Emphasis on Service Level

With inventory level being a function of cycle time and batch size, increasing inventory to buffer against problems is no longer possible. Without the ability to buffer against unexpected problems and given that problems will occur, the only way to improve service level is to have the ability to respond faster when a problem *does* occur. Protection from falling into back order, therefore, depends critically on speed and flexibility. The faster the operation can respond to a sudden change in demand, the better the service level.

The connection between reducing cycle times and improving service level has already been discussed. A similar connection exists between reducing batch size and improving service level:

Smaller Batch Size ⇒ Increased Flexibility ⇒ Improved Service Level

Pushing Full Responsibility Down to Business Unit Managers

With the creation of a system that does not depend critically on forecast accuracy; that automatically produces its own production schedules; that clearly emphasizes the critical metrics for improvement (cycle time and batch size); and that sets inventory levels based only on the critical metrics, the process of managing the system is greatly simplified. The management responsibility, therefore, can reside almost entirely within each business unit. As a result, all non-business unit functions then take on roles of support. For example, consider the role of the central planning group to determe monthly forecasts and inventory policies. Forecast accuracy is no longer critical to the successful operation of the system, and inventory management becomes a calculation based on lead times and batch sizes. The responsibilities of the central group therefore shift from the perfomance-critical duties of forecasting and inventory to the support responsibility for individual business units.

How could the current organization be changed to support the new responsibilities? Table 10.1 displays how the various roles might change in moving from the Monthly Planning System to the Pull System. The role of Master Planning could be transformed into identifying trends in demand that the business units should prepare for. In other words, the Master Planners no longer directly plan production but, instead, analyze demand patterns. A more appropriate new title for Master Planners might be "Demand Analysts[60]." Examples of how the role shift occur with such market events as sales promotions, adoption of new surgical procedures, and market interactions between products. In these cases, the responsibility of the Master Planner (or Demand Analyst) is to warn the business units about the anticipated demand changes and to advise on what actions might be taken to prevent a stockout.

The role of inventory specialists also could be transformed. The inventory specialist could be responsible for providing analytical knowledge and for recommending potential areas for improvement. For example, not all business units will readily

[60]Credit for the title "Demand Analyst" belongs to a colleague at Ethicon Endo-Surgery responsible for helping redefine the current monthly planning process.

understand how to determine inventory and batch sizes. Those that do will likely come across special cases that require special solutions. In any case, the inventory specialist would know how to determine inventory and batch sizes in accordance with the each particular situation. This knowledge would not have to reside specifically in each business unit.

Role	Responsibilities	Metrics
Business Unit Manager (Products)	Delivery of bulk instruments to bulk instrument inventory	Parts Inventory Bulk Inventory Batch Size Lead/Cycle Time Service Level (Bulk instruments & FG) Quality
Business Unit Manager (Packaging / Sterilization)	Delivery of finished goods into FG inventory	FG Inventory Batch Size Lead/Cycle Time Service Level (FG) Quality
Master Planning	Analyzing trends in the market and determining what the business units need to do in preparation	Overall Inventory Service Level
Inventory Specialists	Support of business units in determining order points and order quantities.	Overall Inventory Service Level

Table 10.1. New organizational responsibilities associated with the Pull System.

10.4 Modeling

The model developed for the Pull System has already been described and demonstrated as the Daily Planning System in Chapter 5. The details presented in that chapter will not be repeated here, but I will resurface four important points concerning the modeling effort:

1. The model assumes constant lead times;
2. Actual weekly demand data is used for input;
3. The model considers an instrument composed of several parts where all parts but one are available 100% of the time;
4. The model was completed using a computer spreadsheet software.

The first and third point demonstrate the key assumptions that the model is based on. To account for the constant lead time assumption, the model uses a greater lead time than actual. The third point, assuming all parts but one are available 100% of the time, was necessary to keep the model within a reasonable scope. The assumption is meritable considering that component parts are available for assembly most of the time. Additionally, it is likely that all of the parts experience shortages at approximately the same time since a shortage will typically result from a sudden jump in demand.

The results of the modeling are presented in Chapter 5. The charts on assembly rates (Figures 5.3a,c) demonstrate the Pull System's resilience to unexpectedly high demand. The large production swings as a result of unexpected demand give way to a smooth response. Additionally, the inventory levels demonstrated with the Pull System model remain relatively stable, particularly when compared to the Monthly Planning Model (Figures 5.4a,c). The steadiness shows that the finished goods inventory level can be dropped considerably before worrying about frequent dips below zero.

This same model was used to simulate the Pull System on dozens of different demand patterns. All patterns, based on actual weekly data, produced a similar result -- production swings were reduced and inventory levels remained remarkably stable. This would seem to indicate that the Pull System has merits beyond the organizational enhancements discussed in the previous section. Using the simple OP/OQ method to schedule production would greatly dampen production swings and reduce inventory. Although the complete explanation for this was not an objective of the research, a plausible explanation is that the Pull System provides a simple way to move from monthly planning to daily planning.

The previous discussion also indicated that, in moving from a monthly planning period to a weekly planning period, a system would be produced that is unnecessarily reactive to small, week-to-week changes in demand. In moving to a daily planning period (i.e., to a Pull System) the small variations in demand were effectively dampened. Why was this so? The Pull System has another "control knob" that alleviates the reactivity problem. By altering the batch size, sensitivity to small variations in demand found can be controlled. Therefore, the problem of over-sensitivity that could be expected of a daily planning system can be alleviated. Figures 10.1a-c immediately following this chapter demonstrate the effect on assembly rates of increasing the assembly batch size to two weeks of demand (from the prior value of one week) and then decreasing the batch size to two days. In general, the larger the batch size, the smoother the production. It should be noted, however, that inventory levels (not shown) tend to flatten out as the batch size decreases.

10.5 Conclusion

By using two key variables (order point and batch size) to determine production schedules, the Pull System provides a way to place full product responsibility down to the business unit manager level. Dependency on forecast accuracy is greatly reduced and the determination of inventory levels becomes an objective calculation. The major operations metrics of inventory and service level depend critically on cycle time and batch size (flexibility). The relationships are simple and unambiguous. Modeling results demonstrate the feasibility of the Pull System and should warrant, at a minimum, further investigation.

In the context of the previous chapters, the Pull System allows one part of the organization to combine all critical elements of the production picture -- demand, production, and inventory. The part of the organization that combines demand, production, and inventory happens to also be responsible for the actual production of the product. I believe that this simplifying change could better equip the organization to determine creative and effective ways to improve delivery service in the future.

Figure 10.1a Batch Size of 2 Weeks

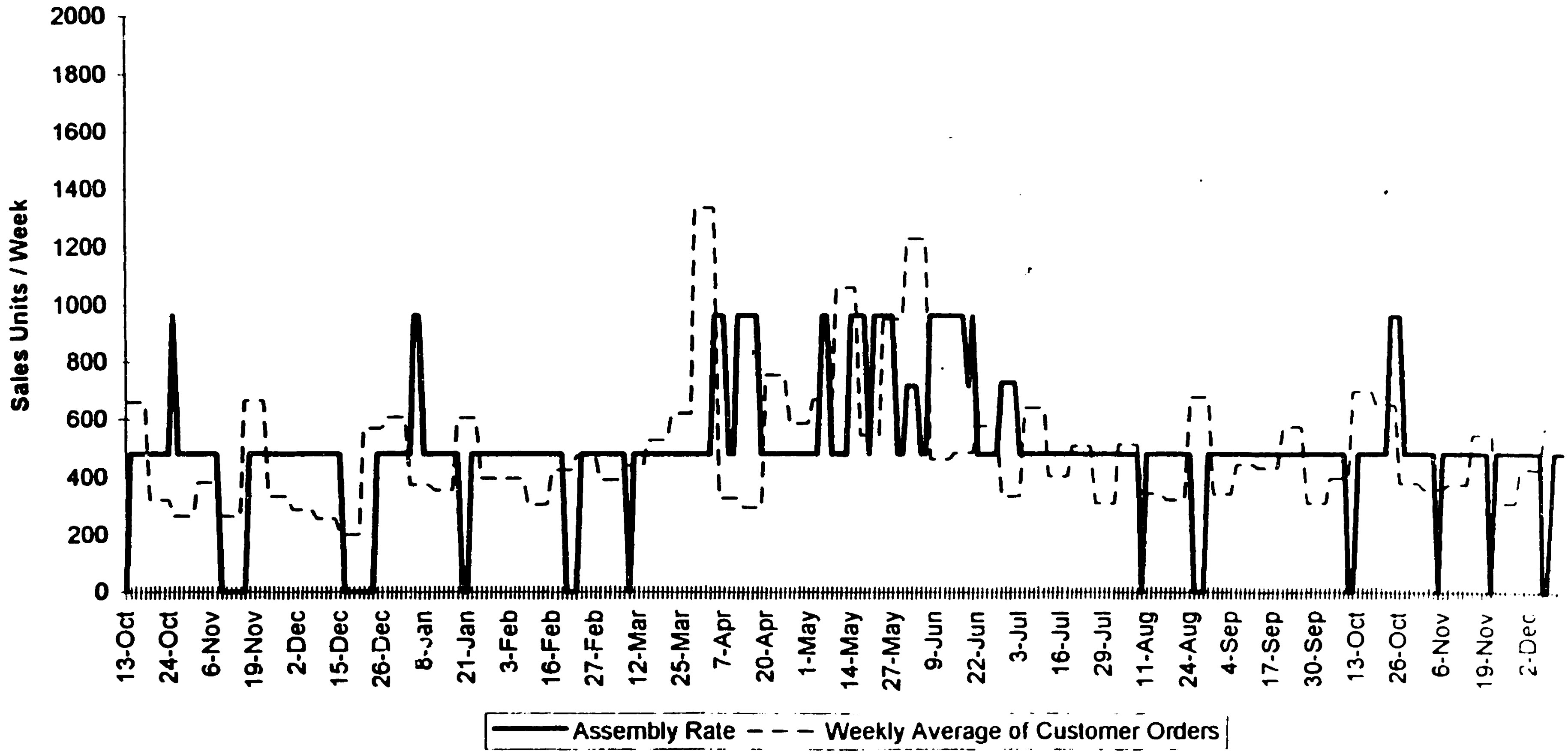


Figure 10.1b Batch Size of 1 Week

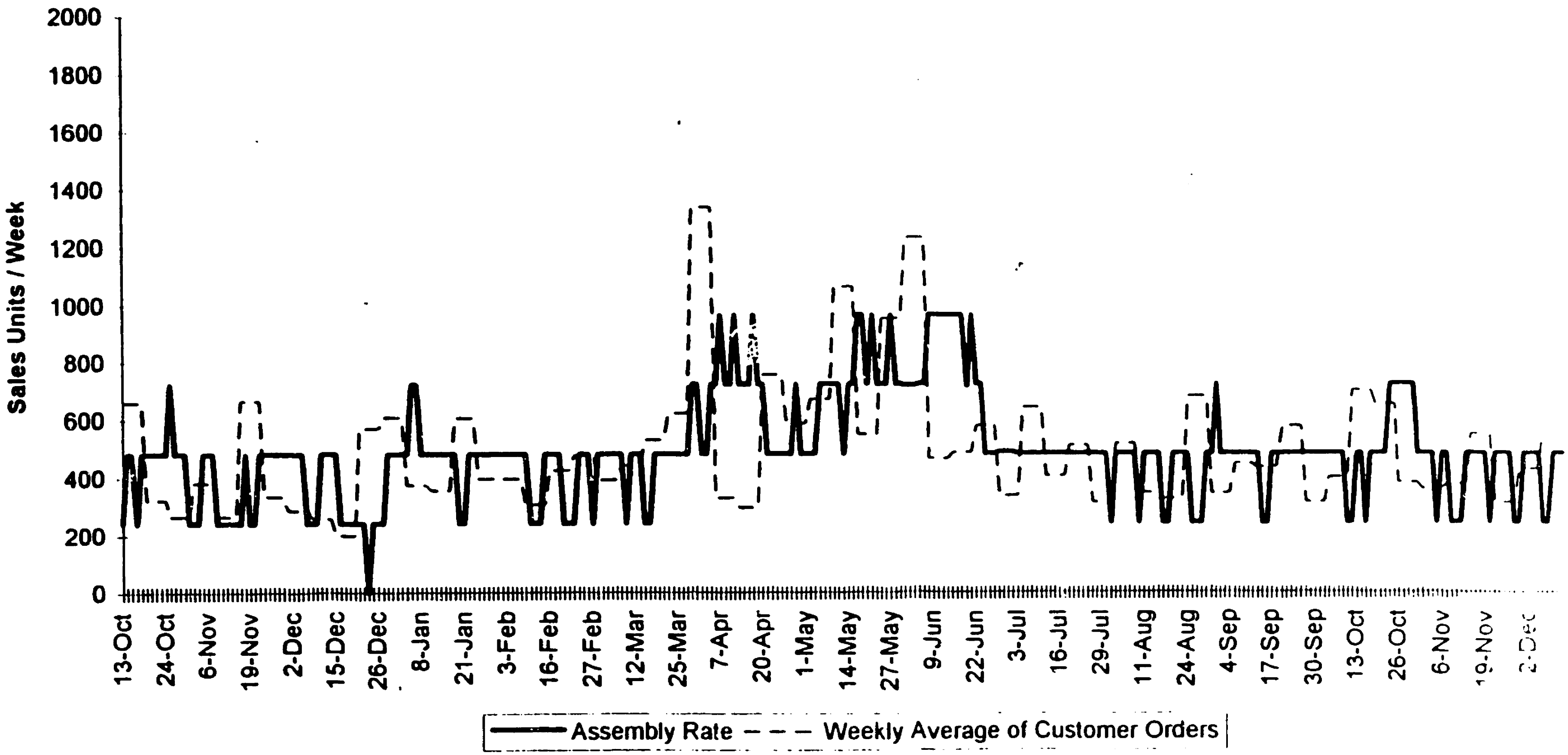
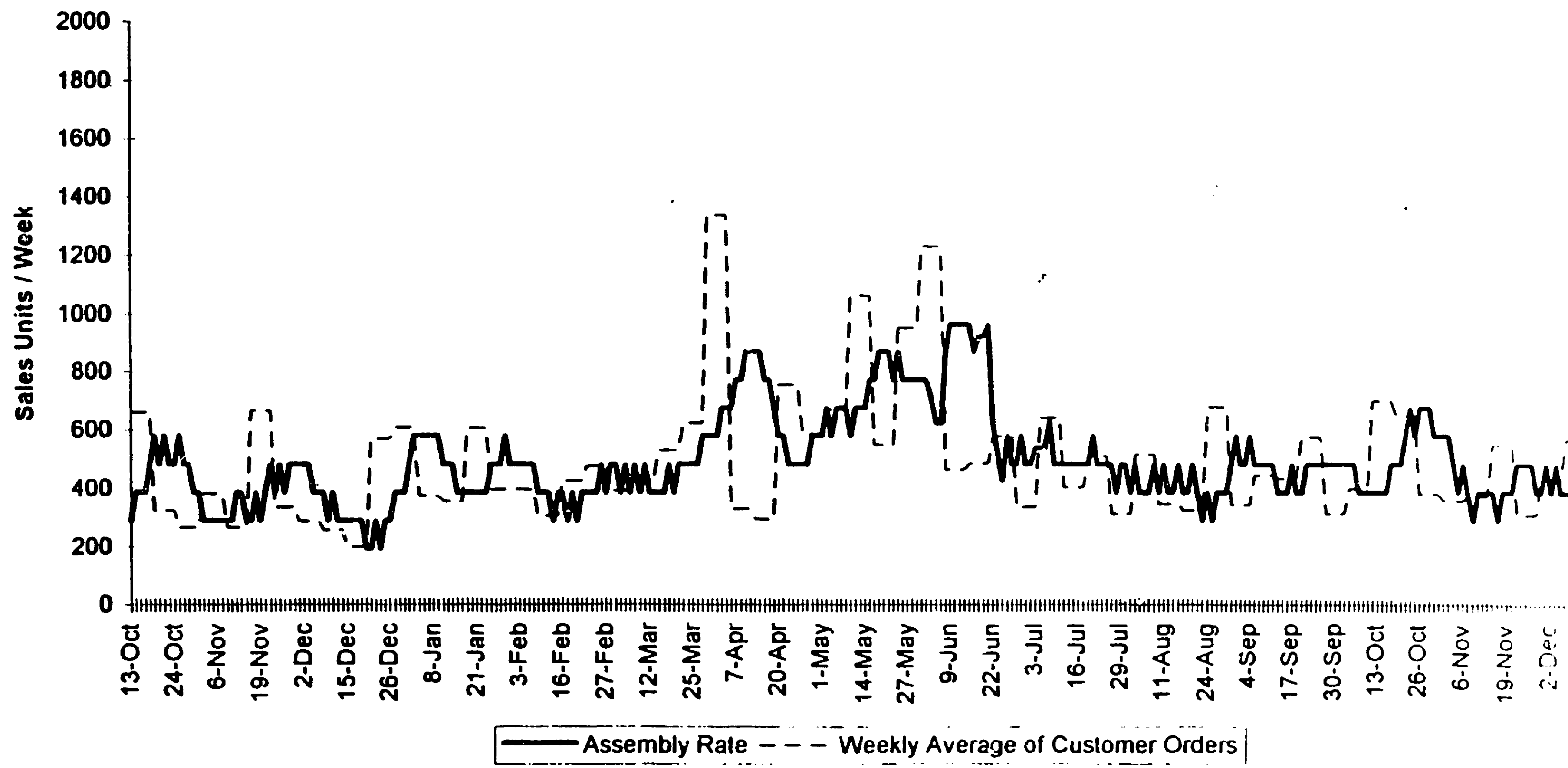


Figure 10.1c Batch Size of 2 Days



Chapter 11 Conclusion

11.1 Introduction

In this final chapter, I review the major themes presented in the preceeding eleven chapters. I then go on to provide some additional areas of interest that have not been covered by the thesis, but are well worth mentioning. The time I spent at the company and the research that was performed raised many further questions that I either could not or did not have time to address. These questions will be raised as areas of interest warranting further investigation. Lastly, I provide three actions that, in my opinion, will help improve Ethicon Endo-Surgery's overall operations. I presented these actions as final recommendations to Ethicon Endo-Surgery prior to my departure from the internship site.

11.2 Thesis Summary

Reflecting back to the beginning of this thesis, the original problem posed was one of understanding what happens when finished product leaves the company. New product introductions, critical to Ethicon Endo-Surgery's aggressive business strategy, would often result in extended supply shortages. Initial meetings with EES representatives hinted largely at developing a market forecasting tool for new products. By having the ability to predict incoming demand more accurately, Ethicon Endo-Surgery could prepare more appropriately for the introduction.

Initial research efforts were devoted entirely to understanding dealer, international affiliate, and hospital ordering behavior. These efforts uncovered a consistent pattern of demand found with new products. Dealers and affiliates would order product in large quantities during the first few weeks of the introduction, driving demand to an initial "spike." This spike was quickly followed by a relatively stable level of demand. In comparing domestic dealer monthly orders with hospital monthly orders, the hospital orders did not exhibit a corresponding initial demand surge. The source of the spike could therefore be attributed to dealers building inventory. By taking the difference in the area between the domestic dealers' demand and the hospitals' demand, we determined the amount of inventory that dealers were stocking. The amount turned out to be consistent with dealer and affiliate inventory policies.

The second and third part of the thesis examined what occurs within Ethicon Endo-Surgery in response to the new product introduction demand spike. The initial spike, typically having been under-forecast, would push the company into back order. After a delay, production would ramp up to restore depleted inventories. At its peak, the level of production would often exceed the peak level of demand. Further investigation revealed a similar reaction with any product that fell into back order -- an unexpected surge in demand would be followed by an equally, if not more, dramatic surge in production. This was interesting because the production system was developed largely to isolate the assembly operation from demand fluctuations. It also raised the question of whether or not EES's quick reactions were approriate from a cost/benefit standpoint. Among other costs in the internal supply chain, inventory levels were found to be in excess of corporate objectives. Current policy stated in terms of weeks of inventory translated into a service level substantially higher than the objective service level. This seemed to indicate that EES's perceived cost of back order exceeded the cost of holding inventory in excess of objective levels.

The historical reasons for the high cost of back order were examined. Original emphases on product development, market growth, and product delivery -- all necessary for Ethicon Endo-Surgery to build market share -- helped create the current organizational and incentive structure. The organizational and incentive structure, which includes information systems, made putting together all of the key pieces to the puzzle difficult.

Lastly, the two final chapters demonstrated "fixes" to the current system. The second-to-last chapter presented a new statistical forecasting technique that was shown to be more accurate than the current, market intelligence-driven methodolgy. The final chapter demonstrated a simplifying change to the overall production system. The "Pull System" helps align organizational incentives in moving product effieciently through the chain. Modeling of the system demonstrated its feasibility and substantial beneifts operationally.

11.3 Areas for Futher Investigation

In reflecting back on the thesis, I found a few areas that would provide further opportunities for interesting research. These areas include understanding how supplier relations influenced the production system and analyzing further why the demand-pull models performed so much better than the monthly planning models.

In a few instances, problems with component parts wreaked havoc on the internal supply chain, slowing production and causing shortages of finished product supply. As a result, unexpected surges in demand were not the only causes of back order. Due to the project's scope and timing, potentially important supplier management issues were not investigated.

As another point of interest, the supply chain improvements demonstrated by the demand-pull models were not thoroughly researched. Previous chapters have suggested that the ability to plan on a daily basis allows the system to react immediately to shifts in demand. The reaction time, therefore, determines the "steadiness" of production and inventory levels. This assumption has not been challenged analytically. Modeling proof alone is inconclusive as assumptions vary from situation to situation. From discussions with representatives from several other organizations, the question of planning regularly, using demand-pull scheduling, or using some hybrid system remains unanswered. I believe many companies such as Ethicon Endo-Surgery would benefit from the results of a more rigorous analysis.

11.4 Final Recommendations to Ethicon Endo-Surgery

The following three recommendations were presented to Ethicon Endo-Surgery management prior to my internship departure. At least one of the three, revising key operations metrics, overlapped with existing company initiatives. In this case, I was able to provide some of the analytical support to further justify the effort. Having an "outsider" walk in, take a different approach to understanding the problem, and come up with the same general conclusion also helped. The other two recommendations were new, although not completely surprising, to the audience managers. Once again, analytics helped justify turning initatives that many had only felt would be beneficial into pursuable actions.

Explanations of how the recommendations were determined will be left to the reader. It is my hope that anyone having read this thesis should have a general understanding of each recommendation's source. Without further discussion, the three recommendations were as follows:

1. <u>Revise Key Operations Metrics</u> -- evaluate Business Unit Managers on the inventory under their control. Measure back order length (i.e., average time to delivery) in addition to back order dollar value.
2. <u>Educate the Organization on Product Demand Patterns</u> -- show the consistent dealer stocking trend associated with new product introductions and

demonstrate the relatively stable demands patterns (predictable with a linear trend line).

3. Consider moving to a pure "Demand-Pull" System -- use order point / order quanitities to schedule production and manage inventory.

In several meetings with EES operations management, the recommendations were met with positive support and acceptance. The most significant recommendation, consider moving to a demand-pull production system, is being pursued by a special project manager. By the time I left the internship site, many details remained to be worked out for the system. Issues were raised concerning information systems and finding a sponsoring Business Unit Manager. Although initial enthusiasm was high, it remains to be seen whether or not the new scheduling system will actually proceed forward.

Appendix A Details of the Monthly, Weekly, and Daily Planning Models

A.1 Introduction

The models presented in Chapter 5 and Chapter 10 of this thesis simulate Ethicon Endo-Surgery's production system under different planning assumptions. The first model, which most closely resembles EES's current system, simulates planning completed on a monthly basis. Weekly and daily production schedules are determined near the beginning of each month based on monthly forecasts. The second model simulates weekly planning where production schedules are updated each week based on forecasts. The final model simulates daily planning where production is scheduled based only on the need to replenish depleted inventories. No forecasts are used, resulting in a demand-pull type of system.

This appendix discusses the details of the variables used in the models and the equations used to derive them. For model results, the reader should refer to Chapters 5 and 10.

A.2 Model Variables

State Variables versus Event Variables: There are two basic kinds of variables in the model -- state variables and event variables. State variables track levels of parts, instruments, and finshed product at each point in the system. These variables include Parts Inventory, Outstanding Parts Orders, Outstanding Assembly Orders, Assembly WIP, Bulk Inventory, Outstanding Pack/Ster Orders, Pack/Ster WIP, and Finished Goods Inventory. Event variables represent the orders throughout the system that cause state variables to change. Event variables include Parts Order, Assembley Order, Pack/Ster Order, and Distributor Order. All quantities for the variables are normalized to represent one sales unit where one sales unit may consist of several instruments of a given product code and one instrument may be composed of several different parts.

State Variables:

Parts Inventory - units of parts available for assembly into instruments. This assumes that one sales unit of parts is required to build one sales unit of instruments and that each unit of parts is ordered and stored as a single unit.

Outstanding Parts Orders - units of parts that have been ordered but not yet delivered into parts inventory.

Outstanding Assembly Orders - units of instruments that have been ordered for assembly but cannot yet be assembled due to a shortage of parts.

Assembly WIP - units of instruments that have been ordered for assembly, have drawn parts from Parts Inventory, but have not yet been fully assembled and delivered into Bulk Inventory.

Bulk Inventory - units of completely assembled instruments that have not yet been packaged and sterilized.

Outstanding Pack/Ster Orders - units of instruments that have been ordered for packaging/sterilization but cannot yet be packaged and sterilized due to a shortage of bulk instruments.

Pack/Ster WIP - units of instruments that have been ordered for packaging/sterilization, have drawn instruments from Bulk Inventory, but have not yet been fully packaged/sterilized and delivered into Finished Goods Inventory.

Finished Goods Inventory - units of instruments immediately available for shipment to customers.

Event Variables:

Parts Order - orders for parts in sales units. Orders are only submitted on Mondays as determined MRP-style by offsetting forecasted weekly demand by parts order lead times and accounting for inventories inbetween.

The equations used vary slightly between the monthly planning and the weekly planning models since parts are ordered weekly in both cases, but the monthly planning model only plans once per month and must determine when to order parts at that time throughout the month. The basic equation for a weekly parts order is:

$$PartsOrder = \begin{cases} PartsOrderQty, \text{ if } ExpectedPartsInventory_{Parts\,LT} \leq PartsSafetyStock \\ 0, \text{ otherwise} \end{cases}$$

where *ExpectedPartsInventory* is the expected level of parts inventory plus outstanding parts orders one parts lead time period into the future. *PartsOrderQty* is the standard ordering quantity for suppliers, and *PartsSafetyStock* is the quantity of inventory in parts maintained for safety purposes. Put in other words, if the total parts inventory level is expected to drop below the safety stock level within one lead time period, a new order is submitted for parts. Exactly one lead time period into the future, the order will arrive into Parts Inventory and may then be used by the assembly process. *PartsOrderQty* and *PartsSafetyStock* are parameters set for the entire model and are discussed below.

For the monthly planning model, parts orders are planned for an entire month but are still placed in weekly increments. The MRP requirements calculated at the beginning of the month determine each weeks' parts orders. The equation now becomes:

$$PartsOrder_i = \begin{cases} PartsOrderQty, \text{ if } ExpectedPartsInventory_{PartsLT+i-1} \le PartsSafetyStock \\ 0, \text{ otherwise} \end{cases}$$

$$i = 1,2,\ldots n \quad \text{where } n = \begin{cases} 4, \text{ for 4-week months} \\ 5, \text{ for 5-week months} \end{cases}$$

where i repesents the number of the week in the planning month. A parts order for the second week of the month is determined by calculating the *ExpectedPartsInventory* one lead time period plus one week into the future. A parts order for the third week is determined from the *ExpectedPartInventory* one lead time plus two weeks into the future, and so on.

Assembly Order - orders for the assembly process in sales units. Once again, orders are only submitted on Mondays as determined MRP-style by offsetting forecasted weekly demand by parts order lead times and accounting for inventories inbetween.

The equations used vary slightly between the monthly planning and the weekly planning models since parts are ordered weekly in both cases, but the monthly planning model only plans once per month and must determine weekly assembly quantities throughout the month. In general, the assembly order is determined by taking the expected quantity of finished goods that will be needed and subtracting what will be available for filling the finished goods needs. The equation takes into account current levels of bulk inventory, finished goods inventory, assembly WIP, packaging/sterilization WIP, assembly outstanding orders, and pack/ster outstanding orders, The basic equation for a weekly assembly order is:

$$AssemblyOrder = \{(\text{What will be needed}) \ - \ (\text{What will be available})\}$$

$$= \{(\text{Forecast} + \text{Desired Safety Stock}) - (\text{Expected Inventory Level})\}$$

$$= \left\{ \begin{array}{l} (Forecast_{AssemblyLT + PackSterLT} + FGSafetyStock + BulkSafetyStock) \\ -\left(\begin{array}{l} ExpectedFGInventory_{AssemblyLT + PackSterLT} \\ \quad + ExpectedBulkInventory_{AssemblyLT + PackSterLT} \end{array} \right) \end{array} \right\}$$

where *ExpectedBulkInventory* is the expected level of bulk inventory, assembly WIP, and outstanding assembly orders one lead time period into the future, and *ExpectedFGInventory* is the expected level of FG inventory, packaging/sterilization WIP, and outstanding packaging/sterilization orders one lead time period into the future. A lead time in this case represents the total time to transform parts into finished goods -- i.e., assembly lead time plus packaging/sterilization lead time. *FGSafetyStock* and *BulkSafetyStock* are the quantities of inventory in finished goods and bulk instruments, respectively, maintained for safety purposes. Put in other words, enough product is ordered into assembly each week to meet demand and cover safety stock levels.

Delivery of assembled instruments into bulk inventory differs from deliveries of parts into parts inventory. Unlike parts ordering where an entire order is delivered all at once, bulk instruments are delivered daily at a steady rate into Bulk Inventory. The rate of delivery is simple the size of the assembly order divided by the number of days in the assembly lead time. Once a lead time period has passed, an entire assembly order will have been delivered into Bulk Inventory.

For the monthly planning model, assembly orders are planned for an entire month but are still scheduled in weekly increments. The MRP requirements calculated at the beginning of the month determine each weeks' assembly orders. The equation now for assembly scheduling now becomes:

$$AssemblyOrder_i = \left\{ \begin{array}{l} (Forecast_{AssemblyLT + PackSterLT + i - 1} + FGSafetyStock + BulkSafetyStock) \\ -\left(\begin{array}{l} ExpectedFGInventory_{AssemblyLT + PackSterLT + i - 1} \\ \quad + ExpectedBulkInventory_{AssemblyLT + PackSterLT + i - 1} \end{array} \right) \end{array} \right\}$$

$$i = 1,2,\ldots n \quad \text{where } n = \left\{ \begin{array}{l} 4, \text{ for 4 - week months} \\ 5, \text{ for 5 - week months} \end{array} \right\}$$

where *i* repesents the number of the week in the planning month. An assembly order for the second week of the month is determined by calculating the

ExpectedFGInventory and the *ExpectedBulkInventory* one lead time period plus one week into the future. An assembly order for the third week is determined from the *ExpectedFGInventory* and the *ExpectedBulkInventory* one lead time plus two weeks into the future, and so on.

Pack/Ster Order - orders for finished goods in sales units. Orders can be submitted as often as every day depending on the finished goods inventory levels.

As discussed previously, packaging/sterilization operates using a pure "demand-pull" method which does not utilize the monthly forecasts. Instead, finished goods inventory levels are monitored on a daily basis, and when the level for a particular product drops below the predefined order point, a new batch of the product is initiated through the packaging/sterilization process. The equation for Pack/Ster Order is similar to Parts Order except that expected inventory is replaced with actual inventory and the safety stock becomes the order point:

$$PackSterOrder = \begin{Bmatrix} PackSterOrderQty, \text{ if } FGInventory \leq FGOrderPo\text{int} \\ 0, \text{ otherwise} \end{Bmatrix}$$

The equation states that when FGInventory falls below FGOrderpoint, a batch of size PackSterOrderQty is initiated through packaging/sterilization and will arrive in its entirety into finished goods exactly one lead time period later.

Distributor Order - orders for finished product from dealers or international affiliates. Actual weekly order data is broken evenly down into daily order data by dividing by the number of days in a week.

A.3 Setting Model Parameters

In addition to variables, several parameters may be set in the model which also influence the results of the simulations. These parameters include Parts Safety Stock, Bulk Safety Stock, Finished Goods Safety Stock, Parts Order Quantity, Pack/Ster Order Quantity, and Pack/Ster Lead Time. All of these parameters remain constant between the monthly planning and the weekly planning models and, therefore, discussion of how they are set is unimportant to the comparison of the models. In general, the parameters are set as closely as possible to values used in the actual supply chain.

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