Information Flow and Demand Forecasting Issues in a Complex Supply Chain

by
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B.S. E. Chemical Engineering, Princeton University (1990)

Submitted to the Department of Chemical Engineering and
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ABSTRACT

Fast cycle time, low product cost and high customer service are contemporary rallying cries for manufacturers to survive and thrive in increasingly competitive markets. Eastman Kodak recognizes the value of this integrated trio in driving its renewal as a world-class manufacturer and has set forth ambitious goals in 1994 for all its businesses:

- 10X cycle time reduction in 3 years
- 2X cost of poor quality reduction in 2 years
- annual improvements in customer service

This thesis discusses the challenges faced by one of Kodak's film manufacturing supply chains in trying to approach these goals. A first step to embracing such ambitious expectations is to develop an understanding of the current state, both structure and behavior. This research maps this current state on two levels, at the supply chain level and at the functional level. Focusing on the core of the supply chain, the Film Manufacturing Flow, I highlight issues concerning the flow of information and variability.

This thesis reveals a complex order management system comprised of a complex MRP II systems architecture overlayed on a functionally driven assemblage of planners. The structure of this system was not well understood prior to this research, and its identification aids an understanding of the sources of demand variability, large inventories and long cycle times.

Using functional inventory management as a window into the flow, I will describe issues concerning variability and forecasting. For a subset of products, I will use a simplistic approach to stock management and forecasting in order to demonstrate the impact of supply and demand variability and the savings made available by demand variability reduction.

I will then return to the supply chain information flow. With the aid of a supply chain simulation, The Beer Distribution Game, I will attempt to explain behaviors observed at the functional level. My analysis will describe potential sources for demand variability as well as the ramifications of variability on inventory control. Actions that can be taken to reduce demand variability and improve the information flow are discussed. Roadblocks to flow improvement are also discussed. Ultimately, I argue that progress toward the three corporate goals relies not on improving information flows and demand forecasts, but rather changing the underlying structure of the Film Manufacturing Flow.

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Information about time cannot be imparted in a straightforward way. Like furniture, it has to be tipped and tilted to get it through the door.

- Tom Robbins[1]

1. Introduction

As part of his strategy to renew Eastman Kodak as a "truly premier corporation," Chief Executive George Fisher has established Cycle Time Excellence as one of the "three essential elements:"

> achieving shorter times in performing all the processes it takes to run this corporation and serve our customers must be looked at as a way to achieve significantly lower operating costs and improve quality.[2]

In the summer of 1994, Fisher formalized these elements in three Expectations for all Kodak businesses:

1. an order of magnitude (10X) reduction in cycle time in three years
2. a 50% (2X) reduction in the cost of poor quality in two years
3. annual improvements in service to the final customer

This first element, which I will refer to as "10X," requires a rethinking of all parts of the business. For example, a supply chain which currently consumes 158 days from order placement to order fulfillment has to shed 142 of those days over the course of three years without compromising service to the final customer. Clearly, 10X is achieved by working smarter, not by working harder. But, as the leading quote suggests, conceptualizing the change necessary to meet 10X is not a trivial task. Today, Reengineering and Supply Chain Management are trumpeted in the business literature and in many companies by consultants trying to aid the change effort. Invariably, one of the initial steps to achieve this wholesale change is the creation and sharing of an understanding of the current state.

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[1] Tom Robbins, *Skinny Legs and All* (New York, NY: Bantam Books, 1990), p. 344.
[2] George Fisher, "Fundamentals For Kodak Renewal," (Eastman Kodak Company internal document, 1994).

People expected to drive the change necessary to achieve 10X must know how time is currently consumed in the business. This includes an understanding of the information flow -- how customer orders are translated into raw materials requirements -- and the material flow -- how raw materials are transformed into finished goods in the hands of the customer. Inventory is an effective means to achieve this flow understanding:

> Studying how organizations control their inventory is equivalent to studying how they achieve their objectives by supplying goods and services to their customers. Inventory is the common thread that ties all of the functions and departments of the organization together.[3]

Returning to the leading quote, the goal of this thesis is to couch the 10X challenge in simple terms using information about inventory. My intent is to raise issues relevant to improving a complex flow of material by looking at the corresponding flow of information. This thesis reveals a complex information and material management system which is a source of excess inventory. I will use demand forecasts, stocking policy and inventory levels as primary symptoms (i.e. the furniture) to better understand the cycle time elements of a film manufacturing supply chain. This data is coupled with observations and insights acquired during a six-month internship at Kodak Park in Rochester, New York to diagnose the current state of the supply chain information flow. Recommendations are made to address the major issues and a course of action is presented which should assist any Kodak film business in meeting the challenges presented by Fisher's Expectations.

1.1 Motivation for and Interpretation of 10X Cycle Time Reduction

The competitive landscape in the sensitized film industry has changed a great deal over the last decade. In many ways, Kodak has been reacting to this change rather than leading it:

> The once proud company, whose ubiquitous yellow boxes identify one of the world's most valuable brand franchises, enjoyed a near monopoly on U.S. film sales from the turn of the century until the 1980s. But Kodak lost its way a decade ago, drifting without strategic direction while such competitors as Japan's Fuji Photo Film and

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[3] Barry Renden and Ralph M. Stair, Jr., *Quantitative Analysis for Management*, 4th ed. (Boston, MA: Allyn and Bacon, 1991), p. 268.

> private-label manufacturers gnawed away at market share, now estimated at about 70 percent.[4]

With increasing frequency, industry players like Fuji, AGFA and Konica benefit when Kodak can not coordinate its film supply to cost-effectively meet demand. Cycle time reduction is essential to fending off this competition and regaining lost share; cycle time excellence is essential to Kodak's renewal.

The value of cycle time reduction has been well publicized the last few years, almost to the point of making it a contemporary business necessity.[5] The benefits of cycle time reduction include:

- increased supply chain nimbleness in responding to customer demand
- lower holdup costs associated with tightly coupled functions and increased inventory turns
- increased productivity
- increased quality fueled by rapid feedback and more cycles of learning

Furthermore, ignoring the systematic impact of long cycle times can bring dire consequences to a supply chain. The Planning Loop, as shown in Figure 1.1, is a concept which describes the reinforcing effect of lead time on cycle time in forecast-driven or 'push' systems, i.e. where material is pushed to meet forecasted demand.[6] As described below, a lack of attention to cycle time can reinforce inefficiencies and spin the system out of control.

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[4] Linda Grant, "A new picture at Kodak," *U.S. News & World Report* (September 19, 1994), p. 59.
[5] For a general discussion of the benefits of cycle time reduction, see George Stalk, Jr. and Thomas M. Hout, *Competing Against Time: How Time-Based Competition is Reshaping Global Markets* (New York, NY: The Free Press, 1990) and Philip Thomas, *Competitiveness Through Total Cycle Time* (New York, NY: McGraw-Hill, Inc., 1990). For Kodak-related discussion of the benefits of cycle time reduction, see Christopher P. Papouras, *Lead Time and Inventory Reduction in Batch Chemical Manufacturing*, MIT Master's Thesis, 1991, pp 6-8 and William B. Hetzel, *Cycle Time Reduction and Strategic Inventory Placement Across a Multistage Process*, MIT Master's Thesis, 1993, pp 8-10.
[6] Adapted from "The Planning Loop" in Stalk and Hout, *op. cit.*, p. 62.

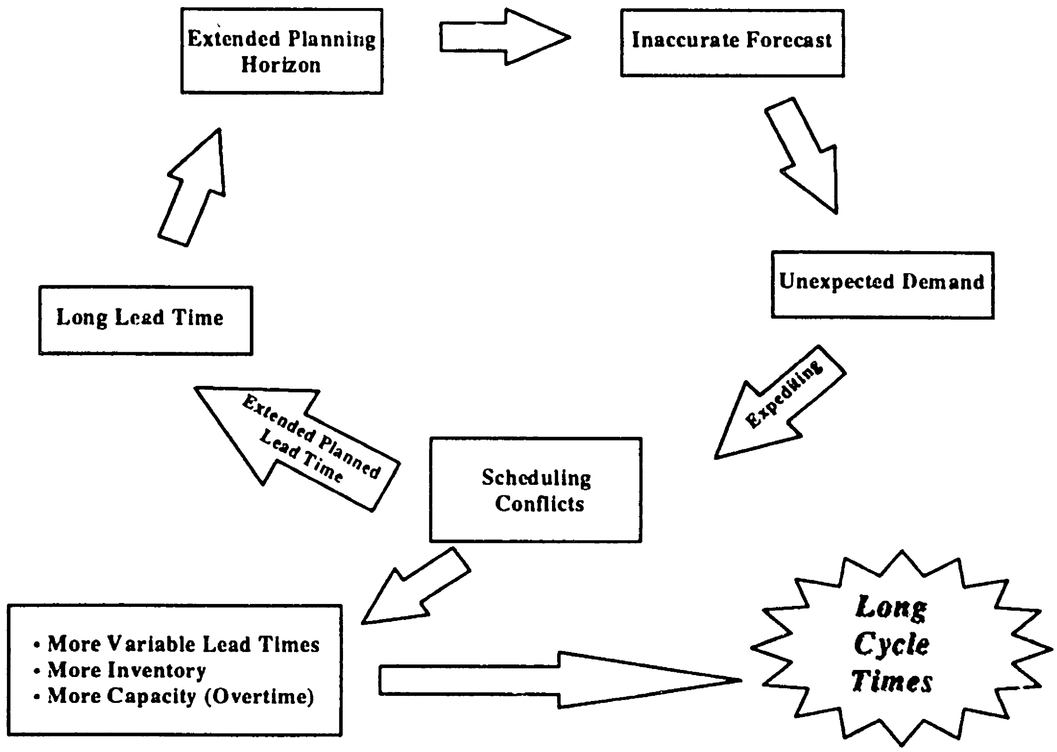

Figure 1.1 The Planning Loop

When a company can not produce fast enough to respond to customer orders, it must use sales forecasts to plan production. The forecast is translated into end-item production requirements in the form of a Master Production Schedule (MPS). Formal planning systems like Materials Requirements Planning (MRP) or Manufacturing Resource Planning (MRP II) convert this MPS into planned order releases for product components based on fixed lead time offsets and waste factors. The production plan is determined over a planning horizon which is based on the longest lead time component of the end item. As lead time grows, so must the planning horizon, which means that the end-item demand forecast is made further out and naturally becomes less accurate. Forecast errors increase the level of unexpected demand and production responds by expediting material which, in turn, crowds out scheduled production, leading to queuing and missed deliveries. Schedule disruptions make lead times more variable and safety stocks more necessary.

System cycle time inevitably builds with the inventories needed to maintain customer service and the extended planning lead times needed to resolve the scheduling conflicts brought about by additional variability.

This loop will drive system variability and the magnitude of cycle time ever higher until some measure of control is instituted. Control can take many forms.

Symptomatic control can be achieved by focusing on improving forecasts and adding extra capacity through overtime/temporary labor or machines. These measures essentially treat symptoms rather than the driver of the system -- long lead times.

Periodic control can be achieved by establishing formal targets for cycle time, inventory and/or service levels (as determined by stockouts). Performance relative to these targets is measured on a periodic basis (monthly or quarterly) rather than continuously.

Process control is a more robust means of control in that it focuses on characterizing then minimizing the statistical variations in the manufacturing processes, thereby effecting more deterministic lead times and accomodating MRP assumptions. But, if the lead times are still long, the system must still rely on forecasts and is therefore limited in its ability to respond to fluctuations in demand. In essence, any operation with long lead times is still susceptible to the Planning Loop.

Setup reduction gets at the heart of the Planning Loop and, in some sense, can be thought of as *real control*. Reductions in setup time can enhance production flexibility and shrink lead times to the point where forecasts are unnecessary. The system becomes very responsive to demand fluctuations. This is the wisdom behind Just-In-Time (JIT) manufacturing systems.

It is also instructive to consider what controls cycle time and inventory rather than how it is controlled. Earlier I suggested that formal planning systems like MRP or MRP II are the sole basis for the Planning Loop. Should manual review of inventory levels govern order releases, then the Planning Loop is subject to *open-loop control*. In such an open-loop or Reorder Point (ROP) system, material flow is coordinated primarily through human interaction rather than item forecasts and leadtime offsets. Scheduling conflicts are resolved by negotiation or prioritization schemes which may be difficult to characterize. Nonetheless, ROP effectively breaks the Planning Loop, using a planner to supplant the functionality of an information system to impart some measure of cycle time and inventory control. In this work, both MRP and ROP inventory control will be considered. I will describe a supply chain with elements of both, but a structure which prevents formal planning according to either system .

In summary, the Planning Loop is an effective way to show the interrelated nature of lead time, variability, inventory and ultimately cycle time. As a lynchpin for MRP II, the Planning Loop provides an effective backdrop for understanding supply chain management by integrating elements of the material and information flows. Through consideration of the manufacturing control system, it provides an instructive way to interpret 10X. Symptomatic and periodic control are insufficient to achieve 10X cycle time reduction. As will be shown, quantifying demand variability and forecast accuracy and proper safety stocking do relatively little for the 10X challenge -- this is working at the edges. The core of 10X improvement is focusing on long lead times and the structure that promotes them. This work is an attempt at describing the *structural impediments* to conceptualizing all three of Fisher's Expectations, not just 10X.

1.2 Motivation for Holding Inventory and the Focus on Safety Stocks

De Groote describes five basic models of inventory theory: seasonal stocks, cycle stocks, decoupling stocks, safety stocks and pipeline stocks.[7] Each is characterized by one economic reason for holding inventory. This thesis considers one of these models, safety

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[7] Xavier de Groote, "Inventory Theory: A Road Map," Teaching Note, Department of Decision Sciences, The Wharton School (December 11, 1989).

stocks, as a means for examining the impact of demand and supply variability on a part of the film manufacturing supply chain.

It is natural to assume inherent variability or statistical fluctuations associated with any process. In a manufacturing setting, variability comes in many forms:

- process yield
- material lead time
- customer demand
- planning lead time
- forecast error

Inventory can buffer against variability in all the above. *Safety stocks, as discussed herein, will be that inventory necessary to buffer against variability in material lead time and customer demand (actual or forecasted) to maintain a target service level to the immediate downstream customer.* In practice, inventory has many components often undistinguishable from one another. Production planning and stock replenishment in complex systems subject to manifold sources of variability make difficult rigorous distinctions among seasonal, cycle, decoupling, safety and pipeline stocks. My focus on safety stocks derives from a need to keep the analysis of variability and the material planning systems simple and compelling.

1.3 Key Definitions

In keeping with the Kodak definition, cycle time includes the time from fixing an order of raw materials through to customer delivery. Cycle time includes time in inventory. Lead time, on the other hand, includes time from fixing of customer order through fulfillment of that order such that the material is available for downstream consumption. Figure 1.2 shows how the definition of cycle time includes lead time and time spent in inventory.

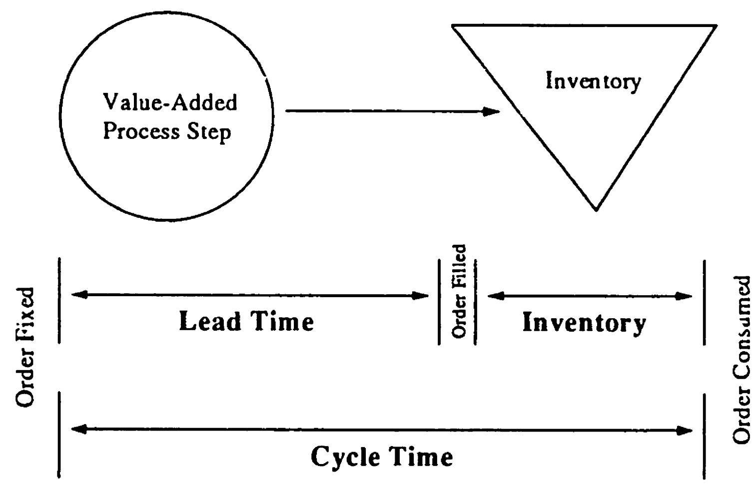

Figure 1.2 Definition of Cycle Time

The time spent in inventory is calculated by dividing the units of inventory by the average demand per unit time. Other key definitions which will be helpful to consider throughout this work include:

- Flow - the movement of information and material wholly driven by and meant to serve the customer.
- Function - a distinct element of the flow, usually with unique technologies and practices. Can be inanimate, like a process step or inventory, or animate, like demand planning or sales forecasting.
- Supply Chain - the domain of functions that makes the information and material flow relevant to serving customer needs.
- Demand Variability - fluctuations in final customer demand or variability in orders placed by a downstream function
- Supply Variability - variability in the supplier's yield, lead time, quality and manufacturing process time

2. The Film Manufacturing Supply Chain

The film manufacturing supply chain is a complex assemblage of people, products and processes. Perhaps the greatest driver of the supply chain's complexity is its comprehensive scope: "We begin with cow bones and produce color film products. You can't get much more integrated than that."[8] Figure 2.1 shows an overview of the film manufacturing supply chain broken into its three components, the Roll Coating Division, the Film Manufacturing Flow and the Line of Business. This work was primarily conducted in the Film Manufacturing Flow, with the information flow study requiring some investigation of Line of Business practices. In contrast, Bill Hetzel's work was sponsored by the Roll Coating Division and extended to the supply chain level. For a more detailed presentation of the film manufacturing supply chain, the reader is urged to consult his work.[9]

The Film Manufacturing Flow (FMF) transforms film support supplied by Roll Coating into packaged film for distribution. The Lines of Business, e.g. Consumer, Professional or Motion Picture Film, are responsible on a regional basis for distributing finished goods to customers. The FMF is a matrix organization, consisting of resources shared across multiple product families. My work was conducted within the context of just one of these product families. In the sections that follow, I describe the structure of the FMF in terms of its processes, its product architecture, and its people and measures as each pertains to this product family.

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[8] Quote from a former VP and General Manager of the Photographic Products Group, as captured by John Preuninger, "Kodak: Control Through Information Management," Harvard Business School, Case 9-191-060, Revised (March 29, 1993), pp. 3-4.
[9] Hetzel, *op. cit.*, pp. 17-20. For additional background on film manufacturing and Kodak culture, the reader is urged to consult H. Kent Bowen et al, *The Perpetual Enterprise Machine: Seven Keys to Corporate Renewal Through Successful Product and Process Development* (New York, NY: Oxford University Press, Inc., 1994), p. 350 and Preuninger, *op. cit.*, pp. 3-7.

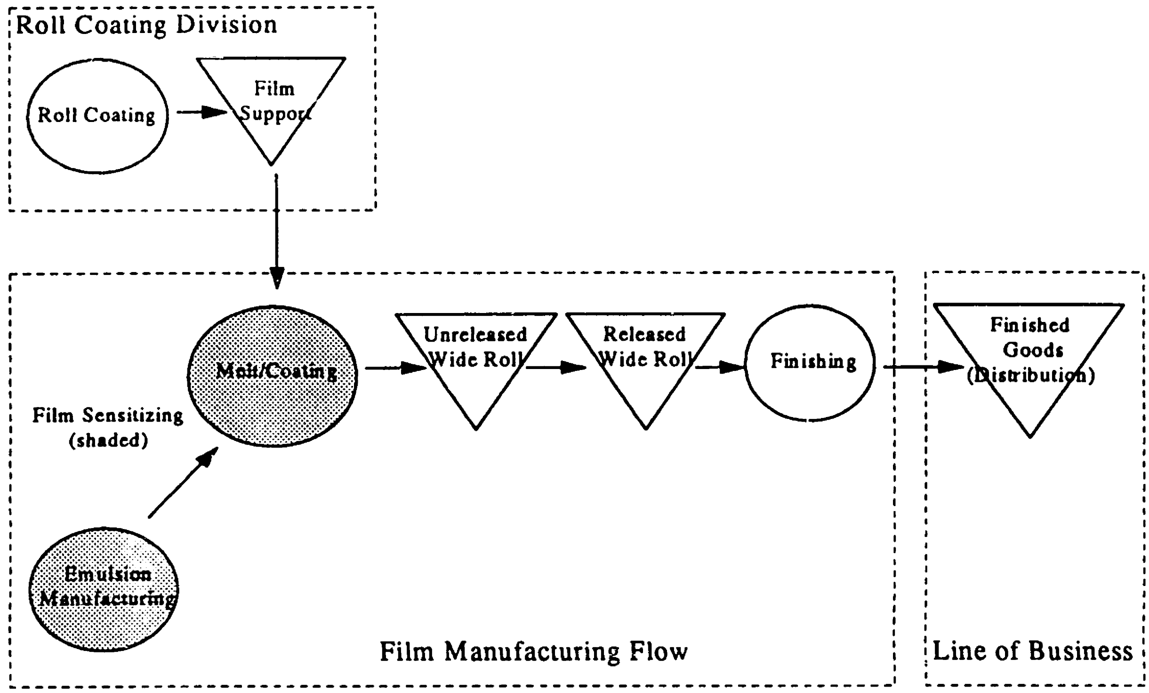

Figure 2.1 Overview of Film Manufacturing Supply Chain

2.1 The Film Manufacturing Flow - Processes

The Film Manufacturing Flow (FMF) represents the core of the Film Manufacturing Supply Chain, a vertically integrated supply chain with many items sole sourced from the Kodak Park Division in Rochester, New York. Each stage in the FMF manufactures in batch fashion and is decoupled with inventory. FMF consists of Sensitizing and Finishing Operations along with Wide Roll storage.[10] Sensitizing is a capital intensive process involving the melting and high-speed coating of multiple layers of photosensitive emulsion, supplied by the Emulsion Manufacturing Unit, onto clear film support supplied by the Roll Coating Division. Upon windup of the master rolls of film after the coating operation, the film or "wide roll" enters unreleased storage. Here the film sits, undergoing aging and multiple tests to insure quality specifications are met prior to release for use in downstream operations. This release process is very complex and will be discussed in

[10] Emulsion manufacturing also maintains some inventory, but an amount considerably less than the other functions. For this reason, emulsion inventory is excluded from the diagram.

greater detail in Section 4. Finishing converts released wide roll, via slitting, spooling and perforating operations, into various packaged formats for Distribution. In this work, discussions of the FMF will include Distribution; Roll Coating is not a part of this investigation.

All production processes are conducted in batch fashion and in the absence of light. Cost and quality considerations drive long production runs in the coating facility. First, the coating "room" is managed as a bottleneck resource, with long runs favored over product changeovers. Second, product consistency is a concern since the quality of wide roll is extremely sensitive to raw material quality and coating parameters. To drive consistency and minimize waste, coatings are scheduled as infrequent campaigns or "events," generally producing enough wide roll to satisfy many weeks of demand for a particular product.

2.2 The Film Manufacturing Flow - Product Architecture

FMF serves fragmented markets with thousands of products based on hundreds of emulsion formulations. We can consider the product architecture in terms of a bow tie configuration shown in Figure 2.2 (all numbers are approximate).

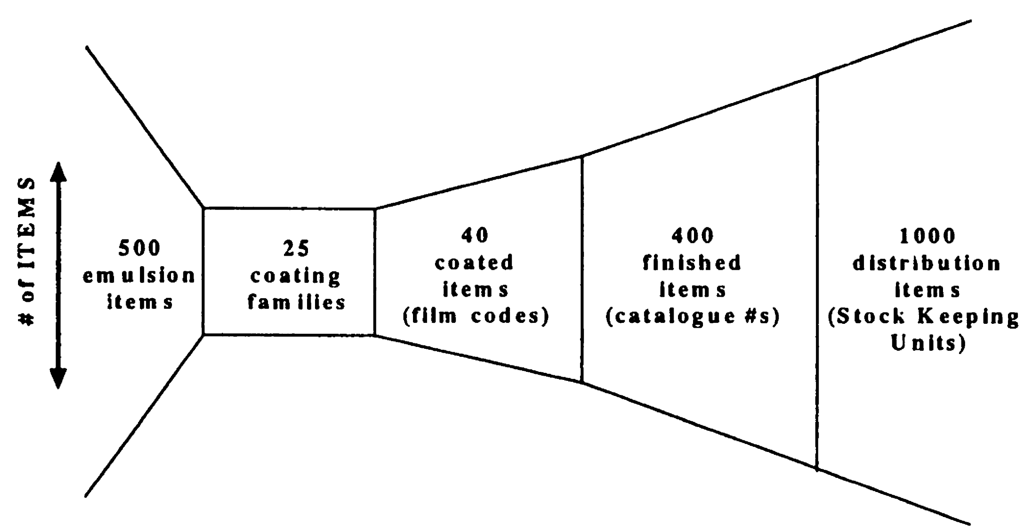

Figure 2.2 Film Manufacturing Flow - Product Architecture

Key points of this figure are listed below.

- Many different emulsion items go into an emulsion layer. Many emulsion layers get coated onto film support. This accounts for the twenty-fold consolidation of items.
- A coating family is an emulsion-specific designation characterized by closely related film imaging features (e.g. speed and color). As such, a coating family can comprise multiple film codes.
- The order-of-magnitude explosion of coated items in Finishing results from different cutting formats and packaging configurations.
- The Central and Regional Distribution Centers account for the thousand Stock Keeping Units.

2.3 The Film Manufacturing Flow - People and Measures

2.3.1 People

FMF is managed as a matrix organization to facilitate sharing of engineering, production, planning and testing resources across multiple families of products. The organizational structure in Figure 2.3 shows how this matrix is configured, including the Line of Business (LOB) and Marketing.

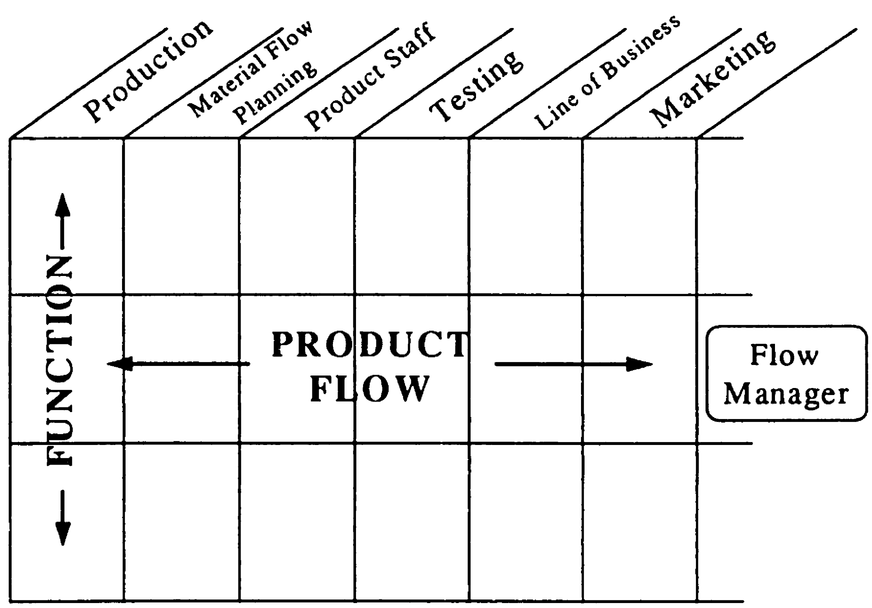

Figure 2.3 Film Manufacturing Flow - Organizational Structure

Further complicating this structure is the matrix reporting described below:

- Business Unit has responsibility for regional LOBs, Marketing, and Supply Chain Manufacturing and Logistics which includes Demand Planning, Sales Forecasting and the associated MRP II information systems.
- Plant Manager has responsibility for Production (Sensitizing and Finishing Operations) and Material Flow Planning.
- The Flow Manager reports directly to the Plant Manager and has a dotted-line reporting relationship with the Business Unit Manager.
- Managers of Manufacturing and Materials ("M cubeds") are the liasons between Production and the Business Unit.

2.3.2 Measures

Although FMF is managed as a matrix, it is very much an assemblage of functionally oriented organizations. The primary measures of these functions, for which the Flow Manager is responsible, are listed in Table 2.1.

Functional Entity	Primary Measure
Marketing	Sales
Line of Business	Customer Service (Item Level Delivery)
Material Flow Planning	Inventory
Production (Sensitizing and Finishing)	Unit Manufacturing Cost
Product Staff	Quality and Coated Yield
Testing	Customer Response

Table 2.1 Functional Performance Measures of the Film Manufacturing Flow

The production portion of the FMF, Sensitizing and Finishing Operations, is evaluated as a cost center on an aggregate basis at the plant level. Cost goals are determined by the yearly budget, referred to as the Manufacturing Annual Operating Plan (MAOP). The MAOP is broken down into a Finishing AOP and a Sensitizing AOP to permit a budgetary evaluation of the respective operations managers. The MAOP is determined as part of the monthly Sales and Operating Planning (S&OP) process which sets production volumes, product cost, and requirements for labor, capacity and raw materials. The S&OP is the business plan charted over an 18-month rolling horizon and agreed to by the regional managers of the LOB, the M cubeds and the Flow Manager. The S&OP also establishes quality and delivery goals for the flow. Quality goals are established in concert with the Product Staff and Testing. Delivery goals are established in concert with SCM&L and the regional LOBs.

The Flow Manager is measured against cost, quality and delivery goals for a particular product family aggregate. In discussing his role, the Flow Manager sees his job as 'making the schedule that Marketing provides.' Cycle time and inventory are not primary flow measures.

2.4 The Film Manufacturing Flow - Complexity and MRP II

At every level, Sensitizing is a complex system. Complexity is partially derived from the interactions of functionally driven people with sophisticated processes to generate a broad product line in high volume, with high quality and low cost. The number and stringent specifications of chemical components going into a master roll of film make formal stock replenishment strategies complicated. The economies of scale in combining coated items into coating families further complicates production planning: a high volume family may consist of items of varying demand levels, thereby complicating the Bill of Materials and inventory control. Cost effective management of the Sensitizing flow is made more complex by time and material buffers and supply and demand uncertainty. We must also consider the impact of capacity constraints.

To sort out this complexity and better coordinate operations across functions, extending from Sensitizing into the Business Unit, investments were made in the late 1980s/early 1990s to implement Manufacturing Resource Planning (MRP II). A former manager of Materials Flow Planning explained:

> MRP II is a structured manufacturing discipline. It necessitates rigid discipline and adherence to a plan. The plan starts with the market's requirements and then flows backwards through the manufacturing cycle. Only the exact quantity of product required is made -- no more, no less. If that means a machine sits idle, that is better than building up inventory. The real key to its success is commitment.
>
> Through MRP II we felt we could reduce our finished goods and work in process inventories...A side benefit would come from understanding the bottlenecks in the manufacturing process and knowing where improvements should be made. Improvements would allow us to cut our cycle time and improve delivery performance.[11]

The MRP II systems architecture relevant to the FMF is shown in Figure 2.4.

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[11] Preuninger, *op. cit.*, p. 8.

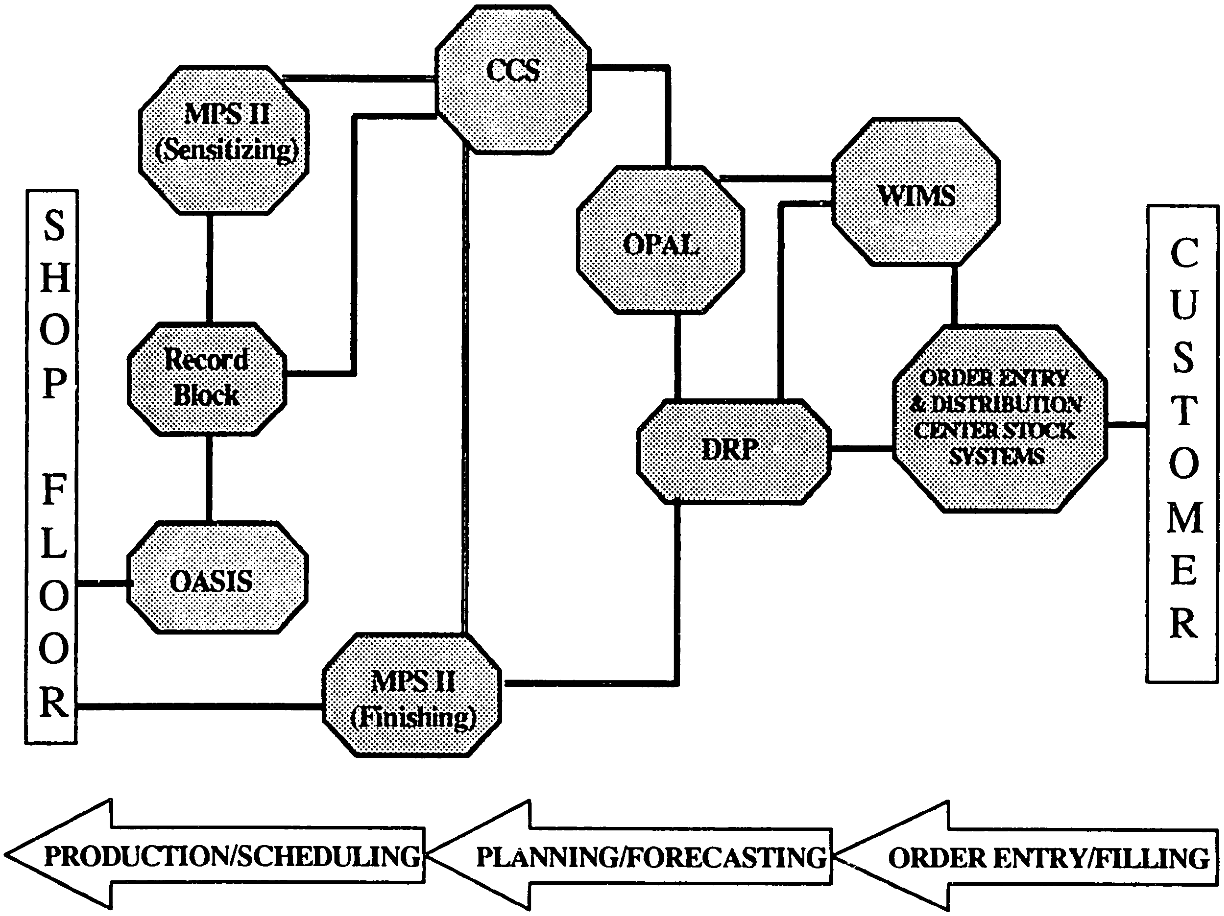

Figure 2.4 Film Manufacturing Flow - MRP II Systems Architecture

Some benefits of coordination have been realized. In the last four years, the Film Manufacturing Flow has witnessed a 36% reduction in cycle time; yet much remains to be done. For perspective on the existing opportunities for improvement, I will invoke a comparison with pharmaceutical industry. In the time it takes to go from placement of an order for a roll of film support through sensitizing, finishing and distribution and into the hands of the customer for the investigated product flow, a world-class pharmaceutical laboratory can produce the first 10 kgs. of a new bulk drug starting from a bench-scale process which supplies but 10 grams. What business do I have comparing film *manufacturing* with pharmaceutical process *development*? Where does all the time go? These questions are best answered in terms of batch size and inventory:

> A common rule of thumb (the "95/5 rule") is that products, information, or paperwork spend only 5 percent (or less) of their total process cycle time having value added and the rest just sitting and waiting or being unnecessarily moved around. Large batch sizes exacerbate this stretching of cycle times. In manufacturing processes, for example, a component must wait in front of a given operation until batches in front of it are finished, and then again while all other aparts in its batch are being completed...Batching is harder to see in business processes but nevertheless creates delays, as when a batch of orders is sent from sales to a warehouse only once per week.[12]

Excluding the wide roll age time, the 95/5 rule applies directly to the FMF. But, whereas 95% of drug process development cycle time is generated by lab work in an effort to *reduce* the complexity of the process (for subsequent large-scale implementation), the FMF's non-value added cycle time component derives from means to *accomodate* complexity, either through planning lead times or emulsion/wide roll inventories. Any efforts to break the 95/5 rule and accelerate the flow of sensitized goods requires an understanding of the existing complexity. It is the overarching goal of this work to enable 10X cycle time reduction by generating this understanding relative to issues concerning the information flow and major sources of variability.

2.5 Motivation for Studying Information Flow and Demand Forecasting Issues in the Film Manufacturing Flow

For the studied product family, the Film Manufacturing Flow is responsible for major portions of the supply chain cycle time (48%) and inventory investment (56%). For the FMF, wide roll inventory represents 68% of the cycle time and 79% of the inventory investment. Clearly, wide roll inventory constrains cash as well as consumes substantial portions of cycle time. In the face of corporate goals for 10X cycle time reduction and a 2X reduction in the cost of poor quality, it becomes obvious that this inventory must be slashed. But, with expectations for customer service improvement simultaneous with these cost and cycle time reductions, this slashing must be rationalized. Rationalizing

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[12] Adapted from Stalk and Hout, *op. cit.*, p. 76, via Arnold Levine and Jeff Luck, *The New Management Paradigm: A Review of Principles and Practices* (Santa Monica, CA: RAND, 1994), p. 19.

inventory to accelerate the flow of goods requires a full understanding of why the inventory exists and this returns us to variability:[13] what are its sources? how well is it predicted? what uncertainty remains? what safety stock is necessary to cope with this uncertainty? In this work, I will attempt to answer these questions as they relate to demand for a subset of Sensitizing products for an FMF product family.

There currently exist no formal answers to the above questions. Many sources of supply and demand variability are known to exist, but there is no clear understanding of the primary ones. Nor is there an understanding of how well forecasts predict demand and how the resulting error impacts inventory policy. Safety stock policies are not data driven to account for this error relative to service level targets. Instead, ad hoc policies are followed, using past experience as a primary determinant of appropriate levels of wide roll stock. In the interest of incremental cycle time reduction, a cross-functional supply chain team was established prior to the start of the internship to address some of these issues. For simplicity, I will call this team Team X. Strategic inventory placement was one of the primary thrusts of Team X. My investigation was to feed into this Strategic Inventory Placement effort -- to first quantify the demand variability and then manage it with inventory to maintain target service levels at lowest possible cost to the supply chain.

The handing down of corporate mandates for 10X cycle time reduction redefined supply chain optimization. The Team X effort was suspended in favor of reassessing operations and ongoing improvement activities. To the extent that Sensitizing production is driven by MRP II practices which link Manufacturing with the Business Unit, the business processes of managing information and stock levels were called into question at a fundamental level.

1. What is the current state?
2. Where do we have to be?
3. How are we going to get there?

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[13] Among other things, inventory also exists due to economies of scale which may dictate large lot sizes and result in cycle stock. Although discussed where appropriate, lot sizing and cycle stocks are not the focus of this paper.

A simple goal like "10X in three years" goes a long way toward answering the second question. But, along with this goal, a rich understanding of the answer to the first question is necessary to begin to suggest feasible scenarios. As part of this enabling process, Supply Chain Logistics Strategies were crafted for a complementary product flow. It is expected that the work reported here will contribute to the laying out of similar strategies for the studied product flow.

Much work in Sensitizing is already underway to meet 10X. There are two cross-functional efforts focused on increasing coating frequency and reducing coating lot sizes using an A/B/C product classification. The need for demand variability and safety stock analysis is elevated since smaller lot sizes lead to reduced cycle stock. With lower average inventory during the order period, the vulnerability to downstream demand uncertainty increases as does the risk of a stockout. Characterization of the forecasting process, including an understanding of the sources of variability and the relationship of horizon and error, is a necessary step to improving the information flow and cashing lead time reductions. As will be shown, the Planning Loop can not be driven toward the virtuosity of fast cycle time without the coupling of information and material flow.

Furthermore, at the time of this study, Sensitizing was endeavoring to achieve MRP II Class A certification. This investigation and the associated findings should be expected to contribute to this effort as well.

2.6 Related Work

2.6.1 Bill Hetzel's Thesis

The prime impetus for this study were the results of an internship sponsored by the Roll Coating Division in 1992. As part of his thesis *Cycle Time Reduction and Strategic Inventory Placement Across a Multistage Process*, Bill Hetzel reported on work with a Supply Chain Optimization Team which studied the flow of a subset of products through a simplified manufacturing supply chain consisting of Roll Coating, Sensitizing and

Finishing. Using a Dynamic Requirements Planning model developed at MIT, the team investigated stocking policies across the chain. Among other supply chain variables, e.g. cost, lead time, production frequency, demand and service level, the model incorporated variance of forecasts of actual demand to optimize the trade-off between production smoothing and inventory variability. A study of the information flow was also integral to the model building and subsequent analysis of results. The team uncovered many issues which are relevant to this presentation. They include the following:

- systematic errors in demand forecasts, suggesting a problematic forecasting process
- a disconnection in the annual planning process between Sensitizing and Finishing, with each function relying on separate inputs
- lead time reductions directly translate to reduced inventory levels
- a 50% reduction in forecast variance can lower inventory levels by more than a 50% reduction in lead time
- forward looking inventory targets set in terms of weeks supply and cascaded demand forecasts together drive excessive inventory build-up, especially upstream in the supply chain

This last point refers to the Springboard Effect, an important phenomenon contributing to long cycle times. I describe this and other information flow issues for a different product flow. Using a more simplistic, focused analysis of a subset of film codes, I will substantiate issues relevant to demand forecasts and safety stocking. Insights obtained through analysis and observation of the supply chain information flow will also be used to extend Hetzel's findings to a 10X environment.

2.6.2 The Beer Game

Halfway through the internship, Sensitizing sponsored a Supply Chain Simulation based on the Beer Game.[14] Representatives from Roll Coating, the Film Manufacturing Flow and the Business Unit attended, including an even distribution of folks from the physical flow (production) and the information flow (planning). The overarching goal of this half-day workshop was to increase the capability of the supply chain personnel in their attempts to meet new corporate goals (i.e. "Fisher's Expectations") for cycle time and cost reduction together with customer service improvements. The workshop observations and survey responses were used to provide insight into the most pressing issues facing the supply chain. As such, they serve as a substantiation of the current state of the supply chain and help to guide and frame this investigation. These issues, captured as three key learnings with relevant quotations of workshop participants, include:

1) More education and understanding of the supply chain are needed before the capability to improve exists.
   - "Encourage the free flow of education."
   - "People need a lot more education in general. You can't have the 'will' [to improve] until you understand what you're trying to do."
   - "We need to share information and work together to win."
2) Goals, objectives and metrics must be carefully chosen, aligned and shared.
   - "We try to do well on what we're measured."
   - "There is a need to work as a team with planning and manufacturing, but there are fixed roles and communications."
   - "People aggregate the metrics to the point that they have no meaning [such that] on average, we're doing fine."
3) A long, disconnected information flow can amplify uncertainty along the supply chain.

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[14]For more information on this supply chain simulation, consult John Sterman, "Instructions for Running the Beer Distribution Game," Teaching Note, System Dynamics Group, MIT Sloan School of Management, (October 1984) and Peter Senge, *The Fifth Discipline: The Art and Practice of the Learning Organization* (New York, NY: Doubleday/Currency, 1990), pp. 27-42.

- "Way too many steps in the communication line."
- The customer demand pattern is not obvious to the middle of the supply chain: "[we're] in the dark...disconnected." "I thought we were seeing a seasonal pattern and I expected it to wash out."
- "Why didn't [the distributor] just yell [the order]...why aren't things more up-to-date?"

From the above reactions, it was clear that the Beer Game Simulation was successful in enhancing cross-functional understanding of the impact of time lags and functionalized behaviors in amplifying demand variability. I endeavor to substantiate these observations with real data from the product flow. In this way, my work can be viewed as an extension of the Beer Game with the primary goal of education and increased understanding as requested in item 1 above.

2.6.3 Safety Stocking 201

A product flow associated with a different business unit than the one considered in this study has implemented formal safety stocking policies which account for forecast error over the leadtime horizon.[15] Safety stock levels are set according to a simple formula which I will refer to as the Kodak Base Stock Method, or simply the Base Method. This method of setting safety stocks is presented below and will be defined and discussed in detail in Section 5.

<u>Kodak Base Stock Method</u>

Safety Stock = Leadtime Horizon * Demand Variability * Safety Factor

I will use this relatively simple model to accomplish three things:

1. show the inappropriateness of current blanket safety stock standards relative to actual production and demand data;

[15] For details on the formulation of this policy, see Robert Bucci, "Safety Stocking 201," Seminar Notes, Eastman Kodak Company (September 1993).

2. illustrate the inventory savings across a product subset derived from improved forecasts;
3. suggest the model's oversimplification relative to lead time variability by applying a stock model more appropriate for the current system.

I will examine the current state of stocking policy by examining inventory profiles for a group of items. Coupling this quantitative assessment with observations of the information flow, I will then make the claim that safety stock and demand variability have little bearing on the current state of wide roll stocking other than speculation. As will be shown, the planner is caught in a reactive mode due to long and uncertain wide roll lead times which inhibit any formal inventory control, including safety stocking.

3. Thesis Overview

3.1 Problem Scope

This thesis raises issues relevant to flow improvement for a complex supply chain. The primary measure of this flow improvement is cycle time. The primary focus of this thesis is a discussion of the inventory component of cycle time as a function of variability. I will carry out this discussion on two levels, one general and one specific. The general discussion will involve a consideration of the film manufacturing supply chain, from Sensitizing out through to the customer. To establish context for the supply chain analysis, the structure of the information flow is described in the next section. This provides background to launch into the specifics of this work. In Section 5, I describe demand variability, forecasting, supply variability and inventory management issues within Wide Roll Planning. I then return to the supply chain in Section 6 to provide explanation for the behaviors identified in Wide Roll Planning. I suggest some of the primary causes for the observed behaviors of poor forecasts, reactive scheduling, variable demand and variable supply, long cycle times and large inventories. Actions to resolve the issues ("Fixes") presented in earlier sections are discussed in Section 7. In Section 8, I discuss insights as they relate to the existing improvement activities and unresolved issues of flow control. Ultimately, I argue that the real opportunities to make progress toward Fisher's Expectations involve people recognizing that the Film Manufacturing Flow is not a flow. Its functional structure to manage information and material promotes the observed behaviors and it is this structure which managers have to commit to changing before any real improvement will be observed.

3.2 Problem Approach

The research for this thesis was conducted at many levels within the supply chain. Primary data sources included individual interviews, cross-functional teamwork and first hand observation of the Beer Game simulation. It should be noted that this sometimes ad hoc research methodology grew out of the breadth of the initial internship charter (supply chain optimization) and the organizational flux experienced by the host film flow. Initially, this research was to complement the efforts of a cross-functional team working toward a 50% reduction in cost-weighted flow time by year-end 1995, measured against a 1990 baseline, for a particular family of products. Corporate mandates for exponential rather than incremental cycle time improvement redefined the environment halfway through the internship, however, making this team obsolete in its current form, while at the same time elevating the need for a more unified, strategic approach to operations. The nature of the research and the structure of this thesis reflects this turn of events in that, upon defining the larger context and presenting functional issues of demand variability, I revisit the supply chain to discuss the implications of my findings relative to 10X.

3.2.1 Interviews

This was the first internship conducted by a non-Kodak employee in the host film flow and, as such, afforded the author "the license to ask the dumb questions" in ferreting out the major opportunities for flow improvement. The complexity inherent in the manufacturing supply chain necessitated a substantial induction period to achieve familiarity with the various functional areas, formal and informal linkages and existing teams. Lacking this systems view of the host would have hampered my supply chain assessment, potentially yielding recommendations actionable for a particular function's gain, but at the expense of the entire flow and ultimate customer. For instance, prescribing reductions in inventory for one function may not reduce the inventory investment across the supply chain if target service levels are maintained.

A considerable portion of the data on which this work is based was collected over three months during 60-90 minute interviews with people throughout the film flow. These interviews were conducted to gain an understanding of the interviewee's specific job function and current issues facing them in their work. The data from these interviews was then used to map out and make a rough assessment of both the material and information flows, in each case highlighting issues critical to flow improvement efforts. Criticality was determined by the frequency of mention of the issue coupled with a subjective assessment of the cycle time implications of not addressing the issue. Kodak input helped steer this work toward the information domain where there existed substantial opportunity for increased understanding of demand variability and its impact on cycle time and inventory; hence, the focus of this thesis.

3.2.2 Teamwork

Three teams were established early on in the internship to improve Sensitizing throughput by investigating a prioritized production scheme - ABC scheduling of coated items. Teams were established for each coating facility and the emulsion manufacturing unit. The work of these teams provided a forum to gather rich insight into the behaviors resulting from the current structure of the FMF. These insights are presented in Section 8 to shed light on issues pertinent to implementing change in FMF.

3.2.3 Data Collection

As stated earlier, the initial basis for the internship was work with a cross-functional team, Team X, to identify opportunities for cycle time reduction for a specific family of products. At the start of Team X's Strategic Inventory Placement investigation, a product subset of four coated items was chosen to delve deeper into issues of demand variability. Weekly demand forecasts were collected manually from printouts for the four items. [Forecasts are written over weekly in the MRP II systems, so weekly reports were saved to capture the data.] Four other coated items were later added to the product subset to round out the investigation. Weekly reports, and therefore, forecasts were not available for these other items. Weekly demand actuals were tracked manually for all eight items. Collection and analysis of this data was coordinated with the Wide Roll Planner, who also supplied information on the unit cost, planned lead time and inventory standards for the eight items as captured in the 1995 Wide Roll Annual Operating Plan.

To supplement this information on weekly demand variability, 3.5 years of monthly coated-item demand from Finishing was collected with the aid of a database manager in

Management Services Division. 3.5 years of monthly coated-item demand from Distribution was collected with the aid of a Demand Planner. This demand history was derived from a monthly summing of Distribution's replenishment orders for end items common to a specific coated item.

To gain an understanding of downstream demand variability, monthly forecasts and demand actuals were collected from reports for a limited selection of finished items (cat#s). Eight months of data was collected with the aid of the Master Production Scheduler.

Lead time distributions for the four original coated items of the eight item sample were collected for the period of January 1993 through November 1994 with the aid of a database manager in Management Services Division. For each wide roll released during this time period, the data of order commitment was established. The lead time was then determined as the time elapsed between order commit and roll release.

Table 3.1 below summarizes the data collected for this investigation.

Data	*units*	*product subset*	*horizon*	*data source*	*coordinator*
Demand Forecasts	film units per week	4 original coated (ctd) items	48 weeks of 1994	MPS II	Wide Roll Planner
Demand Forecasts	film units per month	selected finished items	8 months of 1994	OPAL	Master Production Scheduler
Demand Actuals	film units per week	8 ctd items	48 weeks of 1994	CCS	Wide Roll Planner
Demand Actuals	film units per month	selected finished items	8 months of 1994	OPAL	Master Production Scheduler
Demand Actuals	film units per month	8 ctd items	1991 - 1994	Record Block	Management Services Division
Demand Actuals	film units per month	8 ctd items	1991 - 1994	DRP	Demand Planner
Inventory	rolls per day	4 original ctd items	48 weeks of 1994	Record Block	Management Services Division
Lead Time	days per roll	4 original ctd items	1993 - 1994	"Mega database"	Management Services Division
Lead Time, Inventory, Unit Cost Standards		8 ctd items	1995	Annual Operating Plan	Wide Roll Planner

Table 3.1 Data Collection Summary

3.3 Summary of My Findings

Supply Chain Information: The Structure of Planning, Scheduling, and Material Management

A tortuous flow of information is created by the use of a complex MRP II systems architecture overlayed on a functionally driven assemblage of planners. True customer demand is not captured in this system. Instead, multiple forecasts and information systems are used at every stage to arrive at a demand signal. Orders are cascaded upstream after being adjusted according to each stage's inventory targets. Coated items then proceed downstream through a release process which involves aging and much testing to ensure quality and product conformance.

Wide Roll Planning: Isolated Behavior

The current system does not fall neatly in the category of MRP or order-point order-quantity (ROP). Informal production planning and inventory control are necessary due to demand and supply uncertainty. Weekly MRP II forecasts are rightfully ignored in planning production as they bear no relation to actual demand; the demand signal transferred from Finishing is suspect. Sensitizing is effectively decoupled from the downstream chain by long lead times and large inventory which render the weekly (MPS II) and monthly (OPAL) demand signal useless for planning production. The MRP II system is further ignored in that planned lead times and actual lead times bear no relation to each other. Current safety stock standards are reasonable to account for demand variability, but are insufficient to buffer against the combination of supply and demand variability observed in Sensitizing. Overall, neither MRP nor ROP can come close to classifying the current state. The Planning Loop is broken in many places as the system is characterized by reactive scheduling. The wide roll planner has little to no control over the flow.

Supply Chain Information Flow: Aggregate Behavior Explained and Modeled

The Beer Game is alive and well in the FMF: customer demand gets distorted as it moves through the supply chain. Distortion increases the more you move upstream such that the wide roll planner is entirely disconnected from any customer activity and must react to demand shifts with second guessing and expediting. Wide roll planning does not take place in this system as much as reaction and gaming according to functional measures which promote decoupling of the supply chain.

Bottom Line

Overall, given supply and demand variability, the Film Manufacturing Flow is not a flow as much as a chain of isolated links. Functions are decoupled with policies, behaviors, information systems and physically with inventory. Fisher's Expectations cannot be approached until system variability is better characterized and functions are recoupled. The use of a Distribution demand signal in Sensitizing and changing safety stock targets hold promise for increasing supply line information, reducing handoffs and avoiding overreaction to demand shifts. Collocation of planners, dynamic modeling of the supply chain and cross-functional teamwork may help, but organizational barriers must be overcome before these apparent 'fixes' bear fruit. Management must take ownership for promoting the linkages necessary to effectively manage the supply chain. People must be held accountable for their actions; only then will they understand their consequences and close the Planning Loop to impart control over system cycle time and inventory. The underlying structure of the FMF as it currently exists does not support Fisher's Expectations. People within the FMF recognize this, but the commitment to change is lacking. As a consequence, Fisher's Expectations have remained his expectations and not become FMF goals.

After you map it, you're shocked by the complexity.

- Frank Zaffino, Eastman Kodak, VP of Equipment Division describing another Kodak flow[16]

4. Supply Chain Information Flow: The Structure of Planning, Scheduling and Material Management

4.1 Introduction

With approximately 500 different emulsion items, 25 different coating families, 40 different coated items, 400 different finished items and 1000 different SKUs, coordination of operations across functions and supply chain inventory control would be nearly impossible without the aid of information technology. As mentioned earlier, this fact has been recognized as significant investments have been made to implement and upgrade Manufacturing Resource Planning (MRP II) in film manufacturing over the last few years. Within Sensitizing, this has included customizing a portion of the Advanced Manufacturing Accounting & Production System (AMAPS) to form OASIS -- Operational Assist to Sensitizing Information System. To further improve the information flow, Sensitizing is pushing for MRP II Class A certification.

This section describes the MRP II systems, people and mechanisms in place to manage information along the film manufacturing supply chain. Starting from the customer and working upstream into the factory, I will discuss the translation of customer orders into sales forecasts, production plans and ultimately shop floor schedules. The flow of the demand signal is presented in Figure 4.1. The movement of inventory from Sensitizing out to Distribution is not shown but will be described as well. This information shall set the stage for analyzing the wide roll planning function in the next section. In Section 6, I return to the the larger system to explain the behaviors observed in wide roll as a product of the structures governing information and material flow.

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[16] Frank Zaffino, "Matrix Management at Eastman Kodak," Leaders for Manufacturing Keynote Address, MIT (April 11, 1995).

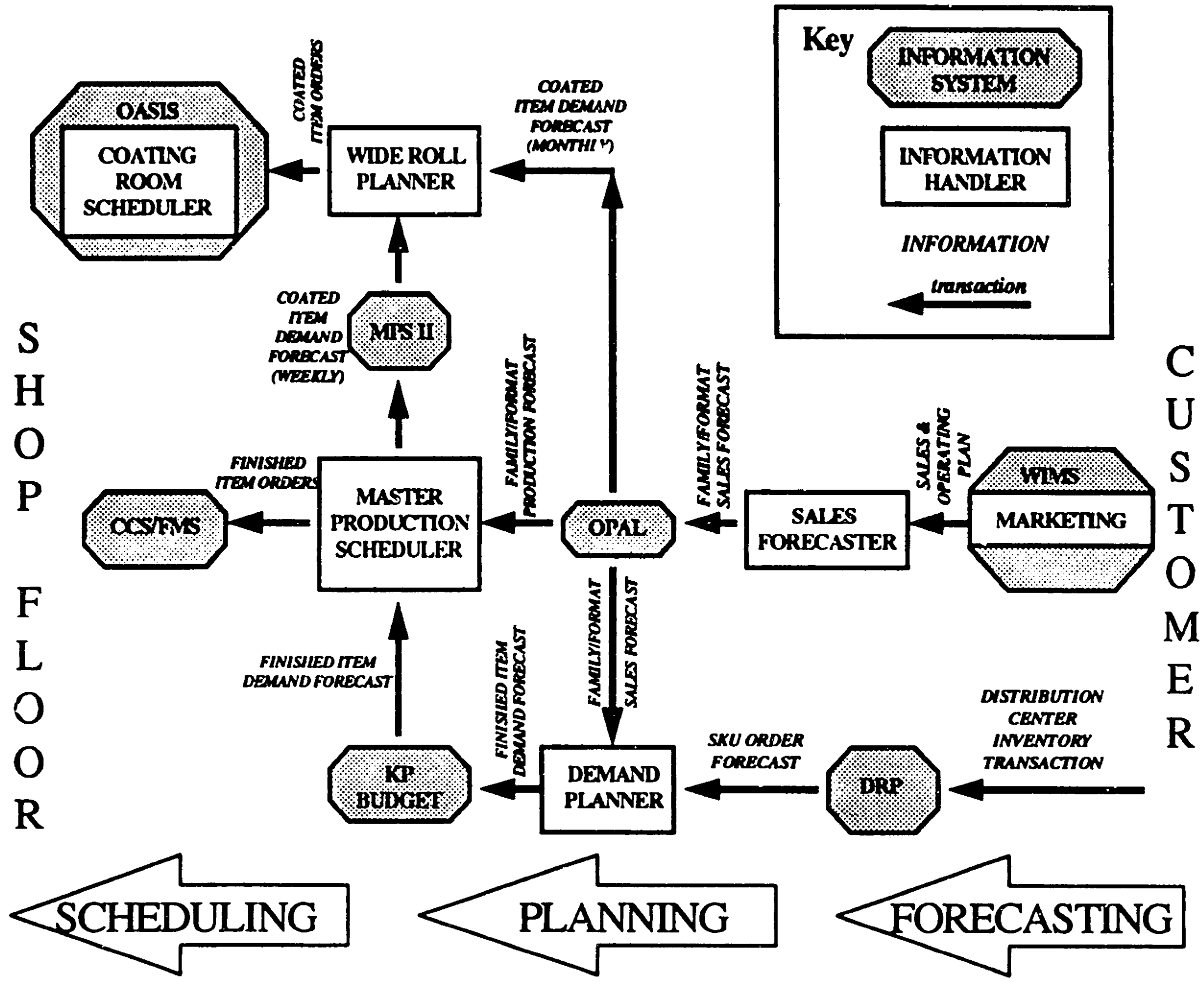

Figure 4.1 Supply Chain Demand Information Flow

4.2 Order Entry

4.2.1 Sales and Customer Orders

Customer orders are captured by the Central and Regional Distribution Centers as inventory transactions. A sale is the movement of product from either a CDC or RDC to a domestic customer or to a foreign DC or customer. Movement from a CDC to an RDC is not a sale. Stock keeping unit (SKU) shipments to fill orders are aggregated across all DCs using Distribution Requirements Planning (DRP). DRP uses SKU forecasting models to output forecasted orders on a monthly basis. The monthly sales information and order forecasts are fed to the Worldwide Inventory Management System (WIMS).

WIMS tracks actual sales information at the product family/finishing format level. The product family is an emulsion-specific grouping whereas the finishing format is a function of the packaged 'cut' of the film, e.g. roll or sheet. WIMS feeds Operational Planning at the Aggregate Level (OPAL) with production actuals, sales actuals and inventory levels on a monthly basis.

4.2.2 Forecasting and Aggregate Planning

OPAL is the planning tool for U.S.-sourced sensitized goods with routines for summing and apportioning to develop domestic production plans from sales forecasts. It is not used for capacity planning. OPAL is updated monthly as part of the Sales and Operating Plan (S&OP) process which is a strategy for emulsion family/finishing format-aggregates charted over an 18 month rolling horizon. The S&OP is agreed to by the manufacturing flow manager, the manager of manufacturing and materials, and regional managers of the marketing units, i.e. the Lines of Business or LOBs. Whereas the LOB owns the S&OP, Sales Forecasting manages it. S&OP demand and production family/format aggregates are fed to OPAL by Sales Forecasting. Sales Forecasting monthly reviews the plan versus actual demand at the family/format level and can propose making changes in the forecast to the LOB. If these changes are accepted, OPAL is updated. There are four components to OPAL output: Production Plan, Demand Forecast, Inventory Plan (Actual) and Inventory Target. OPAL information is combined with marketing intelligence to develop Annual Operating Plans (AOP) for each plant.

There are two AOPs, the Marketing or LOB AOP and the Manufacturing AOP (MAOP), both of which cover the 12 month calendar year . The LOB AOP is hashed out in June and represents what the business unit intends on selling (i.e. the sales forecast) over the next year in each of the four worldwide selling regions. The LOB AOP can be revised no earlier than September and no later than November. The MAOP is the LOB AOP translated to Sensitizing and Finishing. As such, it consists of a Finishing AOP (FAOP) and a Wide Roll AOP (WRAOP). It is formulated and agreed to by the end of July, thereby setting production volume, waste and inventory targets and generating the financials which allow product costing for each plant. Products are priced on a standard cost basis, where overhead is offset with product volume.

4.2.3 Demand Planning and Finishing Scheduling

The monthly OPAL sales forecast is received by Demand Planning from Sales Forecasting. The demand planner compares the OPAL family/ format sales forecasts with order forecasts fed by and aggregated in DRP. These two demand forecasts are supposed to be reconciled within 5% of each other to arrive at the finished item demand forecasts. It is unclear how this reconciling or "tying" activity is accomplished, nor it is apparent how close to 5% the final number comes. These finished item forecasts are then entered into the KP Budget System.

The Finishing Master Production Scheduler sees these numbers in the KP Budget System and, by finished item, ties them within 5% to OPAL's Production forecasts, netting against existing inventory levels and inventory targets (set in weeks of forward supply). In essence, the master scheduler insures that Finishing meets forecasted demand through production and/or shipments from inventory which is tracked in distribution center information systems. Using Common Converting System (CCS), the master scheduler schedules Finishing's shop floor operations for each week, observing lot size and lead time constraints for all Finishing supplies except wide roll, i.e. packaging and labels. On a daily basis, these scheduled finishing items are summed up by coated item and fed to the Master Production Scheduling (MPS II) system by way of Feasible Master Scheduler (FMS), a module of DRP. This MPS II information constitutes Finishing's demand for wide roll.

4.2.4 Wide Roll Planning and Sensitizing Scheduling

The wide roll planner sees this coated item demand information in MPS II, which nets orders against inventory levels (tracked in Record Block/Common Converting System) to generate a twelve-week forward looking snapshot of weekly coated item orders. To provide longer term demand visibility, 18 months of coated item demand, which is aggregated from the finished item demand forecast fed by the demand planner, is available in OPAL and updated monthly as part of the S&OP process. Coated-item demand is evaluated against coating event-size constraints (established by the Product Staff) to align coated item orders by coating family and enter "planned" orders in OASIS/AMAPS. This planned zone is essentially a 26 week window where orders are floated to account for changing inventory and demand levels. Planned orders are "firmed" based on the order due-date and a fixed lead time offset for the longest lead-time emulsion item. For example, an order for a coated item due in week 7 and which incorporates a three-week emulsion item and a three-week age after coating would be firmed in week 1. It is the responsibility of the coating room scheduler to go into OASIS to firm the order. After firming, the emulsion planner takes control of the order and a bill of materials is exploded to the shop floor using a mainframe. This completes the order entry process from customer to Sensitizing.

4.3 Inventory Tracking

When the Melt/Coating operation completes a coating event, wide rolls are received into Record Block/Common Converting System (CCS). Rolls are grouped according to their emulsion component and both a physical and sensitometric hold are placed on these groups to allow time for aging, testing and, if necessary, rework to insure product conformance. These rolls constitute "unreleased" wide roll inventory and are unavailable for downstream processing. Releasing wide roll is done in batch fashion, according to the emulsion groupings, and requires the coordinated efforts of the Testing/Quality Assurance organization together with the Product Staff. To release a roll, both the physical and the sensitometric hold have to be removed; generally the sensitometric hold is removed first. Status of the unreleased material is tracked in CCS and is updated according to the stage of the release process. The various stages of the release process are described in detail below.

4.3.1 Physical Hold

The physical hold is instituted to insure stability of the gelatin coating. An automatic physical hold is placed on all coated items included in this study. Testing appraisers are responsible for evaluating the roll relative to physical specs upon windup from the coating machine. If the rolls do not conform to specifications after this initial assessment, the physical hold is maintained. Responsibility for tracking and dispositioning the rolls turns to the Product Staff rather than Testing. For the studied product family, the physical hold may be extended, anywhere up to fifteen weeks, to insure physical quality specifications are met before releasing the film.

4.3.2 Sensitometric Hold

A sensitometric or "sensi" hold is instituted to insure stability of release sensitometry (i.e. the film's image characteristics) prior to finishing the film. Various coating-release testing options are used to establish product conformance and, therefore, whether to remove the sensi hold on a film roll. Each test involves some aging. The choice of test and technical issues dictate whether the Appraiser or the Product Staff is responsible for removing the hold.

4.3.3 Rework

To salvage some non-conforming wide roll, a rework process can be used in which rolls are run back through the melt/coating operation. Upon rework, the rolls reenter the testing/release process at the beginning, with both a physical and sensi hold put in place.

4.3.4 Discard

After much testing, appraisal and review, a quality engineer may decide that a roll or group of rolls can not be salvaged. The quality engineer must then submit a disposition letter to recommend discarding the item(s). The discard is negotiated with the formulation and coating engineers.

4.3.5 Released Widc Roll

After a roll or group of rolls is determined to be physically and sensitometrically conforming or is otherwise dispositioned for downstream use, the holds are removed in CCS, at which point the released wide roll can be scheduled for Finishing operations. This completes the wide roll release process. For the studied products, release time for the sensi hold - time between roll windup in the coating facility and roll release - ranges from 1 to 180 days with an average of 20 to 32 days.

4.4 Summary of Information Flow and Material Management

A tortuous flow of information is created by the use of a complex MRP II systems architecture overlayed on a functionally driven assemblage of planners. True customer demand is not captured in this system. Instead, multiple forecasts and information systems are used at every stage to arrive at a demand signal. Orders are cascaded upstream after being adjusted according to each stage's inventory targets. Coated items then proceed downstream through a release process which involves aging and much testing to ensure quality and product conformance. As will be shown in the next section, this scrupulous product control coupled with large coating events results in a broad distribution of wide roll lead times.

5. Wide Roll Planning - Isolated Behavior

5.1 Introduction

This section uses a slice of the manufacturing supply chain - Wide Roll Planning - as a forum to describe issues regarding demand variability, forecasting, production planning and inventory management. My analysis will cover a subset of products, referred to as "coated items," which are delivered to Finishing operations as film "wide roll." The eight coated items chosen are a representative cross-section of the product flow in terms of age, volume and finishing format. The subset accounts for one-third of the flow's 1995 Wide Roll Annual Operating Plan (WRAOP) cost. Using this product subset, I will examine the following aspects of wide roll planning:

- sources of variability
- magnitude of variability
- forecast error
- current safety stocking policy

Tools for my analysis include trending, statistical analysis (histograms, mean and variance) and simple stocking models. My goals are to highlight major sources of variability; quantify the impact of that variability in the form of safety stocks needed to meet service level targets; contrast these stocks with current standards and practice; and ultimately suggest means to address the existing variability. What will be shown is a planning system which is MRP II in name only; informal production planning and reactive inventory management define this system which is plagued by long lead times and substantial variability in coated item supply and demand from Finishing.

5.2 The Structure

Figure 5.1 summarizes the complex structure of the Film Manufacturing Flow by combining the production, engineering, testing and planning functions into one diagram.

The information systems used to link each function are drawn near each user. [FEDS is an information system used to track coating process parameters.]

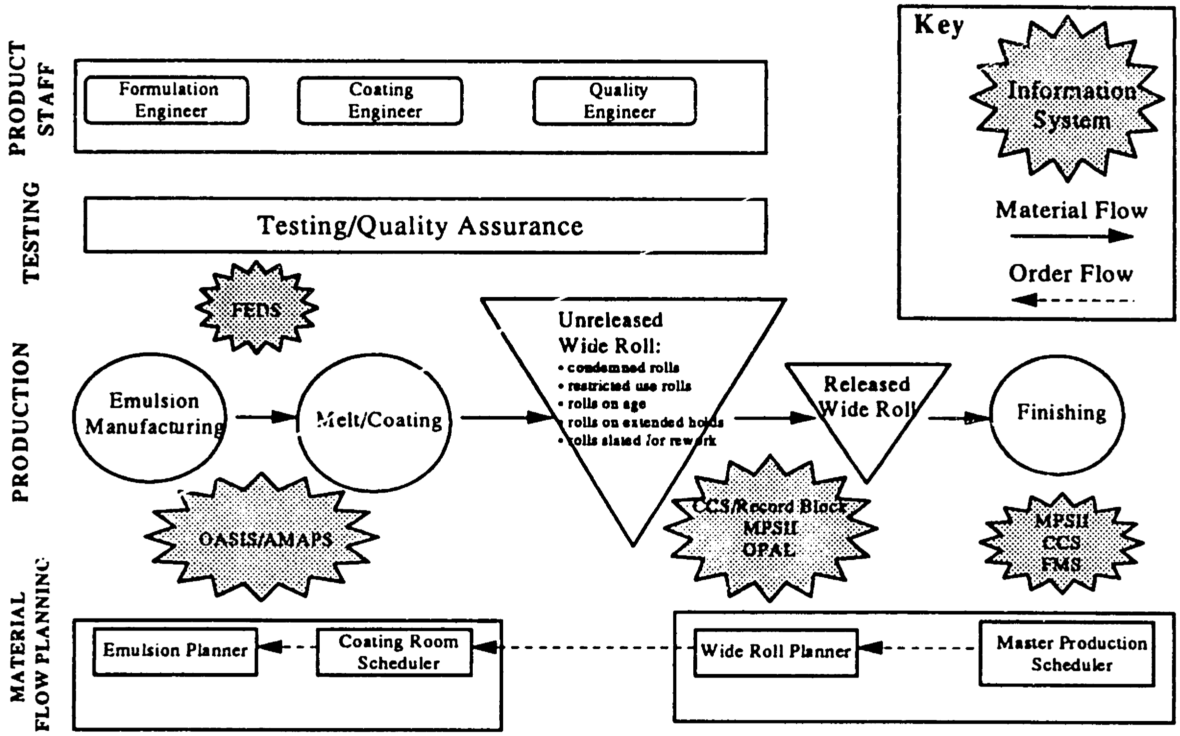

Figure 5.1 A Detailed Look at the Film Manuacturing Flow

Formally, the basis for wide roll planning is a combined system of MRP II and order-point order-quantity, also called reorder point (ROP). The two systems coexist presumably to manage the near and long-term supply of released wide roll. Whereas weekly orders are primarily used to drive long-term supply via coating room production, ROP methods are used to govern wide roll releases. De Groote describes the fundamentals of ROP as follows:

> The inventory level is automatically updated after each transaction (technically, this type of system is referred to as a continuous-review system). Whenever the inventory level falls below the chosen order-point, R, an order of size Q (the order-quantity) is placed. Due to production and transportation delays, the order cannot be filled immediately. A

replenishment period starts when an order is placed, and finishes when the order effectively arrives; the elapsed time is known as the replenishment lead time, L.[17]

In running this hybrid system for roughly 40 coated items, the wide roll planner has five responsibilities.[18]

1. receive coated item demand from Finishing in MPS II, where weekly orders are netted against inventory as tracked in CCS/Record Block;
2. group MPS II coated item orders into coating family orders, accounting for common emulsion components and lot-size constraints;
3. pass 26 weeks of planned coating orders onto the coating room scheduler in OASIS (the room scheduler then fixes these orders according to lead time offsets);
4. maintain a target level of wide roll inventory (unreleased and released) by tracking material in CCS/Record Block and working with the Product Staff to drive releases.
5. maintain a service level of 95% to Finishing for all products.[19]

The first three responsibilities define the MRP II system. The last two refer to the ROP system. Key parameters of wide roll planning are defined in Table 5.1.

Parameter	Definition[20]
R order point	total of unreleased and released wide roll inventory
S safety stock	released wide roll inventory
pipeline stock	unreleased wide roll inventory
Q order quantity	economic order quantity expressed in terms of an emulsion lot size or "melts"
L replenishment lead time	time from placing the coated item order until the order is available in released inventory

Table 5.1 Wide Roll Planning Parameters Defined

[17] de Groote, *op. cit.*, p. 8.
[18] For the purposes of this study, I will not consider interplant transactions which move coated items to other plants for Finishing. The Finishing master scheduler is responsible for these transactions.
[19] This service level refers to the percent of weeks with no stockout, i.e. insufficient wide roll available for Finishing. This is also known as Type I service.
[20] These definitions may be unconventional based on traditional definitions of inventory control parameters, but are appropriate for this discussion.

Inventory standards are expressed in terms of weeks of forward supply, or "weeks covered." In practice, this value is translated into a physical quantity based on a forecast of weekly demand. Figure 5.2 shows the expected inventory pattern for a coated item assuming a constant forecasted weekly demand.

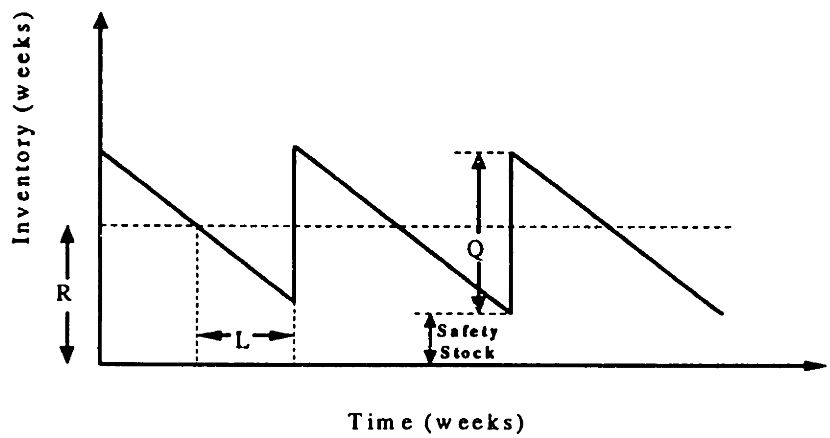

Figure 5.2 Expected Inventory Pattern for a Coated Item

This is an idealized plot. Naturally this system is subject to variability in demand and supply which skew the behavior from ideal. The next section describes this behavior.

5.3 The Behavior

Figure 5.3 is an actual release wide roll inventory profile for coated item B. It provides an indication of the magnitude of variability. Inventory profiles for three other coated items are presented in Appendix 1 and show similar erratic behavior.

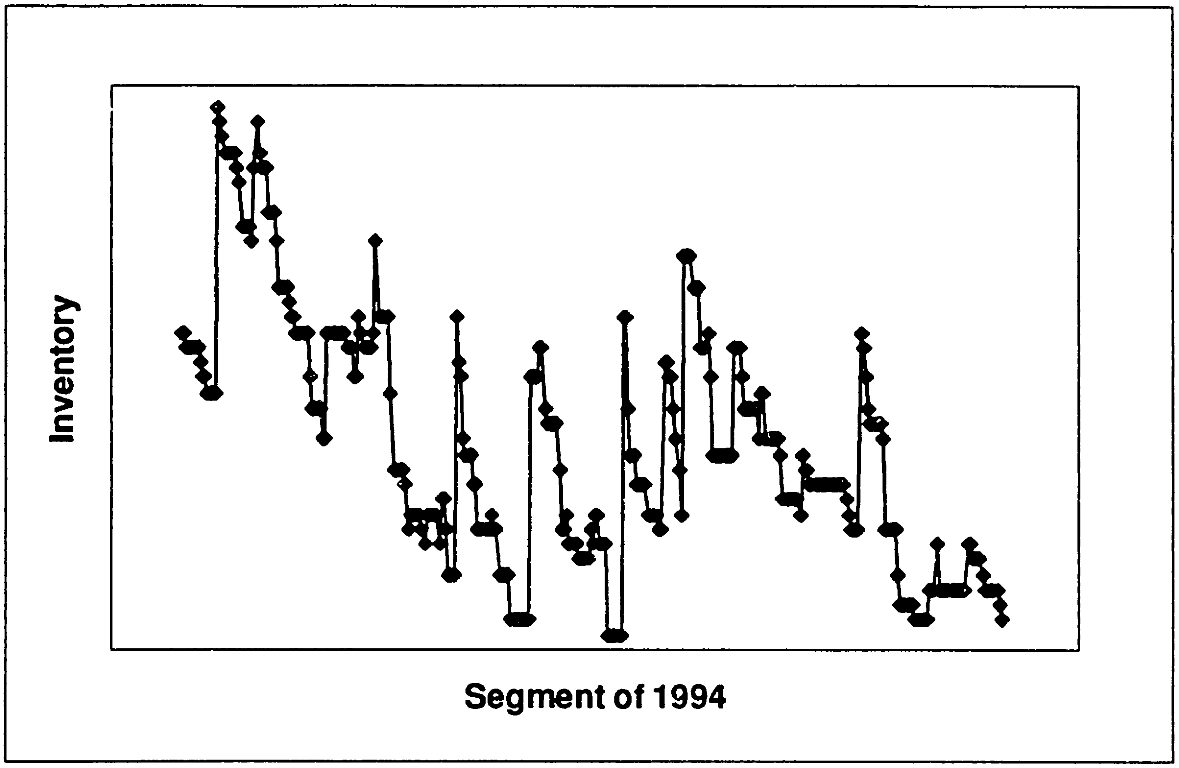

Figure 5.3 Released Inventory Profile for Coated Item B

In comparing these plots to the sawtooth profile in Figure 5.2, it is difficult to discern any formal policy in terms of the reorder point R, the order quantity Q or the replenishment lead time L. The size and arrival of orders and the level of demand are certainly more uncertain than deterministic. It is apparent that the wide roll planner is in a precarious position as he is confronted with manifold sources of variability in trying to fulfill his responsibilities and maintain inventory and customer service targets. Furthermore, his actions are constrained in that he has little control over the order size, Q, and the replenishment lead time, L. These parameters are defined by the Product Staff and Production. The planner's role is confined to tracking R, unreleased and released wide roll inventory. To do this, he must have information on variability. The sources of variability as they pertain to wide roll are described below. I then quantitatively determine supply and demand variability and I use two safety stocking models to show their impact on inventory. The 1995 inventory standards listed in the Wide Roll Annual Operating Plan are used as a basis for evaluation.

5.4 Sources of Demand Variability

Figure 5.4 shows the demand information flow relevant to wide roll planning.

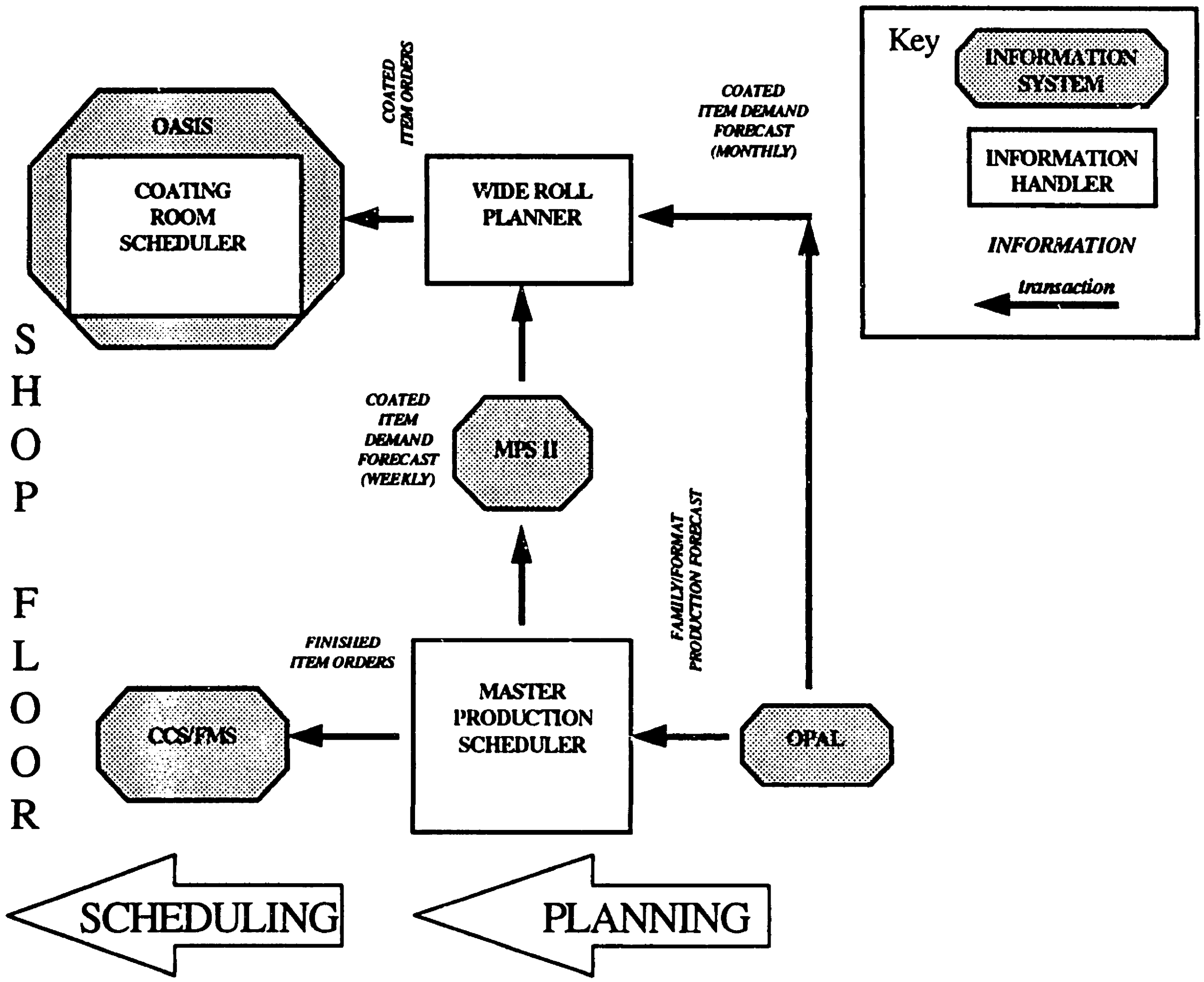

Figure 5.4 Wide Roll Planning Demand Information Flow

Orders for coated items are passed from Finishing to the wide roll planner in MPS II. Finishing's demand is filtered by the master production scheduler. This demand signal is a forecast and is therefore less than 100% accurate. This is one source of variability. Demand variability is amplified, however, by virtue of the use of forward weeks supply as the metric for wide roll inventory targets. Because Finishing operates on weekly cycles, forecasted demand of coated items is updated weekly in MPS II. Target inventory levels (measured as weeks covered) are highly sensitive to these weekly changes. At a minimum, the wide roll release process will get jerked around by these shifting targets. The possibility also exists that production planning is affected with expediting. [The supply chain implications of the use of forward looking inventory targets are discussed in greater detail in the next section.]

In addition to variability induced by shifting customer demand as cascaded in forecasts from Finishing, weekly demand for released wide roll is subject to the variability of supply in Finishing. Longitudinal roll defects identified during wide roll testing are allowed to pass through Released Wide Roll Inventory into Finishing where the defects are removed by slitting. This waste removal operation has a variable yield associated with it, as do the standard Finishing processes (spooling, perforating, packaging). Finishing's demand on released wide roll will vary to the extent its processes vary.

5.4.1 What is the Magnitude of Wide Roll Demand Variability and what Safety Stock is required?

Weekly demand information (forecasts and actuals) for each coated item was collected for 48 weeks of 1994. Each week, a 12-week snapshot of forecasted demand was available in MPS II.[21] As this information is written over each week by new forecasts, hardcopy MPS II reports were saved and the data was entered manually into a spreadsheet. To make the demand variability analysis relevant, the proper time horizon had to be determined as the horizon has to cover the replenishment lead time in MRP II planning. This horizon is the average time it takes for Sensitizing to react to a change in demand, also called the average time for order replenishment or the leadtime horizon. Actual demand was summed over the leadtime horizon and this aggregate was compared with a snapshot of forecasted demand over the same horizon to arrive at forecast error. Table 5.2 shows a sample of six forecasts for one coated item with a four week horizon along with a sample calculation of one week's forecast error. The forecast error, calculated as an absolute

[21] For coated item A, only 11-week snapshots were available; reason unknown.

deviation on a weekly basis, was averaged over all of the weeks in the sample to arrive at a Mean Absolute Deviation (MAD) for each item.

	Week Being Forecasted								
	16	17	18	19	20	21	22	23	24
Week of Report									
16	A	F1	F2	F3	F4				
17		A	F1	F2	F3	F4			
18			A	F1	F2	F3	F4		
19				A	F1	F2	F3	F4	
20					A	F1	F2	F3	F4
21						A	F1	F2	F3

A = actual demand for that week

F1 = forecast for 1 week out

F2 = forecast for 2 weeks out

F3 = forecast for 3 weeks out

F4 = forecast for 4 weeks out

Absolute Deviation

for week 21 = absolute value of [(sum of shaded actuals - sum of shaded forecasts)/(sum of shaded forecasts)]

Table 5.2

To obtain a graphical illustration of how well the forecasts track actual demand, the rolling (weekly) aggregates, in film units, are compared for coated item B in Figure 5.5.[22] Plots for the other three items are presented in Appendix 2.

[22] Forecast data was unavailable for comparison with the last four actual demand aggregates

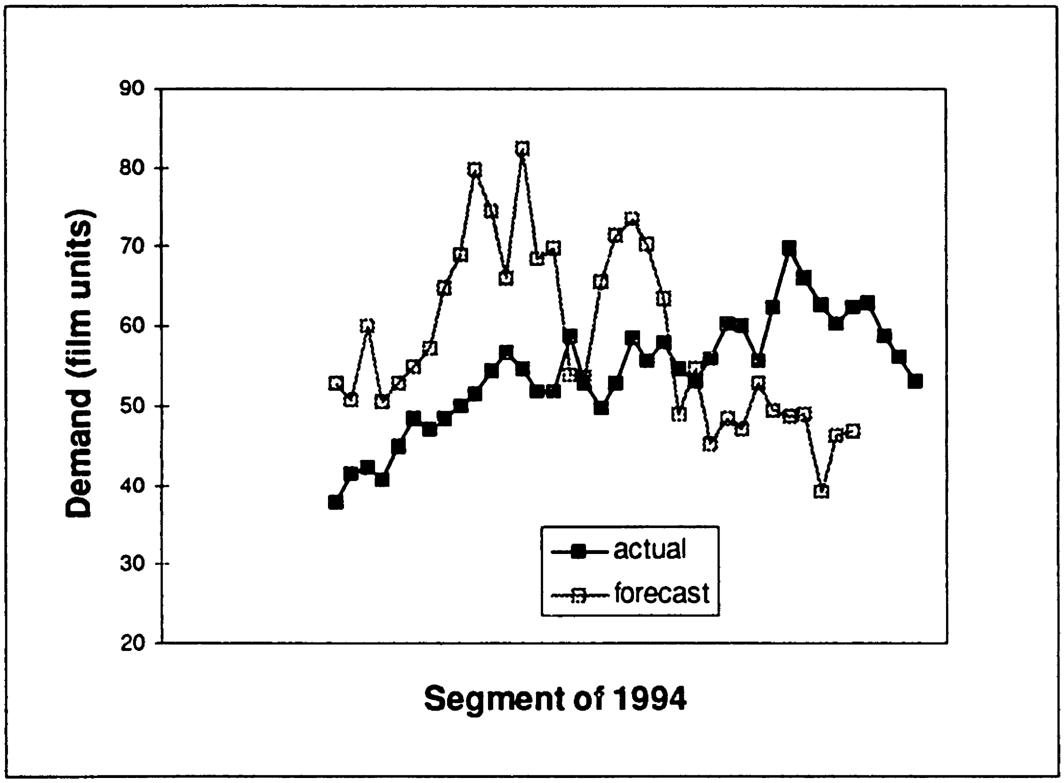

Figure 5.5 12-Week Aggregate Rolling Demand vs. Forecast for Coated Item B

In order to assess the impact of observed demand variability on stock levels and compare these levels with current standards as included in the 1995 Wide Roll Annual Operating Plan, Table 5.3 was constructed.

Weeks of safety stock were calculated using Kodak's Base Stocking Method as follows:

Safety Stock = Leadtime Horizon * Demand Variability * Safety Factor

where: Leadtime Horizon	= Average Replenishment Time
	= Planned Leadtime + (Manufacturing Cycle)/2
Planned Leadtime	= Fixed Zone in OASIS
Manufacturing Cycle	= Weeks between coating events
Demand Variability	= Mean Absolute Deviation
	= Absolute Difference Between Actual Leadtime Demand and Forecasted Leadtime Demand, Divided by Forecasted Lead time Demand
Safety Factor	= Kodak factor to achieve 95% Service Level

To translate weeks of safety stock into a dollar-value investment, the Average Annual Cost of Inventory for the product subset is included at the end of each safety stock column. This cost was determined for each item as follows:

Average Annual Cost = Interest Rate for Holding Inventory * Unit Manufacturing Cost * Safety Stock * Mean Demand

where:

Interest Rate = 20% per year
Unit Manufacturing Cost = 1995 AOP cost ($ per film unit)
Safety Stock = as calculated above in weeks
Mean Demand = Mean 1994 weekly withdrawal by Finishing (film units per week)

coated item	Planned Lead Time (weeks)	Production Frequency (events/yr)	Mfg. Cycle (weeks)	Lead Time Horizon (weeks)	Safety Factor	Current MPS II forecast Mean Absolute Deviation	Base Method Safety Stock (weeks)	Current Standard Safety Stock (weeks)
A	7.0	5.0	10.0	12.0	2.06	0.094	2.3	5
B	6.0	12.0	4.2	8.1	2.06	0.28	4.7	3
C	6.0	12.0	4.2	8.1	2.06	0.29	4.8	3
D	6.0	12.0	4.2	8.1	2.06	0.21	3.5	3
						Avg. Annual Cost ($)	213121	213673

Table 5.3

We see that, according to the Kodak Base Method, the current safety stock standard is insufficient to account for the demand variability of three of the four coated items. Total stock investment for the four items, however, appears reasonable. But a better question to ask is whether this stock investment is *necessary*? Another look at Figure 5.5 reveals that the forecasts bear little resemblance to actual demand. In fact, the two are diverging in many instances Figure 5.6 sheds light on the degree of this divergence by plotting the distribution of the actual demand as a percentage of forecast for the four coated items.

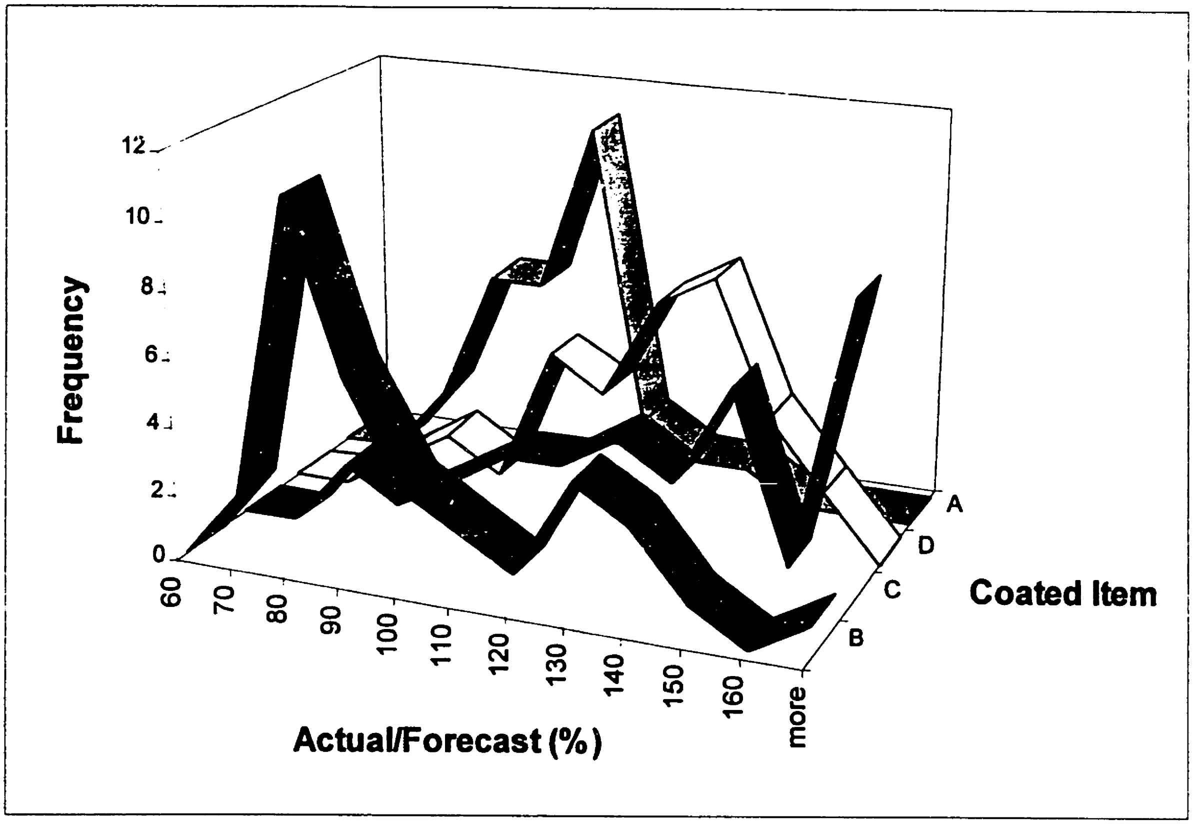

Figure 5.6 Frequency Distribution of Actual Demand Aggregates As a Percentage of Forecasted Demand Aggregates

What we would expect to see if each observation (actual demand as a percentage of forecast) were an independent random variable is a bell shape centered at 100% for each item. In other words, the forecast should underestimate with roughly the same frequency that it overestimates the actual demand. But, instead of this bell shape, we observe systematic underestimation (B) or severe overestimation (C, D); A is the only item for which we see any semblance of a normal distribution around 100%.

To impart some accuracy and show the value of this in potential stock investment savings, I investigated a very simple predictive measure which appears to be wholly ignored in the current system. This measure is the previous week's actual demand aggregate or what I will call the "simple forecast." The simple forecast works as follows: if, in the last 12 weeks, I observe cumulative demand to be 50 units, then the forecast for next week's cumulative demand is 50 units. Using the previous week's actual demand aggregate as the forecast for the current week is an absurdly simple way to demonstrate the opportunity available to decrease demand variability. By inspection of Figure 5.5 and the figures in Appendix 2, we can suspect that this method will consistently tie the forecast more closely to the actual demand. In fact, we do see in Figure 5.7 that the accuracy is more tightly and normally distributed around 100%. Whereas Figure 5.6 shows actual demand to be 60 to 160+% of forecast in the current system, my simple forecast narrows the range to 85 to 115+%.

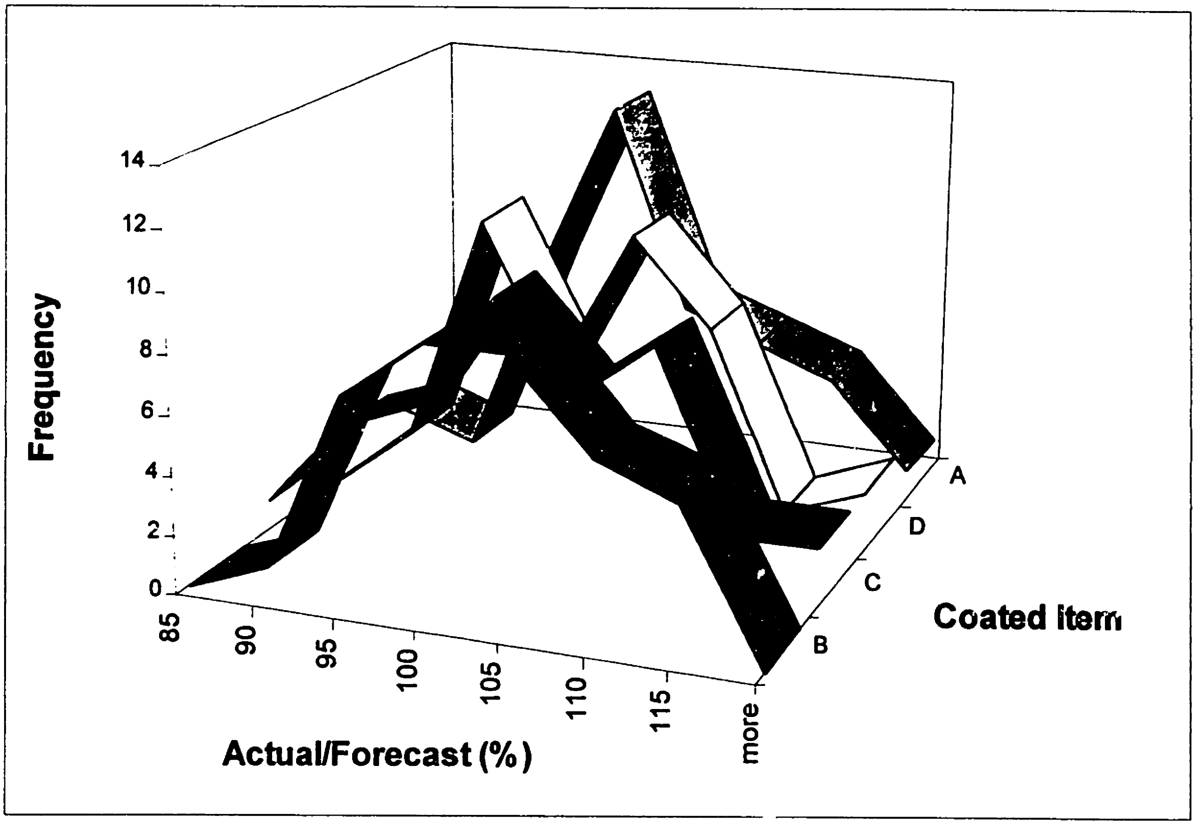

Figure 5.7 Frequency Distribution of Actual Demand Aggregates As a Percentage of Simply Forecasted Demand Aggregates

So what does this better forecast buy in the way of reduced safety stock? Table 5.4 below shows the reduced stock investment afforded by this simple forecast. Using the Base Method described earlier, I have quantified the savings made available by reduced variability in terms of safety stock. For demonstration, I have extended the analysis to include the four other products in the sample. No forecast data was collected for items E through H, but I can assume conservative levels of demand variability with the current MPS II forecasts based on MADs observed for comparable items. These estimated

MADs are italicized in the table below. For comparison, I have included the current safety stock standard as given in the 1995 WRAOP.

			Current MPS II forecast	Base Method (current forecast)	Simple forecast	Base Method (simple forecast)	Current Standard
coated item	Lead Time Horizon (weeks)	Safety Factor	Mean Absolute Deviation	Safety Stock (weeks)	Mean Absolute Deviation	Safety Stock (weeks)	Safety Stock (weeks)
A	12.0	2.06	0.094	2.3	0.062	1.5	5
B	8.1	2.06	0.28	4.7	0.080	1.3	3
C	8.1	2.06	0.29	4.8	0.11	1.8	3
D	8.1	2.06	0.21	3.5	0.090	1.5	3
E	12.3	2.06	*0.25*	6.3	0.12	3.0	3
F	9.1	2.06	*0.25*	4.7	0.13	2.4	3
G	8.3	2.06	*0.25*	4.3	0.16	2.7	3
H	8.1	2.06	*0.25*	4.2	0.13	2.2	3
			Avg. Annual Cost ($)	321626		151048	283308

Table 5.4

For every item except E, we see that this simple predictive method reduces the safety stock relative to the Base Method and the current standard. For the entire product subset, this simple forecast translates into an annual savings of $132,260 (47%) over the current safety stock standard and an annual savings of $170,578 (53%) over the Base Method with the current forecast. This reduced inventory investment corresponds to a potential one-to-two week reduction in cycle time across the product subset.

5.4.2 Is the Planning Loop Applicable in Wide Roll Planning?

It is conventional wisdom to assume that the nearer the event one is trying to predict, the greater the accuracy of the prediction. We all have a pretty good idea of what exactly we will be doing tomorrow, but we are generally less certain of what will transpire in our lives 6 months from now. This phenomenon in an MRP II environment is best interpreted using the Planning Loop (see Figure 5.8).

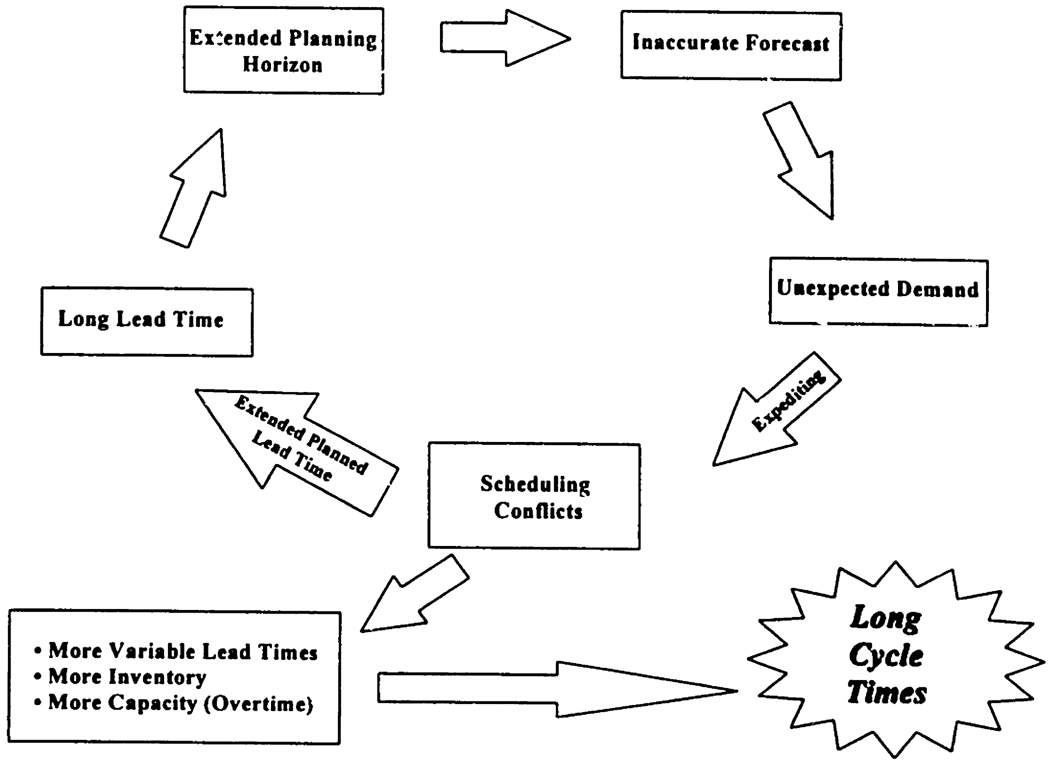

Figure 5.8 The Planning Loop

Shorter lead times require forecasts over shorter planning horizons which decreases forecast error and the level of unexpected demand. This reduced demand uncertainty requires smaller safety stocks which reduces the consumption of time in the system. Simply improving the demand forecasts can reduce this uncertainty and therefore cycle time without reducing lead times. We saw this effect in Table 5.4. This is the symptomatic control of cycle time discussed in the first section. In the context of 10X cycle time reduction, however, it is important to consider whether forecasts improve with a shorter planning horizon. Does the Planning Loop apply?

Figure 5.9 below was constructed to answer this question for four coated items.

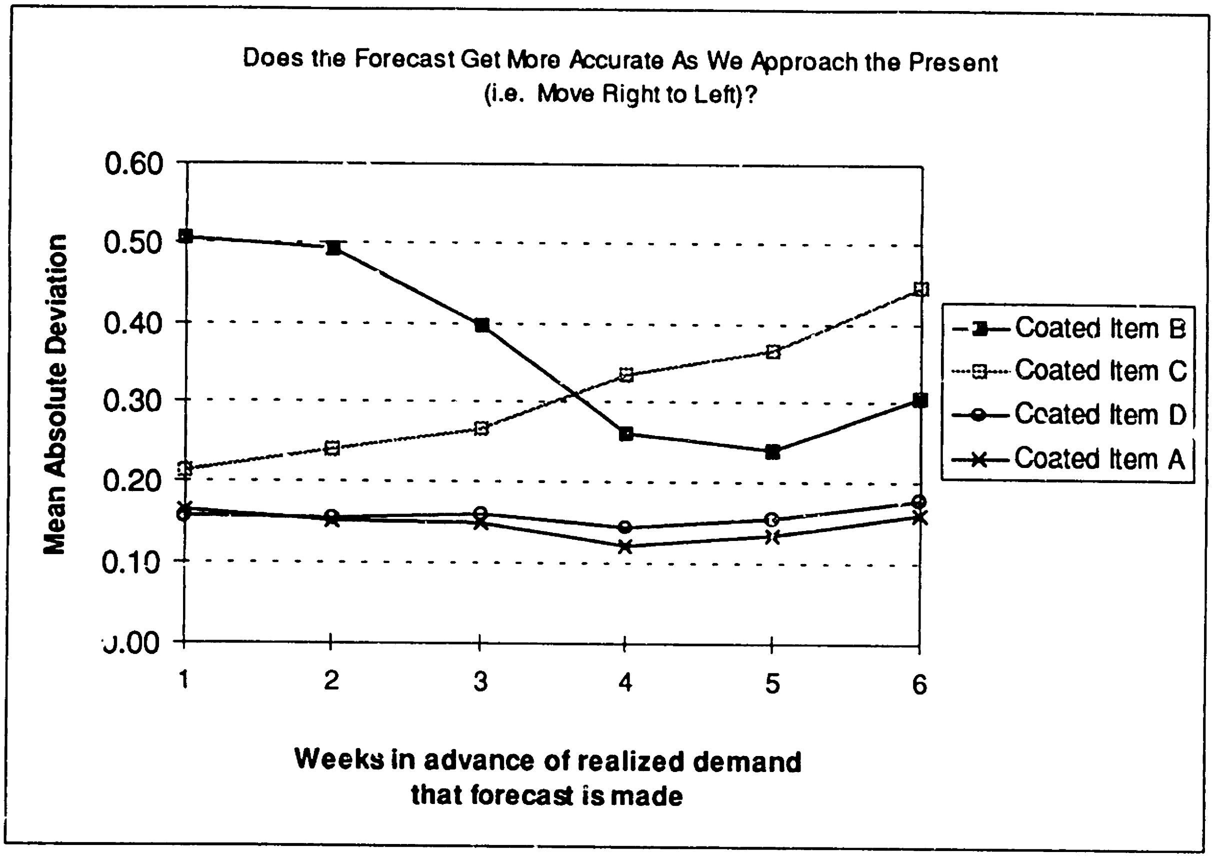

Figure 5.9 Coated Item Forecast Errror Tracked Over Time for 6-week Demand Aggregates

Demand realized over six-week aggregates is compared, on a rolling (weekly) basis, to six-week aggregate forecasts made one to six weeks in advance of realized (actual) demand.[23] The error is presented as mean absolute deviation relative to realized demand. To interpret this graph, consider the overlapping points at the lower left portion of the plot. For coated items A and D, a six-week forecast snapshot made one week in advance is, on average, 16% in error relative to realized demand. In other words, a forecast snapshot for weeks 39 to 44 demand, available at the start of week 39, differs by 16%, on average, from demand realized in weeks 39 to 44. Looking at the lower right portion of the plot, we see that the forecast snapshot available for D and A five weeks earlier (i.e. six weeks in advance) is, on average, not much worse. The error increases slightly from 16% to 18% for D; there is no observed increase for A. It is clear that the D/A forecasts don't

[23] Six weeks was chosen to approximate planned lead times for the coated items. Weekly updates of the forecast snapshot in MPS II permit the rolling comparison of demand and forecast aggregates.

get any more accurate the nearer they are made to the present. For coated item C, however, conventional wisdom applies in that error is decreased as we approach the present. But, for B, we see an inverse relationship: the forecasts get more accurate, on average, the further in advance they are made. In fact, one month's time elapsing doubles the mean error of forecasts for coated item B. To illustrate this finding, imagine having *less* of an idea as to the sex and health of a fetus one month into a pregnancy relative to the knowledge at conception. These findings could have significant implications:

1. The Wide Roll Planning Loop is not a loop in that forecast error and the planning horizon seem unrelated or inversely related, i.e. one MRP II assumption appears violated for some coated items.
2. Since the coated item forecast is handed upstream by Finishing, Finishing's demand forecasts may be suspect.

The first implication is not surprising since we have seen earlier that the weekly forecast aggregates are quite erratic and inaccurate. The increase of error nearer the present is likely due to weekly forecast updates which do not improve accuracy. To investigate the second item, Figure 5.10 was constructed.

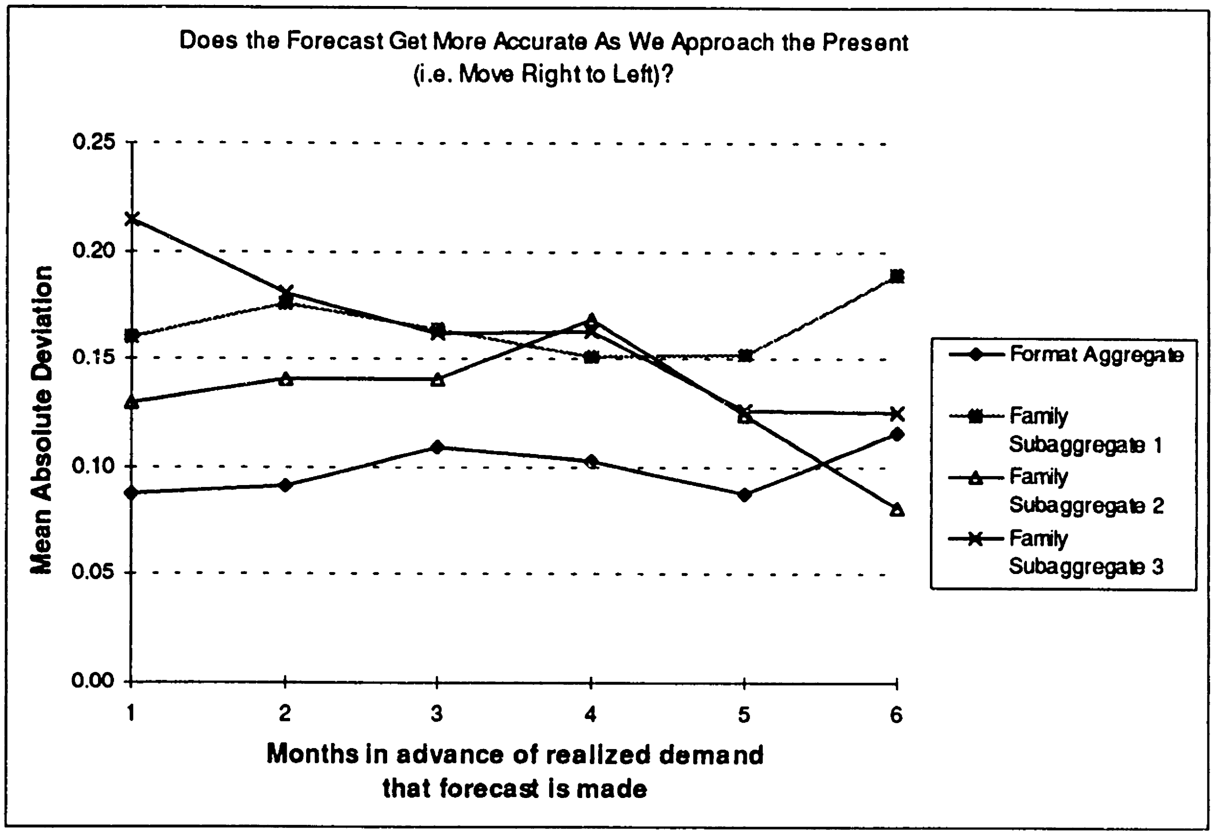

Figure 5.10 Finished Item Forecast Error Tracked Over Time for Monthly Demand Aggregates

This figure should be interpreted in the same way as Figure 5.9, except the items considered are a Finishing format aggregate and three product family subaggregates with demand aggregated monthly (since finished item planning is done monthly in OPAL). As with coated items, it does not appear that these updates are effective in reducing forecast error. The Planning Loop does not appear to apply in Finishing.

Overall, for the product subset examined, the coated item forecasts are grossly inaccurate and they generally do not improve the closer they are made to the present. The following two comments serve to echo these observations:

- The Master Production Scheduler: "I know the [forecast] information is bad when it arrives [from Demand Planning]."
- The Wide Roll Planner: "OPAL [monthly Finishing forecasts] could go away."

The observed behavior of the supply chain information flow is described in Section 6 to better understand the behaviors observed in wide roll planning.

5.5 Sources of Supply Variability

In Sensitizing:

> type and quality of raw material were critical...as minor variations in raw materials could produce significantly different emulsions of varying quality. Control of the variables in the emulsion-making and -coating operations were equally critical as variations in formula and cycle time could dramatically affect the grade and quality of emulsions.[24]

To control the variable output from the melt/coating operation, coated items are subjected to rigorous testing and review.[25] Much wide roll sits idle in unreleased inventory. Testing time, extended ages, reviewed releases and rework all contribute to the uncertainty of coated item supply. In addition, the size of a release is made uncertain by variable coating yields. Hard data quantifying the specific sources and relative magnitude of supply variability is not readily available. Anecdotal information and point estimates of testing time, age time, release time and release size predominate. When asked for information on the distribution of coating yield for a specific item, one planner responded "anywhere from 0 to 100%." Additionally, over the last three years, coating size for this item has varied from 6% to 120% of the EOQ (given in terms of emulsion "melts"). The seemingly random inventory levels presented in Figure 5.3 (coated item B inventory profile) and in Appendix 1 are a prime manifestation of this supply variability. Were supply more certain, the inventory increases would appear more regular and the plot would approach the ideal sawtooth presented in Figure 5.2.

With so much uncertainty, it is not surprising that a relatively small portion of the planner's time is spent planning: "Four out of five days each week, I worry about

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[24] Preuninger, *op. cit.*, p. 4.
[25] See Section 4.3 on Inventory Tracking for more details on the review and release of coated items.

starving Finishing operations." The planner invariably spends "a lot of time tracking down a release." The information systems are not the primary tools of the planner's trade; the telephone and face-to-face interaction are. To do his job, the planner must work closely with the master production scheduler to get an up-to-date picture of Finishing's demand; with the Product Staff and Testing to assess the status of newly-coated/unreleased material, i.e. get an up-to-date picture of inventory; and with the coating room scheduler to shuffle orders. Information systems are adjuncts rather than primary instruments of Wide Roll Planning. MRP II is not helping Wide Roll Planning. As discussed in the next section, Wide Roll Inventory is under open-loop, manual control.

5.5.1 What is the Magnitude of Wide Roll Supply Variability and what Safety Stock is required?

Working with a database manager in Management Services Division, lead times were established for every roll of coated items A, B, C and D released to Wide Roll Released Inventory between January 1993 and November 1994. Remember, lead time is defined as the time elapsed from the fixing of the coated item order until the order is filled and available for downstream consumption. Figure 5.11 shows the probability distribution of wide roll lead times for coated item A. Appendix 3 presents similar data for coated items B, C and D.

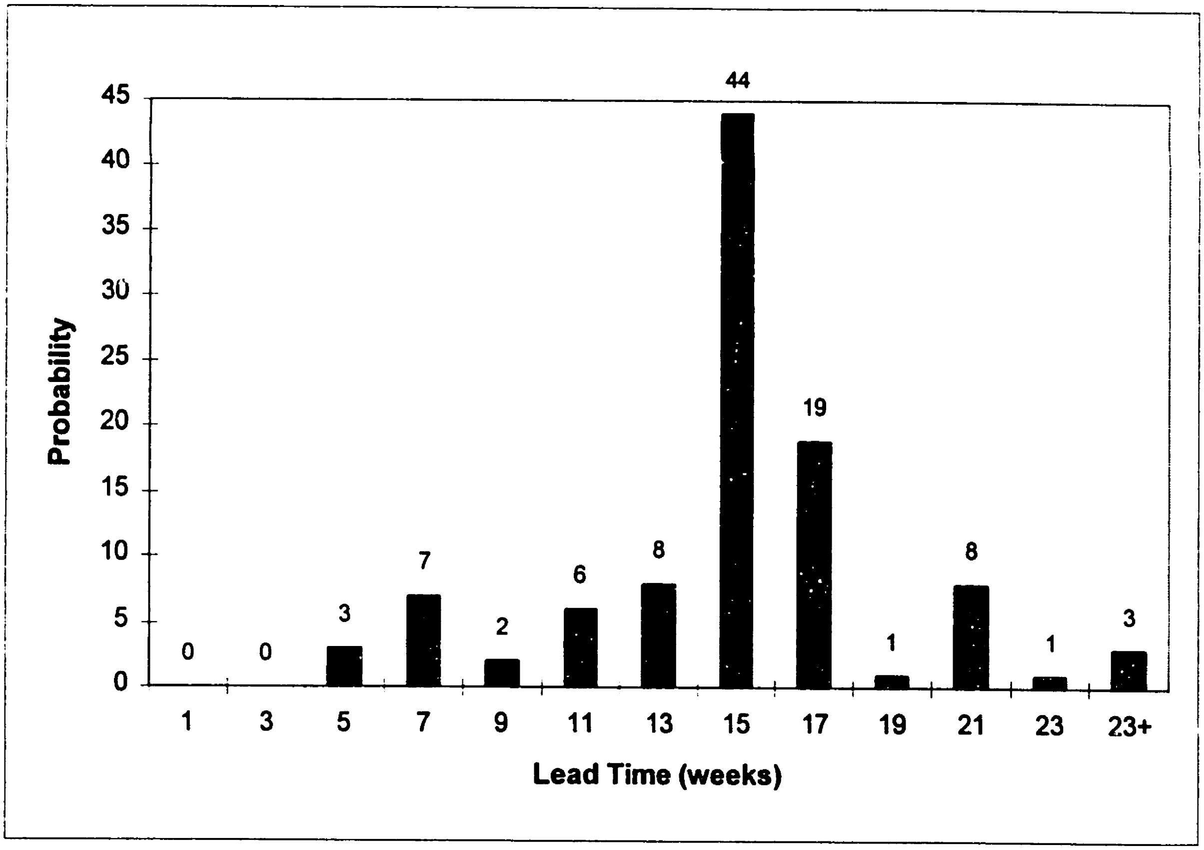

Figure 5.11 Probability Distribution of Roll Lead Times for Coated Item A

For the purposes of this analysis, lead time τ for each coated item is assumed to be a normally distributed random variable, i.e. the lead time distribution approximates a bell curve. Figure 5.12 summarizes the coated item supply variability according to the mean roll lead time which is compared with the planned lead time for a coated item order.

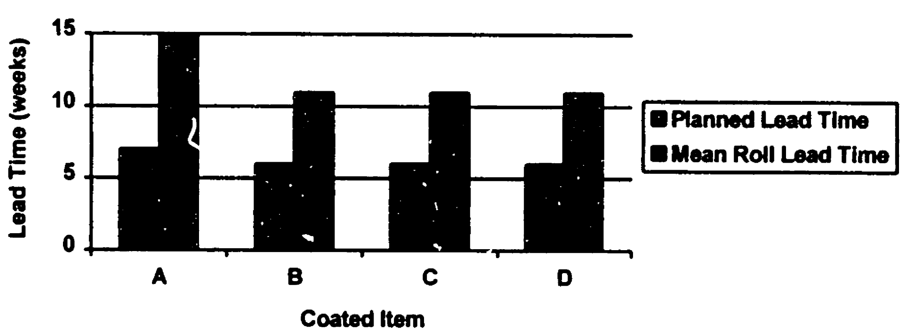

Figure 5.12

We see that the mean lead time for each item is almost double the planned lead time. In fact, the probability distributions in Figure 5.11 and Appendix 3 show that nearly all rolls (>90%) arrive after the planned lead time. This finding has two significant implications:

1. The large discrepancy between planned lead times and actual lead times clearly establishes that Wide Roll Planning is an open-loop system under manual control. As with coated item forecasts and actual demand, MRP II lead times bear little relationship to actual lead times.
2. Neither MPS II weekly forecasts nor OPAL monthly updates in Finishing are meaningful to Wide Roll Planning because roll lead times are generally in excess of two months. With such long lead times, only Marketing's aggregate family forecast is useful for Wide Roll Planning. It's value-added is limited, however, because it provides little intelligence at the coated item level. Instead, Marketing's forecast is isolated to the combined emulsion family/finishing format aggregate.

As lead time variability is not accounted for in the Kodak Base Stocking Method and the Wide Roll Planning Loop has been established as open, a reorder point (ROP) system is more applicable to the management of wide roll inventory. Using an ROP stocking model, I will quantify the impact of lead time variability on stock levels. Recalling from earlier in this section, ROP assumes continuous review of inventory levels to prompt order placement. When the level of wide roll inventory reaches a minimum level R, an order for Q units is placed which will arrive in τ units of time. R has two components, unreleased wide roll inventory, or pipeline stock, to account for demand during the coated item disposition period, and released wide roll inventory, or safety stock S. Optimal levels of R can be established using cost tradeoffs or service level targets.[26] As the latter situation applies in Wide Roll Inventory, R and S should be determined by

[26] Determining optimal levels of the order size Q is a more complex exercise and beyond the scope of this discussion on variability. Suffice it to say that Sensitizing decouples the problem into two relevant order quantities, a production EOQ or "minimum melt size" in Melt/Coating operations and a transaction Q or "minimum release size" for Wide Roll Inventory.

$$R = \mu + S$$

$$S = \sigma z$$

where μ is the mean demand realized during the replenishment lead time (i.e. the time from coating order placement until coating order release), σ is the standard deviation of demand realized during the replenishment lead time and z is the standardized variate. The standardized variate is determined by the target service level and serves a function similar to the safety factor used in Kodak's Base Stocking Method described earlier. For 95% service as stipulated by Wide Roll Planning, z = 1.65.[27]

If we assume coated item demand in any time t has a mean λt and variance $v^2 t$ and lead time τ is a random variable with mean μ_τ and variance σ_τ^2 (as given above)[28], it can be shown that the demand during the lead time has a mean and standard deviation as follows:[29]

$$\mu = \lambda \mu_\tau$$

$$\sigma = \sqrt{\mu_\tau v^2 + \lambda^2 \sigma_\tau^2}$$

Weekly wide roll demand data was incorporated with the roll lead time data to calculate the appropriate safety stock for the four coated items. This information is shown in Table 5.5 along with current standards for comparison.

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[27] This is for Type 1 service, where all coated item orders placed by Finishing are filled in 95% of the order cycles (weeks) as mentioned in Section 5.2.

[28] Note that these parameters relate to lead time for rolls, *not orders*. This is currently the best available surrogate for lead time variability. Substantial yield variability makes unwieldy the calculation of coating order lead time and no such information existed at time of writing.

[29] See Steven Nahmias, *Production and Operations Analysis*, 2nd ed. (Boston, MA: Richard D. Irwin, Inc., 1993), p. 266. This model assumes that orders do not cross, i.e. that orders are received in the sequence with which they are placed, and that successive lead times are independent. It also assumes lead time and demand are normally distributed. For the purposes of this analysis, these are all reasonable assumptions.

coated item	μ_τ (weeks)	σ_τ^2 (weeks²)	λ (film units per week)	v^2	σ (film units)	z	ROP: S = σz Safety Stock (weeks)	Current Standard Safety Stock (weeks)
A	15	19	9.8	32	48	1.65	8.0	5
B	11	8	4.2	6.2	14	1.65	5.7	3
C	11	17	7.3	32	35	1.65	7.9	3
D	11	19	5.2	9.6	24	1.65	7.8	3
						Avg. Annual Cost ($)	444814	213673

Table 5.6

We see that accouting for lead time variability requires more than a doubling of the inventory investment for the four items. Were these safety stocks implemented, the product subset cycle time would *increase* by roughly three to four weeks. Not only does this model suggest the impact of one aspect of supply variability on cycle time, but it also permits quantifying the benefits of a smoother demand signal, as will be reported below.

5.6 Reducing Cycle Time (Safety Stock) By Reducing Demand Variability

As was discussed earlier, demand variability arises from two sources, the customer and the forecaster. Customer demand has inherent statistical fluctuations. The accuracy of forecasts of this demand will vary as well; the imperfect nature of forecasting will tend to distort the demand information and augment variability. The demand variability which is relevant to managing inventory (i.e. setting safety stock levels) depends on the planning system. In MRP II, the demand signal is derived from an end-item sales forecast which is aggregated to provide an MPS II forecast of weekly coated-item demand. I have shown earlier how improving the MPS II forecast translates into reduced safety stock needs for a subset of coated items.

An ROP system, however, requires no forecasts; coating orders are placed according to the level of on-hand released wide roll inventory. The relevant demand signal is wide roll demand history, which can be used to establish target inventory levels as shown in Table 5.6. In the current systems architecture, this demand history can come from three sources, a manual tracking of Finishing demand, OPAL or Distribution's information system, Distribution Requirements Planning (DRP). OPAL is currently used by the wide roll planner and is discounted as an effective planning aid ("OPAL could go away").[30] DRP is not used, but could provide an alternative coated-item demand signal as shown in Figure.

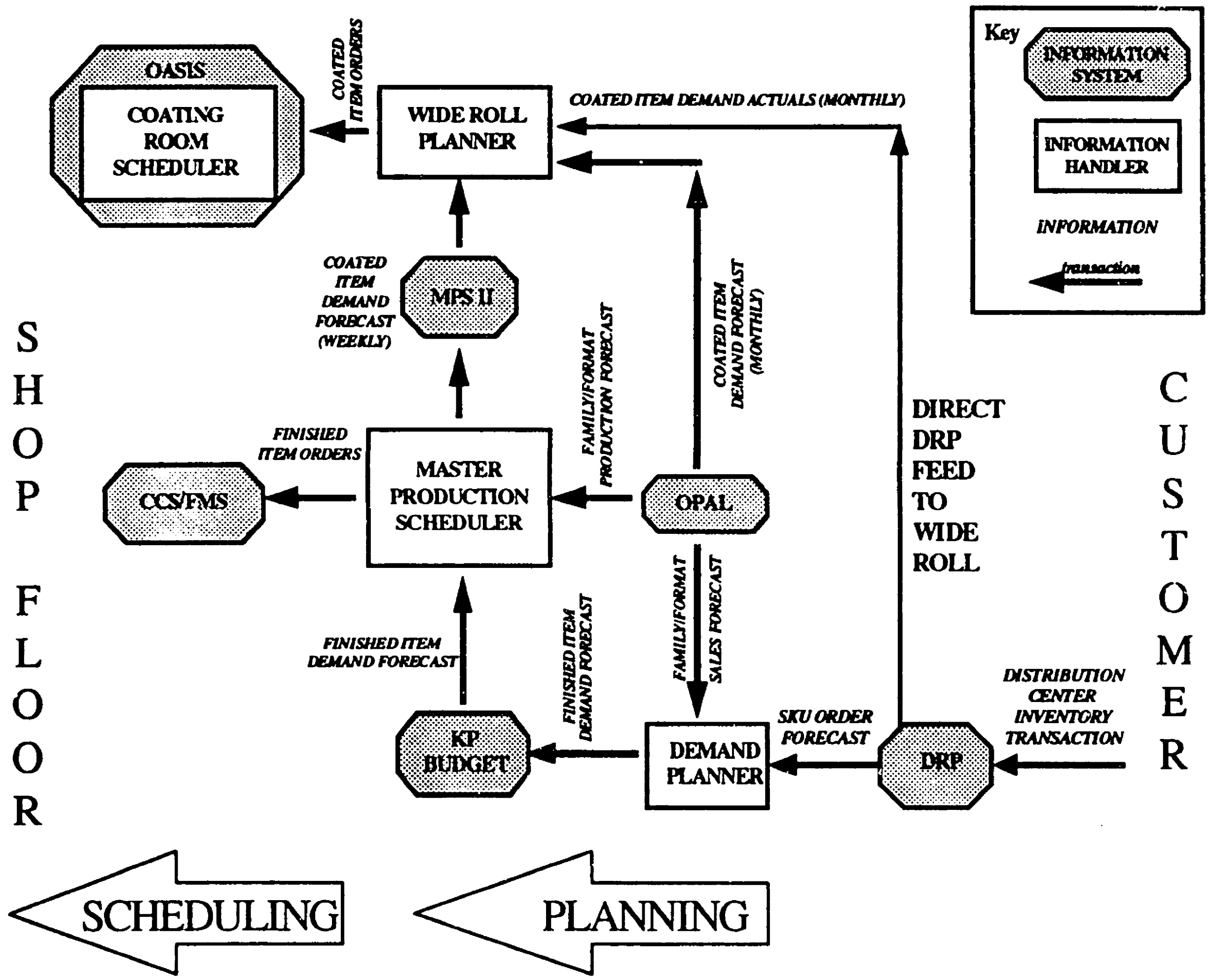

Figure 5.13 Direct Feed of Coated Item Demand via DRP

SKU orders tracked by DRP can be aggregated to the coated-item level to provide monthly worldwide demand history. Recognizing Finishing as a source of additional demand variability (see Section 5.4), I postulated that eliminating the filter in Finishing would render demand for coated items relatively less variable.

[30] This point is discussed further in Section 6.2. No OPAL coated item demand data was collected for this investigation, so a data driven assessment of its worth as a wide roll planning aid is left for others to consider.

Using the ROP model, safety stock was calculated to account for the coated-item demand variability of the Distribution and Finishing demand signal for the four original coated items. Three years of DRP monthly order history was collected and compared with Finishing's 1994 weekly order history.[31] In Figure 5.14, the stock level determined with the Distribution signal is compared to the stock level determined with the Finishing signal and the current standard for safety stock.

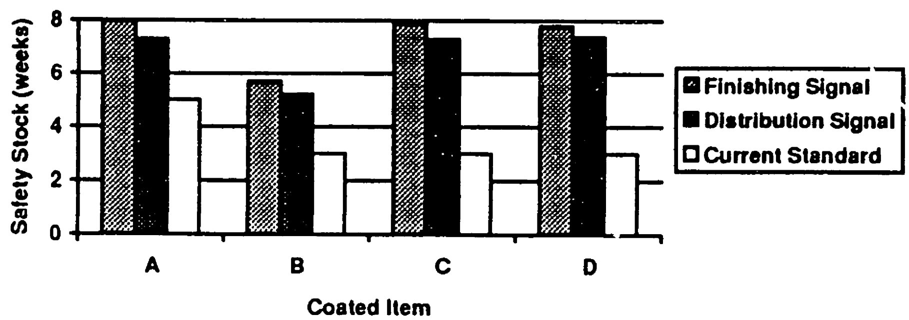

Figure 5.14

For the four coated items, the reduced demand variability of the Distribution signal affords a modest annual safety stock investment savings of $127,575 relative to the Finishing signal. This corresponds to a cycle time reduction of three to four days. More importantly, it is clear from Figure 5.14 that the current safety stock standard for this subset is insufficient to account for the variability observed in wide roll demand and supply. More striking is the difference, shown in Figure 5.15, between the current standard for the reorder point R and the reorder point calculated to account for leadtime variability.

[31] Data collection was not a trivial exercise since this information had never before been obtained from DRP by the Demand Planner.

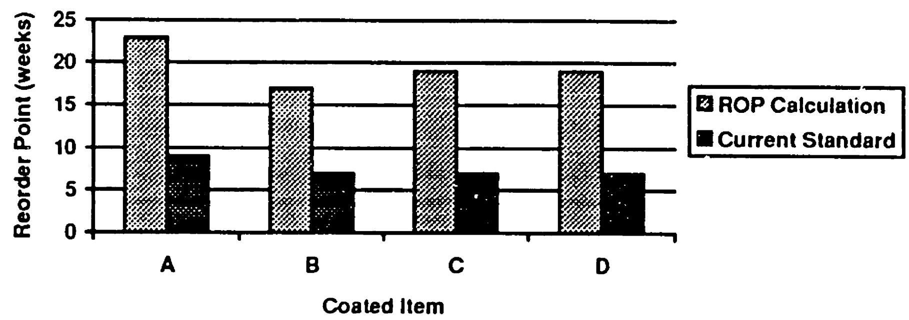

Figure 5.15

Based on supply and demand variability for this product subset, it is clear that the current wide roll inventory standards are insufficient to achieve a 95% service level to Finishing operations. Does this mean that wide roll inventory is improperly managed for this product subset? No, but it does mean that the inventory standards do not account for the variability in the system and it calls into question how these standards were arrived at. Lacking data on the coated item service levels, it is difficult to determine exactly how well wide roll is managed given demand and supply variability.

5.6.1 Limitations of this Analysis of Wide Roll Planning

This analysis of variability and safety stocks for coated items is not intended as much for implementation as it is for education. I do not recommend changing WRAOP stock levels as much as I advocate formal tracking of coated item supply and demand variability and proper safety stocking according to service level targets. It is obvious from the current inventory standards and the comments from personnel in the FMF that variability is a problem but is poorly understood. As with Hetzel's work, it is also clear that forecasts are poorly understood in the film manufacturing supply chain. Once the commitment is made to improve the information flow and reduce variability, data collection is a first step for increasing this understanding. Data collection, in fact, was where Team X's cross-functional supply chain improvement activity left off prior to disbanding. It is hoped this analysis will aid such an effort should it be revisited in the future.

Finally, I have relied on current inventory standards as a basis for my analysis of wide roll planning. Another means for evaluating the management of wide roll inventory given the level of variability is to compare the calculated stock levels with the current state rather than the current standard. For example, what is the average safety stock or reorder point for each coated item? Unfortunately, the data is not available to do this for separate coated items. Daily inventories for each coated item are tracked on a roll-by-roll basis and each roll corresponds to a different square footage of film. However, Management Services Division's practice of translating inventory units into time does allow some understanding of the current state. The average replenishment lead time (coated item order placement to releasing of the coated item) for the product family aggregate is 21 weeks and the average safety stock (released wide roll) is 5 weeks. *We see that eliminating all variability and therefore the need for safety stock only cuts 20% from the cycle time.* The real opportunity for 10X cycle time reduction does not lie with reduced demand variability, but rather lies with coated item lead time, the time from fixing an order until that order arrives in released wide roll inventory.

5.7 Summary of Findings to This Point

The current system does not fall neatly in the category of MRP or order-point order-quantity (ROP). MRP II only describes the systems architecture; it in no way describes the behavior. Informal production planning and reactive inventory control are necessary due to long lead times and demand and supply uncertainty. Weekly MRP II forecasts are rightfully ignored in planning production as they bear no relation to actual demand; the demand signal transferred from Finishing is suspect. Sensitizing is effectively decoupled from the downstream chain by long lead times which render shifting weekly (MPS II) and monthly (OPAL) demand signals useless for planning production. The MRP II system is further ignored in that planned lead times and actual lead times bear no relation to each other. Current safety stock standards are reasonable to account for forecast variance, but are insufficient to buffer against the combination of supply and demand variability observed in Sensitizing. DRP affords a less variable demand signal, but reducing demand variability does very little for reducing cycle time. Overall, neither MRP nor ROP can come close to classifying the current inventory control system governing Sensitizing. The Planning Loop is broken in many places as the system is characterized by reactive scheduling. The wide roll planner has little to no control over the flow. The next section describes why this is the case.

For an organization to cope effectively with a rapidly changing environment of the sort we see increasingly in today's global context, it must be able to (1) import information efficiently; (2) move that information to the right place in the organization, where it can be analyzed, digested, and acted upon; (3) make the necessary internal transformations to take account of the new information; and (4) get feedback on the impacts of its new responses, which starts the whole coping cycle via information gathering all over again. In this organizational coping cycle, the flow of information is critical to the health and effectiveness of the oganization. Therefore, any evidence that improved information flows via IT [information technology] are failing to be adopted or implemented is potentially very serious.

- Edgar Schein[32]

6. Supply Chain Information Flow - Aggregate Behavior Explained and Modeled

6.1 Introduction

After the Beer Game simulation was run, the participants were asked to identify applications of the learnings from the simulation to their supply chain experience. Almost unanimously, the participants expressed that they did not feel in control in their daily activities. In the previous section, I tried to verify this lack of control from the perspective of the wide roll planner. Considering Fisher's Expectations for the flow and the supply chain investments in MRP II, we see from the leading quote the importance of explaining this lack of control on a supply chain level. This section aims to provide evidence that MRP II is not helping the FMF by tracking the flow of demand information and supply chain behaviors starting from the customer and working upstream to Sensitizing. By integrating observation, quotes and insights acquired during the internship with the earlier description of the information flow (Section 4) and the analysis of wide roll planning (Section 5), I will show that the current FMF structure promotes long cycle times, large inventories and reactive 'planning.' I will rely on the Beer Game experience to show that structure indeed causes behavior in this system. I will also report on similar findings

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[32] Edgar H. Schein, *Organizational Culture and Leadership*, 2nd ed. (San Francisco, CA: Jossey-Bass Publishers, 1992), p. 277.

observed by Hetzel in a related supply chain. I will close with a summary of the issues uncovered.

6.2 Aggregate Behavior Broken Down

True customer demand is not captured in this system. Instead, Marketing, via the Sales & Operating Plan (S&OP) process, and Distribution, via DRP, separately provide interpretations of the customer's ordering patterns. These interpretations, or forecasts, comprise the inbound demand signals, respectively aggregate sales and SKU orders. As no forecast is 100% accurate, demand is already distorted, and on two fronts. As I will show, the signal gets more distorted the further up the chain we move.

The aggregate sales forecast is arrived at by Marketing which engages in promotional planning by selling region. To promote sales, the S&OP/AOP are inflated and this is widely observed. As one sales forecaster said, "games are being played." There is no incentive for anyone to challenge these forecasts. The Film Manufacturing Flow Manager and the Manager of Manufacturing and Materials (the liason between the Business Unit and the factory) respectively view their roles as to make the schedule that Marketing provides and to make conservative decisions. The sales forecaster, the agent of the plan, adds, "I don't get paid to second guess Marketing's AOP." These forecasts are updated monthly in OPAL.

Promotional planning not only leads to inflated (optimistic) forecasts, but also demand spikes which increase variability. As a way to meet sales targets, promotions may be instituted at the end of the month or quarter. These promotions expose Distribution to variable customer ordering patterns. This creates problems for the demand planner who has roughly 1000 SKUs to track in DRP. With so many products, it is nearly impossible to update DRP's statistical models, resulting in erroneous SKU order forecasts. A check of one months forecast for 86 SKUs showed a 41% aggregate underprediction. The sheer number of SKUs also makes it difficult to track backorders, thereby widening the gap between orders and sales. The situation goes from bad to worse.

To arrive at the finished item forecast which is the basis for the Master Production Schedule, the demand planner reconciles inaccurate OPAL information with inaccurate DRP information. This is essentially comparing rotten apples to frostbitten oranges: OPAL's numbers are derived from aggregate sales targets whereas DRP's numbers are derived from statistical SKU order forecasts. The gap between orders and sales is highly variable and unquantified, but somehow the demand planner ties these numbers (i.e. reconciles them) to within 5% of each other and, via the KP Budget system, passes them on to the master production scheduler who "knows the information is bad when it arrives."

The master production scheduler then has to perform his own magic act by tying these demand numbers to OPAL production forecasts within 5% to arrive at the master production schedule. In response to finished item demand uncertainty arising from bad forecasts, the master scheduler, who is concerned about stocking out Distribution, boosts Finishing's production to build inventory.

The effects of demand uncertainty are compounded by the highly variable delivery performance of Sensitizing (see Figure 5.11). Preuninger describes:

> To the extent that marketing companies [regional LOBs] were limited to a single source, product availability became a problem which impaired delivery performance and ultimately hurt Kodak's reputation and competitiveness. This dilemma predisposed operating managers at every stage of the production planning process to request more inventory than needed. For instance, distribution managers would take a forecast for a particular product and add a buffer stock to it. This extra inventory would hedge them against the possibility of poor delivery performance from manufacturing. Then, managers in the finishing department would take that requirement and add more buffer inventory to reduce the chance of downtime due to poor delivery performance from sensitizing. The net result of this behavior was exceptionally high work in process and finished goods inventories, which ate into the company's operating capital, reduced asset productivity, and weakened the company's competitive cost position.[33]

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[33] Preuninger, *op. cit.*, pp 4-5.

Production planning in Sensitizing only makes things worse with large coating events and long wide roll lead times. Preuninger continues:

> As products [coated items] were priced on a standard cost basis, forcing plants to offset overhead through product volume, plant managers tended to pursue a planning pattern that reduced uncertainty. At the beginning of each planning cycle, as a hedge against unanticipated downturns that might reduce plant utilization and product volume, they would load their plants with as broad a product mix as possible. To keep volumes high and cover allocated overhead, they would then emphasize long production runs with little changeover. A plant manager who succeeded in producing more products than planned could spread the allocated overhead over more products, which would yield a lower product cost and higher margin contribution. Such a plant would be viewed as an outstanding performer. The natural consequence of this operating plan was long product lead times (which were already long given the level of vertical integration) and high inventories.[34]

Coated item lead times of more than a month make weekly MPS II changes and monthly OPAL updates noise inducers rather than planning aids. In Section 5, we saw how variable and inaccurate the MPS II information is. The OPAL information is equally troublesome as this coated item demand is aggregated up from the inaccurate finished item demand fed by the demand planner. In the words of the wide roll planner, "OPAL could go away." The MRP II systems do not provide the planner with sufficient forward demand visibility. Instead, the planner must resort to an aggregate product family forecast as well as an offline spreadsheet with historical demand. At this point, the chance that the coated item production plan is at all aligned with true customer demand is next to nil. Andre Martin, in his book *DRP: Distribution Resource Planning*, puts it best: "They don't make probabilities that small."[35] Invariably, Sensitizing must react to demand changes by expediting the release of wide roll and shifting production orders around. The wide roll planner spends 80% of his time worrying "about starving Finishing operations" and "tracking down a release." The coating room scheduler is a self-professed "juggler," occasionally responding to production problems and demand shifts with changes to

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[34] Preuninger, *op. cit.*, p. 4.
[35] Andre J. Martin, *DRP: Distribution Requirements Planning* (Essex Junction, VT: Oliver Wight Limited Publications, Inc., 1990), p. 164.

coating orders already firmed and released to the shop floor. On average, the coating room scheduler fields requests for schedule changes from the wide roll planner on a daily basis and from the product staff or coating room manager on a weekly basis. In effect, there is much less planning than monitoring of the stream of orders and expediting to accomodate requests for schedule changes.

Supply chain inventory and demand variability are amplified by the autonomy of the information handlers and the functionalized performance measures. The wide roll planner, the master scheduler, the demand planner and sales forecasters/marketers all sit in different buildings. The latter two actually sit in corporate headquarters, miles from the plant. Remoteness introduces a level of comfort and makes it relatively easy to question the inbound demand signal.[36] Furthermore, each function has its own information system, allowing the information handlers to act on their mistrust and reduce the risk of schedule interruptions by altering the demand signal to meet their needs. In fact, during the Beer Game, the wide roll planners openly admitted to this second guessing and boosting of planned orders to cope. In identifying a personal plan of action to improve the supply chain, one planner committed to working with the master production scheduler and LOB customers "to provide 8-12 weeks of realistic demand to eliminate the need to second guess."

Lacking supply chain metrics for forecast accuracy, the information handlers are not held accountable for this second guessing. It appears as though there is no capability to store information on how well the AOP predicts actual sales. Although there is historical AOP and OPAL data, the forecasts are written over with actuals and no error tracking is done by Sales Forecasting more than one year back. No one currently is measured on this demand forecast error. Not surprisingly, the demand planner was unaware of DRP's statistical model editing function to improve the SKU forecasts, adding "To be honest, we just look at the [monthly] numbers." Also, no error tracking is done in MPS II. Not only

[36] During discussions with the master scheduler, it was clear that he relished his distance from the other planners as it permitted an autonomy and a sense of control amidst "bad" information.

does the lack of forecast accountability perpetuate mistrust, but it also makes data driven safety stocking impossible. The entire information flow lacks the feedback driven by collocation, integrated information systems and shared accountability for variance reduction. Functional metrics and lack of accountability for inventory leave the planners in the lurch as they have little control over inventory resulting from asynchrony due to supply variability.

Exacerbating the effects of this functional autonomy is the fact that each function tends to be populated by functionally trained people having little direct experience outside of their respective functions. Functional autonomy and excellence, along with "100% customer service," have been traditions at Kodak for a century; but it is these same cultural artifacts which drive people to expedite and hedge orders, unaware of the impact of their actions on the larger system. This functionalized structure coupled with a lack of accountability for variances ultimately promotes the gaming which yields FMF's long cycle times, large inventories and variable demand.

6.3 Modeling the Behavior - The Beer Game and the Springboard Effect.

As mentioned earlier in this work, the FMF engaged in a supply chain workshop involving the Beer Game. The Beer Game is a supply chain simulation using a four-stage production/distribution system with role playing to manage the flow of beer, represented by pennies, from factory through to the customer. In comparing the structure and behaviors associated with the Beer Game to those of the Film Manufacturing Supply Chain, I will try to show that indeed the Beer Game provides rich environment to model the dynamics of the film manufacturing supply chain.

In Table 6.1, I compare the structure of the Beer Game supply chain, as reported by John Sterman[37], with that of the film manufacturing supply chain to validate the simulation.

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[37] John Sterman, "Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment," *Management Science*, Vol. 35, No. 3, (March 1989), pp. 326-323.

Structure of the Beer Game Supply Chain[38]	Structure of the Film Manufacturing Supply Chain[39]
independently managed stages: retailer, wholesaler, distributor and factory	independently managed stages: Distribution (LOB), FMF, Roll Coating Division
orders cascaded from customer upstream to factory	orders cascaded from Distribution upstream to factory
each stage places orders based on available inventory and individual interpretation of game objective	each stage places orders based on available inventory and functional interpretation of supply chain objectives
shipping delays and order receiving delays at each stage	long and variable lead times at each stage, especially upstream in Sensitizing
stockout costs are twice as much as the inventory holding cost per unit per period	heavy emphasis on avoiding starving the downstream operation: wide roll planner spends 80% of his time worrying "about starving Finishing operations"
"each stage has good local information but severely limited global information"	in referring to customer demand, the middle of the supply chain stated, "[we're] in the dark...[we're] disconnected"
"customer demand pattern is not known to any of the subjects in advance"	true customer demand is not captured and there are inaccurate forecasts at each stage: "I thought we were seeing a seasonal pattern and I expected it to wash out in the end."
"subjects are unable to coordinate their decisions or jointly plan strategy"	• "We try to do well on what we are measured," which are functional objectives • "There is a set of business rules and culture to adhere to." • "The structure of the business is 'reactive' rather than 'preventative' due to limited resources and initiative."

Table 6.1 A Comparison of the Beer Game Structure with the Film Manufacturing Supply Chain Structure

The film manufacturing supply chain and the Beer Game supply chain are aligned in many ways. The true test of the simulation, however, is whether the behaviors apply to the system being modeled. After the Beer Game was run, participants were asked to apply their learnings to their experience in the supply chain. The following comments were captured:

- In our business, there are many risks of suboptimization.
- In our business, there is a feeling of not being in control.
- Changes are magnified as you go back in the chain.
- All delays, in both material and information flows, amplify variability.

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[38] Sterman, *op. cit.*, p. 328.
[39] All quotes come from Beer Game participants.

- Changes are magnified as you go back in the chain.
- All delays, in both material and information flows, amplify variability.

Sterman reports similar reactions/observations in his discussion of the simulation.[40] I realize that qualitative data rather than quantitative data is used to verify the applicability of the model, but perhaps it is the most convincing in that the FMF people recognize their system. Finding hard data in the FMF to substantiate traditional Beer Game behaviors of order oscillation and amplification is difficult due to the complicated bills of material for each item with numerous components and variable waste factors, in addition to the different production lot sizes used at each stage. Ironically, finding hard evidence is made difficult by the same functionalized, complex structure that generates the postulated behaviors. However, Beer Game behaviors have previously been identified in a similar film manufacturing supply chain at Kodak.

Hetzel described these behaviors in terms of the "Springboard Effect." The Springboard Effect refers to how two aspects of the FMF order management process lead to amplification of variability and upstream inventories.[41] More specifically, it relates the MRP II demand cascade to forward-looking inventory targets set in weeks to explain a hypersensitivity to demand fluctuations which results in excess inventories. This effect as it applies to FMF is best illustrated using Hetzel's words:

> Marketing says finished goods demand for item Z is increasing by 50%. Because the finished goods inventory aim is measured in weeks of forward supply, its invenotry quantitiy must also increase by 50%. So Finishing must now produce 50% of what it currently has in inventory. Finishing then dutifully passes along this information to Sensitizing. Now Sensitizing, who also measures its inventory in forward weeks supply, must increase its own inventory quantity by 50% because of the demand change. Plus, it

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[40] Sterman, *op. cit.*, pp. 328-336.

[41] A similar phenomenon, called the Bullwhip Effect, has been reported in the literature and is also instructive in explaining behaviors observed in FMF. In Hau Lee, Paddy Padmanabhan and Seungjin Whang, "Information Distortion In a Supply Chain: The Bullwhip Effect," Working Paper, Stanford University, (January 1994), the authors report on four sources of demand information distortion, two of which are relevant to this discussion of the FMF:
1) Demand signal processing. This refers to how demand observed at the downstream stage is transmitted upstream in "exaggerated form." This is closely related to Beer Game behavior and the Springboard Effect.
2) Price Variations. "The bullwhip effect in this instance is created by the 'forward-buying' behavior of retailers vigorously acting on the price promotions used by the manufacturer." In the FMF, [Ma]rketing's promotional planning can cause this information distortion.

> must now produce 83% of what it currently has in inventory, 50% for itself and 33% for downstream inventory. The springboard has started![42]

The situation is mirrored when the forecast is decreased, as increasingly smaller upstream inventory targets leave excess material only to be consumed when downsteam stages deplete their own inventories. Functional performance metrics serve to promote this Springboard Effect. Marketing is measured on meeting quarterly sales targets and planners are measured on meeting inventory targets. So, when Marketing holds sales promotions to boost volume and meet their targets, the expected increase of orders inflates the demand forecast which is passed on to Finishing and Sensitizing because each successive stage responds by boosting production to meet demand *and* the inflated inventory targets. It is the structure which promotes the large inventories and long cycle times as well as the variable demand. It is the structure which gives people the feeling of not being in control. It is the structure that creates the FMF behavior. And, in an environment of 10X cycle time reduction, it is the structure that must be changed.

6.4 Summary of Information Flow and Demand Forecasting Issues

- numerous handoffs in a long, vertically integrated supply chain
- inaccurate forecasts start in Distribution and Marketing
- forecast variance propagates through the supply chain due to suspect "tying" activities (i.e. reconciliation of disparate forecasts) and filtering of cascaded demand at each stage to meet functional inventory targets
- updates to the forecasts do not seem to make them more accurate in Finishing or Sensitizing
- demand variability is not characterized throughout the flow as forecast errors are written over and accountability for forecast error is lacking
- wide roll safety stock standards are insufficient to account for supply and demand variability and meet target service levels

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[42] Hetzel, *op. cit.*, p.70.

- variability of wide roll supply is substantial and planned lead times bear no relation to actual lead times
- decoupling of planners through location at different sites and functional information systems permit second guessing of the inbound demand signal
- long coated item lead times force the wide roll planner to react to weekly and monthly forecast updates rather than enabling planning
- structure of the information flow, including functional measures and a lack of accountability for variability and cycle time, does not support 10X cycle time reduction

We need to share information and work together to win.

- Beer Game participant

7. Fixes

7.1 Use A Direct Feed of Distribution Demand in Wide Roll Planning

As there is minimal tracking of demand variability, no ownership of forecast variance and multiple handoffs among many information handlers, the current structure of the information flow facilitates the distortion of the inbound demand signal. Marketing distorts the customer demand signal with promotions and quarterly sales targets. Sales Forecasting is an agent of this error, passing it on to Demand Planning in OPAL. Demand Planning couples this with the demand distortion found in the erroneous DRP forecasts to somehow arrive at an inaccurate demand signal fed to Finishing. Finishing uses this demand signal to schedule production. Due to forward-looking inventory targets updated with this "bad information," Finishing orders more than actual shipments if Distribution's demand is larger than forecasted, and less if shipments are smaller than forecasted. Thus, Wide Roll Planning and Sensitizing are faced with a highly variable order pattern from Finishing. At this point, Sensitizing has no idea what true customer demand is and can only react to Finishing's fluctuating demand. How do we arrest this series of events - the Springboard/Bullwhip Effect - which builds excess inventory all along the chain, such that Wide Roll is actually *planned*?

The Beer Game participants actually answered this question by asking another during the simulation: "why didn't the [distributor] just yell [the order]?" With the current MRP II architecture, the cascaded demand signal drives oscillation. Distribution's minimum inventory levels are tracked in forward weeks of supply such that fluctuations in customer orders are compensated for by updating demand on Finishing. Upstream filtering of this demand signal according to functional inventory targets overcompensates for the demand change, inflating orders and propagating demand variability through the supply chain as described in the Springboard/Bullwhip Effect. Lee, Padmanabhan and Whang show that "bullwhip effect can be eliminated and efficiency restored if the manufacturer can have access to the sell through data at the retail outlet."[43] Lacking point-of-sale capture, the Distribution Centers are the closest thing to a retail outlet in this chain. Aggregating and apportioning routines in DRP make it relatively easy to obtain coated-item demand in Distribution.

A direct feed of DRP demand would allow the wide roll planner to identify long-range demand changes and alter coated item safety stocks accordingly. More importantly, the feed would reduce handoffs, demand variability, time lags in acquiring demand information and overordering brought about by the current MRP II system. Furthermore, decoupling Sensitizing production from Finishing demand with a DRP feed and formal wide roll stocking policies are aligned with the ongoing ABC classification of coated items to formalize event scheduling in Sensitizing.

7.2 Characterize Coated Item Supply Variability

Behaviors observed in the Beer Game and the FMF are oscillating orders and high supply chain cost due to excess inventories. Sterman shows that one probable cause for the Beer Game behavior is that "the subjects underestimated the lag between placing and receiving orders." Furthermore, he suggests that "subjects should fully account for the goods in the supply line to prevent overordering."[44] Overordering is known to exist in the FMF. Also, planned coated item lead times are much less than actual coated item lead times, suggesting the same underestimation observed in the Beer Game. To curb Beer Game behaviors, FMF planners need a lot more supply line information.

The supply line in Sensitizing is the time from placing a coated item order until reciept of that order in released wide roll inventory, i.e. the coated item lead time as described earlier in the document. The bulk of the supply line is unreleased wide roll inventory. The

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[43] Lee, Padmanabhan, and Whang, *op. cit.*, p. 24.
[44] Sterman, *op. cit.*, p.334.

Product Staff and Testing continually update the status of unreleased coated items in Record Block/CCS. The dispositioning done primarily by the Product Staff is a very stochastic process and there is little understanding of the magnitude of supply variability for coated items. Coated item disposition strategies, lead time distributions and yield variances are not visible to the planner; he can only *react* to demand shifts by tracking orders with the Product Staff and Testing and expediting material. Characterizing coated item supply variability and providing accurate supply line information will eliminate the need for overordering and free the wide roll planner from tracking releases, thereby allowing him to plan. This will require Production and Planning functions to work more closely together. Using the words of one Beer Game participant to sum up this fix: "Know the limitations of your suppliers."

7.3 Collocate Planners

To enhance knowledge of the supply chain inventories and prevent overordering, I recommend collocating the planners. Currently planners are separated by time, space and information in the functionalized FMF structure. Collocation using a "command center" approach as suggested during the Beer Game would promote coordination and trust in processing orders and managing supply chain inventories. Furthermore, a DRP feed into this command center would enhance the global information on customer demand and ensure that planners were working from the same demand signal.

7.4 Change Coated Item Safety Stock Targets

Setting safety stock targets in forward weeks of supply helps promote the Springboard Effect. I recommend changing coated item safety stock targets to be less sensitive to weekly shifts in the forecast by basing them on average DRP demand rates rather than immediate forecasted demand levels. This would dampen demand noise and smooth out production, thereby reducing system inefficiencies (expediting and excess inventory) due to overcompensation for demand variability. Toward this end, using DRP demand is doubly advantageous. DRP not only provides an unfiltered demand signal, but also forecasting capabilities which afford the planner forward visibility of demand and sufficient information to update safety stock targets.

7.5 Reduce Coated Item Lead Times

The essence of supply chain responsiveness, and therefore the essence of 10X, is lead time reduction. The aforementioned recommendations speak to the need to increase coordination and reduce the information lead time, i.e. the time from recognizing a change in downstream demand until placing an order for upstream production. Supply chain coordination only goes so far, however. Regardless of how good the demand information is or how fast it arrives, long coated item lead times will ultimately limit the supply chain's ability to cost-effectively respond to the customer.

7.6 Change Supply Chain Performance Measures

The current film manufacturing supply chain performance measures promote suboptimization: Marketing is measured on sales, so they inflate the forecast; the Line of Business is concerned with customer service, so they keep large finished goods inventories; FMF Operations are measured on Unit Manufacturing Cost, so they compete for volume; the Product Staff is measured on quality and waste, so they hold onto coated items, building wide roll inventory; the Flow Manager is measured on cost, quality and delivery - *inventory and cycle time are secondary considerations*. The entities that measure inventory and cycle time, Material Flow/Demand Planning and Management Services Division, have the least control over them. Moreover, it is unclear who has responsibility for variability, which is a key contributor of inventory and cycle time.[45]

Fisher's Expectations require supply chain optimization, not suboptimization. 10X can not be achieved with the current structure. To make progress toward Fisher's Expectations, I recommend that product flows elevate and share accountability for

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[45] Tom Davis, in "Effective Supply Chain Management," *Sloan Managment Review* (Summer 1993), p. 36, summarizes such a scenario leading to excessive supply chain inventories: "most organizations are designed to create winners and losers; working together for system optimization receives little more than lip service."

inventory and cycle time and variability. The next section gets at some of the issues which must be considered before moving past this last but most important recommendation, toward implementation.

There are many good problem-solving methodologies. Sometimes the greatest challenge is not solving a problem, but finding the correct problem to solve.

- Shoji Shiba

8. Insights

8.1 Management Commitment is the First Step

8.1.1 People Know What the Problems Are

The people in the FMF know what the problems are. Their comments during the Beer Game revealed:

- supply chain is too long
- no understanding of true customer demand
- demand variability propagates through the supply chain
- current performance measures constrain their actions
- long lead times and supply variability make the situation worse
- planning and production are decoupled

Furthermore, people know what steps are necessary to fix the problems:

- "It is a large supply chain. We need to communicate more often." "Maybe the [information handlers] have to be in the same room, perhaps a command center."
- "the customer demand rate should be announced to the rest of the supply chain."
- "measure demand variability at three levels: Customer, Finishing and Sensitizing."
- "Integrated strategies/objectives need to be communicated along the supply chain."
- "We must reduce our cycle time to meet the customer needs if we want to stay in business."
- "We need to share information and work together to win."

If people know what the problems are and know how to fix them, what is constraining their behavior? Once again, the structure is the answer.

At the time of this investigation, the Film Manufacturing Flow Manager was measured on three primary items: cost, quality and delivery. Cycle time information was tracked and owned by Management Services Division. Delivery targets were based on a negotiated schedule rather than the ability of FMF to respond to unconstrained customer demand. The importance of cycle time and supply chain responsiveness must be elevated if people are to be able to embrace the 10X challenge. Management must commit to changing a structure which lacks cycle time and variance accountability before any of the above issues get addressed. A comment from the Beer Game is particularly telling in this regard. In response to a workshop follow-up survey question on people's purpose in attending the Simulation Workshop, one participant stated: "to gauge [an FMF manager's] commitment." When the people of FMF sense that management does not stand behind cycle time reduction as a primary goal, how can they be expected to put their solutions into practice? How can they see a workshop like the Beer Game adding value to the supply chain? The answer is they can't. Another survey comment is appropriate here. When asked to state one way the workshop added value to the supply chain, one person stated: "As an isolated exercise, it did not add value. If there is follow-up and a breaking down of current structure, it could have an impact." Perhaps this work can be considered as value-added follow-up by breaking down the structure of the information flow and wide roll planning. Yet there is still one element of the underlying structure which must be mentioned before concluding this document.

8.2 The Product Staff Controls the Flow

Efforts to identify the greatest opportunities to reduce cycle time by 10X while meeting corporate mandates for cost and customer service must involve, among other things, a full scrutiny of inventories as these consume roughly 70% of the FMF's critical path cycle time. As Hetzel states in his work, "The ultimate cycle time vision foresees a supply chain capable of blasting goods through to respond to customer needs with the barest amounts of inventory between each stage." In essence, this vision is one of maximizing throughput -- the rate at which money is generated through sales -- while minimizing inventory and operational expense. To accomplish this involves identifying the bottleneck resource and coordinating its output with market demand. Where is the bottleneck in the flow? Within the studied film flow, it is accepted by management that the bottleneck resource is the coating facility. It is managed as such, with little if any extra capacity or "headroom" built into the coating schedule. Yet, during the Beer Game, the question arose: "Do we understand what the bottlenecks are in the system?"

> "Don't you see?" I ask them. "If we've got a Herbie [a bottleneck], it's probably going to have a huge pile of work-in-process sitting in front of it."
> "Yeah, but we got huge piles all over the place out there," says Bob.
> "Then we find the biggest one," I say.[46]

Looking at 1993 supply chain data for the product family under consideration, wide roll represents 53% of the inventory, two-and-a-half times the next largest portion, finished goods inventory. Does this make the finishing operation the bottleneck? Perhaps, but the cycle time of finishing is seven days, whereas the cycle time of Sensitizing, as measured from the commitment of an order for wide roll to the scheduling of that roll for Finishing, is 150 days. Of these 150 days, almost half are taken up as queue time from coating to disposition of the coated item. This coat-to-disposition segment of the flow has two inventory components, unreleased and released wide roll. For the four codes studied in this work, a breakdown of year-long average inventory levels shows 64% unreleased, 36% released. *So where is the bottleneck? It could very well be the operation that takes an unreleased roll of inventory and turns it into a released roll.*

In its current state, the release of a wide roll of film for downstream processing is a lengthy, extremely variable and, in some cases, uncharacterized process. Upon windup in

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[46] Eliyahu M. Goldratt and Jeff Cox, *The Goal: A Process of Ongoing Improvement*, 2nd rev. ed. (Croton-on-Hudson, NY: North River Press, Inc., 1992), p. 144.

the coating facility, all coated item information flows directly into and out of Testing and the Product Office. The quality imperative and heavy staff involvement in dispositioning coated items makes cycle time both long and variable. Current performance measures do not help cycle time reduction. One coating engineer stated: "As an engineer, I was never evaluated on cycle time." Nor are engineers evaluated on inventory. Clearly, 10X reduction must start here for the effort to be effective and ingrained across the flow. Without a focus on the coating process and up front commitment from the Product Staff, the 10X effort will be bottlenecked.

8.2.1 EMFIT and Data Ownership

The emulsion manufacturing flow improvement team (EMFIT) was a cross-functional team composed of representatives from the shop-floor (emulsion manufacturing unit or EMU), planning, product staff, industrial engineering and management functions. They met once each week with the accepted mission of identifying and prioritizing ways of increasing film throughput, then executing the resulting path forward. With an extensive list of ongoing improvement projects in hand (essentially satisfying the 'identifying' part of the mission), and no framework to prioritize, the team set about to map its process flow. During the course of this extensive mapping exercise (which took roughly a month), two things became apparent. First, the team did not have a firm grasp on how transactions in the shop-floor control and new MRP II systems fit in with material transformations, product testing or dispositioning. Second, the team did not have a firm grasp on how its existing cycle time metric was calculated. Concurrent efforts were made to remedy these two roadblocks to improved throughput.

A flow map was constructed showing EMU activity from commitment of a coated item order all the way through to emulsion melting during the coating room event. This map included off-line item dispositioning steps performed by the Product Staff and information system ('exception') messages resulting from flow interruptions, e.g. late orders or unavailable materials. The team's efforts were subsequently focused on formalizing the cycle time and exception message metrics as keys to measuring the team's progress. The

EMU cycle time starting point was reconfigured to measure from initiation of shop floor activity rather than from a planner commitment which, in some instances, had been observed as more fluid than firm. A member of the Product Staff manually tracked cycle time for a few items and verified these numbers with a database manager external to the team. While this effort was ongoing, the team was educated as to the workings of the exception message system through a series of presentations. Upon learning about both metrics and agreeing on their value, the team took ownership for cycle time and exception messages and went about prioritizing flow improvement activities using the map.

A primary learning derived from the above teamwork was the importance of coupling the material and information transactions/transformations into a shared understanding of the flow, as represented by the map. Without this understanding, the team lacked the ability to effectively measure its performance, either by cycle time or exception messages, and thereupon engage in focused improvement efforts. The exercise of constructing this comprehensive flow map also brought to light a new constraint in EMU, thereby allowing effective prioritization of ongoing activities. Furthermore, the adoption of exception messages as a team metric was quite noteworthy in that it represented a first attempt to monitor delivery performance.

In many ways, EMFIT's activites are symbolic of the path the supply chain has to take in tackling Fisher's Expectations. EMU had plenty of flow maps in hand prior to the one configured by EMFIT. EMFIT's map was different, though, in that it was verified by all team members, spanning different job functions, e.g. shop floor, product staff, flow planning, industrial engineering and flow planning. The cross-functional sharing and verification generated ownership of both physical and information flows on one inclusive map. Also, cycle time had been measured for EMU by a database manager from Management Services Division (MSD) for three years prior to EMFIT's formation. Cycle time ownership, however, did not become evident until a *product engineer* sitting on the EMFIT manually tracked the metric for a couple products and then verified these numbers with the database manager. Similarly, ownership for delivery performance was enhanced by the adoption of the exception message system.

The experiences of EMFIT with data ownership have significant implications for other cross-functional improvement activities such as dynamic modeling of the supply chain. In particular, any dynamic modeling of the supply chain is doomed for failure unless the data and assumptions on which the model are based are understood and shared by the model users. The successful implementation of Bill Hetzel's supply chain optimization work owes a great deal to the shared efforts of team members to embrace the modeling activity.[47] Contracting out a model to MSD without actively engaging team members in data collection and parameterization will only result in one thing - an unused model. Furthermore, model construction and application will be hampered if the team members feel unempowered to use the model to make changes to the system. This indeed was the case with Team X's stalled Strategic Inventory Placement modeling effort. Team members were aware of questionable sponsorship and chose to focus their attention elsewhere (like "supply issues"). Recognizing the control the Product Staff has over the flow should be a first step toward sharing ownership for flow improvement and making any modeling, mapping or flow measuring activities fruitful.

[47] Hetzel, *op. cit.*, p. 54.

A bold plan, a nice try and a good excuse used to be good enough."
- an FMF manager

9. Conclusion

Cycle time reduction can be achieved many ways. Machine speed can be elevated or new machines can be brought in to elevate throughput. But if production is not synchronized with customer demand, inventories build and so does cycle time. If extra capacity is bought, costs are incurred. If quality is not kept in check, customer service is sure to suffer. Quality can be insured by inspecting everything; but this comes at a cost and extends cycle time. Customer service can be bought with huge inventory, but this comes at a cost and extends cycle time. How, then, does one approach Fisher's goals of 10X cycle time reduction, 2X cost of poor quality reduction and annual customer service improvement? The answer lies with the flow, not the functions. Fisher's goals can not be viewed separately; moving toward these goals can not be functionalized. Moving toward these goals requires flow thinking and shared accountability. Management must create a culture of coordination, planning and responsiveness through integrated people, processes, products and goals which reflect the strategies of the business. The FMF structure must be changed to promote integration, not functionalization of the material and information flows.

Integration requires holding people accountable for their actions. Without accountability, cause and effect will be decoupled in every supply chain transaction/transformation. In essence, the system will remain under open-loop functional control - the Planning Loop will be populated by independent elements and blaming will prevail, as suggested in Figure 9.1.

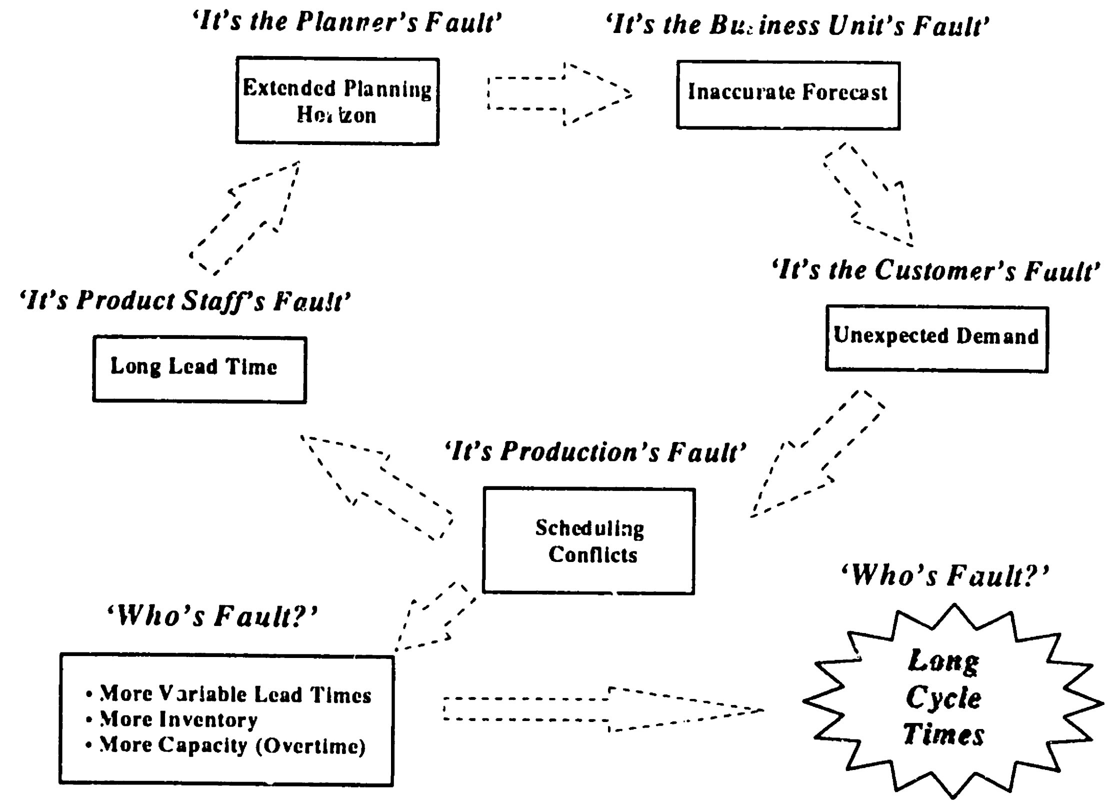

Figure 9.1 The Open Loop of Supply Chain Blame

A bold plan, a nice try and a good excuse will suffice in this system as long as the focus is external and as long as people are not held accountable for their plans.

This brings me back to a comment made by one FMF manager near the start of this work and which helped to guide this investigation: "I need demand variability and forecast accuracy - hard data that shows [the Business Unit] is not helping the flow." Asking for better forecasts is merely a symptom of the open-loop FMF structure. In explaining Beer Game behavior, Sterman comments:

> Most subjects attribute the dynamics [of the supply chain] to external variables which they believe to be closely correlated in time and space with the phenomenon to be explained. These explanations reflect an 'open-loop' conception of the origin of dynamics, as opposed to a mode of explanation in which change is seen as arising from the endogenous interactions of decision makers with their environment. Learning from experience may be hindered by such misperceptions of the origins of dynamic behavior. When asked how they could improve their performance, many call for better forecasts of customer demand. The erroneous open-loop attribution of dynamics to exogenous events thus draws subjects' efforts to learn away from the high leverage point in the system (the stock managment policy) and towards efforts to anticipate and react to

> external shocks. *While better forecasts are likely to help, the key to improved performance lies within the policy individuals use to manage the system and not in the external environment. Even a perfect forecast will not prevent a manager who ignores the supply line from overordering.*[48]

The real focus for meeting Fisher's Expectations should be to challenge the functional policies and structure which promote long lead times, thereby decoupling the information and material flows. The real focus should be to connect the FMF elements - effectively closing the supply chain Planning Loop, building trust and sharing ownership for cycle time, inventory and variability. If the Beer Game and this thesis aid these activities, then they should be considered successes.

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[48] Sterman, *op. cit.*, p. 336 (emphasis added).

Appendix 1: 1994 Released Inventory Profiles for Three FMF Coated Items

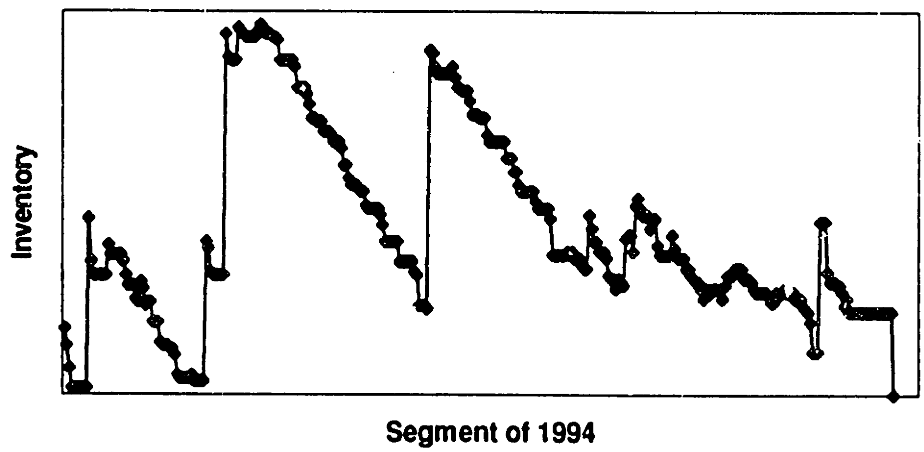

Figure A1.1 Released Inventory Profile for Coated Item A

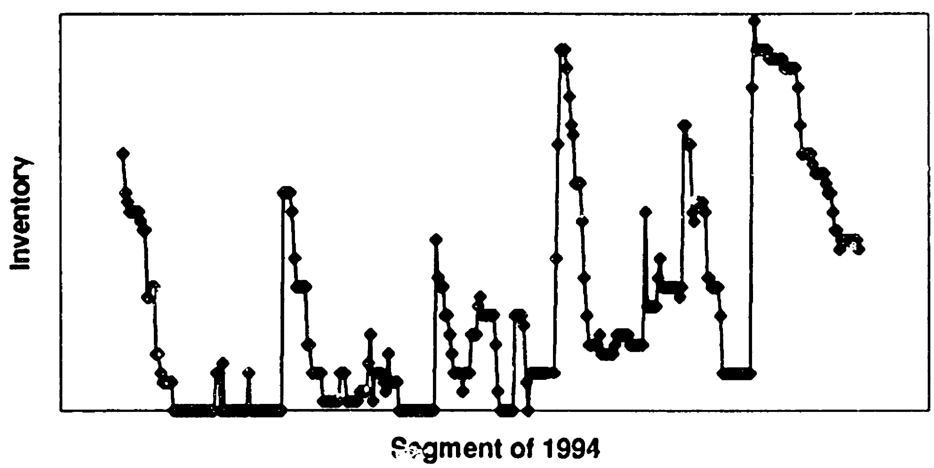

Figure A1.2 Released Inventory Profile for Coated Item C

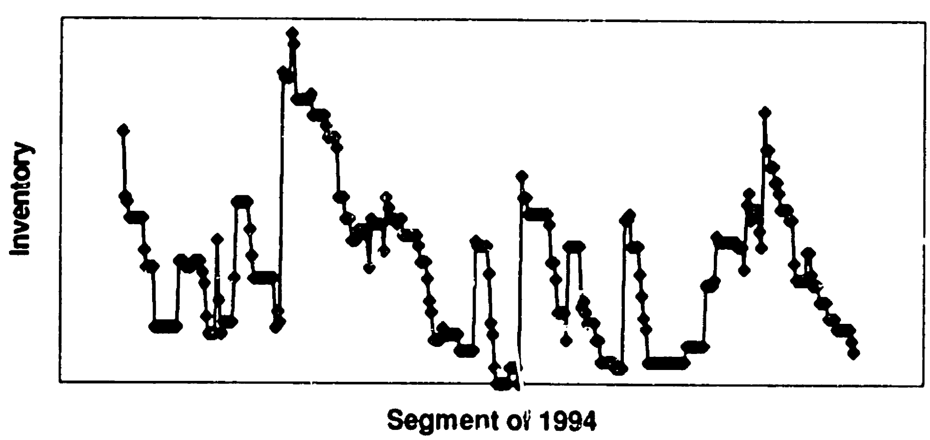

Figure A1.3 Released Inventory Profile for Coated Item D

Appendix 2: 1994 Demand vs. Forecast for Three FMF Coated Items

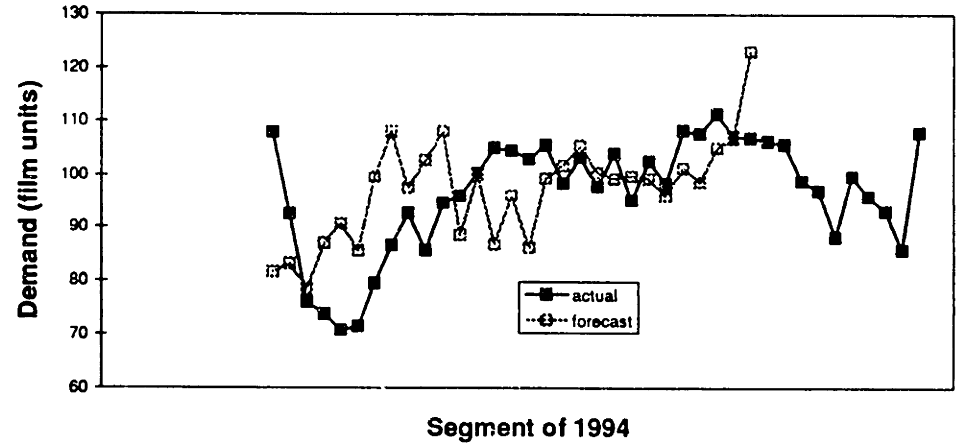

Figure A2.1 11-Week Aggregate Rolling Demand vs. Forecast for Coated Item A

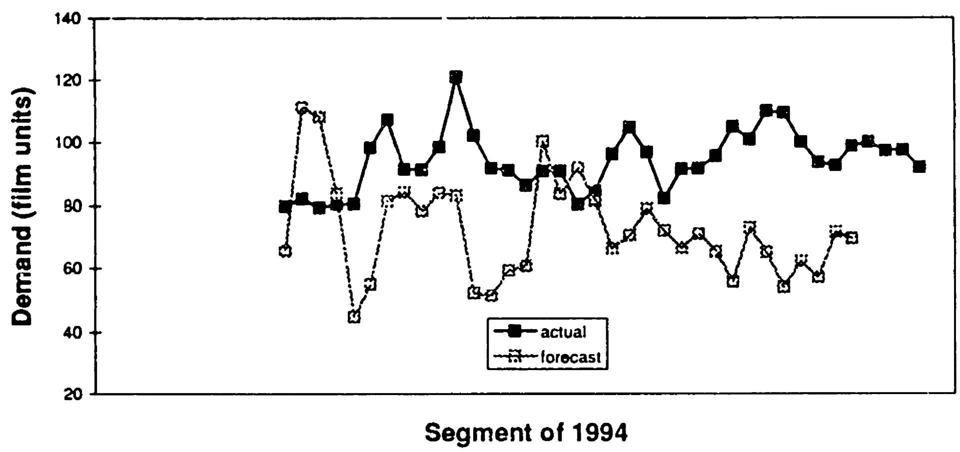

Figure A2.2 12-Week Aggregate Rolling Demand vs. Forecast for Coated Item C

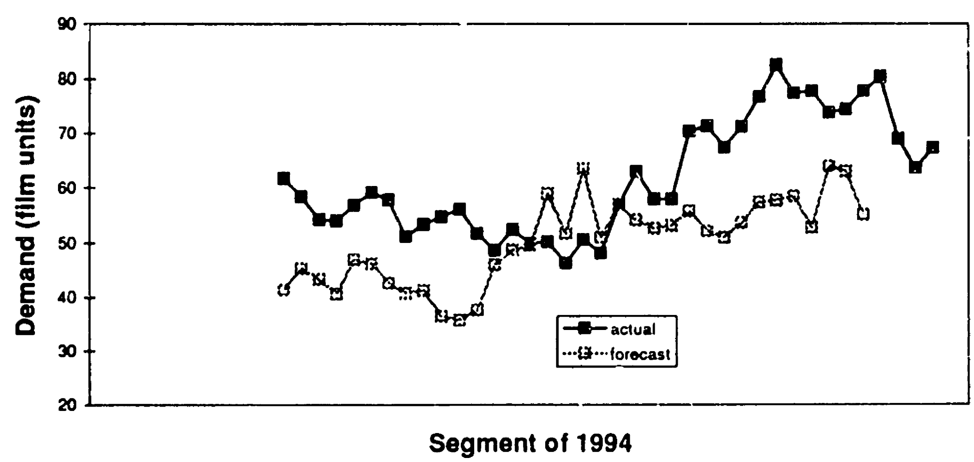

Figure A2.3 12-Week Aggregate Rolling Demand vs. Forecast for Coated Item D

Appendix 3: Probability Distributions for 1993/1994 Roll Lead Times for Three FMF Coated Items

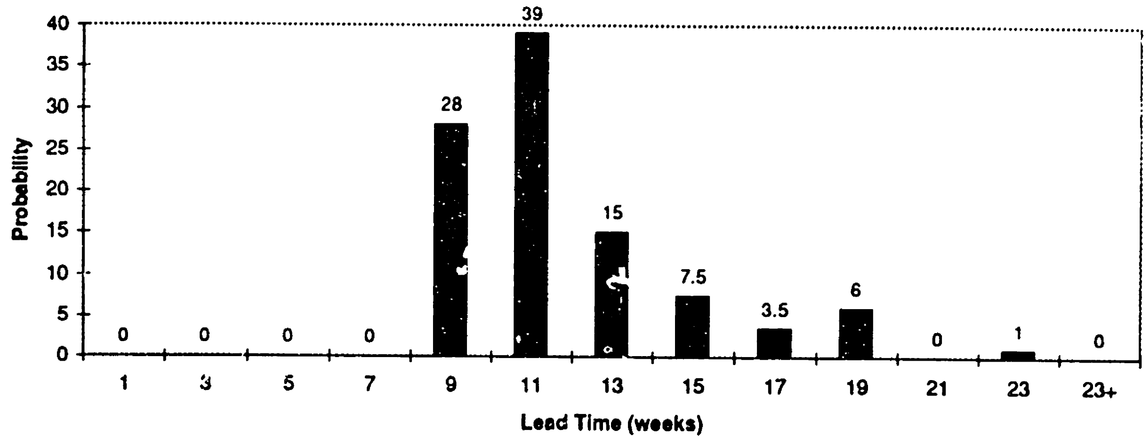

Figure A3.1 Probability Distribution of Roll Lead Times for Coated Item B

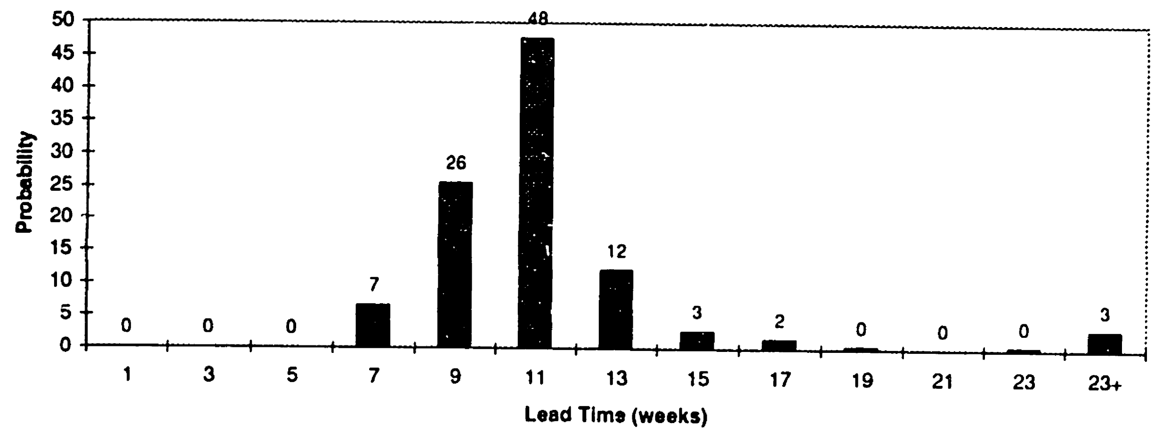

Figure A3.2 Probability Distribution of Roll Lead Times for Coated Item C

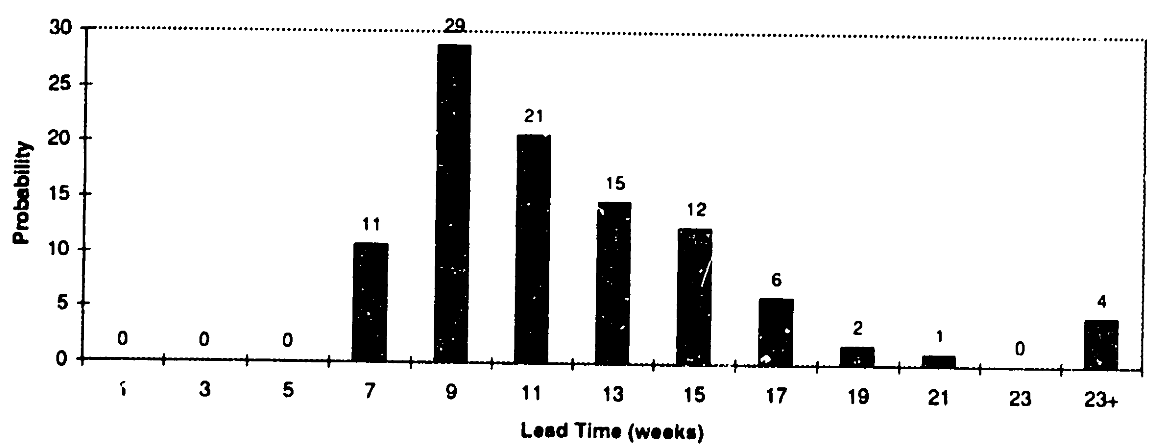

Figure A3.3 Probability Distribution of Roll Lead Times for Coated Item D

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