

**The Use of Strategic Inventory and Packaging Postponement to Address
Daily Demand Variability and Seasonal Demand Patterns
in a Demand Flow Environment**

by

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B.S. Chemical Engineering – West Virginia University, 1991

Submitted to the Sloan School of Management
and the Department of Chemical Engineering
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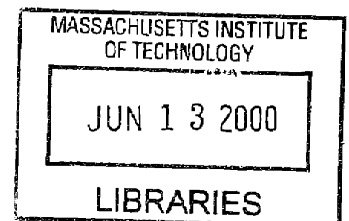
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ABSTRACT

This LFM thesis describes how Eastman Kodak Company (Kodak) used a strategic buffer of in-process inventory and delayed final packaging of end-items to address two issues that surfaced after a recent implementation of a demand-driven process in their film finishing operation. By select placement of inventory and a judicious prebuild of spools upstream of the packaging operation, Kodak has reduced manufacturing costs, maximized their ability to respond to consumer demand patterns, and minimized end-item delivery concerns associated with both daily demand variability and seasonal demand patterns.

This research work was conducted during a six and a half-month internship at the manufacturing site, Kodak Park in Rochester, New York. The internship was affiliated with the Massachusetts Institute of Technology's Leaders for Manufacturing program.

This thesis describes the technical analysis and justification for the decision to pursue this manufacturing strategy at Kodak. The concepts of strategic inventory placement and packaging postponement (delayed differentiation) are discussed in the context of this particular application and are generalized for other manufacturing processes. In the interest of protecting company confidentiality, the numbers presented in this thesis have all been disguised. The justifications for pursuing this particular strategy within Kodak as well as generic guidelines for when these strategies may be applicable are discussed in the context of this thesis.

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Chapter 1: Introduction and Overview

Managing complexity in the face of competitive cost pressures has become a major initiative for many manufacturing organizations. Increases in the number of product offerings have resulted in manufacturing processes and inventory systems where it is increasingly difficult to control the delivered cost of end-items. The additional production complexity driven by product diversity combined with increasing pressure from low cost manufacturers as well as impending threats from outside technologies has forced companies to focus on reducing manufacturing costs in order to provide sustainable revenue and earnings growth. Eastman Kodak Company (Kodak), the site of this research, is no exception.

Following an increased domestic manufacturing and marketing presence in the 1990's by their primary competitor, Kodak has found themselves operating under increased pressure to provide the lowest cost product¹. This pressure coupled with the potential disruption to the established silver halide film market by evolving digital imaging has forced Kodak to strive to reduce their manufacturing costs in their core business. As such, the company's financial performance objective is to deliver an average annual increase in earnings per share of at least 10% over time. In order to do so, they "must combine sustainable revenue growth with improved efficiency and manufacturing performance"². Improved usage of both equipment and inventory play a vital role in achieving these manufacturing performance objectives.

In order to increase asset utilization and return on equity (ROE), many companies have increased their focus on having the minimal amount of inventory required for their manufacturing process.

¹ "A Dark Kodak Moment," *Business Week*, August 4, 1997, pp. 30-32.

² Fisher, George M.C., Remarks made at Annual Shareholder Meeting, May 12, 1999.

Clearly some level of inventory is necessary for an optimal process. Some of the rationale for holding inventory includes the following:

- (1) Inventory can be used to buffer against demand or process variability resulting in stable manufacturing shop floor operations and production output.
- (2) Customer or market conditions may require rapid order fulfillment. That, combined with manufacturing limitations, may necessitate holding inventory.
- (3) Inventory may be cheaper than capacity; therefore, a prebuild of inventory may be justified as opposed to providing adequate capacity to handle peak or seasonal demand.
- (4) Additional set-ups to reduce batch sizes (and related cycle stock) may be cost or time prohibitive.
- (5) The workforce size may be fixed due to unique skill requirements or labor regulations; therefore, during low demand periods rather than having idle time, production may be scheduled in excess of actual demand resulting in an inventory build. If labor is a significant part of cost of goods, an inventory build may be justified.

Clearly there are instances where some measure of inventory is both justified and beneficial.

When attempting to improve asset utilization how does one ensure that the appropriate amount of inventory is located in the optimal location? Having less inventory for the same manufacturing costs is good; however, what is the break point where lower inventory levels result in a related increase in manufacturing costs that do not justify the decrease in inventory?

This thesis describes the research that was undertaken at Kodak's film finishing operation to examine this particular dilemma. Kodak had recently (within the past year) instituted a demand-driven (or pull) process in their manufacturing organization. The crux of this research was predicated on determining how to improve the performance of the manufacturing operation while operating in a demand-driven environment. As with most industrial research projects, the analysis and solutions were bounded by several system constraints that will be highlighted in the following chapters. Also, it should be noted that in the interest of company confidentiality, the actual capacity and demand numbers have been disguised. The concepts, issues, and methodologies applied to this particular concern, however, are real.

1.1 Concept of Strategic In-Process Inventory Placement

After acknowledging that inventory can be beneficial, how does one determine if it is situated in the right location and in the right amount? A judicious buffer of inventory may prove to be beneficial when demand variability impacts either product delivery or shop floor operations. For highly variable processes, inventory may be a requirement. A significant amount of operations management research has been performed in the area related to “strategic” placement of in-process inventories³.

1.1.1 Benefit of Strategic Buffers

Buffers are designed to protect the manufacturing operation against either process or demand variability. Depending upon the specifics of the manufacturing process, buffering from variability can be very important. For example, demand-driven manufacturing processes, such as a just-in-time (JIT) system, do not work well with highly variable demand streams⁴. This is because a demand-driven process that is subject to a highly variable demand stream could result in sizeable peaks and troughs in production. That is periods of high demand may likely be followed by brief periods of either low or possibly no demand. A stylized example is shown in Figure I.1.

³ Willems, S. P., “Strategic Safety Stock Placement in Integrated Production/Distribution Systems”, Master’s Thesis, MIT Operations Research Center, May 1996.

⁴ Hopp, W. J., and M. L. Spearman, *Factory Physics – Foundations of Manufacturing Management*, (1996) Irwin/McGraw Hill.

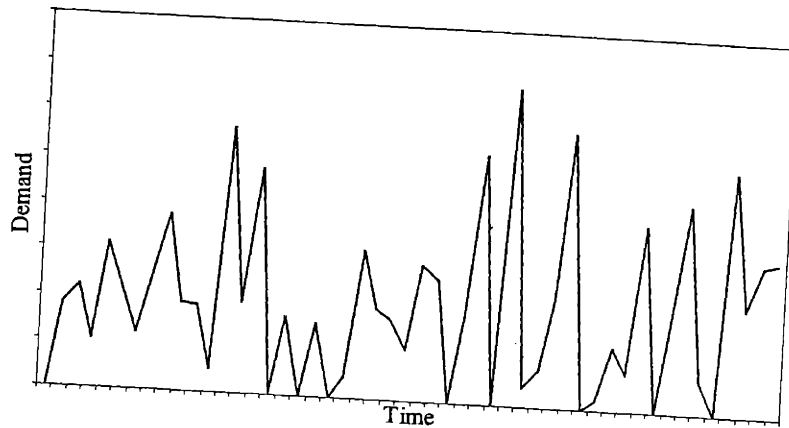


Figure I.1 Stylized Example of Daily Demand Variability

For processes subject to highly variable demand profiles, daily replenishment of manufactured items may not be feasible. This is because of the constraints that daily replenishment places on the manufacturing operation. For example, daily replenishment of end-items requires that the factory has sufficient capacity to produce the volume of product sold during the highest sales day. For a highly variable demand profile, this could result in a capacity requirement that is significantly larger than the average daily demand.

In order to smooth the demand profile and to lower the capacity requirements, the concept of a production-smoothing window is commonly used with a demand-driven process⁵. The smoothing window affords additional time to aggregate demand streams to level or “smooth” the size of the orders placed on the shop floor. The end effect is a lowering of the peak demand requirements in the smoothed demand profile. The stylized effect of demand smoothing can be seen in the Figure I.2.

⁵ Cruickshanks, A. B., Drescher, R. D., and Graves, S. C., “A Study of Production Smoothing in A Job Shop Environment”, *Management Science*, 30 (1984), 368-380.

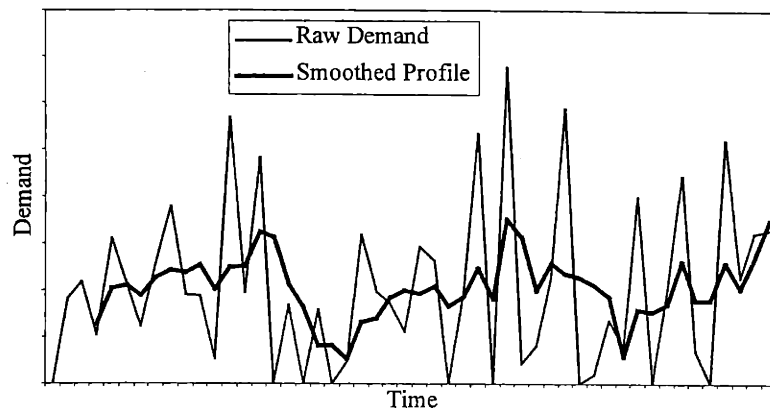


Figure I.2 Stylized Example of Production Smoothing

Even with a smoothed demand profile, there may be periods where the demand replenishment requirements exceed the nominal manufacturing capacity. Namely, if capacity is provided at a level that is consistent with the average demand value, there will be periods where the smoothed demand profile exceeds the nominal capacity. This is because the inherent variability in the demand stream results in oscillations around the average demand. The magnitude of the oscillations is directly proportional to the variability of the customer demand and inversely proportional to the size of the smoothing window. The impact of these oscillations relative to the mean demand is shown in the Figure I.3.

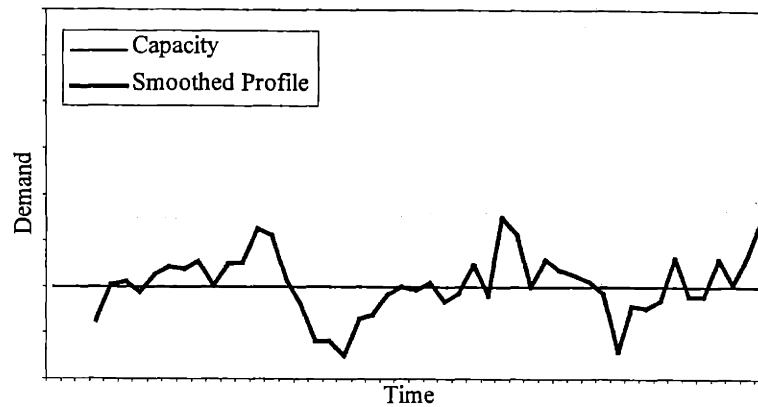


Figure I.3 Stylized Example of Capacity Imbalance Due to Variability

Daily demand variability results in periods where the demand profile exceeds the average demand value. In order to ensure that product delivery remains consistent during intermittent periods of higher than average demand, a capacity buffer must be provided. The buffer can either be in the form of capacity (labor and/or equipment) or inventory (“stored” capacity).

1.1.2 Examples of Strategic Buffers

Buffer as Capacity. Capacity buffers are commonly provided in JIT systems. A capacity buffer implies that either the manufacturing operation is not scheduled to be operational for the entire workday, or additional unscheduled equipment or labor is readily available if needed. In this scenario, the capacity line shown in Figure I.3 would simply be shifted upward so that the smoothed demand line falls beneath the capacity constraint for some percentage of the time depending upon the desired service level. The unallocated capacity (production time or equipment) provides the capability to provide additional manufacturing should the actual equipment performance, material delivery, or demand data differ from what was originally anticipated. Such differences are common because of inherent variability in process systems.

Buffer as Inventory. Strategic buffers can also be in the form of “stored” capacity, i.e. inventory. In this scenario the inventory is used to supplement production during periods of higher than average demand when the manufacturing organization is unable to match the customer demand patterns. Doing so ensures uninterrupted product delivery to downstream operations. Inventory or stored capacity is created when demand is less than the average demand over the scheduling period.

The tradeoffs between buffering as either capacity or inventory must be analyzed under the context of the particular circumstances. In general, the cost of excess capacity (either equipment or labor) versus the cost of holding additional inventory (cost of capital and holding costs) should be evaluated to determine the appropriate strategy. Relative characteristics of when you would choose a particular buffering strategy are shown in Figure I.4.

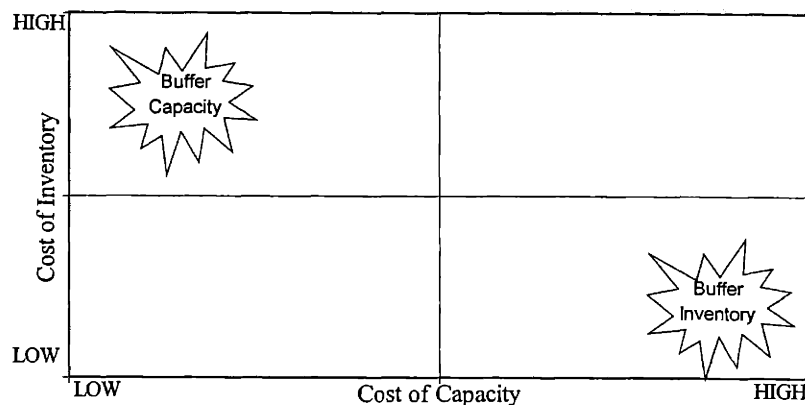


Figure I.4 Preferred Means to Buffer against Demand Variability

The classic JIT system, often revered and imitated, is the Toyota Production System (TPS). TPS is commonly referred to as the benchmark when companies discuss their efforts to improve the efficiency of their manufacturing operations. What may not be obvious is that even within

Toyota they recognize that there will always be variability within a manufacturing process.

Contrary to the notion that a true JIT system must operate with zero inventories (a goal of many manufacturing operations), Toyota chooses to hold inventory for specific circumstances⁶. One of these is related to the variability of the customer demand signal.

This thesis examines a specific case at Kodak to evaluate means to buffer against demand variability in a demand-driven process. After the implementation of a demand-driven process, Kodak experienced product delivery concerns within the finishing operation that were related to daily customer demand variability. In the end, the concept of strategic inventory placement was evaluated to determine the benefits of buffering against the daily demand variability. The costs and benefits of the proposals are weighed in the context of this particular case.

1.2 Concept of Delaying Product Differentiation

The concept of delayed product differentiation has also received a significant amount of attention in the operations management research in recent years.⁷ In efforts to increase market share, many companies have extended their product lines. This has resulted in increased complexity of manufacturing systems due to a proliferation of product offerings. The high degree of product proliferation has also made it very difficult to obtain accurate forecasts for each unique end product. Competitive pressure to provide high service levels, coupled with inaccuracies in the forecasts of individual products, has resulted in high inventory levels throughout many

⁶ Spear, Steven, and Bowen, H. Kent, "Decoding the DNA of the Toyota Production System," *Harvard Business Review*, September-October (1999), 96-106.

⁷ Nahmias, S., "Production and Operations Analysis", 3rd ed. (1997), Irwin, Chicago.

manufacturing systems⁸. Unfortunately, high inventory is counter to efforts to increase return on equity (ROE).

As a result of competitive pressures, companies with expanding product varieties are faced with increasing problems in getting accurate demand forecasts for different products, controlling the proliferation of inventory, and providing high service for the customers. To compete in the world market, product variety is needed for marketing and sales promotions. However, product variety has a significant impact on inventory level and service performance⁹.

1.2.1 Benefit of Delayed Product Differentiation

Delaying product differentiation enables the manufacturing organization to pool the demand variability at a point of reduced product differentiation. The lower level of variability for the pooled item reduces the quantity of inventory that must be held across the aggregate product portfolio. Delayed product differentiation benefits manufacturers in two ways: it increases their flexibility by enabling them to commit their work-in-process to a particular end product at a later time, and it may decrease their cost of complexity by reducing the variety of components and processes in the system¹⁰. This later benefit is particularly true if the inventory in the downstream location is completely pulled further upstream at a point of lower product differentiation.

⁸ Garg, A., and C.S. Tang, "On postponement strategies for product families with multiple points of differentiation", *IIE Transactions*, (1997) 29, 641-650.

⁹ Lee, H. L., and C. S. Tang, "Modeling the Costs and Benefits of Delayed Product Differentiation", *Management Science*, Vol. 43, No. 1, January (1997), 40-53.

¹⁰ Garg, A., and C.S. Tang, "On postponement strategies for product families with multiple points of differentiation", *IIE Transactions*, (1997) 29, 641-650.

Delaying the point of differentiation increases the “flexibility” of the process to cope with the market uncertainties and lowers the inventory level for the same target service level. Even if it is necessary to carry inventory in order to provide short customer lead times, it may not be necessary to carry the inventory in the form of fully finished product. In some cases, it may be possible to stock the product in semifinished form and assemble or customize to order.

Semifinished inventory is more flexible, provided it can be used to produce more than one finished product. The aggregate risk pooling may make it possible to carry less total inventory.

1.2.2 Examples of Delayed Differentiation

A classic example of delayed product differentiation that has been applied in industry is the Benetton Group. Benetton is a large producer and marketer of garments whose items are sold in several thousand retail stores around the world. Rather than relying on sales forecasts that estimate demand by unique stock keeping unit (SKU), Benetton elects to use aggregate forecasts for garment types. Specifically the clothing manufacturer maintains an inventory of white clothing components that are only knit and dyed once an order specifying the desired style and color is received from a store¹¹. The delay in finalizing the configuration of a product until a customer order is received is referred to as “postponement”. Companies that employ this strategy are postponing the final production decision until as late as feasibly possible.

This thesis examines a specific case at Kodak to determine whether the concept of postponement is applicable. The postponement strategy in this research was applied to a product portfolio that is subject to a seasonal demand pattern. The seasonal pattern results in periods where the demand exceeds the nominal production capacity of the film finishing operation. An analysis of

the relative capacity of the various process steps within the finishing operation is performed to determine the applicability of a postponement strategy in order to address the seasonal concerns. The research at Kodak demonstrates that judicious postponement of end-item packaging (delayed differentiation) could be used to enable the company to alleviate seasonal capacity concerns and reduce their overall manufacturing costs.

1.3 Thesis Overview

This thesis explores the film manufacturing operation at Eastman Kodak in Rochester, New York. The material and information flow through the film finishing operation is closely examined and recommendations are provided to provide flexibility to facilitate the response to both seasonal demand patterns and daily variability. The concepts of strategic inventory placement and delaying product differentiation are tested and evaluated for Kodak's film finishing operation. In addition, guidelines are included to assist the reader in making a determination of when the strategies may be applicable in other instances.

This thesis begins by discussing Kodak's move from a forecast-based manufacturing planning to a demand-driven system. Under the forecast-based system, the level of finished goods inventory was significantly higher than what was provided under the demand-driven process. In addition, the timeframe for setting the manufacturing shop floor schedule was longer under the previous forecasting system. Both of these characteristics masked the concerns associated with daily demand variability and seasonal demand patterns.

¹¹ Zinn, W., "Should You Assemble Products Before an Order is Received?," *Business Horizons*, 33 (1990), 70-73.

After implementing the demand-driven process, several concerns were encountered. Specifically, the manufacturing operation experienced difficulty coping with the daily demand variability and the seasonal demand patterns of their products. These two concerns resulted in a higher than desirable use of overtime labor and poor delivery performance from the manufacturing organization. This research was conducted in order to identify improvements to the demand-driven process that could help Kodak achieve lower delivered costs of their film products.

For a demand-driven process to operate efficiently, the system must be buffered from the daily demand variability. Two options are available to buffer the system. One option would be to provide additional capacity while an alternative option would be to provide a buffer of inventory, that is stored capacity. Both options are considered in the context of Kodak's situation and recommendations are provided to determine when one option would be preferable to another.

The notion of providing a seasonal buffer of in-process inventory as a means of postponing the final packaging operation (delaying product differentiation) is also considered. An evaluation of this concept is applied to the situation where capacity constraints of an upstream processing step limit the ability to match the seasonal demand patterns. In addition guidelines are provided to assist the reader when evaluating other potential applications of postponement.

Lastly, like most industrial research activities, this research was limited by both scope and time constraints. Therefore, not all possibilities related to these production problems were considered. Recommendations are provided for further study and additional considerations are included as part of the final analysis.

Chapter 2: Project Setting and Background

2.1 Company Background, Position, and Outlook

From the *"You press the button. We do the rest."* marketing slogan created as part of an advertising campaign for the company's initial camera in the late 1800's, Kodak evolved into a company that was involved in every aspect of the manufacturing of silver halide film and related photographic equipment. Based on its founder's strong beliefs, the company also developed into one that maintains a pressing desire to please the consumer. The manufacturing complexity created by this vision combined with almost market exclusivity during the early part of the company's history resulted in manufacturing processes that were inflexible, and at times inefficient, yet they were capable of producing high quality product.

In recent years, competitive pressure within the core film business combined with the threat of digital technologies has resulted in a reevaluation of the company's manufacturing processes. The focus has been to reduce manufacturing costs in order to maintain strong earnings growth in the face of these threats. This chapter discusses the history of Kodak and the market forces that the company is currently operating under.

2.1.1 The Early Years

When George Eastman sold his first camera in 1888, he laid the foundation for making photography available to everyone. The camera was pre-loaded with film and, unlike conventional dry plate technology at that time, it could be easily carried and handheld during operation. After the film was exposed, the whole camera was returned to Rochester, New York

where the film was developed, prints were made, new film was inserted, and the camera, film, and prints were sent back to the customer.

In the very early years of the company, George Eastman was devoted to the idea of supplying the tools of photography at the lowest possible price to the greatest number of people. The rapid growth of the business made large-scale production a necessity. The creation of ingenious tools and processes for manufacturing film enabled the new company to turn out high-quality merchandise at selling prices that put them within the reach of the general public. It also made the company highly vertically integrated. Early in the company's history many of the decisions to in-source production may have been born out of necessity. Today, however, competitive pressures have necessitated that the company reevaluates their degree of integration.

Kodak Park is Kodak's premiere manufacturing and R&D center. Located in Rochester, New York, it is truly at the heart of the company for it was established in the early 1900's by the company's founder, George Eastman, after his film business rapidly expanded beyond the walls of the initial manufacturing site. The primary products produced from Kodak Park include various grades of photographic paper, chemicals, and film. These products serve customers as diverse as health imaging x-ray film, aerial surveillance photography, professional photography, and family vacationers.

2.1.2 Changing Business Environment

After relatively no serious competitive threat during their first three-quarters of this century, the competitive playing field for Kodak changed significantly. During the last fifteen years, Fujifilm established a significant marketing presence followed by a growing manufacturing presence in

the United States¹². After an initial round of "price wars" in 1997, Kodak was forced to lower the price for many of its film products or risk losing sales volume. While prices have stabilized, in order to avoid lost earnings from its film businesses, Kodak has been forced to reduce its manufacturing costs. "It is our intention to have the most competitive cost structure in the industry¹³." Consistent with that objective, Kodak has committed to cost reductions by year-end 1999 of \$1.2 billion. In 1998 alone, Kodak achieved \$730 million in cost reductions and had set a goal of an additional \$470 million in 1999.

In addition to cost pressure within the silver halide imaging business, another competitive threat looms ominously on the horizon. With the introduction and market acceptance of digital technology, the market for conventional silver halide film product will likely be negatively impacted by the replacement technology. Recognizing this threat, there is a push from Kodak management to ensure that they position themselves in the emerging digital market.

Nevertheless, the established silver halide image business (film, paper, and chemicals) still accounts for 50% of Kodak's revenue¹⁴. When one considers that the margins in silver halide imaging are higher than the margins for many of Kodak's other products, silver halide imaging likely accounts for an even higher percentage of the company's earnings.

Due to competitive pressure on the silver halide film business from both industry competition as well as the threat from digital capture technologies, there is significant effort being made to reduce the manufacturing costs in the mature film business. A strategic assessment of Kodak's businesses places the silver halide imaging business in the lower left hand corner on a Boston

¹² Fujifilm press announcement, 2/10/00, about further expansion in Greenville, SC.

¹³ Fisher, George M. C., Remarks made at the Annual Shareholder Meeting, May 12, 1999.

¹⁴ 1998 Eastman Kodak Company Annual Report.

Consulting Group (BCG) industry growth versus market share matrix as depicted in Figure II.1¹⁵.

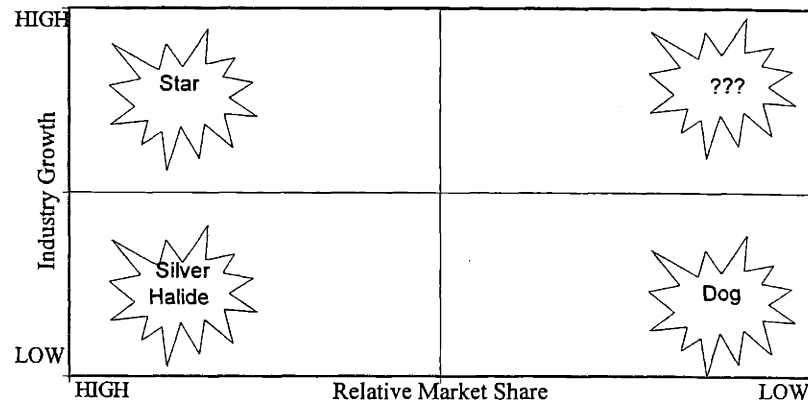


Figure II.1 BCG Growth/Share Matrix

Conventional strategic management theory states that it is not desirable for established companies to have a majority of their products lie within a specific quadrant. In particular it is not desirable for companies to have the majority of their sales and earnings in low growth markets. Therefore, conventional wisdom indicates that Kodak should use the earnings from the silver halide products to seed new product offerings to fuel sustainable company growth. Kodak management has recognized the dilemma with the mature silver-halide image market and has sought to diversify their imaging portfolio to capitalize on higher growth markets. Consistent with this objective, Kodak has evolved into a company that has three waves of image capture products flowing through it in different stages of the product life cycle. The first is the silver-

¹⁵ Oster, S. M., *Modern Competitive Analysis*, 2nd Edition, New York/Oxford, Oxford University Press, 1994, p. 130.

halide wave, the second is a digitization wave (e.g., Advanced Photo System (APS) films¹⁶), and the last is a purely digital wave.

Silver-halide film is a huge part of the company's heritage; however, the later waves may possibly prove to be its future. Eastman Kodak is in pursuit of riding "each of these three waves to sustainable top line growth – and to a consistent annual earnings performance over time¹⁷."

The focus of this research is to reduce the manufacturing costs in the silver-halide business. Doing so will enable Kodak to maximize the earnings from the mature, first wave.

2.2 Silver Halide Film Manufacturing Process Flow

The process used to manufacture silver halide film can best be described as part art and part science. The two chief components of photographic film are its base and its light-sensitive emulsion. In the manufacturing process, the emulsion is applied to the base in a dark, sensitizing operation. The final piece of the film manufacturing operation is the finishing operation where the film is cut and packaged to the appropriate specifications. A schematic of the film manufacturing process is shown in Figure II.2. Detailed descriptions of each operation in the film manufacturing process are provided in the following paragraphs.

¹⁶ The Advanced Photo System combines conventional silver halide capture with magnetic capture in order to "marry" the old with the new technology. For more information about APS, see the company's web pages at www.kodak.com.

¹⁷ Carp, Daniel A., Remarks made at the Annual Shareholder Meeting, May 12, 1999.

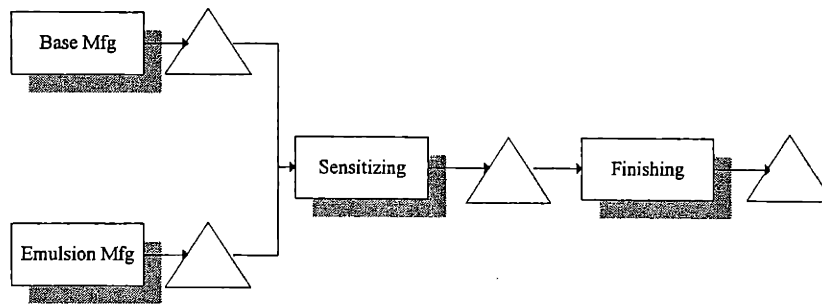


Figure II.2 Film Manufacturing Supply Chain

Emulsion Manufacturing. The emulsion used in silver halide film manufacturing consists of micro-thin layers of a gelatinous material in which light-sensitive ingredients are suspended. To make the emulsion, gelatin is dissolved in pure distilled water, and then solutions of potassium iodide and potassium bromide are carefully mixed with it. Silver nitrate solution is added to this heated mixture, and the desired light-sensitive silver halide (silver iodide and silver bromide) salts are precipitated as fine crystals. Because these crystals are suspended in the gelatin, the mixture is called an "emulsion."

Base Manufacturing. The base for film manufacturing is a transparent, flexible sheet on which the light-sensitive emulsions are coated. The type of base used for most camera films is cellulose acetate, which is manufactured from wood. Another form of base is polyester film; a petrochemical used for sheet films, such as x-ray and graphic arts films.

The process of making acetate base starts with cellulose, in the form of pulp, which is treated chemically to produce a thick, syrup-like cellulose acetate liquid. The cellulose acetate liquid is then precipitated in the form of pellets, which are washed and dried, and then mixed with solvents to form a clear, honey-like liquid called "dope."

To form the plastic sheet, the dope is coated into a thin layer and the solvents are removed. In the base manufacturing operation, a constant flow of thick dope is spread in a highly uniform layer on a turning wheel. As the wheel turns, solvents evaporate and are removed by air circulation, permitting the dope to dry so it can be separated from the wheel as a sheet. For ease of handling, the base is coiled in long rolls, several thousand feet in length. These large rolls are now ready for the sensitizing process, where the photographic emulsion is coated on the base.

Sensitizing. Once the emulsion is adjusted and tested for the desired photographic and physical features for the film grade being made, it is piped to large machines where, in a continuous operation, rolls of base are unwound and the emulsion is applied to one side of the base film. The emulsion is applied in extremely thin layers; a dried layer of some emulsions can be 0.006" thick. Color film requires several successive layers of different emulsions and additional color-forming chemicals. Each layer is specifically designed to absorb a unique wavelength of light so that an image is projected.

Finishing. After the film is coated and the emulsion hardens and dries, the film is slit into rolls of the appropriate size and width for packaging in the familiar yellow, Kodak cartons. A more detailed discussion of the steps involved in the finishing operation is provided in the following section.

2.3 Film Finishing Process Flow

The film finishing operation is where the large rolls of sensitized film are transformed into usable items for the consumer. A schematic of the film finishing operation is provided in Figure

II.3. In addition, detailed descriptions of each operation are provided in the following paragraphs.

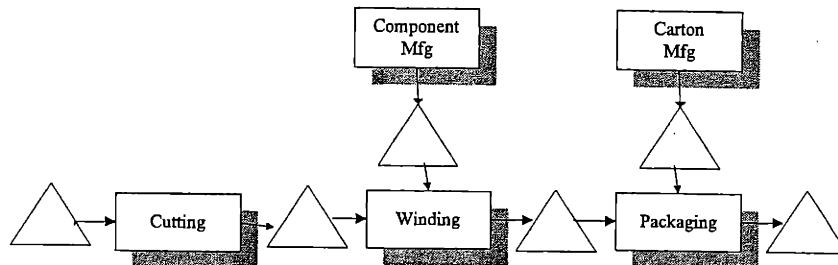


Figure II.3 Film Finishing Supply Chain

Cutting. The cutting operation is as the name might sound. It is here that the wide rolls of sensitized film from the upstream Sensitizing operation are slit to the appropriate width.

Because of the technology and capital intensive nature of the Sensitizing machinery, the “bulk” film is sensitized onto sheets that are several feet wide and thousands of feet in length.

Obviously, in order for the film to be usable by the consumer, it must be cut and packaged to the appropriate dimensions. The cutting operation involves cutting the film to the necessary size and providing slots (or holes) to enable the film to be aligned and fed properly through the camera.

Because of the long lead times in the Sensitizing operation and because of the diversification that takes place in downstream operations, a significant portion of the in-process inventory in the film manufacturing supply chain is held in the wide roll form upstream of the Finishing operation. In order to facilitate responsiveness, a kanban type system is used to balance some of the wide roll inventory between the wide roll and cut format; however, because of ease of handling, the majority of the sensitized in-process inventory is held in the wide roll format.

Component Manufacturing. The cut film must be inserted into the appropriate cartridge for the camera that the product is intended. Component manufacturing is an ancillary operation that provides the necessary components, both metal and plastic, required for the winding operation.

Because of the cost and commonality of the components relative to the value of the sensitized film, the component manufacturing operation is not scheduled in conjunction with specific orders for coiled film products, hereafter referred to as spools. Rather, a separate reorder-point based inventory system for components is provided to ensure component availability.

Winding. The winding operation entails inserting the slit film into the appropriate metal housing. This operation is currently coupled to the downstream packaging operation. When an order is received and approved for shop floor manufacturing, the packaging operation is scheduled depending on the particular packaging format and a subsequent winding order is generated off the packaging order. The winding operation is designed to run with a minimal time buffer of spools between it and the downstream packaging operation.

Carton Manufacturing. In-store visual displays and packaging are crucial characteristics used to differentiate the product from the competition. The carton manufacturing process operates using a reorder point based system that is separate from the winding and packaging orders. This is because the cost of the cartons is significantly less than that for the spools placed in the cartons and because the lead-time for carton manufacturing extends beyond that for the finishing operation. In essence, the carton operation operates in a fashion that is similar to that for components.

Packaging. In the packaging operation, the spools are placed inside the appropriate carton depending upon its packaging format. There is a reasonable degree of automation as well as some degree of specificity to the format capability for the various packaging machines.

Distribution. Depending upon the product's final disposition, it is sent to either a central or regional distribution center. In order to facilitate customer responsiveness, a significant balance of film inventory is held at the distribution centers. The exact amount is determined based on the quantity needed to supply the anticipated demand for a particular end-item over the time to replenish it in the finishing operation. More about the level of inventory held in the distribution centers is provided in Chapter 3.

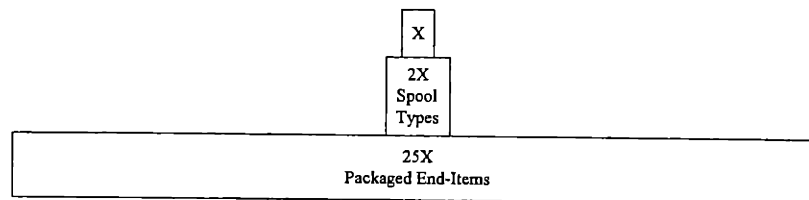
2.4 Characteristics of Product Portfolio

The last piece describing the film finishing operation hinges on the product portfolio. Before diving into the crux of this research, there are several characteristics of both the finishing operation and product makeup that are worth discussing.

Item Differentiation. The film finishing operation can best be described as an explosion of product diversity. As described in the previous section, the process entails "slicing and dicing" operations followed by operations that package the spools in a number of unique packaging formats. As a result the number of items increases dramatically across the finishing operation.

The film finishing process contains two main or principal points of differentiation. These are the winding and packaging operation. In the winding operation, a given film type is inserted into the appropriate film canister based on the particular size of the end product. Examples of film types would include 100 speed, 200 speed, and 400 speed film, whereas, the spool types may include

film canisters of varying exposure lengths. In the packaging operation, the various spools are grouped and packaged together in a multitude of possible configurations. The approximate degree of differentiation in each of these operations is illustrated in Figure II.4.



where: X = Number of Unique Film Types

Figure II.4 Approximate Degree of Differentiation across Finishing Supply Chain

When looking at the differentiation across the film finishing supply chain, the most obvious finding is that there is a large degree of differentiation between a given type of spool and the packaged end-items. Namely, the packaging portion of the supply chain has an order of magnitude greater differentiation relative to the differentiation that occurs in the winding operation. The high number of unique packaging formats dictates this phenomenon. This particular characteristic of the product portfolio is important since it provides an opportunity for risk pooling that forms the basis for the decision to evaluate a packaging postponement strategy when addressing the seasonal demand concerns.

Large Orders. The size of the individual finishing orders can also be significant. This is in a large part due to the increase in the popularity of discount retailers and warehouse membership clubs over the past decade. In addition to inducing large shocks to the manufacturing system, the large orders from these customers result in “spiky” daily demand patterns. This is largely due to the tendency for the retail chains to desire their products for all of their stores at the same time (the time that the circular is placed in the newspaper). The large orders and spiky demand

patterns result in a high degree of daily demand variability. An example of the volatility can be seen in Figure II.5.

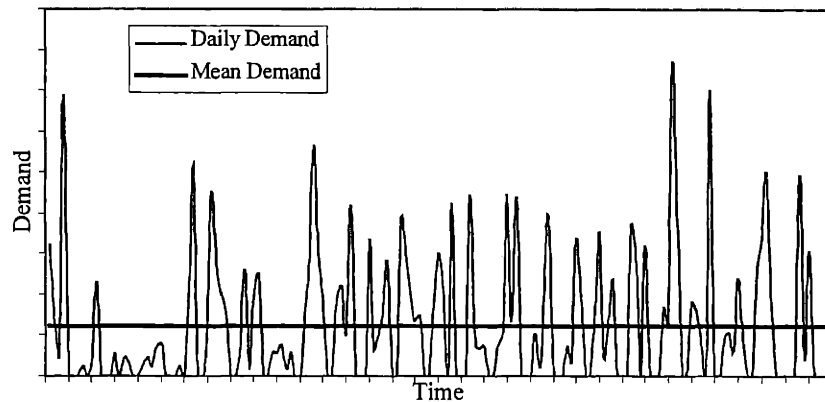


Figure II.5 Example of Variable Demand Pattern for a Typical Packaging Format

Multi-Pack Formats. In addition to increasing the frequency of large orders, the growth of discount retailing has resulted in an increase in the amount of film that is sold in packaged end-items that contain a multiple number of spools. The increased popularity of multi-pack items exacerbates the demand signals that are placed on the manufacturing shop floor, primarily for winding, due to the aggregation of the end-item demand to spools. The growth in multi-pack formats also exacerbates the seasonal demand patterns seen by the winding operation.

Number of Packaging Formats. The number of packaging formats can also be significant. For example, over the past ten years, Kodak has offered film in a variety of packaged formats. These include 1, 2, 3, 4, 5, 6, 7, 9, and 10 pack bundles of spools. Considering that the majority of film sales during the first century of the company's existence were in singles and two-packs, the increase in the number and popularity of unique packaged formats over the past decade is significant. From the beginning, George Eastman imbedded the company with the conviction

that fulfilling customer needs and desires is paramount to attaining corporate success. This vision continues today in the diversity of the company's product portfolio.

Seasonal Demand Pattern. Lastly, the large customers and multi-pack formats tend to exacerbate the seasonal purchasing demand patterns. Because retailers desire to have their film in their stores at the onset of the peak consumer demand season and because they compete with each other for the same customers, the demand data is skewed towards particular times of the year. An example combining both highly variable daily demand data with seasonal tendencies is shown in Figure II.6.

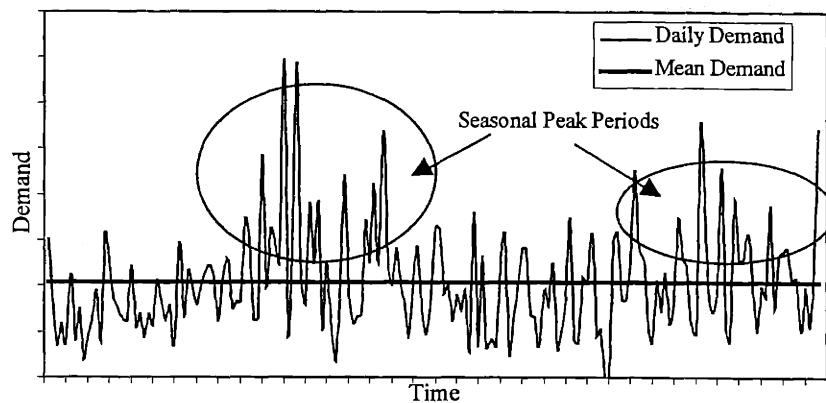


Figure II.6 Example of Seasonal Demand Pattern

Chapter 3: Shop Floor Scheduling

3.1 Production Scheduling: The Move from Forecasting

3.1.1 Historical Forecasting Process

Historically, Kodak used extensive, end-item forecasting to anticipate customer buying habits and to set the shop floor schedules utilizing the sales projections. This forecasting process enabled the film finishing operation, namely winding and packaging, to be scheduled in weekly “buckets”. The production buckets afforded the opportunity to optimize the factory across the week. As a result, the material flow through the factory was simplified and planned labor was aligned with the scheduled production.

3.1.2 Demand-Driven Process

In an effort to move to a “lean” manufacturing environment and to reduce cycle time¹⁸ a pull system was implemented in Kodak’s film manufacturing processes during the later half of 1998. At that time a demand-driven process was instituted for the film finishing operation. The demand-driven process required daily replenishment of end-items as opposed to an “arbitrary” build to inventory. Therefore the film finishing operation had to be scheduled on a daily basis as opposed to the customary weekly buckets.

Herein lies the source of the concern. Because of the lack of daily flexibility in the labor staffing levels, the workforce in the film finishing operation is typically staffed at anticipated monthly

¹⁸ Cycle time is defined as the amount of time material spends in the manufacturing organization and distribution center. Reductions in cycle time will increase inventory turns and related return on equity.

production levels. The aggregate monthly forecasts are updated periodically as more recent demand data is obtained; however, they are typically “set” a month or two in advance.

While on the aggregate the monthly actual volume may closely match the forecast, the daily demand signal rarely comes in level across the month. The biggest difference between the forecasting process and the demand-driven process is that the latter required that the manufacturing shop floor make what the customer wants based on the customer’s actual buying patterns. Responding to a daily demand signal made visible the magnitude of daily demand variability versus hiding it with inventory and forecast smoothing. In addition, scheduling issues that were not experienced under the previous forecasting system surfaced under the pull system.

3.2 Smoothing Window Concept

Obviously, an immediate response to customer purchases can be costly, if not impossible. To minimize the impact of the daily demand variability, Kodak chose to use a demand-driven process that incorporated the concept of a manufacturing “smoothing window”. The smoothing window allows the demand for a particular end-item to be aggregated over a period of several days prior to instituting a manufacturing order for replenishment. The exact size of the smoothing window is dependent on the balance between manufacturing frequency (set-ups and lot sizing) versus the cost of holding inventory. The manufacturing window is designed to avoid costly set-ups for small volume items and allow the shop floor scheduler to “optimize” the shop floor within the predetermined smoothing window.

The effect of the smoothing window is that the demand is averaged over a period of time, the size of the smoothing window, rather than requiring an immediate response. Specifically, the

window allows the shop floor scheduler to divide the demand up most efficiently within the confines of the smoothing window. A stylized example (albeit simplified) of production smoothing where three products are manufactured on a shared piece of equipment can be seen in Table III.1.

Day	Demand Item A	Demand Item B	Demand Item C	Total Demand	Capacity	Prod'n Item A	Prod'n Item B	Prod'n Item C	Total Prod'n
1	10	5	0	15	20	10	5	0	15
2	12	11	0	23	20	12	8	0	20
3	16	2	0	18	20	15	5	0	20
4	5	3	3	11	20	6	3	0	9
5	9	10	3	22	20	9	10	0	19
6	10	8	0	18	20	10	8	0	18
7	12	0	1	13	20	12	0	7	19
8	12	2	0	14	20	12	2	0	14
9	18	9	4	31	20	18	2	0	20
10	13	6	8	27	20	13	7	0	20
11	10	5	0	15	20	9	11	0	20
12	4	12	0	16	20	5	12	0	17
13	8	7	0	15	20	8	7	0	15
14	3	6	0	9	20	3	5	12	20
15	12	4	0	16	20	12	5	0	17

Table III.1 Stylized Example of Production Smoothing across Three Items

In the simple example presented in Table III.1, the total demand for the three items exceeded the nominal production capacity on four separate occasions, i.e. more than 25% of the days. The boldfaced type indicates these times. Being able to schedule production within an allotted smoothing window allows a production schedule that differs slightly from the actual demand pattern, thus affording the opportunity to reduce the peaks in demand. For a properly determined smoothing window, the demand across the aggregate product portfolio must be less than the capacity. Therefore, the size of the smoothing window is related to both the daily demand pattern and the manufacturing capacity. A detailed discussion of smoothing windows and how an appropriate smoothing window size is determined is presented in the Appendix 1.

In the stylized example presented in Table III.1, the size of the smoothing window used for items A, B, and C would be 2, 2, and 6 days respectively. That is the demand for items A, B, and C never were more than 1, 1, and 5 days in backlog prior to order fulfillment.

A view of actual, aggregate daily demand versus production can be seen in Figure III.1. The ability to aggregate demand for a given item over a period of days affords the opportunity to shift demand within the confines of the smoothing window in order to “optimize” the shop floor production schedule and maintain adequate service within a fixed capacity constraint. In addition, the ability to aggregate smaller orders over a period of days allows the manufacturing organization to reduce the number of set-ups required for the low volume items. For example, in the stylized example demand for Product C was taken on five separate occasions; however, production orders were scheduled on only two separate days.

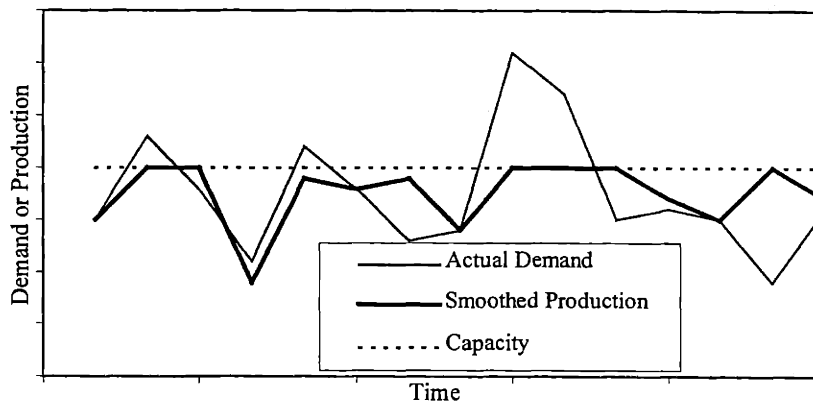


Figure III.1 Stylized Example of Production Smoothing across Three Items

From an inventory standpoint, finished goods are stocked in the downstream distribution center to cover the anticipated demand over the time required for item replenishment. This time is a function of the size of the smoothing window, the time required for manufacturing (the touch and

queuing times in the factory), and the time for logistics (demand signaling, scheduling, and transportation). Clearly, efforts to reduce these three times can result in a lower level of finished goods inventory for a given customer service level.

Because not all end-items pass through the same equipment sequence and because the factory may not desire to make all items with the same manufacturing frequency, it is common to have a different smoothing window size (manufacturing frequency) for different end items. For high volume or high cost items it is typically desirable to have a shorter replenishment lead-time in order to avoid a high amount of capital tied up in inventory. As a result, with a demand-driven process, the size of the smoothing window tends to be inversely proportional to the demand of the particular item. That is, those items that are high in demand tend to have a short smoothing window while those that are low in demand tend to have a long smoothing window. This relationship, illustrated in Figure III.2, balances manufacturing and inventory holding costs.

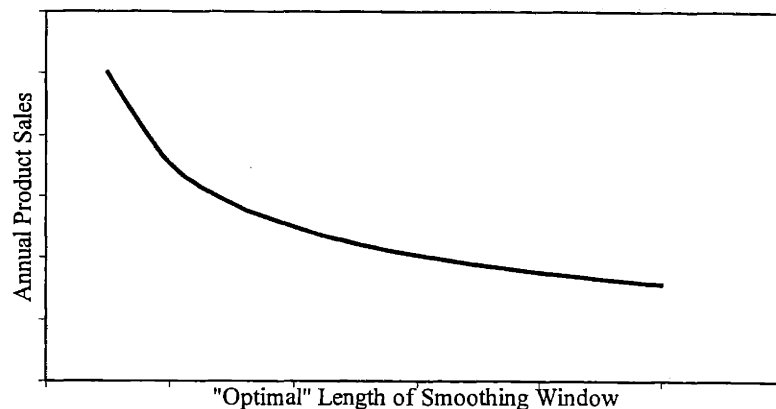


Figure III.2 Relationship between size of Smoothing Window and Annual Sales

The reader should note that the trend in Figure III.2 is a simplification. The relationship assumes similar demand variability for the items being compared. In general, the desired size of the

smoothing window is directly proportional to the demand variability. This relationship is discussed in more detail in Appendix 2.

The optimal relationship between sales volume and smoothing window size also would ideally include some measure of manufacturing complexity. This is especially true for product mixes that require unique processing steps for the various products. For product families that share common processes, such as the film finishing operation at Kodak, the simplified relationship holds.

3.3 Differences between Demand-Driven and Forecasting Processes

Besides the obvious difference between scheduling weekly buckets versus daily scheduling, there are several other key differences between the demand-driven and forecasting processes. Having an understanding of these differences proved to be important when attempting to diagnose the concerns that Kodak had encountered during their initial months while operating under the demand-driven process. Some of the key differences are as follows:

Capacity Requirements. The capacity requirements for a demand-driven process tend to be higher than one that incorporates forecasting and a Materials Requirements Planning (MRP) system. The demand-driven process requires that the manufacturing shop floor has the flexibility to be able to respond to daily demand variability as well as to handle any seasonal peak demand periods. Forecasting processes, on the other hand, can readily address seasonal demand peaks by bringing some portion of the demand forward and establishing an inventory buffer in advance of the high demand period. The large inventory buffer of finished goods also buffers the manufacturing operation from the effects of the daily demand variability. A detailed discussion

of the relationship between capacity requirements and demand variability is presented in Appendix 2.

Flexibility. By its nature, the demand-driven process requires some degree of scheduling flexibility. As illustrated in Figures II.5 and II.6, customer demand patterns rarely arrive in a smooth and steady fashion. Therefore, in order to match the customer demand patterns; a demand-driven process must provide some degree of equipment, material, and labor flexibility. Equipment flexibility relates to providing additional capacity to address sporadic peaks in demand. Material flexibility addresses the same concerns as well as unanticipated changes in demand for various product offerings. Labor flexibility is closely related to equipment flexibility and could include both overtime and contractor (seasonal) support.

Inventory. Because the end-item-forecasting process is eliminated and subsequent forecasting errors are reduced, the amount of finished goods held in inventory would typically be lower for a demand-driven process. In addition, the increased frequency of item replenishment from the factory for some items (in particular the high volume items) reduces the time to replenish a given item in the downstream distribution center. The shorter replenishment time combined with decreased forecasting errors reduces the amount of inventory that must be carried to service demand. For example, it was reported during this research effort that prior to instituting the demand-driven process, the level of inventory held in the distribution center prior to the seasonal period was twice the level that was carried this past year¹⁹. In addition to lowering cycle time, reduced inventory levels also result in lower levels of obsolescence.

¹⁹ Information obtained from personal communication with Kodak personnel.

Manufacturing Efficiency. A process that entails higher levels of inventory and a “predictable” shop floor scheduling process will generally result in a higher level of manufacturing efficiency at the shop floor level. Therefore, a forecasting based scheduling system will have a higher efficiency since production planners are able to optimally schedule the shop floor. The optimal schedule provides for “stability” and minimizes the daily variability issues that are inherent in a demand-driven process. Therefore, one would expect less expediting and overtime charges with a forecasting process. This, of course, assumes a reasonably high forecast accuracy in order to avoid an expediting mode due to inaccurate product build. If forecasting errors are high, customer service and optimal inventory levels will suffer.

Finally, in comparing forecast-driven versus demand-driven scheduling systems, a lot depends on the ability to forecast demand. For example, if perfect forecasts were attainable, then a forecast-driven schedule might be preferred – even with weekly buckets. At Kodak, however, it was determined that it was not possible to forecast end-item demand with a high degree of accuracy. Therefore, the forecasts do not really supply much information.

Chapter 4: Problems Encountered by Demand-Driven Process

The move to the demand-driven process revealed a couple concerns. Both were related to the inability to reliably ensure availability of spools to the downstream packaging operation.

Because of this dilemma the packaging operation was often running sub-optimally. A discussion of the problems that surfaced is presented in this chapter.

4.1 Daily Production Scheduling vs. Monthly Staffing

Staffing levels in Kodak's film finishing operation are typically set based on aggregate monthly demand forecasts. This is because it is not easy to rapidly adjust staffing levels on a short-term basis. The planner sets the staffed capacity to be "flat" throughout a given month based on the projected aggregate volume of sales. This results in a planned capacity that is equal to the anticipated mean daily demand over the scheduling timeframe. Historically, this planning method sufficed since production was planned such that it matched the staffing levels. The demand-driven process, on the other hand, requires that orders be fulfilled based upon customer order patterns. Because of inherent demand variability, the daily demand pattern does not match the flat profile projected from the aggregate monthly forecast.

Variability in the customer purchases can result in a significant discrepancy between the ability to make products and the actual orders that need to be fulfilled under the demand-driven process. Even if the aggregate monthly forecast is precise (i.e. future demand closely matches the prediction), the actual daily demand and subsequent requirements on finishing tend to oscillate around the mean staffing levels. Therefore, there will be periods where staffing (i.e. planned

capacity) will be adequate; however, these periods will quickly be followed by periods where there is a capacity shortfall. A schematic of this phenomenon for two months is illustrated in Figure IV.1 below.

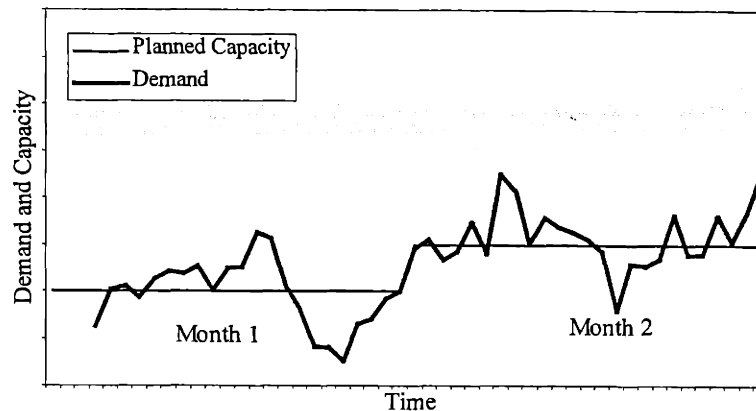


Figure IV.1 Aggregate Planning Dilemma

In Figure IV.1, the thin line represents the staffing level for a given month that is based on the projected sales volume for that month. The bold-typed line represents the demand requirements after utilizing the scheduling flexibility of the manufacturing-smoothing window. The end result of the combination of setting staffing levels equal to the mean demand and attempting to respond to daily demand variability is that the manufacturing organization is constrained from being able to truly match the daily demand pattern.

4.2 Packaging Limited by winding Capacity

As discussed previously, the historical shop floor scheduling process used end-item forecasts to determine what items to build ahead of anticipated orders. From a material flow and labor standpoint, this resulted in relatively smooth operations in the finishing operation. After the move to the demand-driven process in the later half of 1998, problems were encountered

associated with an inability to ensure that the packaging lines remained full. Consequently the peak output from the packaging lines was below the maximum attainable.

Part of the reason for the problems with the availability of spools centered around the way that the winding and packaging operations are scheduled. In the current process, the winding and packaging operations are coupled. When scheduling the shop floor, the planner schedules the appropriate packaging line based on the specific format of the end-item to be manufactured. A subsequent winding order is generated directly off the packaging order that was scheduled by the planner. Recognizing the impact of process variability, the system is designed for winding to operate approximately 8 to 24 hours ahead of the packaging operation.

Herein lies the concern. Because of the higher aggregate packaging capacity versus winding capacity, there are many times when the availability of spools limits the packaging output to a value below that attainable for a given packaging line. During peak demand periods, the higher volume packaging lines should run at peak capacity; however, in order to do so, spools had to be diverted from the lower volume end-items. This maximized the ability to satisfy demand for the high volume end-items at the expense of the delivery performance for the low volume end-items. It was estimated that improved the availability of spools could result in an increase in effective packaging throughput of 15% across all of the packaging lines.

A buffer of spools can be used to ensure reliable delivery of spools to the downstream packaging operation. Based on a typical lead-time for the winding operation and the demand characteristics of the spools, the average buffer inventory (for a given service level) that should be situated

between the winding and packaging operations can be determined. The approximate buffer inventory placed between the two stages can be estimated using the following equation²⁰:

$$\text{average buffer inventory} = \frac{\mu}{2} + z\sigma\sqrt{n+1} \quad (4.1)$$

where: μ = mean daily demand
 σ = standard deviation of daily demand
 n = lead time of upstream production stage
 z = “safety factor” associated with service level

For Kodak’s film finishing operation it was determined that an average buffer inventory that amounts to approximately 2-3 days of average demand would be necessary to ensure “reliable” delivery of spools from the winding operation to the packaging lines. Clearly this value is higher than the currently employed buffer of 8 to 24 hours.

Another problem that impacts the demand for spools is the film finishing operating schedule. The finishing operation typically operates on a 5-day work schedule; therefore, the concerns related to spool availability were most often observed at the beginning and end of the week when the packaging lines had quickly consumed any remaining spools from the 8 to 24 hour time buffer. The inability to satisfy packaging demand in the early part of the week was also compounded by the fact that a disproportionate amount of the demand enters the system early in the week. Because of the 5-day work schedule, an appreciable time buffer of spools between the winding and packaging operations is typically not available early in the week.

There are a couple of reasons that a greater amount of demand enters the system early in the

²⁰ Lee, H. L., and C. S. Tang, “Modeling the Costs and Benefits of Delayed Product Differentiation”, *Management Science*, Vol. 43, No. 1, January (1997), 43.

week. First, it is possible for inventory to be removed from the product distribution centers over the weekend. This demand would accumulate and enter the film finishing demand system on Monday morning, the start of the workweek. The second reason for higher demand earlier in the week is due to an internal Kodak system constraint used when scheduling promotional orders. For items that may require additional or unique packaging, an equivalent week of demand would be aggregated and placed into the demand system in one-fell-swoop. Similar to the weekend sales, the special orders also enter the system early in the week. The placement of a disproportionate amount of demand early in the week compounds the problem associated with the availability of spools.

In an aggregate view, the winding operation is the system bottleneck for it constrains end-item delivery under most circumstances. This is because the total winding capacity is less than the aggregate packaging capacity. It should be noted that having the system bottleneck in the winding operation is understandable considering that winding is the most capital and labor intensive step in the finishing operation. This ensures that the most capital-intensive piece of machinery is utilized to the highest degree.

After the move to the demand-driven process, production personnel observed an imbalance between the ability to make spools and the ability to consume them in the downstream packaging operation. This had resulted in periods where production (i.e., packaged end-items) was limited by the availability of spools to go into the end-items. That is there are times when the finishing operation would like to be able to package a higher volume than can be sufficiently produced in the winding operation. It was believed that either a capacity buffer in the winding operation or a working buffer of spools in between the two operations could alleviate many of the concerns

related to the availability of spools caused by daily demand variability. The result would be the ability to achieve higher customer service with less overtime and/or late delivery charges.

4.3 Demand Seasonality

As mentioned previously, prior to the second half of 1998, Kodak used end-item forecasting to set the production requirements. As a result, many items were built ahead of anticipated customer orders. The large product portfolio (high degree of differentiation between winding and packaging) coupled with the timeframe of production versus demand resulted in an inability to accurately predict end-item demand. The end result was a higher than desirable level of obsolescence and longer cycle times.

The move to a demand-driven process required that Kodak configure the manufacturing organization to be able to closely match the daily customer purchase requirements. This reduced the amount of finished goods inventory in storage to a minimum; however, the demand-driven process raised issues regarding whether there was adequate capacity to fulfill orders in a manner that closely matched the customer demand patterns. In addition to the daily variability concerns previously discussed, the film finishing operation found itself unable to match the demand volume during extended peak demand periods. Because of the lower winding capacity relative to packaging, this was observed as the inability to wind product to match the magnitude of the seasonal demand peaks. A stylized example of this relationship is shown in Figure IV.2.

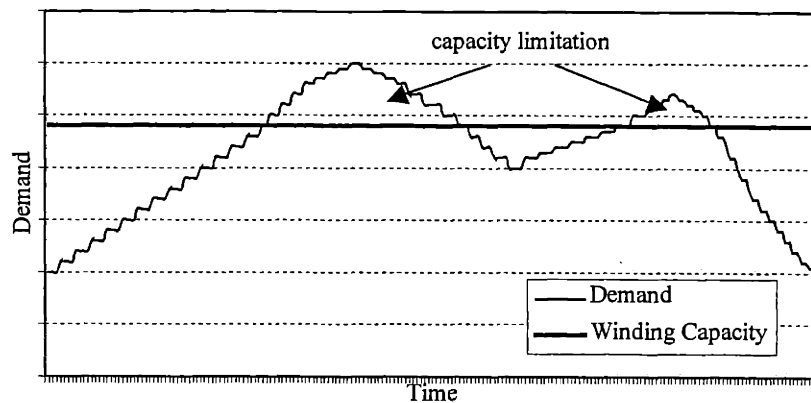


Figure IV.2 Seasonal Demand Pattern Results in Capacity Shortages

Contrary to the demand-driven process, the forecasting process had permitted production to be brought forward prior to the peak season. In effect, forecasting allowed the end-item and subsequent winding demand to be “leveled” over the course of the year. This lowered the seasonal production requirements such that peak capacity problems were generally not an issue. A stylized example of the production strategy prior to the institution of the demand-driven process is shown in Figure IV.3.

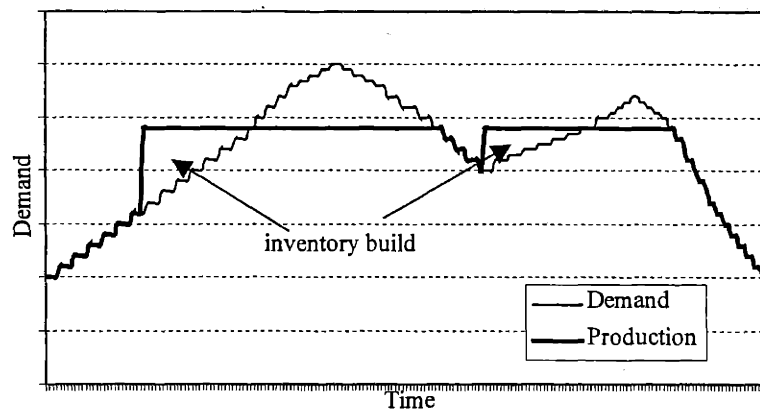


Figure IV.3 Capacity Shortage Historically Handled through Inventory Build

As a result of the “demand leveling”, finished goods inventory levels were higher (at a peak just prior to the peak demand season) when operating under the forecasting system. Overtime and seasonal staffing, however, were kept to a minimum unless significant problems were encountered with unforeseen end-item demand. The major concern with the forecasting system was that the finished goods inventory levels were high, and there was no guarantee that the right items were held in inventory. With the high degree of product differentiation that occurred in the packaging operation and the dynamic nature of the packaging formats (the number of new formats in the past decade), the probability of error was exacerbated. If the end-item forecasts were not accurate, which was judged to be likely, overtime may still have been required in order to provide products that originally were not anticipated to have been in high demand.

After implementation of the demand-driven process, it became evident that there were seasonal periods where aggregate demand exceeded production capacity²¹. Unlike the daily demand variability concerns discussed in Section 4.2, the duration of the seasonal peak demand periods (weeks) extended well beyond the size of the manufacturing smoothing windows (days). As a result, during the seasonal peaks in demand, the “smoothed” demand requirements exceeded the nominal production capacity for some period of time. This resulted in significant overtime and poor product delivery performance – both of which were deemed unacceptable. The challenge was to identify cost effective means to alleviate the seasonal concern.

²¹ Capacity shortages occurred in both winding and packaging; however, they were primarily located in the winding operation. Format specific packaging capacity concerns were also addressed in this research to help ensure that winding capacity dictated overall production capability.

Chapter 5: Responding to Daily Demand Variability

Responding to customer demand when the order patterns and preferences are highly erratic proved to be difficult. At many times the packaging operation did not run at peak efficiency due to the unavailability of spools from the upstream winding operation. As a result of this dilemma research was conducted in this area to determine what steps could be undertaken to improve the performance of the demand-driven system.

This research and analysis focused exclusively on the manufacturing organization. This was based on the premise that collaborative forecasting and demand management were outside the scope of the research. In addition, point of sale demand data and customer inventories managed by Kodak were also not considered. More discussions regarding these concepts and their potential benefits are provided in Chapter 8.

5.1 Production Planning Time Horizon Differs from Daily Replenishment

After implementing the demand-driven process, Kodak continued to schedule their workforce labor based on aggregate monthly forecast projections. The shop floor scheduling system, however, was modified to facilitate the response (with some measure of demand smoothing) to the daily customer demand signals. As discussed in Section 4.2, the anomaly between time horizons for the planned capacity (monthly) and demand (daily) resulted in intermittent periods where the demand requirements exceeded the production capability. Recognizing that some degree of demand variability will always be present, steps were taken to understand how best to buffer against the demand variability.

Buffer Capacity. Production planning anomalies caused by either demand or production variability must be considered with demand-driven processes. Classic JIT systems commonly address these types of problems by installing a capacity buffer. Typically these systems operate by scheduling a facility for less than 24 hours per day thereby allowing the production line to catch up if it falls behind. If production gets ahead of the desired rate, then the workers are either sent home or given other tasks²². The amount of unscheduled time required for a given operation is related to several factors including the equipment reliability, process yield variability, as well as the degree of demand variability.

To create a capacity buffer, a contingency buffer would need to be added to the projected staffing levels. The additional staffing would provide a cushion necessary to ensure sufficient capacity is readily available to protect against the daily demand variability. If daily demand comes in greater than anticipated (i.e. the mean daily demand over the workforce planning time horizon), the additional staff could provide the production capacity required to meet the extra demand. If demand comes in equal to or lower than anticipated, the staff would have to be reassigned to other activities for there would be no work for them to process.

Such a planning approach would entail maintaining excess capacity approximately half of the time. In addition, this approach would assume that there is adequate capacity (both labor and fixed equipment) to meet any peak demand periods. During the low demand periods (the majority of the time) this assumption would be appropriate; however, during the peak demand months when equipment utilization is extremely high, little to no winding capacity cushion is

²² Hopp, W. J., and M. L. Spearman, *Factory Physics – Foundations of Manufacturing Management*, (1996) Irwin/McGraw Hill, (1996), p. 157.

available. This concern was highlighted in Section 4.3. During the peak demand periods, it is therefore likely that the demand requirements would exceed the nominal production capacity. Therefore, for a highly capacitated process, using capacity to buffer against variability would not be a viable alternative.

Buffer Inventory. Another approach to buffer against daily demand variability would be to “buy” capacity by prebuilding some items. In this scenario, the size of the inventory buffer would fluctuate since (assuming that the aggregate monthly forecast is reasonably accurate) brief periods of capacity shortage should be followed by periods of excess capacity. Assuming that there is not a significant trend for demand to be skewed to a specific part of the month (e.g., first half consistently higher than second half), the size of the capacity imbalance periods should be relatively short. Lastly, the size of the buffer required would be proportional to the variability of the daily demand signals, the number of unique items buffered, and the tendency for the demand to clump in particular parts of the month. These concepts are examined more thoroughly in later sections of this chapter.

Because of capacity concerns during the peak demand periods, the option of scheduling unplanned labor or equipment was not seriously considered for Kodak. Instead, the notion of providing a buffer of spools in between the winding and packaging operation was chosen as the only viable alternative. It was determined that a buffer of spools would improve the packaging efficiency and enable the manufacturing organization to reduce the labor costs in the finishing operation. The primary driver for this decision was a reduction in the amount of overtime due to reliable spool availability and a higher packaging output. It was estimated that reliable delivery

from the winding operation would result in a 15% increase in the ability to package items²³.

Other considerations when deciding on this particular strategy included the costs of labor versus the cost of holding the inventory. If overtime were a relatively cheap solution relative to the cost of goods, it may have been considered.

5.2 Decoupling Winding and Packaging

To enable the formation of a buffer of spools, the production planning system had to be modified to separate the scheduling of the winding and packaging operations. As discussed previously, the historical shop floor scheduling system linked these two operations. The linkage was as follows. Based on the characteristics (format) of the particular packaged end-item, the appropriate packaging operation was scheduled and a subsequent winding order was generated and driven off the packaging line schedules. The related winding order was scheduled to run a day ahead of the packaging schedule. In order to enable the installation of an appreciable buffer of spools in between the two operations, this linkage had to be modified and/or broken.

The modified scheduling system had to allow for separate winding and packaging schedules. Because of the cost of transporting spools between the winding machines and the packaging lines, it was decided that some portion of the winding equipment would continue to be “linked” to a particular packaging line; however, some portion of the spools would be scheduled separate from any packaging operation. The research performed in conjunction with this thesis was used to determine which spool types would need to be accommodated in this fashion as well as the volume that would be required to ensure spool availability considering the variability of the demand pattern.

²³ Capacity estimate based on actual packaging experience and conversations with Kodak personnel.

5.3 Strategic Placement of In-Process Inventory

Size of Spool Buffer. The intent of the spool buffer is to ensure that spools would be readily available to package when needed. To determine the minimal size of the spool buffer, an evaluation of the largest cumulative period of capacity shortage relative to periods of excess planned capacity was performed. The following formula was used to calculate the inventory level at any given time.

$$I_{i-1} - D_i + P_i = I_i \quad (5.1)$$

where:

I	=	buffer inventory at time i
D	=	demand for time period i
P	=	planned capacity for time period i

NOTE: P was set to be equal to the average anticipated demand over the scheduling time period, generally a month.

To determine the size of the buffer, a given value for the starting inventory, I_0 , was chosen so that $I_i \geq 0$ for all i, where i covers all time periods within the planning window. As mentioned previously, the planned capacity, P, is determined base on the aggregate monthly demand forecast. For this analysis, it was assumed that no adjustment of the capacity was possible within the planning time window, generally one month. If adjustments in staffing levels were possible, a relationship could be developed to adapt the capacity depending on the real-time inventory level. That is, if the level of inventory began to decrease faster than anticipated or reached a precariously low level, an increase in capacity could be made. Likewise, capacity reductions could also be made if warranted. A stylized example of the relationship between demand, production capacity, and inventory is depicted in Figure V.1. The actual analysis at Kodak was done by simulation using actual demand history for the previous 12 months.

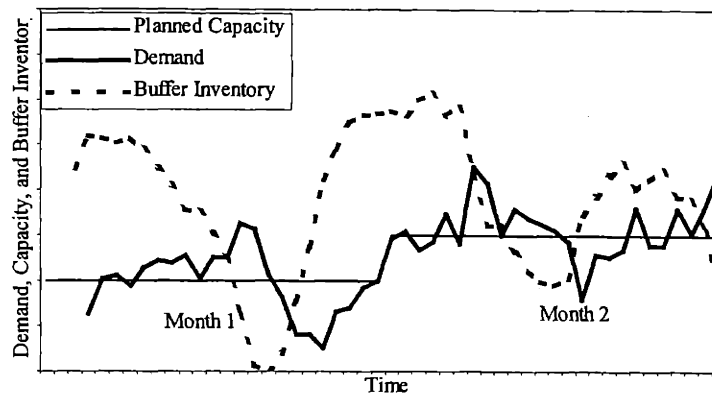


Figure V.1 Stylized Example of Spool Buffer Inventory Over Time

The relationship between spool buffer inventory and demand is relatively straightforward. If demand is less than the planned capacity the size of the spool buffer increases as spools are added to the buffer. If demand exceeds capacity, on the other hand, the size of the buffer is decremented. Several points should be noted from the stylized example. First, for this particular example, shown in Figure V.1, the minimal buffer size (I_0 , the initial buffer level) is approximately equivalent to 2-3 days of normal demand volume. This size is driven by the need to buffer against the variability around the mean demand. Secondly, the analysis was based on the aggregate spool demand. That is, for the initial analysis, the assumption was made that spools were not unique. In actuality, the variability of demand for the various spool types must be considered. This topic will be addressed in following sections.

Spool Types to Place in the Buffer. An extensive analysis was performed to determine which types of spools to place in the buffer. In addition, an analysis of the variability of demand was performed to determine the required size of the buffer and how many spools would need to be in the buffer in order to ensure uninterrupted spool availability.

To determine the type of spools to place in the buffer, an ABC analysis of spool demand was performed. The ABC analysis separated the types of spools based on their sales volume with type A being the highest and type C being the lowest. The analysis depicted in Figure V.2 pointed the direction when deciding which spools would be the best candidates for placing in the spool buffer. In order to reduce the complexity of the spool buffer and to minimize its size, focus was placed on the spool types that are greatest in demand, that is, the type A spools.

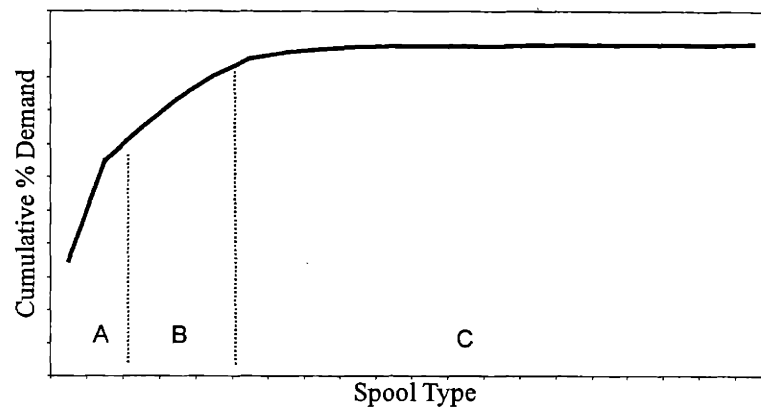


Figure V.2 ABC Analysis of Spool Demand

To ensure that there were adequate spools (capacity) placed in the buffer, an analysis was performed looking at the combined daily demand for spool types that were not placed in the buffer. The minimum number of unique spool types was chosen to put in the buffer such that the demand for the non-buffered spool types on any given day was lower than the average demand for all spools over any given month (the staffed capacity level). The ABC analysis was used to decide on inventorying the fewest number of unique types of spools while ensuring that there would be adequate capacity to spool the remaining spool types on any given day. A schematic of this analysis is depicted in Figure V.3. For this analysis, the smoothed demand profile for the

non-buffered spool types was evaluated to ensure that it was below the planned capacity for all time periods.

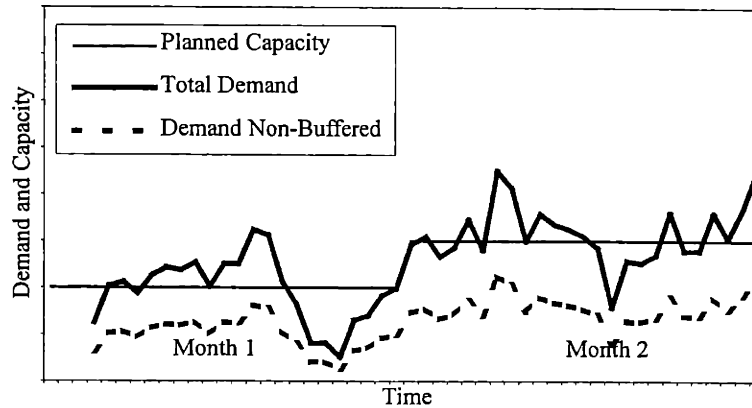


Figure V.3 Capacity vs. Demand for Items Not Placed in Buffer

The figure above illustrates the desired operation of the spool buffer. For the spool buffer to function properly, the demand for items not placed in the buffer (the dashed line in Figure V.3) must not exceed the staffed capacity. The ABC analysis of the spool demand was used to determine the high volume spool types to place in the buffer. An analysis of the demand for the remaining spool types was performed to ensure that the demand for these spool types did not exceed the planned production capacity (i.e., the mean demand for a given month).

Chapter 6: Meeting Seasonal Demand Patterns

After implementing the demand-driven process, another significant problem was experienced in the film finishing operation. This problem was related to the inability to “match” the magnitude of the seasonal demand pattern. This phenomenon was discussed in Section 4.3. The problem was due to extended periods of time where the customer demand volumes exceeded the manufacturing capability. The high demand periods resulted in a smoothed demand profile that exceeded the production capacity. As such, it was difficult, if not impossible, to closely match the actual customer demand patterns without incurring significant overtime charges.

In recognition of this dilemma, attempts were made to identify what steps could be taken in order to bring the manufacturing requirements below the manufacturing capability. In order to do so, one must understand the detailed relationship behind the convention used to “smooth” the demand on the manufacturing organization.

6.1 Available Options

A significant amount of operations research has been conducted on the benefits of production smoothing; therefore, I will assume some level of understanding of the smoothing process when identifying some of the options that could be employed to lower the seasonal requirements. A detailed analysis of the derivation of the equations used in this chapter as well as the theory behind production smoothing is provided in Appendix 1.

Utilizing the concepts of production smoothing, an equation can be derived to relate production requirements in a demand-driven environment. Specifically, as illustrated in Appendix 1, the

degree of production smoothing and overall capacity requirements are related to average daily demand, the standard deviation of the daily demand, the desired service level, and the size of the smoothing window.

$$\text{capacity required} = \mu + \frac{z\sigma}{\sqrt{2n-1}} \quad (6.1)$$

where:

μ	=	average daily demand
n	=	length of smoothing window
z	=	service level
σ	=	standard deviation of daily demand

Having an understanding of this relationship enables one to focus on the steps that could be undertaken to reduce the peak capacity requirements dictated by the seasonal demand pattern.

Lengthen the Smoothing Window. Because of the inverse relationship between the size of the smoothing window and the capacity requirements, one option would be to lengthen the existing smoothing window such that the average demand within the longer smoothing window falls below the production capacity. The caveat is that because of the square-root relationship between capacity and size of smoothing window, there are diminishing returns to lengthening the smoothing window. Often a large smoothing window may be required to bring the average demand below the capacity ceiling. Lengthening the smoothing window, of course, results in increased inventory as well as the risk of inventory obsolescence. A stylized example of the effect of window size on capacity requirements is provided in Figure VI.1 on the following page.

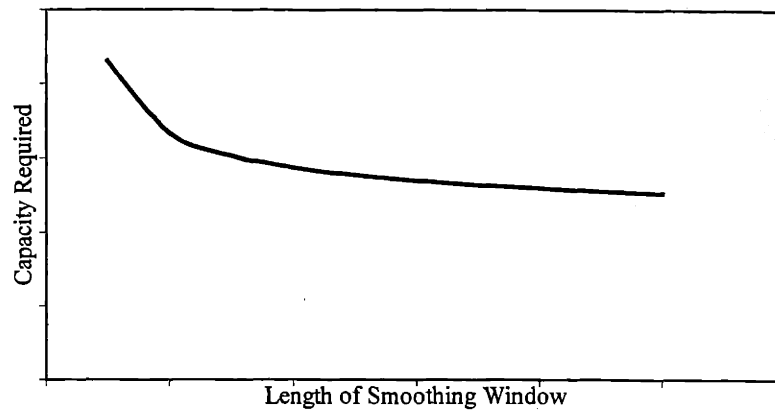


Figure VI.1 Capacity Requirement is Related to size of Smoothing Window

Decrease the Service Level. Capacity requirements in a demand-driven process are also related to the manufacturing service level. One option for reducing the capacity requirement would be to allow for a lower percentage of the orders to be fulfilled within the allotted smoothing window. After brief consideration, this alternative does not seem to be a viable solution.

Because of the competitive nature of the film industry, a lower service level would not be justifiable for the majority of the end-items. If a lower service level strategy were to be implemented, it would only be applicable for the lower volume end-items that do not amount to any appreciable volume. Therefore, reducing the service level for the low volume items may not really alleviate the production capacity concerns during the peak season. In addition, the impact of lowering the service level does not result in significant reductions in the required capacity. A stylized example of the effects of adjusting the service level is shown in Figure VI.2 on the following page.

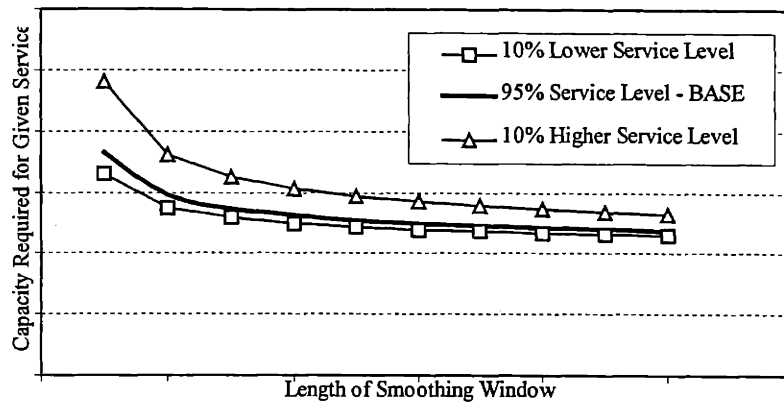


Figure VI.2 Capacity Requirements as a Function of Service Level

Add Incremental Capacity. Providing additional capacity during the peak season is the cleanest and simplest solution when determining the best means to address demand seasonality. However, as one might imagine, seasonal capacity can also prove to be costly. The seasonal demand problem is relatively short lived (in the scheme of the production year); therefore, the benefits of additional capacity would only be for several weeks. If incremental capacity were to be provided, excess capacity and fixed costs would be incurred during the balance of the year.

When deciding on a strategy that provides additional capital investment, one must also consider the maturity and potential growth of the silver halide film market. Adding significant capacity was an option, but was considered to be outside of the scope of this internship.

Seasonal Prebuild – Reduce Peak Demand. A seasonal prebuild would alleviate the peak demand; however, this steers the organization back to the concerns about the prior end-item forecasting process. As highlighted previously, the inability to accurately predict end-item demand when operating under the forecasting process resulted in a combination of high

inventory levels as well as the risk of obsolescence. Therefore, a seasonal prebuild of end-items was not considered to be a viable alternative.

Manage the Demand Stream. The final option that could be employed to reduce the peak demand values would be to closely link the Sales and Marketing organizations to the Manufacturing organization. Doing so would, ideally, enable them to provide appropriate incentives to customers (namely retailers) to shift their purchase patterns in order to lower the magnitude of the peak. Improved coordination between Sales and Manufacturing could also reduce the variability of the daily demand and lower the magnitude of some of the extraneous demand spikes.

6.1.1 Strategy Chosen

In the end, it was concluded that managing the demand through either some sort of seasonal prebuild or customer intervention has the greatest impact on the manufacturing operations during the seasonal period relative to the cost of implementation. This is especially true when one considers that for a seasonal demand pattern the required size of the production-smoothing window is driven by the magnitude of the demand during the peak demand periods. In addition, the high demand periods last for a relatively short period of time (several weeks) relative to the scope of a year.

Rather than lengthen the smoothing window or lower the service level for a problem that occurs for only several weeks per year, it was decided that steps designed to specifically reduce the magnitude of the peak that the manufacturing organization experiences is most warranted. Because of the relative winding versus packaging capacity previously discussed and because of

the level of differentiation that takes place in the film finishing operations, a prebuild of spools prior to the peak season could alleviate the seasonal winding capacity concerns. Such a strategy would also work in conjunction with a spool buffer designed to address daily variability and improve packaging efficiency on a daily basis throughout the year.

6.2 Revisit Product Portfolio Differentiation

As discussed in Chapter 2, there is approximately a 13:1 level of differentiation between spool types and packaged end-items. That is, for every unique spool type (exposure size and film speed), there are thirteen unique end-items in the product portfolio. The large degree of differentiation in the packaging operation combined with the dynamic nature of the packaging formats had contributed to the difficulty experienced when attempting to forecast end-item demand.

The ABC analysis of spool demand illustrated in the previous chapter demonstrated that there is a “high” amount of demand concentrated in a few spool types. The degree of differentiation in packaging combined with the concentration in spool demand provides the opportunity to be able to predict demand for a large percentage of the spools with a much greater degree of accuracy than that for end-items. This factor combined with the winding limitations on end-item delivery formed the basis of the logic behind the idea of “packaging postponement” – i.e. prebuild spools and wait to package end-items. In essence, package postponement is a form of delayed product differentiation.

6.3 Delaying Product Differentiation: Packaging Postponement

In an aggregate view, winding capacity restricts packaging output. This is because the packaging lines have higher aggregate capacity than winding. Assuming that the makeup of the demand stream closely matches the ability to package the various formats, this implies that winding production limits the ability to manufacture saleable product when the spool demand exceeds the nominal winding capacity.

The proposal to postpone packaging was predicated on the idea that the majority of product differentiation occurs in the packaging operation. Consequently, the ability to predict the demand for spool types is significantly greater than the ability to predict that for packaged end-items²⁴.

A packaging postponement operation for Kodak's film finishing operation would require that the winding operation be scheduled separately from the packaging operation. Doing so would allow the opportunity to establish a buffer of spools in between winding and packaging. It was understood that prebuilding spools would help alleviate the winding capacity concerns during the peak seasonal periods; however, all of the issues associated with the postponement strategy had to be considered.

6.4 Guidelines for Implementing a Postponement Strategy

Before diving into the notion of postponement it was necessary to develop an understanding of when a postponement strategy is applicable. A considering amount of operations management

²⁴ The benefits of risk pooling are discussed in another LFM thesis by Scott Roza, "Using Forecast Variability and Risk Pooling to Determine Optimal Safety Stock Levels within a Supply Chain", 1998.

research has been conducted in recent years related to this topic. This section borrows liberally from the research and these specific items that were addressed as part of this research are listed as general guidelines that should be considered for the generic application of postponement.

When deciding on a postponement strategy there are several factors that need to be considered:

- (1) Relative lead times for winding and packaging operations
- (2) Relative split of film in the winding operation
- (3) Storage issues
- (4) Demand correlation between spool types

6.4.1 Relative Lead Times

This first criterion for postponement required that the winding operation be much more capacity constrained than the downstream packaging operation. Under a demand-driven process, a higher capacity relative to demand for packaging implies that the size of the smoothing window required for the packaging operation would be significantly lower than that for the winding operation. In order to check the viability of the postponement strategy, an analysis of packaging capacity versus demand was conducted for the major packaging formats. The attempt was to determine whether winding capacity, indeed, would dictate the size of smoothing window required for a given end-item.

This analysis discovered that, contrary to initial beliefs, there were indeed periods of time where the capacity of some packaging formats limited the ability to produce saleable product. As a result the smoothing window required for some of the packaging operations would actually be greater than that for the winding operation. This fact had never been uncovered because when the initial demand analysis was performed prior to instituting the demand-driven process, a thorough capacity analysis of format specific packaging lines was not performed. In addition

because of the dynamic nature of the packaging formats, the determination of capacity for the original data set would have differed greatly from that derived from recent demand data.

Because of this analysis a decision was made to increase the packaging capacity for some formats such that the smoothing window required for the winding operation would be equal to or greater than that required for the packaging operation for all packaging formats.

6.4.2 Split between Spool Types

Prior to instituting postponement an analysis of the demand of spool types was also performed. For postponement to be beneficial there should be a small degree of differentiation to spools relative to packaged formats and a large portion of the spool types spooled to a specific size (e.g. number of exposures). The first criterion has already been discussed in Chapter 2. A review of the spool demand data indicated that the second criterion was also satisfied.

A logical question is what happens if the split between the spool types is equal. If this is the case, a postponement strategy will result in larger amount of inventory in the system due to the variability of the individual demand streams relative to the demand for the aggregate film type upstream of the winding operation. If the split between spool types is relatively equal then as inventory is moved from the upstream to the downstream operation, more inventory will need to be held in order to adequate buffer against stock-out. In Kodak's case, the split is concentrated to a few spool sizes; therefore, the increase in inventory as film is transferred from the cut film buffer to spools was proven to be negligible.

6.4.3 Storage Issues

The many issues involving the storage of the intermediate product also have to be considered. Many times, a production process operates with buffer locations based on factors that are not driven by obvious cost factors.

Quality. The first concern with establishing a spool buffer was quality concerns. Before instituting a buffer of spools management had to be convinced that there were no additional quality concerns related to inventorying spools versus cut film. In the end, it was believe that these concerns could be mitigated; however, the concern remained as an intangible that we were unable to quantify a cost.

Space. The amount of space required to maintain inventory of the material in one format or another should also be considered. Many times the volume occupied by the intermediate product can be significantly greater than that for the form of the upstream operation. The volume occupied by the spools relative to that for the cut film had to be quantified. Any large differences could preclude the postponement option.

Handling. The level of manual touches and the procedure/equipment required for material transport must also be considered. It was believed that if establishing a postponement buffer required a significantly higher amount of manual operations, then the logistics costs of transport spools throughout the finishing operation could be cost prohibitive.

6.4.4 Demand Correlation

The last factor that was considered was the demand correlation between the various spool types (exposure lengths). For the postponement strategy to be a viable option, it would not be desirable to establish a buffer of one spool type if different exposure lengths are highly correlated. The reason is that it would be likely that you may need more than one size at the same time.

Chapter 7: The Appropriate Level of Postponement

After deciding that postponing final packaging could be a viable option to address the seasonal winding capacity concerns, one of the first issues that needed to be resolved was deciding what level of postponement to install. Should all spool types be placed in the buffer or is a lesser amount optimal? This chapter provides a discussion of two alternatives, either “full” or “select” postponement that were considered. These two choices represent the extremes of the postponement strategy. That is, postpone either all spool types (full) or a minimum number of spool types (select).

It also may be prudent, at this time, to clarify what is meant by “postponement”. In much of the operations management research literature, the notion of postponement is used to identify situations where the manufacturing process is re-engineered so that a differentiating step takes place later in the process. For example, many postponement strategies have been implemented where final packaging is done at the distribution center as opposed to within the confines of the manufacturing operation. For this example, the term postponement is used to loosely define the scenario where fully finished inventory continues to be held at the distribution center, however, some measure of intermediate inventory is held in “postponed” or unpacked form at the manufacturing site. The postponed inventory is used to improve forecast accuracy and, in this particular case, to relieve capacity constraints related to seasonal demand patterns.

7.1 Full Postponement

The idea behind a full postponement strategy was to prebuild all of the spool types that go into the high volume (type A and B) end-items. The ABC analysis of the end-item demand revealed

a classic 80/20 situation. That is, 80% of the demand is contained in approximately 20% of the end-items. Therefore, full postponement would require prebuilding all of the spool types that are used to produce the highest volume end-items. These spool types amounted to nearly all of the types produced in the winding operation.

7.1.1 Advantages of Full Postponement

Full postponement affords the “opportunity” for rapid replenishment of the high volume end-items. By prebuilding components (spools) upstream of the packaging operation, spools would readily be available for the majority of the end-items. The potential result is a decrease in the amount of finished goods inventory because the lead-time to replenish an item in the distribution center could possibly be decreased. The magnitude of the reduction is related to the amount of packaging headroom relative to that for the winding operation. The amount of headroom is related to the size of smoothing window that would be necessary for either the winding or packaging operation.

Full postponement also provides the potential for simplified (optimized) scheduling of the winding operation. By decoupling the winding and packaging operations, the winding schedule does not necessarily have to follow the packaging schedule. The potential associated with decoupling these two operations is to realize labor savings at the expense of additional inventory costs. The winding operation could be operated relatively “flat” while the packaging operation would operate more on a demand-driven nature. A schematic depicting the relative spool production versus consumption is provided in Figure VII.1.

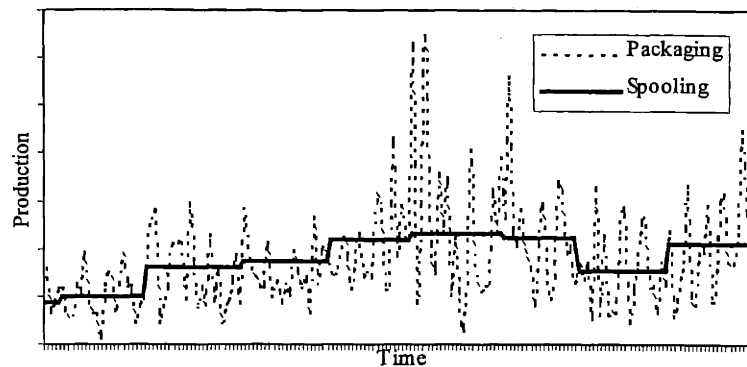


Figure VII.1 Spool Production Relative to Packaging Consumption of Spools

7.1.2 Disadvantages of Full Postponement

The biggest deterrent of the postponement strategy is the cost to establish the spool buffer. These costs include the up-front and holding costs associated with the spool inventory, the logistics charges, the amount of space occupied by the postponement buffer, the infrastructure required to implement the postponement strategy, and any quality concerns related to the change in production sequence.

Spool inventory. As mentioned previously, no appreciable in-process inventory of spools is currently held in the film finishing operation. If a spool inventory is established, the cost of capital for the inventory must be considered. In addition, if demand forecasts prove to be inaccurate, there may be some level of obsolescence. The concern of obsolescence would be particularly true for some of the lower volume spool types.

Logistics. The logistics costs include the costs for spool transport within the factory and any modifications to the shop floor scheduling system and operations to facilitate the implementation of the postponement strategy. As mentioned previously, the postponement operation would

break the winding and packaging flow-line coupling. For full postponement, all spools would be required to pass through the buffer. Therefore, the cost for transport of spools to and from storage and any safety concerns associated with this transport have to be considered.

Space. The amount of space that the spool buffer occupies within the factory also has to be considered. The appropriate accounting charges must be applied to the space being utilized for the new or expanded spool buffer.

Infrastructure. The cost of storage containers and equipment necessary for the spool buffer must also be included. In addition, any modifications to equipment in order to facilitate feeding of spools from the buffer must be included.

Quality concerns. Film is a perishable product; therefore, any process changes that affect the flow of film through the factory raise quality concerns. Because under a full postponement option all material must travel through the buffer there is a potential for extended storage times. Systems must be set up to assure that film flows in a first-in first-out (FIFO) fashion.

7.1.3 Advantages Measured against the Disadvantages

The major cost drivers of the postponement strategy as well as the directional influence of costs and potential savings are depicted in Table VII.1. In general, postponement requires establishing a buffer of in-process inventory with the benefit of labor efficiencies and lower finished goods inventory. The lower level of finished goods inventory is driven by a reduction in the amount of time required to replenish an item in the downstream distribution center. The lower labor charges are the result of improved packaging efficiencies due to spool availability and improved

scheduling of the winding operation due to the demand leveling that takes place with the spool prebuild.

DRIVER	COST
Winding and Packaging Labor	↓
In-Process Inventory	↑
Finished Goods Inventory	↓

Table VII.1 Relative Cost Drivers under Packaging Postponement

For the full postponement case evaluated in this research the disadvantages outweighed the advantages. Of particular concern was that the packaging response time was not significantly faster than that for winding. Therefore, no appreciable finished goods inventory reduction would be possible since the size of the smoothing window required for the winding operation was similar to that for the packaging operation for many of the packaging formats. There was also quality, space, and cost concerns associated with the size of the necessary spool buffer. In the end, the size of the spool buffer versus the potential cost savings due to reduced overtime during peak demand periods and lower finished goods inventory precluded pursuing this particular strategy.

7.2 Levers Impacting Size of Spool Buffer

In light of all of the concerns associated with establishing a sizeable postponement buffer, there was still a strong belief that postponement would prove to be a viable option that could be used to address the winding capacity concerns during the peak season. With the full postponement option the largest concern was the size of the postponement buffer relative to the magnitude of potential reduction in the inventory of finished goods. Therefore, the next logical step entailed looking at the levers that could be manipulated in order to reduce either the size of the

postponement buffer or the amount of finished goods inventory while operating under a postponement operation. The levers within our control include the following:

- (1) Manage the demand data
- (2) Increase the winding capacity
- (3) Increase the packaging capacity
- (4) Reduce the number of unique spool types in the spool buffer

The first three items are all related to demand and capacity data. The relationship between these three issues was well understood. Considerable capital investment would be required in order to provide any substantial capacity increases for either winding or packaging. Increased capital investment was outside the scope of this research. Also, as mentioned previously, managing the demand data through interaction with the Marketing and Sales organizations was considered to be outside of the scope of this immediate research. Therefore, this left the final lever to be manipulated - the relationship between inventory and the number of spool types.

From the beginning of this research, the relationship between buffer size and the number of spool types was not well understood. The daily demand variability for individual spool types in the buffer must be considered when designing a system that readily provides for spools to be available when needed. As such, because the demand between the various spool types was not perfectly correlated, it was believed that a larger number of spools in the buffer would result in a larger buffer size. Since the full postponement strategy previously evaluated entailed having a buffer of essentially all of the unique spool types, it likely represented a near maximum on buffer size. Another option to consider would be to simplify the postponement buffer and include a minimum number of spool types. In order to either prove or disprove this premise, evaluations were performed to quantify the effect that the number of unique spools in the buffer has on the

overall size of the postponement buffer. The details of these evaluations are included in Appendix 3; however, qualitative discussions of the results are included in the remainder of this chapter.

The detailed evaluation showed that by reducing the number of spool types the relative size of the spool buffer did in fact decrease. The exact relationship between buffer size and the particular postponement strategy, either full or select, is depicted in Figure VII.2. For either scenario, the total volume of spools produced over a given timeframe is identical. The difference is the level of inventory that must be established and maintained across all of the spool types in the buffer to ensure spool availability when needed.

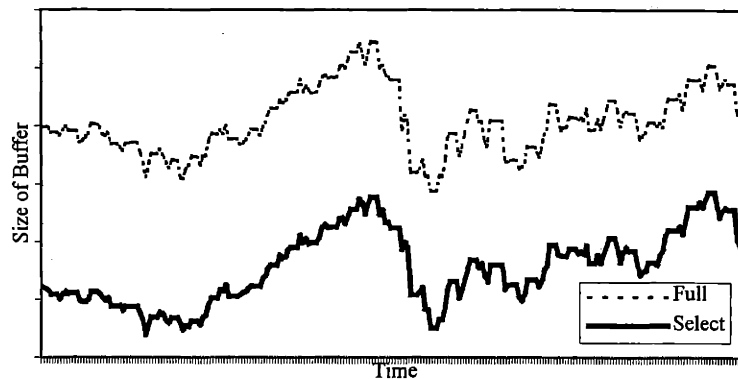


Figure VII.2 Relationship between Number of Spool Types and Size of Buffer

Because of the daily demand variability of individual spool types, the select postponement option resulted in a peak inventory approximately 50% less than that for the full postponement option. The lower peak value favorably impacted the up front costs of establishing the postponement buffer. In addition, the average inventory in the postponement buffer under the select postponement option was approximately 60% less than that for full postponement. This implied

that another favorable decrease in the inventory holding costs could be realized for the select postponement option.

7.3 Select Postponement

After recognizing the relationship between the number of unique spools that were being postponed and the overall size of the postponement buffer, alternative plans were developed to achieve the benefits of postponement without incurring the high costs of establishing a large buffer. The goal was to get the greatest benefit in manufacturing efficiency and finished goods reduction with the least amount of spools in the buffer. In addition to reducing the size of the spool buffer, a smaller number of spool types in the buffer afforded the opportunity to focus on the highest volume spool types for which there would be the greatest forecast accuracy.

The reasons for pursuing a select postponement option were the realization that the cost driver for the full postponement strategy was the size of postponement buffer. In addition, the ability to respond “rapidly” to package orders would not be entirely possible due to packaging headroom constraints. Therefore, the full postponement option required a large investment to establish a spool buffer; however, there were little finished goods inventory savings to offset these costs. These quandaries left the dilemma of deciding how to achieve the benefits of postponement yet alleviate the problems that were related to the full postponement option. The select postponement option entailed postponing a limited, or select, number of spool types rather than virtually all spool types. As a result, not all of the spools produced in the finishing operation would pass through the postponement buffer.

Prior to implementing the select postponement option, assurance had to be provided that there was adequate winding capacity during the peak demand periods to enable a demand-driven response for the remaining spools that were not placed in the postponement buffer. The select postponement of packaging for some spool types required that a buffer of the minimum number of spool types be established. The quantity of spools contained in the buffer had to be adequate to cover the daily variability concerns for the remaining spool types. To ensure that this was attainable, an ABC analysis of spool demand was used to determine the high volume spool types. Iterative calculations were performed to determine the point where the aggregate smoothed demand of the non-buffered spool types exceeded the nominal winding capacity. The breakpoint where smoothed demand exceeded the winding capacity determined the minimum number of spool types.

$$P_T - D_{NB} = P_B \quad (7.1)$$

where:

P_T	=	planned total spool production
D_{NB}	=	smoothed daily demand for non-buffered spools
P_B	=	production of buffered spools

A simple mass balance around the winding operation was used to determine where the breakpoint occurred. The procedure entailed aggregating the demand for the non-buffered spools and using the desired smoothing window size to determine a smoothed demand profile for this subset of spools. As a first pass, the single highest volume spool type from the ABC analysis was used as the sole item placed in the spool buffer. The smoothed demand rate for the remaining spools was compared to the total planned production to ensure that it did not exceed it on any given day, that is $P_B \geq 0$. If D_{NB} exceeded P_T , additional calculations were performed in a similar fashion, this time including the next highest volume spool in the buffer, to determine

whether the demand versus capacity criterion was satisfied. In doing so, the number of spool types placed in the buffer was incremented by one during the iterations. The point at which P_B was not negative for all time periods determined the minimum number of spool types that could be placed in the spool buffer.

7.3.1 Advantages of Select Postponement

The primary advantage of select postponement is that it ensures spool availability with as few spool types as possible. Consequently, the size of the required spool buffer can be reduced. The magnitude of this reduction relative to the full postponement strategy can be significant. In addition, by reducing the number of spool types in the buffer the transport and logistics issues associated with the in-process buffer are greatly simplified.

The smaller buffer size also reduced the space requirements and enabled the buffer to be located closer to the point of usage, i.e. packaging lines. In addition, the decision to not route all spools through the buffer enabled maintaining the flow-line linkages between winding and packaging as best as possible. This minimized the logistics costs associated with spool transport throughout the manufacturing facility. In addition, select postponement achieved less quality concerns due to a smaller amount of product passing through the buffer. The fewer number of items minimizes the likelihood of product mix-up and simplifies the FIFO age issues.

7.3.2 Disadvantages of Select Postponement

Obviously, the select postponement option does not allow the opportunity for finished goods inventory reduction across all of the high volume (type A and B) end-items. This concern was mitigated after the realization that a packaging-smoothing window that was significantly shorter

than that required for winding would not be attainable. This reduced the potential for any finished goods inventory reduction due to the postponement buffer. Probably a greater concern is that the select postponement strategy requires a hybrid scheduling system. Specifically, the scheduling systems had to be modified to enable the packaging lines to be able to receive spools either directly from the upstream winding operation or from the postponement buffer.

Contrary to the full postponement strategy previously evaluated, the financial advantages of a select postponement strategy outweighed the costs. The main drivers for the bias towards a select postponement strategy were the significantly lower up front costs due to the significantly smaller spool buffer size combined with the realization of labor and packaging efficiency savings that were still attainable with a select postponement strategy.

7.4 Option Chosen

In the end, Kodak management supported implementation of the select postponement option. In the final analysis, the costs versus benefits for both postponement options were compared to the base case scenario. The base case required a prebuild of a significant level of finished goods inventory as well as extensive overtime during the peak season. These levels were significantly reduced under either postponement option because of the prebuild of spools as well as the higher attainable packaging production rate due to reliable spool availability during the peak season.

Relative to the full postponement option, the select postponement option significantly reduced the size of the postponement buffer while requiring a small amount of additional finished goods inventory. The additional finished goods inventory under select postponement was necessary because reductions in finished goods inventory, relative to the base case, were only possible for

end-items that were produced from spools contained in the buffer. Since the select postponement option contained less spool types in the buffer, there were fewer end-items impacted by the establishment of the postponement buffer. The results of the final business case analyses using the cost drivers shown in Table VII.1 are depicted in Table VII.2.

	# Spool Types in Buffer	Relative NPV
Base Case	-N/A-	0
Full Postponement	~ 10X	(\$1.0X)
Select Postponement	X	\$2.5X

Table VII.2 Comparison of Two Postponement Options

Chapter 8: Conclusions and Directions for Future Research

At the end of the day, it was shown that increasing the amount of in-process inventory and modifying the way the shop floor was scheduled could be used to address daily variability and seasonal capacity concerns. More importantly, doing so could result in lower delivered cost of Kodak's film products.

8.1 Summary

This research evaluated two concerns that surfaced after an implementation of a demand-driven process. The first of these was related to daily demand variability and its impact on scheduling and manufacturing delivery performance. Because the time frame of production planning (monthly) is significantly longer than that for shop floor scheduling (daily), the move to the demand-driven process resulted in difficulty ensuring spool availability when needed. This is due to inherent daily demand variability that results in oscillations around the average demand over the longer planning horizon. Because of high capacity utilization during peak periods, using a capacity buffer to address the daily variability concerns was not a viable option. It was determined that a buffer of spools situated between the winding and packaging operations could be used to ensure that the packaging operation is fully utilized when demand requirements dictate that it do so.

The second issue addressed in this research was related to improving factory performance in light of a seasonal demand pattern. During peak demand periods, factory performance was limited by winding capacity for the majority of the product mixes. It was shown that an expansion of the spool buffer used to address the daily variability could be a viable option to

reduce manufacturing costs during the peak seasonal periods. This is because, in the aggregate, winding capacity restricts the ability to produce saleable product during the peak demand season.

The analysis in this research evaluated two alternatives: full postponement and select postponement. It was determined that the full postponement option would only be warranted under certain circumstances. The most compelling was that packaging lead-time must be significantly less than the lead-time for the winding operation. For this particular case, postponement of all spool types was not justifiable. In short, the spool inventory costs are too large relative to the finished goods inventory savings.

To improve upon the idea of full postponement, the notion of select postponement was considered. Select postponement would limit the size of the postponement buffer by only stocking a select set of high volume spool types while still providing protection against both daily demand variability and seasonal capacity imbalances. The select postponement option resulted in a spool buffer that was significantly less than that required for the full postponement option.

The primary cost of the postponement proposal was related to establishing the buffer of spools upstream of the packaging operation. The benefits of the packaging postponement strategy are reduced labor and packaging charges due to better management of the workforce and reliable spool availability. Packaging postponement at Kodak is estimated to yield a reduction in labor charges in the film finishing operation as well as an increase in the sustainable packaging throughput with minimal capital investment. The reduction in labor charges is predicated on reducing the amount of overtime spent during peak demand periods. In addition, the reliable availability of spools on a daily basis will result in a reduction in the packaging charges due to

better scheduling. Lastly, in-process placement of spools will enable a small reduction in the replenishment lead-time to the downstream distribution center due primarily to the elimination of the time required for the winding operation versus the current operation.

8.2 Recommendations

This research concluded with the recommendation that Kodak establish a minimal buffer of a select number of spool types in between the winding and packaging operations. Doing so would permit the film finishing operation to reduce their manufacturing costs when operating under the demand-driven process. The spool buffer would ensure spool availability on a daily basis and would be used to offset winding capacity constraints during peak demand periods.

When addressing the peak periods, the notion of packaging postponement was testing and proven to be a viable alternative. The rationale for the final recommendations has been discussed thoroughly in the context of this thesis. Packaging postponement results in lower labor charges in the film finishing operation, a higher level of in-process inventory, and a lower level of finished goods inventory relative to the base case. The remainder of this chapter concentrates on additional steps to further improve the performance of the film finishing operation.

8.3 Directions for Future Research

As with most industrial research projects, not all issues were addressed. This is because of both scope and time constraints that bounded the initial stages of the research. A significant amount of the time spent at Kodak was in the exploratory stages; that is, understanding the effects associated with the move to the demand-driven process as well as understanding the finishing

operations capabilities. This section is devoted to identifying the steps that are likely candidates to further improve the film finishing operation.

8.3.1 Demand Management

As illustrated in Appendix 2, both the mean and standard deviation of the daily demand dictate capacity requirements under a demand-driven process. Reducing either will help reduce capacity constraints in the film finishing operation. One recommendation, along this vein, is to not take orders in excess of capacity. The Sales and Marketing organizations should be linked with Manufacturing so that each mutually understands the others strategy and limitations. Steps should be taken to better understand the end-item that are sold during the peak season, and incentives should be considered in order to shift the sales patterns for some items earlier in time such that they occur prior to the peak demand season.

The impact of promotional sales on the manufacturing system should also be minimized. The current Kodak information systems limit the ability to controllably load the promotional demand to the factory. These orders are currently dropped in as weekly orders that may not be due to the retailer for several weeks. The demand-driven process recognizes these orders as routine end-item demand that has been pulled from the distribution center. Therefore, attempts are made to replenish the promotional orders within the allotted smoothing window which is significantly less than the lead time required by the retailer. Compounding this problem is the fact that the promotional items tend to be the high volume (type A) items. Therefore, the desired smoothing window is short. This exacerbates the problems that the manufacturing organization faces when trying to fulfill these orders.

8.3.2 Spool Postponement plus End-Item Prebuild

An obvious question at the end of this research is how can the size of the postponement buffer be reduced even further. One option to consider would be to combine the select packaging postponement strategy with a judicious prebuild of “some” fully finished end-items. At the end of the day, it may make sense to use a combination of approaches, such as a limited finished goods inventory buildup combined with some excess capacity and some floating labor, if feasible²⁵. Such a strategy would take place secondary to any attempts to manage the demand stream. By evaluating the demand during the peak season, a prebuild can be focused on a few, predictable end-items. Any strategy that requires prebuilding end-items would entail concentrating on the end-items that have the highest forecast accuracy.

The advantage of a select end-item prebuild would be a further reduction in labor charges and lower delivered cost for the film finishing operation. Even with the reduced overtime labor charges associated with the spool prebuild and packaging postponement strategies proposed in this research, some overtime is still required to closely match the seasonal demand patterns. This is because given the current capacity constraints additional smoothing days would be required to satisfy the peak demand within the allowed smoothing window. Rather than increase the smoothing window for a seasonal concern, a balance was chosen that combines a smoothing window size that is sufficient for the majority of the year, spool postponement to address the winding capacity imbalance during the peak, and overtime labor during the peak when necessary. Therefore, both postponement scenarios entailed some degree of overtime in the

²⁵ Hopp, W. J., and M. L. Spearman, *Factory Physics – Foundations of Manufacturing Management*, (1996) Irwin/McGraw Hill, p. 576.

finishing operation. Without an increase in packaging capacity or decrease in the peak seasonal demand this will continue to be so.

8.3.3 Seasonal ROP Adjustment

If Kodak pursues a judicious prebuild of finished goods to offset the seasonal capacity concerns to further reduce the size of the spool buffer, provisions must be provided to facilitate inventory and production management under the demand-driven scheduling system. A major change in the film finishing operation in the move to the demand-driven process is that it removed the ability to easily manage the manufacturing lever of prebuilding end-items to address seasonal capacity concerns.

The pull process utilizes a base-stock reorder-to-point method to set the appropriate inventory level and to place orders into the system. In this system orders are placed whenever an item is removed from the distribution center. The forecasting-based process, on the other hand, only required that the manufacturing organization be concerned with the forecasted demand as opposed to the actual downstream inventory levels. Therefore, adjustments to the inventory level in the distribution center under the old method were simplified because there was no direct feedback from the distribution center inventory levels that impacted the production schedules on short notice.

Any adjustments to the inventory levels under the demand driven process are complicated because sales from the distribution center continue to impact the orders placed on manufacturing regardless of the level of the inventory. A move from the base-stock model to a traditional reorder-point model may afford the opportunity to prebuild end-items and at the same time,

reduce the amount of demand placed on manufacturing. The reorder-point model would permit additional inventory to be placed into the distribution center prior to the seasonal period and would be designed to not place orders into the system unless the inventory level dropped below a predetermined level, the original reorder-to-point under the current system. In this fashion, the production requirements for the manufacturing organization could be moderated during the peak demand periods by working off some of the prebuilt inventory. That is, a production order would not be generated unless the inventory level dropped beneath a specific value.

8.3.4 Product Portfolio

The final recommendation is related to truly understanding the cost of the complexity in the film finishing operation. As highlighted in this research, there is a significant degree of differentiation that takes place in the packaging operation. This differentiation is the primary reason that the finished goods prebuild was such an unattractive lever when addressing the seasonal demand concerns.

Efforts to rationalize the product offerings and aggregate stock-keeping-spools (SKUs) for end-items that lie within a particular packaging format would increase the likelihood of being able to accurately predict end-item demand. Such an approach would result in larger “predictable” sales in fewer end-items that could be “safely” brought forward. SKU rationalization would also reduce the number of unique components that go into the products as well as the logistics costs associated with managing the inventory of the components. Therefore, it may be possible to combine improved management of the product portfolio with a select end-item prebuild and a packaging postponement strategy to deliver a lower cost product.

Chapter 9: Appendices

Appendix 1: Smoothing Concept

A fair amount of discussion has been provided in this thesis regarding a concept referred to as the manufacturing-smoothing window. This appendix is designed to expand the discussion of this concept to provide the reader a reasonable understanding of the theory behind production smoothing and its relationship to factory performance and inventory levels. This discussion is designed to be a cursory overview of the academic research. A significant amount of operations management research has been conducted in this area; therefore, the reader is advised to go there to supplement this appendix²⁶.

A1.1 Inventory Levels

Under a demand-driven process, the level of finished goods inventory is set to cover the anticipated demand over the time required to replenish an item in the downstream distribution center. Assuming a normally distributed demand pattern, a classic base-stock inventory model can be used to quantify the appropriate level of inventory required for a given service level.

$$\text{base stock} = \mu t_R + z\sigma \sqrt{t_R} \quad (\text{A1.1})$$

where:	μ	=	mean daily demand
	t_R	=	time for order replenishment to the distribution center
	z	=	service level to the distribution center
	σ	=	standard deviation of daily demand

²⁶ Cruickshanks, A. B., R. D. Drescher, and S. C. Graves, "A Study of Production Smoothing in a Job Shop Environment, *Management Science*, 30 (1984), 368-380.

The amount of inventory that is held in the downstream distribution center is a function of the average demand rate, the variability of the demand rate, the desired service level, and the size of time required for order replenishment. Generally, either the service level or replenishment lead-time is manipulated in order to impact the level of inventory. The time to replenish a given end-item is a function of several factors.

$$t_R = t_M + t_S + t_L \quad (A1.2)$$

where:

t_M	=	manufacturing time
t_S	=	length of smoothing (or planning) window
t_L	=	logistics time (order placement, transportation, etc.)

The key time under consideration in this research is the size of the smoothing window, t_S . In the following sections, a discussion of the theory and rationale of production smoothing is provided. Two models, a Moving Average Model and a Backlog Model, are discussed in the context of production smoothing. The advantages and limitations of each are also discussed.

A1.2 Moving Average Model

Extensive operations management research has been conducted to understand the impact of demand smoothing on production requirements²⁷. From this research equations have derived that relate the variance of the production rate to the characteristics of the demand stream and the size of the smoothing window. Manipulation of these equations yields a relationship between the required production rate and the size of smoothing window for a given service level.

²⁷ Cruickshanks, A. B., R. D. Drescher, and S. C. Graves, "A Study of Production Smoothing in a Job Shop Environment, *Management Science*, 30 (1984), 368-380.

$$\text{required production capacity} = \mu + \frac{z\sigma}{\sqrt{2n-1}} \quad (\text{A1.3})$$

where:

μ	=	mean demand
n	=	length of smoothing window
z	=	service level
σ	=	standard deviation of demand

Demand smoothing of the raw demand results in a moving average of the demand over the size of the smoothing window. The degree of “smoothing”, therefore, is dependent on the size of the smoothing window.

If the demand characteristics are known and the production capacity is fixed, the lever manipulated in actual operation usually becomes the smoothing window length. Algebraic manipulations of the proceeding equation yield a relationship that can be used to estimate the required size of the smoothing window, n , based on the demand characteristics, production capacity, and desired service level.

$$n = \frac{\left(\frac{z\sigma}{C-\mu} \right)^2 + 1}{2} \quad (\text{A1.4})$$

where:

C	=	production capacity
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The equations presented for the Moving Average Model are useful for understanding the effect of demand smoothing on the production variance. A higher degree of smoothing yields a lower production variance. This corresponds to lower capacity requirements for a given service level. While the model is useful for understanding this relationship, it unfortunately does not work well with seasonal demand patterns or with capacitated processes.

For highly capacitated processes, such as the film finishing operation studied in this research, the replenishment lead-time becomes in large part a function of the production capacity relative to the demand. The strategy used to ensure that the manufacturing requirements are lower than the nominal capacity remains to increase the production lead-time (i.e., lengthen the smoothing window); however, the means by which the appropriate window size is determined differs from that demonstrated in the Moving Average Model.

A1.3 Backlog Model

The film finishing operation is what can be termed a “capacitated” process. That is, for a significant period time, the facility is operating at or near its peak capacity. The moving average model presented in the previous section is predicated on a smoothing convention that provides peak capacity requirements near the capacity limit. That is, the Moving Average Model yields smoothed production requirements that are normally distributed and reach the capacity limit only a limited percentage of the time (dependent on the desired service level). In actuality, this limit could be reached for extended periods for a capacitated process.

Rather than using a moving average of demand over the size of the smoothing window, in actuality many production processes are scheduled up to their capacity limit. The production scheduling system is designed to backlog any demand greater than the production capacity.

$$(D + B)_i = D_i + (D_{i-1} - P_{i-1}) \quad (A1.5)$$

where:

D	=	demand
B	=	backlog
P	=	production

For the capacitated process, it is common for production to be limited by the process capacity as depicted in Figure A1.1. Therefore, comparison of the demand plus any backlog and the production capacity dictates the production rate. The minimum of these two values determines the production for time period i .

$$P_i = \text{Min}[C, D + B]_i \quad (\text{A1.6})$$

where: C = production capacity

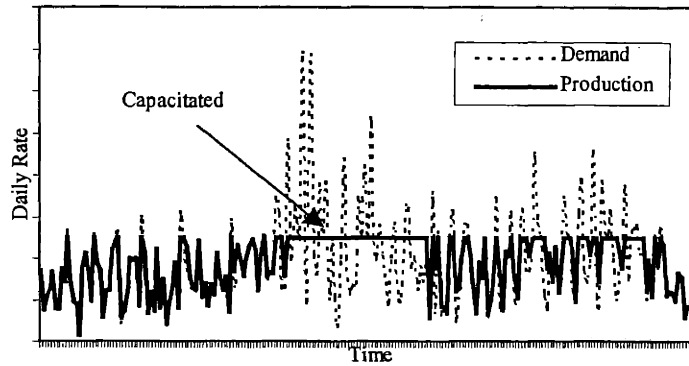


Figure A1.1 Demand vs. Production in a Capacitated Process

In general, if the demand plus backlog is less than the production capacity, the production rate will follow the actual demand. If it exceeds the production capacity, the process is capacitated and a backlog of orders will accumulate upstream of the process operation. A tally of the cumulative backlog should be taken for all time periods in the scheduling window. After evaluating the production versus demand for all time periods, an evaluation of the maximum lead-time over the entire time window can be determined using the maximum backlog.

$$\text{lead time} = \frac{\text{Maximum } (D + B)}{C} \quad (\text{A1.7})$$

The idea behind the backlog method is to determine the maximum number of days that production orders are backlogged upstream of the capacitated process operation. This peak value sets the required size of the smoothing or production window in order to ensure that order delivery matches the manufacturing capability. Therefore, the appropriate inventory should be in place in the downstream distribution center based upon this length.

The size obtained from either of the two methods can differ significantly. Figure A1.2 depicts a histogram of the production rate using both a Moving Average and Backlog method. For each case, the production lead-time was based upon that required for the Backlog method.

Consequently, the percent of the time that the “smoothed” production rate exceeds the capacity limit for the Moving Average model (12%) is much higher than what would generally be acceptable. If the Moving Average Model were used exclusively, the size of the required smoothing window would be 150% greater than the one obtained from the Backlog Model. The difference between the performance of the two models is driven by the fact that the demand stream contains a seasonal demand pattern.

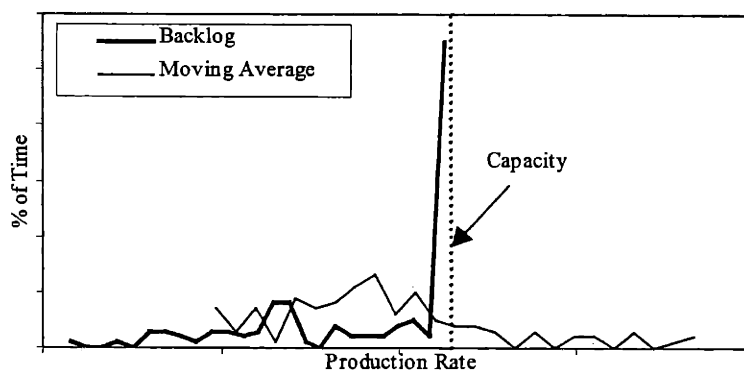


Figure A1.2 Production Rate Frequency

If the demand history is known on a daily basis, then a Backlog Model is most appropriate for a capacitated process and one that is subject to demand seasonality.

Appendix 2: Demand Variability and Capacity Requirements

The move to the demand-driven process revealed that it was not obvious that the impact of daily demand variability on capacity requirements was fully understood by the film finishing organization. This appendix has been included in order to shed some light on this relationship. It is an extension of the production smoothing theory discussed in Appendix 1.

In this thesis it has been discussed how daily demand variability results in intermittent periods where demand is greater than the average daily demand for the month. Unfortunately, because of aggregate production planning schedules, the anticipated average daily demand for a given month is used to determine the planned capacity and related staffing levels.

The magnitude of the capacity imbalance due to daily demand variability can be large even when smoothed under the demand-driven smoothing conventions. The magnitude of the discrepancy between demand and capacity is a function of the variability of the daily demand. This can be shown by comparing the discrepancy size as a function of the coefficient of variation (CV) of the demand stream.

$$CV = \frac{\sigma}{\mu} \quad (A2.1)$$

where:

CV	=	coefficient of variation
σ	=	standard deviation of daily demand
μ	=	average daily demand

Using Equation (A1.3) presented in Appendix 1, a relationship between capacity requirements and demand variability can be determined. This relationship is depicted in Figure A2.1.

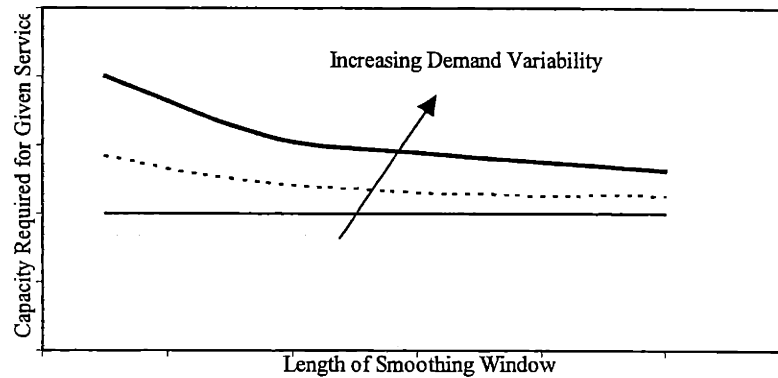


Figure A2.1 Capacity Requirement Depends on Demand Variability

As the variability of the demand stream, CV , increases, the level of capacity required to service a given percentage of the demand also increases. For a highly variable demand stream, the capacity requirements can be significantly greater than that required for a level demand, $CV=0$. Not until you reach excessively high smoothing window lengths will the capacity discrepancy be significantly mitigated.

The impact of the daily demand variability on capacity requirements must be considered when scheduling a demand-driven process. As discussed in the context of this thesis, two means for addressing the demand variability are either a capacity buffer or inventory buffer.

Appendix 3: Buffer Size vs. Number of Spool Types

A critical aspect of the decision to postpone the packaging operation and establish a buffer of spools upstream of the packaging operation was deciding how many spool types to place in the buffer. Initially, it was believed that to achieve the benefits of postponement, the majority of the spool types needed to be placed in the buffer. The purpose of majority (or full) postponement would be to simplify the scheduling of the packaging operation and capitalize on the ability to shorten the replenishment lead-time for many of the high volume end-items. As outlined in the thesis, the size of the spool buffer relative to the savings in operational efficiencies and finished goods reductions precluded pursuing this strategy and an alternative strategy that required postponing a minimum number of spools was developed. This appendix is constructed to explain the rationale used to decide the spool types that should be placed in the buffer and the procedure used to evaluate the impact that the number of spool types had on the overall buffer size. In this appendix, the notion of full and select postponement is consistent with that described in the context of this thesis.

A3.1 Spool Types in the Buffer

The first step of the select postponement analysis was to establish a buffer of the highest demand spool types. This required performing an analysis of the spool demand by type to highlight the spool types that should be targeted for postponement. The result of this analysis was an ABC classification of the spool types similar to that depicted in Figure V.2.

Of critical importance when deciding on the spool types to place in the buffer was ensuring that there was adequate winding capacity to spool the remaining types that were not placed in the

buffer within the allotted end-item lead-time. Such replenishment had to take place within the replenishment time window requirements as dictated by the demand-driven process. Assurance had to be provided that the “smoothed” demand of the non-buffered spool types did not exceed the nominal daily winding capacity. An example schematic is depicted in Figure A3.1.

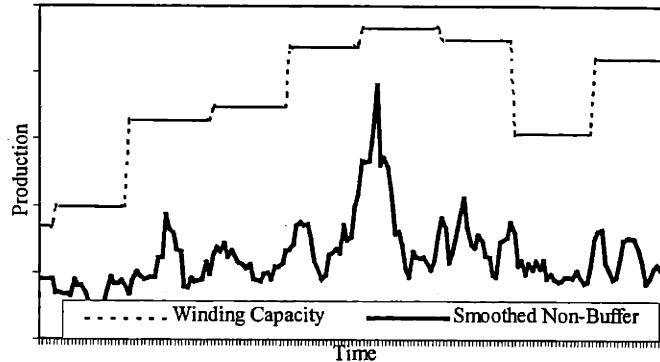


Figure A3.1 Capacity versus Demand for Non-Buffered Spool Types

The procedure used to determine adequacy was an iterative process. That is, a minimum number of spool types was chosen and a check of the winding capacity versus the smoothed demand for the non-buffered types was performed to ensure compliance with the process requirements. If the smoothed demand profile exceeded the winding capacity, the next highest volume spool type was placed in the buffer and the capacity verification was performed again. In the end, the final number of spool types placed in the buffer under the select postponement option was the minimum amount necessary to ensure that this relative capacity criteria was satisfied.

A3.2 Modeling of Film Finishing Operation

To model the performance of the finishing operation and the relative size of the spool buffer the following procedure was used. Since the non-buffered spools would still be produced on a

demand-driven basis, the scheduling of items made from these spools would continue to be linked to the scheduling system for the demand-driven process. A modification to this process, however, required that a buffer of spools be established for the high volume spool types that it was deemed to place in the buffer. This change required modifying the current system by decoupling the scheduling of the winding and packaging operations. Instead of winding orders being generated directly of packaging orders, flexibility would be provided to facilitate scheduling these two operations separately.

The capacity requirements for the finishing operation were modeled using a moving average demand-smoothing model. Based on historical demand data, the demand profile for the non-buffered spool types was smoothed using the allotted production window. This resulted in a smoothed demand profile for the non-buffered spools to be produced on any given day.

The smoothed demand profile was deducted from the planned winding capacity to determine the net winding capacity on any given day. This capacity would be equivalent to the area between the two curves in Figure A3.1. The net capacity was the capacity available to produce spools specifically for the buffer. Production was allocated to the various spool types placed in the buffer was based on their recent demand history. That is, spool types that were greatest in demand were given a greater proportion of the net winding capacity. A ratio of the demand for a given spool type relative to the total demand for buffered spools was used to determine the net capacity to be allocated to a given spool type to be produced for the buffer. An example graph depicting the production of a given spool type using the allocation criteria described previously is depicted in Figure A3.2 on the following page.

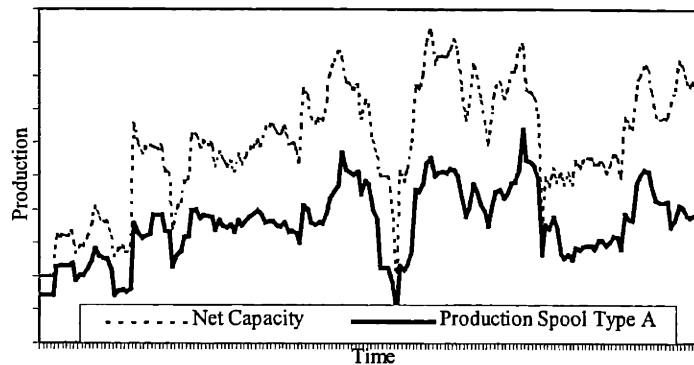


Figure A3.2 Spool Production Versus Net Winding Capacity for a Given Spool Type

A3.3 Buffer Size

The overall buffer size was determined by setting a preseason inventory target for each of the spool types in the buffer so that the amount of inventory in the buffer is minimized yet the demand over the seasonal period is fully covered. Of critical importance was ensuring that spool types in the buffer were available when demand for an end-item that contained one of the buffered spool types entered the system. An EXCEL solver routine was used in order to vary the preseason inventory target for each of the spool types in the buffer such that the peak and average inventory levels of the buffer were minimized.

The result of minimizing the number of spool types in the buffer was an overall reduction in the amount of spool inventory contained in the buffer. This inventory relationship is depicted in Figure VII.2. The primary reason for lower inventory levels with the select postponement option is due to demand variability of the individual spool types. Because the demand for the spool types placed in the buffer were not perfectly correlated, additional safety stock needed to be present to ensure spool availability at any point in time.

Chapter 10: Bibliography

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