A Supply Chain Strategy for Digital Camera Products

By

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B.S. Electrical Engineering, McGill University 1996

Submitted to the Sloan School of Management and the Department of Electrical Engineering and Computer Science in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration
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Master of Science in Electrical Engineering and Computer Science

In conjunction with the Leaders for Manufacturing Program
at the Massachusetts Institute of Technology
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ABSTRACT

Rapid growth in the digital imaging industry has created unique supply chain challenges for companies in this business. Successful companies must have supply chain systems capable of dealing with significant demand variation, fast product obsolescence and poor forecasting abilities. The supply chain should also be flexible enough to support the growth objective of the company. Kodak's Digital and Applied Imaging Division sought to obtain competitive advantage through supply chain improvement.

A new supply chain strategy was developed for Kodak's consumer digital cameras, one that improves the responsiveness to market change and reduces excess inventories in the system. The new design will link Kodak, its suppliers and distributors more closely with consumers. The strategy also has the potential to reduce up to 50% of the total inventories in the camera supply chain. The proposed supply chain framework improves Kodak's resource management process through better demand forecasting and capacity planning.

This thesis analyzes the supply chain in the context of high volume camera manufacturing and distribution. The analysis utilizes tools such as the Lean Supply Chain Concept, Base Stock Inventory Model, event simulation and the safety stock model with production smoothing. The analysis highlights issues and critical components in supply chain design for new products. The research result provides guidelines for process changes towards supply chain optimization.

Implementation of the lean supply chain strategy has begun at Kodak. A cross-functional team has been established to lead the supply chain reengineering effort. This lean supply chain initiative is a continual effort, but Kodak is on its way to reap further benefit from the new supply chain strategy.

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1 Supply Chain Challenge

The objective of this thesis is to establish a framework that can be used to improve the supply chain design for digital cameras. The thesis includes the analysis of supply chain requirements, a quantitative model for inventory estimation, methods of capacity planning and overall supply chain management principles. I conducted the research for this thesis at the Eastman Kodak Company's Digital and Applied Imaging Division from June through December of 2000.

1.1 Kodak's Digital Camera Business

The Digital and Applied Imaging Division (D&AI) of the Eastman Kodak Company supplies digital imaging products, services, and solutions to consumers and businesses. The division's products include digital cameras, digital projectors, inkjet printers, scanners, photo CDs and other digital imaging related services. D&AI creates value for Kodak by taking a path to leadership in the digital imaging business.

Eastman Kodak is the world's leading manufacturer of consumer and commercial photographic products. The company is a pioneer in traditional analog, film-based technology and imaging technology. Recently, Kodak has made giant strides in the electronic capture, manipulation and transmission of images across the Internet. With innovations such as Picture Maker Kiosks, Network Services and Picture CDs, Kodak strives to offer virtually all the benefits of digital imaging without the requirement of any changes of habit by its consumers. Successful implementation of such a strategy will provide new growth opportunities for Kodak in the future.

At present, D&AI is going through a period of rapid growth in the digital imaging industry. As such growth provides tremendous opportunity for Kodak, it also gives rise to major challenges within the organization. While Kodak makes the effort to bridge the gap between the traditional business and the digital business, process changes and infrastructure changes are required to facilitate the transition. In particular, supply chain designs for the traditional analog, film-based products and the digital products have drastically different requirements. The requirements for digital products are the focus of this thesis.

1.2 Industry Dynamics in Digital Imaging

As the Internet and computers tighten their grip on the world, the photography industry is gradually shifting from chemical-based technology to digital-based technology. According to an industry report[1], the digital camera market has exploded over the past three years with a 70% compounded annual growth rate. The double-digit growth is expected to continue for another decade. **Table 1-1** shows the estimated worldwide sales of digital still cameras for 1999-2005.

Table 1-1 Digital Still Camera Market Worldwide: Annual Estimation/Projections for 1999-2005 (in million units)
Source: Global Industry Analysts, Inc.

1999	2000	2001	2002	2003	2004	2005
4.30	6.29	9.27	12.3	19.6	27.7	40.1

The digital imaging industry as a whole is marked by rapid innovation in products and services. The emerging industry throws competition wide open to various players. These players range from traditional photographic product suppliers to small online companies. As a result of the intense competition, a technology device model has emerged in the digital imaging business. Companies using this model acquire their customer base through sale of high-tech devices and obtain long-term revenue streams from related service offerings. For Kodak's D&AI, a digital camera is the high-tech device. Related services include online picture sharing and printing. This model will become more apparent as digital cameras become connected to the Internet with wireless technology. Online services will likely be bundled with hardware.

Based on the technology device model, Kodak has pieces in place to be a leader in the digital photo arena. Apart from the company's strong brand name in the traditional photo industry, Kodak is also the number two digital camera manufacturer in the world (with Sony being number one). More importantly, Kodak has the unique capability to offer both digital cameras and all the related services. The following is a list of the company's advantages in service offerings.

- Kodak technology addresses the longevity of inkjet prints, the media for home printing.

[1] "Eastman Kodak Company: Looking for Value Part 5 – Consumer Digital", Credit Suisse Fist Boston Equity Research Report, May 2000

- Kodak's Kiosk business provides unique printing infrastructure. The large and growing installed base of Kodak Picture Maker kiosks around world offers consumers the ability to "process" digital pictures as they do films.

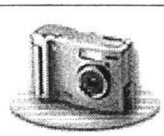
- Through wholesale photo finishing, Kodak has access to 360 million rolls of film processed annually. This is a valuable customer base for the company as people transition from traditional film to digital.

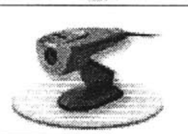
Even though many industry analysts question whether the digital cameras business will ever be profitable, Kodak's D&AI is well positioned to profit through a complete offering of hardware and services.

1.3 Kodak's Consumer Digital Products

Kodak offers a variety of consumer digital camera products in the consumer segment. These products include low-end and high-end digital still cameras, computer video cameras and Palm Pilot attached cameras. The product profile intends to serve emerging household needs for digital imaging. The product selection also covers a wide price range. **Table 1-2** lists Kodak's major consumer digital product offerings.

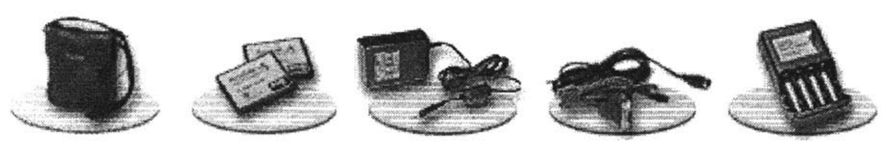
Table 1-2 Kodak's Major Consumer Digital Product Offerings
Source: Kodak Web Site

	Model	Product Highlight
	DC4800	Resolution: 3.1 megapixels. SLR-like flexibility and creativity. 3x optical zoom. 2x digital zoom. Small, compact design.
	DC3800	Resolution: 2.1 megapixels. Pocket size. Easy to use. Sleek Style.2x digital zoom.
	DC5000	Resolution: 2.0 megapixels. Rugged weatherproof design. 2x optical zoom. 3x digital zoom.

	DC3400	Resolution: 2.0 megapixels. Easy to use. Simple connection. 3x optical zoom. 2x digital zoom.
	DC3200	Resolution: 1.0 megapixels. Internal memory. Affordable. 2x digital zoom.
	DC215	Resolution: 1.0 megapixels. Sleek and fashionable design with a metallic body. 2x optical zoom.
	EZ200	Resolution: VGA (0.3 megapixels). Pocket-Sized and Portable. Video clip and live video call feature. Snap action sequence with burst mode.
	DVC325	Resolution: VGA (0.3 megapixels). Internet videoconferencing camera. Easy-to-use software expands the fun. Wide tilt range movement.
	PalmPix	Resolution: VGA and SVGA. The easiest way to extend Palm handheld into digital imaging.

Apart from the camera bodies, retail packages for digital cameras also incorporate various accessory items. Typical accessories include camera bags, camera memory cards, AC adapters, power cables, computer connection cables, batteries, and battery chargers. These items enhance the functionality of the cameras by increasing power and connectivity options, as well as expanding picture storage capacity. Consumers can also purchase extra accessory items from Kodak. **Figure 1.1** shows some of the typical camera accessory items.

Figure 1.1 Camera Accessories



Camera Bag Memory Cards AC Adapter Computer Cable Battery Charger

The selection of accessory items included in the retail package varies from product to product. Different sales regions also have different retail package contents due to the variation in power and connectivity requirements. Kodak also uses variation in retail packages to stimulate sales. As market trends move, the retail box content can be altered constantly to better suit customer needs.

1.4 The Process Flow for Digital Camera Products

As rapid innovation and product release define the landscape of the digital camera business, it is necessary for Kodak to source cameras externally. Collaboration with external manufacturers allows Kodak to rapidly expand its product portfolio. Most of Kodak's digital cameras are manufactured by subcontractors located in Japan and other Far East countries.

Product design is usually a joint effort between Kodak and the camera manufacturer. The manufacturer is generally responsible for sourcing most camera components. However, in cases that Kodak can exercise its buying power with a downstream vendor, the company will choose to buy the components and consign it to the manufacturers.

For each camera product, Kodak generally commits to a production schedule for the first few months after a product launch. The manufacturer then determines the production line capacity according to the volume requirement and estimated ramp-up. Throughout the production life of the camera, a shipping schedule is communicated from Kodak to the manufacturer on a weekly basis. Significant changes in production volume have to be negotiated by Kodak and the manufacturer.

A packaging operation puts the manufactured camera bodies into different retail packages along with the appropriate accessory items. Packaging is either done by the camera manufacturer at the end of the production line or by Kodak packaging facility in the particular sales region. Sourcing accessory items is generally the responsibility of the packaging facility. Kodak is currently experimenting with both packaging options to evaluate the pros and cons.

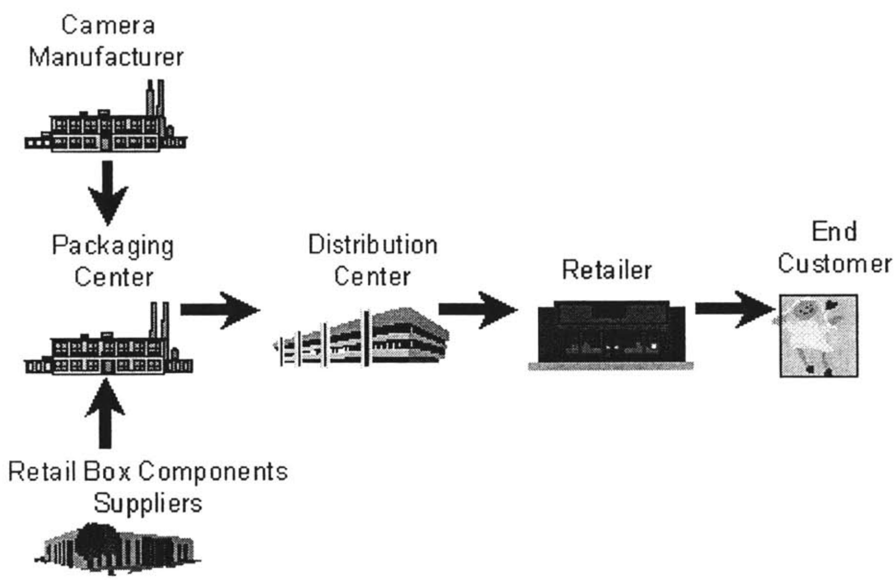
Camera retail boxes are then shipped to Kodak customers, either large retail chains or distributors that sell to small retailers. Digital cameras currently ship to most regions in the world. There are two shipping modes for digital camera distribution, via Kodak distribution channels or via direct-ship third party vendors. In the former case, digital camera products will be consolidated with other Kodak shipments to the same region and enjoy economy of scale for shipping costs.

However, consolidation and going through layers of the Kodak distribution system can cause delay in shipments. In the latter case, orders of digital camera products are shipped directly from packing locations to customers with a guaranteed delivery time. The company has to pay a premium for this service.

From camera distributors or the distribution centers of large retail chains, the camera retail boxes are shipped to individual stores where they are sold to the consumers. Due to intense competition and the high-tech nature of the product, Kodak is responsible for any price degradation related to product obsolescence before consumers purchase cameras.

Figure 1.2 shows an overview of the process flow.

Figure 1.2 Digital Camera Process Flow Chart



1.5 Supply Chain Requirements for Digital Cameras

As illustrated previously in **Table 1-1**, the digital imaging industry is going through a period of rapid growth and innovation. Eastman Kodak is uniquely positioned to become the leader in this arena. To succeed in this endeavor, the company has to effectively deliver new products into the hands of consumers worldwide at competitive prices. The need for a responsive and low-cost digital camera supply chain is critical.

The supply chain for digital cameras also differs significantly from those of Kodak's traditional businesses. Over the years, Kodak has established a worldwide supply and distribution system with strong focus on the film and paper business. This system will poorly serve the need of the digital business. The difference in the characteristics of the traditional and digital businesses requires distinct different supply chain strategies. **Table 1-3** illustrates the difference in characteristics.

Table 1-3 Characteristics of Kodak's Traditional and Digital Business

	Traditional Business	Digital Business
Growth Opportunity	Stable and mature business with exception of a few developing countries.	Rapidly growing business with double-digital growth rate.
Competitive Environment	Two major players (Fuji and Kodak) with Kodak being the worldwide leader	Big established companies as well as new small entrants. Constant innovation. No clear technology leader.
Overall Present Business Goal	Profit generation.	Market penetration and customer acquisition.
Product life cycle	More than two years.	12 to 18 months.
Demand Characteristics	Stable end-customer demand pattern. Product demand predictable from historic data.	Unpredictable end-customer demand for individual products. Highly seasonal demand.
Critical Supply Chain Objective	Cost saving.	Product delivery.

While the existing supply and distribution systems at Kodak stresses cost savings, the desired supply chain designs for digital cameras and other digital products have different requirements. The difference lies between an efficient supply chain and a responsive supply chain described by

Marshall Fisher (1997).[1] The following list summarizes some crucial aspects of an effective supply chain design for innovative digital products.

- Enable rapid and effective product delivery to improve customer satisfaction
- Respond quickly to unpredictable market conditions in order to minimize stockouts, forced markdowns and obsolete inventory.
- Increase flexibility in the supply chain design to accommodate product innovation, broad collaboration and channel alignment.

1.6 Project Approach and Outcome

My thesis research at Kodak intended to identify opportunities for supply chain improvement. I approached the problem by modeling the supply chain using different quantitative tools. These include Base Stock Inventory Model, simulation with historic data, and the safety stock model with production smoothing. I also performed benchmark analysis against supply chain practices of other companies.

The supply chain modeling was based on historic order, sales and inventory information recorded in a D&AI database as well as product cost information I collected. These data showed sales patterns, inventory trends and channel behaviors. They illustrated the behavior of different parties involved in the supply chain. *Due to confidentiality, data appearing in this thesis have been disguised.*

My research also revealed different companies' approaches to similar problems. Best-in-class practices include Dell, HP, Sports Obermeyer, etc. I also reviewed academic papers that address supply chain design issues for innovative products with unpredictable demand. The research result provided building blocks for my suggested approaches to D&AI's digital camera supply chain problem.

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[1] Fisher, Marshall L. "What is the Right Supply Chain for Your Product?" Harvard Business Review, March-April 1997

The management of D&AI has appointed a team to implement the integrated lean supply chain as advocated by my research. The framework I established during my project will help supply chain design for future digital camera products and other similar products in the division.

1.7 Overview of Chapters and Appendices

This chapter provides an overview of the supply chain challenge at Kodak's D&AI Division. It describes the background for the project. This chapter also highlights the top-level objectives and approaches.

Chapter 2 presents inventory savings opportunities for new supply chains. This chapter reviews general principles and models of inventory placement. Data analysis highlights the problems and opportunities. Desired inventory policy and its impact are discussed.

Chapter 3 provides a model for capacity planning. The chapter also describes the benefit of an improved demand forecasting method. General demand trends are reviewed through data analysis. A simple demand forecast method is proposed. Impacts on inventory and other supply chain performance are presented.

Chapter 4 provides an overall framework for supply chain design and management at D&AI. The chapter highlights issues that affect supply chain decision-making. A product-specific supply chain decision model is discussed.

Chapter 5 presents the results and conclusion from my thesis research. Recommendations for further improvements are summarized.

2 Inventory Management

Inventory management policies determine the behavior of business entities at different stages of a supply chain network. They also control demand signal propagation through the supply chain.

As I will show in my analysis, inventory is closely linked to customer satisfaction. Although inventory cost is high in this industry, the even higher cost of stockouts requires that Kodak keep enough inventories to handle the demand variation. The company can establish an effective inventory system to reduce current inventory levels without sacrificing customer satisfaction.

2.1 Current Inventory Problems

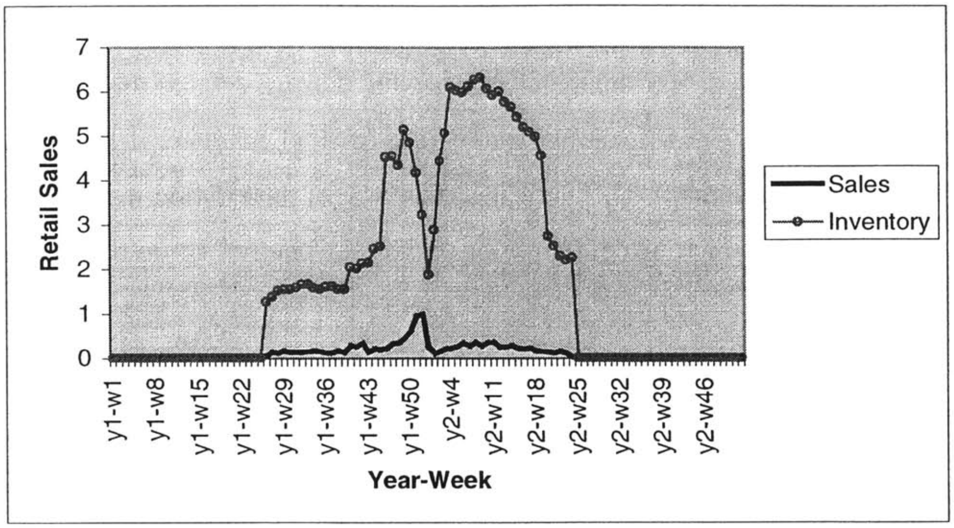
The current supply chain for consumer digital cameras suffers from low inventory turns. The problem expands beyond Kodak into downstream distributors and retailers. Since Kodak is responsible for price degradation until consumers purchase camera products, excess inventories anywhere in the supply chain are costly to the company.

Another aspect of the inventory problem is the mismatch between inventory and demand. It is often the situation that total digital camera inventories are high while certain items have long back orders. The mismatch occurs between different models as well as between different configurations of the same model. As a result, the company is forced to mark down certain products to avoid inventory obsolescence. This negatively impacts both Kodak's profitability and brand image.

Mismatches also occur between inventory location and demand. All digital camera products have worldwide distribution. Due to inaccurate demand forecast and long distribution lead times, it often happens that some retailers and distributors have excess inventory while others have demand that they cannot satisfy.

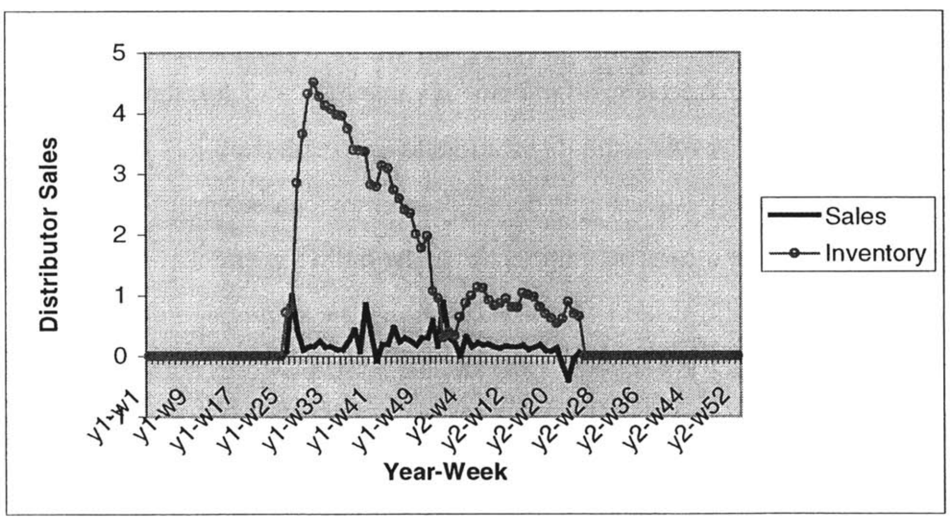
Figure 2.1 and **Figure 2.2** illustrate some of these inventory problems. **Figure 2.1** shows the total weekly sales of one camera model reported by Kodak's major US retailers and the inventories supporting these sales. **Figure 2.2** shows the same data reported by major Kodak distributors. These represent a significant portion of Kodak sales. Absolute volume numbers are disguised due to confidentiality. However, the relative relationship between weekly sales and inventories is preserved. The horizontal axis shows the time frame (year and week) in which the data were reported.

Figure 2.1 Weekly Retailer Sales and Inventory for One Camera Model



Note: The inventory drops to zero at Y2-W25 because that is the end of the reported data.

Figure 2.2 Weekly Distributor Sales and Inventory for One Camera Model



Note: The negative sales levels represent product return.

The inventory drops to zero at Y2-W25 because that is the end of the reported data.

As one can see, the total inventories reported by retailers exceed their total sales in the following week throughout the life of the product. The same is true for distributors with the exception of a short period after the Christmas peak season. In other words, the inventories in the whole system are almost always enough to satisfy the demand.

However, the Kodak sales representatives reported that the product was on allocation for significant periods of time. In those periods, the orders placed by distributors and retailers to Kodak were bigger than the actual shipments indicated by **Figure 2.1** and **Figure 2.2**. Although the figures show enough inventories in the system to satisfy end-customer demand, the retailers and distributors had ordered more. This indicates that some of the existing inventories were either at the wrong places or in the wrong configurations. These inventories could not be used to satisfy demand in the next period.

2.2 Causes of Inventory Problems

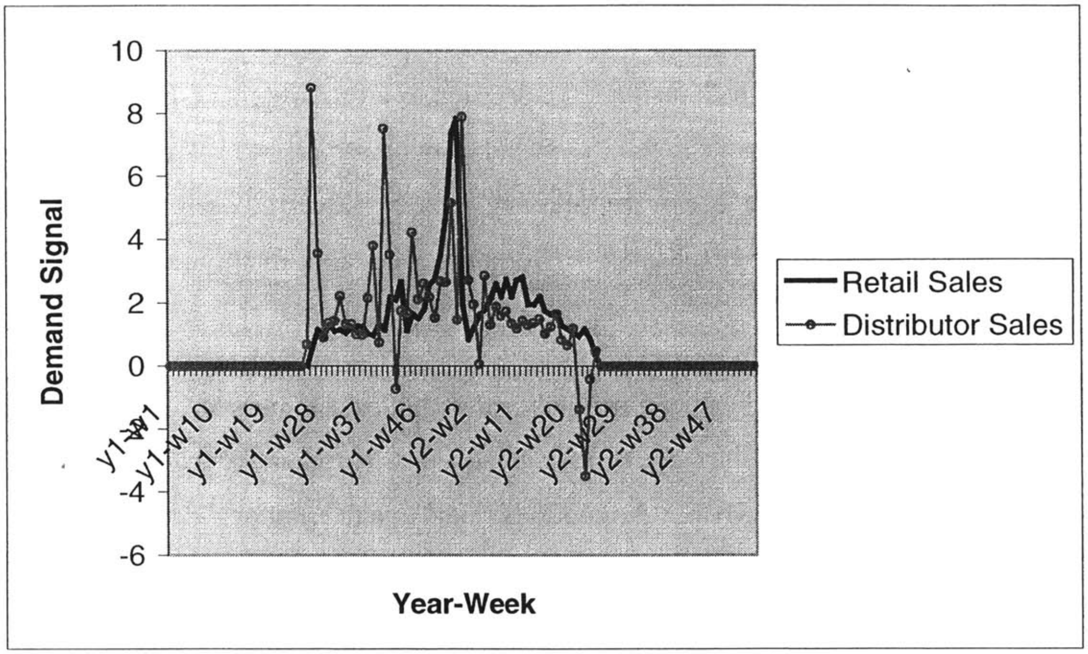
To address the inventory problems for Kodak's digital camera business, one needs to discover the root cause of the phenomena. Here, I suggest two major causes of the inventory problem - the bullwhip effect and manufacturing constraints.

2.2.1 The Bullwhip Effect

The bullwhip effect has been recognized in many diverse markets. It refers to the phenomenon where orders issued by the downstream distributors to upstream suppliers have larger variance than their sales to buyers. The amplification in demand variation can be significant through a multi-stage supply chain. Among other cost implications, the bullwhip effect can result in higher inventory accumulation in the system. **Figure 2.3** shows the aggregated demand signal processing from retailers to distributors for a specific camera model. The figures shown here use disguised data. Due to the lack of historic data collected on real orders placed by retailers to distributors, sales volumes are used as proxies. It should be noted that distributors might stock out, resulting in sales volumes less than the original orders. Since sales data are used as proxies to illustrate demand signal propagation, the amplification of demand variation will be smaller than actual in my estimates. The bullwhip effect can still be easily observed from the graph.

Lee, Padmanabhan and Whang[1] suggested that there are four sources of the bullwhip effect – demand signal processing, rationing game, order batching and price variation.

Figure 2.3 Demand Signal Processing from Retailers to Distributors



DEMAND SIGNAL PROCESSING occurs when different stages in a supply chain have different forecasts and end customer demand is not visible to upstream suppliers. Although Kodak has made an effort to collect sell-through information from retailers and distributors, the data has not been adequately used to drive inventory decisions. The effort is also limited to only part of the US region. Orders made by Kodak customers are still the major driving factors for operation decisions. Lee, Padmanabhan and Whang mathematically analyzed the situation where suppliers set a higher inventory target based upon a demand upswing. Such rational behavior leads to amplification of demand variation. The longer the supply lead time, the larger the resulting demand variance for upstream suppliers. When such amplification occurs along the digital camera supply chain from retailers, through distributors, to manufacturers, it puts cameras on backorder until a downturn in customer demand. Due to short life cycle and extreme seasonal demand of the products, the high inventory levels at the distributors and retailers become very costly to Kodak

1 Lee, H. L., V. Padmanabhan, and S. Whang, "Information Distortion in s Supply Chain: The Bullwhip Effect," Management Science, Vol. 36, No. 6, June 1990, pp724-738.

when there is a sudden drop in demand. Such a downturn will often force Kodak to hold the obsolete inventory for an extended period of time until a price markdown.

RATIONING GAME refers to the behavior where distributors inflate their orders because demand exceeds supply and products are being rationed. It is common practice to allocate products in proportion to unfilled orders, which justifies the decision to inflate orders in the rationing game. Lee, Padmanabhan and Whang illustrated that such behavior also results in variance amplification. Anecdotal evidence supports the use of the rationing game by Kodak customers (distributors or retailers). The inflated orders cause Kodak to overproduce certain camera models that stay in the system as excess inventories.

ORDER BATCHING defines the phenomenon when multiple customers have similar review cycles and make orders around the same time (e.g. most distributors make their monthly orders at the beginning of the month). PRICE VARIATION refers to a distributor's decision to order more or less than what downstream demand requires based on the change in price. Although it is quite possible that both phenomena occur within the digital camera supply chain, there is not enough evidence to support their occurrence.

2.2.2 Supply Constraints

The bullwhip effect describes the factors that impact inventory from the demand side. Also important are constraints on product supply. These include raw material constraints, manufacturing constraints and distribution constraints. They limit Kodak's ability to produce cameras that satisfy fluctuating customer demand. To the extent that supply is constrained, inventories build up in anticipation of growing demand. It is difficult to accurately forecast demand in a rapidly growing and highly competitive industry. Hence the desire to capture more market share often results in overestimation of product demand. The anticipation stock cannot be consumed by actual customer demand.

RAW MATERIAL CONSTRAINTS come in the form of long lead times. Many raw material components (e.g. DSP chips, LCDs, memory cards) are also used to manufacture cell phones, personal handheld devices and other popular electronics products. Vendors quote long lead times and require production commitments well in advance. The production rate is therefore set by the availability of components at the outset.

MANUFACTURING CONSTRAINTS are based on equipment and labor capacity. Production equipment is usually specific to camera models. Line capacity is determined in advance of product launch. Workers also need to be trained for camera manufacturing. It will normally take a few months to add shifts to existing operations. In the short term, the production rate is constrained by the existing shift operation.

DISTRIBUTION CONSTRAINTS are generally not binding. But digital camera sales are highly concentrated around Christmas. Nearly all products are manufactured in Japan and the Far East. The heavy traffic from the world's manufacturing base to the rest of world around holiday season causes shipping delays.

All the constraints contribute to the increase of anticipation stock and lead to higher inventory costs. Section 2.4 analyzes system stock levels in more detail. Chapter 3 introduces methods for capacity planning.

2.3 Pull System with Decoupling Inventory

To combat the bullwhip effect, inventory should be used as safety stock to maintain customer satisfaction amid uncertain demand. Instead of allowing inventory buildup as a result of supply chain dynamics, Kodak can actively manage the inventory in the system to serve specific goals.

A pull replenishment system defines the interaction between different stages in a supply chain. At each stage, the buyer pulls products from the supplier. When customers enter retail stores to purchase cameras, items are pulled from retail inventories. Then the retailers pull from the distributor to replenish the consumed products, triggering the upper stage replenishment processes. As long as the inventory levels are always enough to satisfy downstream demand over the next period, each stage can just order the amount consumed in the last period. Thus the end customer demand signals will propagate through the supply chain without distortion, as opposed to the bullwhip effect.

The purpose of decoupling inventory is to isolate a stage from demand variation. Each stage will always order from its upstream suppliers the same amount as orders placed on it, hence no amplification of demand variation. The stage continues to ship from the inventory stock buffer while waiting to be replenished by upstream vendors. The decoupling stock approach takes into consideration the overall demand process (i.e. the mean demand rate and the demand variation) and sizes the buffer to handle the uncertainty in demand.

Using the pull system and decoupling inventory buffers, companies can alleviate the bullwhip effect. Inventories in the pull system are used as investment against uncertainty. The following sections present the quantitative analysis of this approach.

2.4 The Base Stock Model

Although the actual inventories in a supply chain with a pull system will depend on the specific implementation of the policy, some theoretical models can be used to estimate to expected inventories in the chain. Here I use the Base Stock Model summarized by Graves (1988).[1] Detailed explanation of the concept is included in Silver and Peterson (1985).[2]

The Base Stock Model has two major assumptions:

- Lead time is fixed.
- Demand is a time independent, identically distributed (i.i.d.) random process with a known distribution (which we will assume is normal).

Neither of these assumptions is very well satisfied by the digital camera problem I analyze. Lead time varies with respect to the demand/supply ratio and seasonality. By using a reasonable upper bound for the lead time I can estimate the maximum required inventory levels. Digital camera demands vary through time with high peaks around Christmas time. In the analysis using the Base Stock Model, I assume that the Christmas peak will be handled through other management means.

---

[1] Graves, Stephen C. "Safety Stocks in Manufacturing Systems" Journal of Manufacturing and Operations Management, 1988, Vol. 1, No. 1, 67-101

[2] Silver, E.A., and R. Peterson, "Decision Systems for Inventory Management and Production Planning", 1985, 2nd Edition, New York: John Wiley & Sons

To the extent that there are still timing patterns of demand (e.g. ramp-up and decline), treating them as random signals will overestimate the variance and hence the inventory. I conclude that analysis using the Base Stock Model will provide good estimate of expected inventory for operation in normal season.

A form of simple base stock formula is:

$$B_i = \mu_D * (S_{i-1} + L_i - S_i) + k * \sigma_D * \sqrt{S_{i-1} + L_i - S_i} \qquad (1)$$

Where: B_i = Base stock at stage i, includes pipeline stock and safety stock

μ_D = single period mean demand

σ_D = single period standard deviation of demand

S_{i-1} = service time quoted by stage i-1 to stage i

L_i = production lead time at stage i

k = customer service level factor, 1.65 represents 95% satisfaction level

Base stock at each stage is set to cover the downstream demand while waiting to be replenished by the upstream suppliers and complete production at this stage. Intuitively, when an order is received at stage i, it waits S_{i-1} periods to get the parts from suppliers. Stage i then uses L_i periods to complete production of the order. Shipments against the order will occur S_i periods after receiving the order. Base stock will therefore be used to ship against orders during the time up to $S_{i-1} + L_i - S_i$ periods.

It is useful to conceptually break the base stock inventory into its two components. Pipeline stock is equal to $\mu_d *(S_{i-1} + L_i - S_i)$, which is the mean demand during the period orders are covered by base stock. Safety stock is equal to $\sigma_d *\text{sqrt}(S_{i-1} + L_i - S_i)$, which represents the variation in demand during the same period.

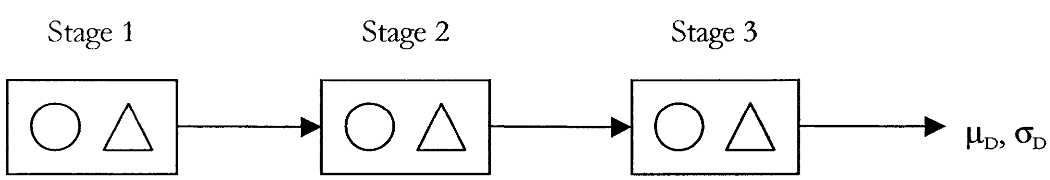
When considering a multi-stage supply chain, the base stock in the system is the sum of base stocks at all stages. For example, the base stock for the three-stage supply chain in **Figure 2.4** is:

$$
B = B_1 + B_2 + B_3 = \begin{array}{l} \mu_D * (S_0 + L_1 - S_1) + \sigma_D * \sqrt{S_0 + L_1 - S_1} + \\ \mu_D * (S_1 + L_2 - S_2) + \sigma_D * \sqrt{S_1 + L_2 - S_2} + \\ \mu_D * (S_2 + L_3 - S_3) + \sigma_D * \sqrt{S_2 + L_3 - S_3} \end{array}
$$

$$
B = \mu_D * (S_0 + L_1 + L_2 + L_3 - S_3) + \sigma_D * (\sqrt{S_0 + L_1 - S_1} + \sqrt{S_1 + L_2 - S_2} + \sqrt{S_2 + L_3 - S_3}) \qquad (2)
$$

S_0 is the upstream service time to the whole supply chain. One can consider it the raw material procurement time. S_3 is the service time required by the customer. In the case of consumer demand, the required service time can be zero. Thus, pipeline stock in a multi-stage system is only dependent on the production lead time of different stages and external constraints. It is not related to the interstage service time policy. The safety stock on the other hand does depend on the interstage service time.

Figure 2.4 A Three-Stage Supply Chain



2.5 Cost Consideration in Inventory Management

The Base Stock Model and other quantitative models provide a framework for analyzing inventories in supply chains. Using these models, companies can estimate the inventory levels at different supply chain stages. Inventory management decisions are then made by trading off inventory cost with stockout cost, cost to increase manufacturing capacity, cost to reduce lead time, etc. In the case of digital cameras, it is often difficult to derive these costs precisely. The following paragraphs provide a conceptual framework for evaluating these tradeoffs.

Inventory cost includes storage cost, capital cost and obsolescence cost. Storage cost is the expense to physically keep inventory at certain stages in the supply chain (i.e. warehouse cost). Capital cost refers to the opportunity cost of capital associated with inventory investment. Obsolescence cost captures the average price erosion (e.g. forced markdown) or rework expense of inventories. In the case of Kodak digital cameras, the storage and capital cost are similar to that of other Kodak products. But the obsolescence cost is much higher due to the short life cycle and volatile demand for digital cameras.

Inventory level in a supply chain is directly related to the product stockout probability. By investing less in safety stocks, the stockout rate will increase. No supply chain design will eliminate stockout completely. Companies have to make conscious tradeoffs between the two. In the case for D&AI, stockout results in not only lost revenue but also lost future sales from the potential customer. As mentioned in Section 1.2, digital cameras are presently used as customer acquisition devices by players in the industry. Therefore stockout is especially costly.

Shortening lead time is another way to reduce inventory investment. As with Just-In-Time (JIT) manufacturing, when lead time is reduced to allow the manufacturers to start production after they receive a firm order, inventory can be reduced to a minimum. Although it is not possible to begin manufacturing the digital camera after consumer purchases one, faster but more expensive transportation methods can be used to shorten the pipeline between production and sales.

Another alternative to inventory investment is capacity enhancement. When manufacturing capacity is increased to accommodate demand upswing, the inventory requirements will be less for the same level of demand variation. In periods where demand exceeds average, if companies can use some extra capacity for production towards excess orders, safety stock requirements will decrease. Though it is hard to quantify such a tradeoff, a simple mechanism will be used in Chapter 3 to illustrate and develop an estimate. In addition, Colgan (1995) [1] presents an interesting approach to the problem.

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[1] Colgan, James, "A Business Planning Model to Access the Tradeoff Between Inventory and Capacity for a Stage 1 Manufacturing Process", LFM Master's Thesis, Sloan School of Management, 1995

In general, it is expensive to carry inventory in a digital camera supply chain because of the high cost of obsolescence. But the even higher cost of stockout forces companies to maximize product availability. Industry analysis also suggests that the digital imaging industry has a winner-take-most economy, making it essential for players to acquire customers early on. Although capacity enhancement and lead time reduction can help to reduce the inventory requirement, I conclude that it is good business practice to install safety stocks that minimize stockouts. For later analysis, I use a customer satisfaction factor k=2.32, corresponding to a 99% customer satisfaction level.

2.6 Inventory System for Digital Cameras

An inventory control system can be established using the Base Stock Model. The system requires that each stage in the supply chain have a target base stock level. Every stage examines its inventory level and expected shipments weekly and places orders to maintain the target base stock.

In calculating the expected inventory in the supply chain, I assume a pull replenishment system with decoupling inventory buffers. This system will allow the end customer demand signal to propagate up the supply chain without variation amplification.

To perform inventory analysis using the Base Stock Model, I assembled the weekly point of sales data supplied by major retailers in the United States. Demand statistics were then extracted from the data with the data for the short period around Christmas excluded.

I also made the assumption that the retail box components can be supplied within the time frame it takes to procure the camera. Therefore, only the service time quoted by the camera manufacturer enters into consideration. The service time required by the end customers is set at zero.

Figure 2.5 shows the definition of stages in my Base Stock Model Analysis. Replenishment from an upstream stage to a downstream stage is assumed to occur weekly with guaranteed service time. The service time used in the analysis is estimated based on historic observations with a bias toward its maximum. It is worth mentioning that in the situation where the supply chain is under the control of one company, interstage service time can be optimized to minimize inventory cost in the entire system. This is done through tradeoffs between carrying small quantities of expensive inventories downstream and carrying large quantities of cheap inventory upstream. Such optimization can also be realized through full collaboration between different companies in a supply chain. Graves and Willem (1995) [1] present a solution to this problem and introduce an optimization tool.

Table 2-1 summarizes the inventory analysis based on the historic demand of a particular product. The service time and production lead time assumed for each stage are also listed. The estimated base stock inventory levels for Packaging Centers, Distributors and Retailers are all significantly lower than the actual demand measured. Part of the difference results from the effect of the peak demand period since the observed data include Christmas season while the computed levels do not. However, the reduction clearly shows the potential for improving the current inventory system using the Base Stock Model.

Figure 2.5 Stages in Base Stock Model Analysis

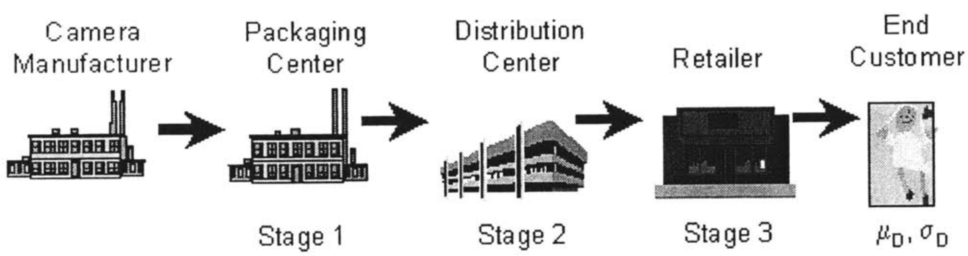


Table 2-1 Inventory Analysis Using Base Stock Model

	Retailer	Distribution Center	Packaging Center
Mean Demand		100	
Demand Standard Deviation		40	
Upstream Service Time	2	2	3
Production Lead Time	0	2	2
Downstream Service Time	0	2	2
Customer Service Factor (k)	2.3	2.3	2.3

1 Graves, Stephen C. and Sean P. Willems "Optimizing Strategic Safety Stock Placement in Supply Chains", Manufacturing & Service Operations Management, Winter 2000, Vol. 2, No. 1, pp. 68-83.

Expected Pipeline Stock	200	200	300
Expected Safety Stock	130	130	160
Expected Total Base Stock	330	330	460
Expected Total Base Stock (in weeks of Demand)	3.3*	3.3	4.6
Average Inventory Observed * (in weeks of demand)	17.8	8.9	6-8

Notes: Production Lead Time for the Packing Center is the time required to package the products and transport them to the Distribution Center.

Production Lead Time for the Distribution Center is the time required to receive the retail package and transport it to the Retailer.

It is not practical to achieve the theoretical base stock level for retailers. Large retailers have many stores. Individual stores may only sell 1-2 cameras per month, yet they will need to carry at least 3-4 cameras to deal with sudden demand surge. A more realistic estimate will be 2-3 times the theoretical base stock level. In later analysis, I will use a target stock of 8 weeks.

The average inventory observed for Distribution Centers and Retailers are computed based on the weekly data reported. The average inventory for Packaging Centers is based on various Kodak internal estimates. All these data include the Christmas period.

Using the same set of historic data, I also performed a simulation of a specific implementation of the Base Stock Model. Again, historic weekly retailer sales for one camera model were used as proxies for the product's end-customer demand. In this simulation, all stages were initially set to have the target base stocks. A pull system was used for the simulation. Products consumed at the retail stage were restocked using the inventories at the distributors, triggering the replenishment process of upstream stages. Unsatisfied demands were backordered. **Table 2-2** shows the resulting stock out frequency and average safety stocks. These also show promising improvement over existing conditions. Detailed analysis on multiple camera products is presented in **Appendix A**.

Table 2-2 Simulation of Base Stock Model

	Retailer	Distribution Center	Packaging Center
Stock Out Frequency	1.92%	1.92%	7.69%
Average Safety Stock (in weeks of demand)	1.3	1.3	1.7

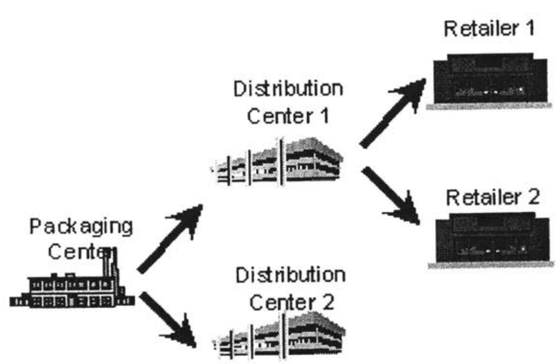
2.7 Benefit of a Pull Replenishment System Using Base Stock Model

In Section 2.6, I analyzed the pull replenish system using Base Stock Model for one camera model. In this particular example, the new inventory policy can potentially reduce inventory by up to 15 weeks at retailers and distributors, and by up to 3 weeks at packaging centers. The inventory reduction at retailers and distributors reflects over 50% saving in price erosion costs. The inventory reduction at the packaging centers reflects up to 30% saving in carrying cost at Kodak packaging facilities.

The significant saving results from changing the push system to a pull system. The existing inventory management is constrained by the push system. Inventories accumulate in the supply chain as a result of a discrepancy between planned production and end-customer demand. The pull replenishment system much more rapidly links the end-customer demand with all upstream suppliers. The Base Stock Model sets inventory buffer levels to handle overall demand variation.

My analysis uses a simplified serial model shown in **Figure 2.5**. The actual supply chain networks have more branches as illustrated in **Figure 2.6**. The simple serial model analyzes one branch in the network. To the extent that one distributor serves multiple retailers, there can be inventory pooling at the distributor (i.e. the variation of aggregated demand will be smaller than that for single retailer, therefore less inventory required). The same is true for the packaging center. Therefore, my analysis underestimates the saving.

Figure 2.6 Supply Chain Networks



3 Capacity Planning and Demand Forecasting

Capacity planning and demand forecasting are important to the performance of the digital camera supply chain. Capacities at different stages of the supply chain limit the output rates. Mismatches between capacity and demand characteristics lead to long lead time and excess inventory. Accurate demand forecasting provides guidelines in capacity planning.

In this chapter, I will present a method for determining the capacity requirement for a manufacturing stage based on the demand characteristics. Analysis of the tradeoffs between capacity and inventory will be given. I will also show that demand forecasting for the Christmas season can help in making decisions about additional shift operations.

3.1 Current Capacity Planning Process

Capacity planning for digital cameras includes planning for manufacturing capacity and packaging capacity. Both long-term and short-term planning are needed for camera manufacturing and packaging to minimize production lead time and ensure the efficient utilization of capacity.

3.1.1 Manufacturing Capacity Planning

Camera manufacturing is product specific. Before product launch, D&AI works with the camera manufacturer to secure manufacturing capacity. This will include the purchase of equipment and long-lead-time components, as well as hiring a labor force. The available labor force sets the limit for the short-term production rate while equipment capacity sets the limit for the long-term production rate. As camera components can have lead times up to 12 months, the availability of components sometimes also becomes a binding constraint.

Once production is started on a particular product, the output rate remains fairly constant throughout the life of the product. The contract between Kodak and the camera manufacturer usually requires that the production rate remain unchanged for the period of a month and this rate can be changed by 10%-20% from month to month. When a product approaches the end of its life, the production line will be shut down and Kodak sells the remaining inventories.

3.1.2 Packaging Capacity Planning

Packaging is a manual process of putting items into the camera retail box. With all items available, packaging capacity is determined by the available labor force. Camera products can be packaged either by the manufacturer or by Kodak's packaging facilities in various sales regions. In both cases, D&AI determines the percentage split of different retail configurations of the same camera bodies according to the demand in different regions.

If the manufacturers are responsible for the packaging, they will require advance notices for the breakup of each batch of cameras into different configurations. Such notices are generally expected shortly before the completion of camera production. The manufacturers' ability to produce the specific configuration depends on the availability of the required accessory items. They are also sometimes reluctant to add new configurations to the existing mix. The packaging capacity is usually not a constraint since the manufacturer has a fixed production schedules and plans to package all the camera products.

If the cameras are packaged by the regional facilities, Kodak determines the division of shipping destinations for each batch of cameras. The camera bodies are shipped to the region and packaged into various configurations sold in that region. Each packaging facility plans the capacity according to estimates of the overall demand in that region. Since market conditions can change rapidly from region to region, temporary work forces are often used to allow flexibility.

When the aggregate orders in all the regions exceed camera production, the product is on allocation. The division of cameras between regions and configurations is decided according to actual sell through, marketing needs, and other factors. When camera production exceeds overall demand, excess products are shipped to certain packaging facilities either in camera-body form or in a popular configuration. Manufacturers usually do not keep finished goods inventories.

3.1.3 Effects of the Planning Process

The planning process described above is a push system where the production schedule controls the flow of the products in the supply chain. Since the production rate can only be loosely linked with overall demand (i.e. on a month-to-month base), coupled with the bullwhip effect in the other parts of the supply chain, the possibility of underproduction or overproduction is very high.

When demand exceeds supply, Kodak loses potential sales. . When supply exceeds demand, Kodak needs to estimate the future demand in different regions and allocate products accordingly. Imperfect estimation will cause some cameras to be packaged or shipped a second time before reaching their final sales destination, adding cost to the product.

Most importantly, the mismatch between demand and supply results in inventory accumulation in the supply chains. When supply exceeds demand, products accumulate at various places in the supply chain. When demand exceeds supply at the manufacturing stage, downstream stages observe longer lead times. They increase their safety stocks as a result. Longer lead times also increase the amplification of demand variation in the bullwhip effect, which also leads to more safety stock investment. Therefore, short periods of product rationing will trigger the bullwhip effect and raise inventory levels in the long run.

3.2 Capacity Planning Based on Demand Variability

Alternatively, manufacturing capacity can be determined based on both average demand and demand variation. If the production rate can be altered more frequently and in a wider range, Kodak can continuously change the production rate such that it closely matches the demand, avoiding the above mentioned problems. However, manufacturing flexibility comes at a price due to the low utilization of equipment and labor. In deciding the level of flexibility, companies need to tradeoff cost of inventory and cost of capacity. Cost of capacity is hard to estimate for Kodak's digital cameras because of the outsourcing of manufacturing. This section will only attempt to estimate the effect of production flexibility on inventory without considering its cost.

Graves (1988) [1] provides a model for estimating the tradeoff between inventory and manufacturing flexibility. This model assumes a maximum reasonable output level, given by $\mu+\chi$ where μ is average output level, which is set to the mean demand. χ denotes the slack that is normally available at the production stage. The flexibility to change the production rate is defined by a dimensionless parameter $F = \chi/k\sigma$, where k is the service factor and σ is the standard deviation of demand. When $F<1$, the production slack in one period is not enough to accommodate demand

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[1] Graves, Stephen C. "Safety Stocks in Manufacturing Systems" Journal of Manufacturing and Operations Management, 1988, Vol. 1, No. 1, 67-101

change associated with the service factor k (k=2.3 corresponds to a probability of 99%), and production smoothing is required. The model assumes that the manufacturing system has a planned lead time of n. In each period, the production quantity is equal to 1/n of the work-in-process inventory. Smoothing is achieved at the production stage by using the work-in-process inventory to average out fluctuation in the demand process. The model gives the appropriate lead time n for a given F and the base stock inventory level as follows:

$$n = (1 + F^2) / 2F^2 \tag{3}$$

$$B = n\mu + k[n\sigma / \sqrt{(2n-1)}] = [(1 + F^2)/2F^2][\mu + kF\sigma] \tag{4}$$

Using this model, I calculated the appropriate planned lead time n and expected base stock inventory B for the manufacturing stage based on the demand characteristic of the product presented in Section 2.6. **Table 3-1** lists the value of n and B for different flexibility factors F.

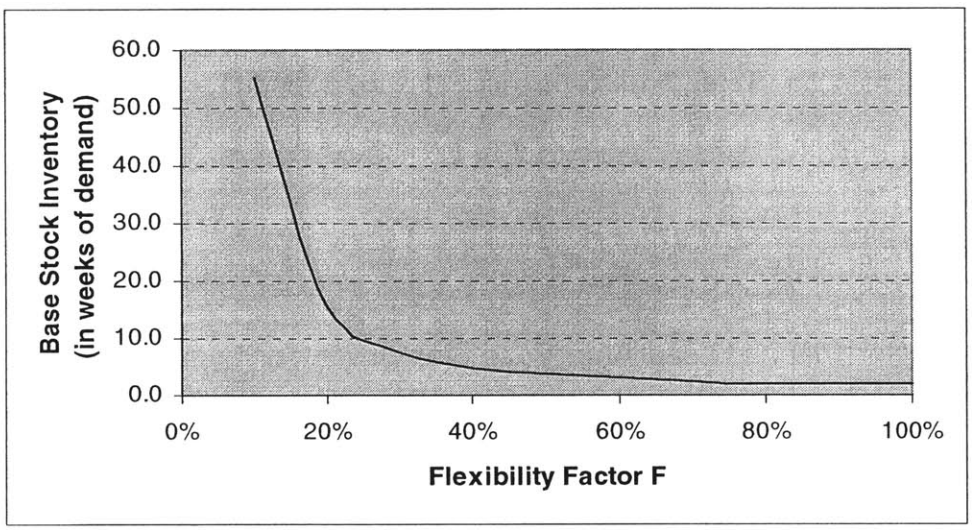
Table 3-1 Planned Lead Time and Expected Inventory for Different Flexibility Factor F
Mean Demand = 100, Standard Deviation of Demand = 40, k=2.3

Flexibility Factor (F)	Planned Lead Time (n)	Base Stock Inventory (B)	Base Stock Inventory (in weeks of demand)
10%	50.5	5516	55.2
20%	13.0	1540	15.4
30%	6.1	773	7.7
40%	3.6	496	5.0
50%	2.5	365	3.7
60%	1.9	293	2.9
70%	1.5	250	2.5
80%	1.3	223	2.2
90%	1.1	204	2.0
100%	1.0	192	1.9

The planned lead time n illustrated here is a decision variable and represents the total time that is planned for each item to spend at the production stage. The actual time may deviate from the planned lead time due to production smoothing. The actual lead times correspond closely to the planned lead time and are very reliable. In my inventory calculation in Section 2.6, I assumed a service lead time from manufacturing to packaging of 3 weeks. The required manufacturing flexibility is close to F=50%. The expected inventory is approximately 3.7 weeks.

Figure 3.1 presents the graphic relationship between the base stock inventory and flexibility factor. In considering digital camera manufacturing, one can think of F as the percentage of weekly capacity in excess of average demand. For example, F=10% means that the factory can produce up to110% of average weekly demand each week. The graph in **Figure 3.1**, along with the cost of capacity increases, can be used to make decisions about the optimal F.

Figure 3.1 Base Stock Inventory vs. Flexibility Factor
(Mean Demand/Standard Deviation of Demand=0.4, k=2.3)



3.3 Importance of Demand Forecasting

Forecasting plays a critical role in capacity planning. The current forecasting process anticipates demand up to six months into the future. The forecasts are first derived from an annual financial forecast. As the year progresses, the marketing group and regional sales groups will update the forecasts to reflect the change of market conditions in different regions. Decisions are then made to increase or decrease the manufacturing and packaging capacity.

The accuracy of demand forecasting has a major impact on the performance of the supply chain. As illustrated in Section 2.6, inventories in the entire supply chain network can be over eight months of demand. Even using the pull replenishment system, there will still be up to three months of inventory. Decisions about production increases or decreases have to be made months in advance, based on future demands, to avoid excess inventory or stockout conditions. Inflexible supplier contracts with the camera manufacturers and long component lead times also require better forecasting of future demands.

Demand forecasting is especially important for handling the peak demand season – the Christmas season. As innovative high-tech products, digital cameras are always great holiday gifts. As a result, retail sales for digital cameras have a large spike around Christmas. Since the demand spike is relatively short in duration and the holiday seasons poses special challenges to the supply chain (e.g. longer shipping times, manufacturing capacity constraints), it is desirable to handle the peak season through special operations. Such operations will include multiple-shift production and packaging, expediting shipments, etc. Arrangement of these operations requires significant lead times. In my calculation of inventories and capacity above, I used demand characteristics for the period excluding the six weeks around Christmas.

Demand forecasting also plays a role in product obsolescence. Knowing more about when the demand of a product is going to expire, Kodak can terminate production and let the inventories in the supply chain deplete. An immature termination of production can cost Kodak valuable market opportunity. However, to the extent that new products replace old products, the company has some control over the obsolescence of products.

The existing demand forecasting is a combination of financial forecasting and market intelligence. Rapid product innovation and intense competition in the digital camera industry result in difficulties in predicting product demand. The urge to satisfy Kodak's customer demand also leads to decisions to increase or decrease capacity according to orders received by Kodak instead of sell-through information. These decisions may be ill advised due to the bullwhip effect that delays information and amplifies demand variation.

3.4 Time Pattern of Demand

Although sell-through data are collected from many retailers (accounts for 30%-60% of total Kodak sales in US), the data are not currently used for demand forecasting! By plotting retail sales data over time, I observe highly consistent time patterns across different products. Understanding this pattern, as well as possible quantitative models, can help improve the forecast accuracy.

Figure 3.2 shows weekly retail sales of a single camera model over time. **Figure 3.3** plots the sum of retail sales for the 6-week period up to the current week. The scale of the vertical axis is altered for confidentiality. Other products show very similar patterns. In my analysis, I use these data as proxies for end-customer demand. Stockout conditions at individual retail stores may have caused me to underestimate the demand by using retail sales data. However, the data also show that total inventories at the retailers almost always significantly exceed their total sales, making the approximation a reasonable one. The following is a summary of qualitative observations about the sales patterns:

- Products have life cycles ranging from 12 to 18 months.
- Retail sales peak in Week 51 or Week 52 of the year in which the product is introduced. (This could be an artifact due to customer buying habit, marketing campaign, etc.) The demand spike for the Christmas season lasts approximately 6 weeks.
- Demand exhibits an overall-increasing trend before the Christmas peak. Although weekly demand fluctuates significantly from one period to the next, cumulative demands for multiple weeks are relatively smooth.
- Demand sharply decreases after the holiday season and bounces back to a higher level. For the period after Christmas, demand exhibits an overall-decreasing trend with periods of demand upswing possibly due to promotion.

Figure 3.2 Time Pattern of Weely Retail Sales

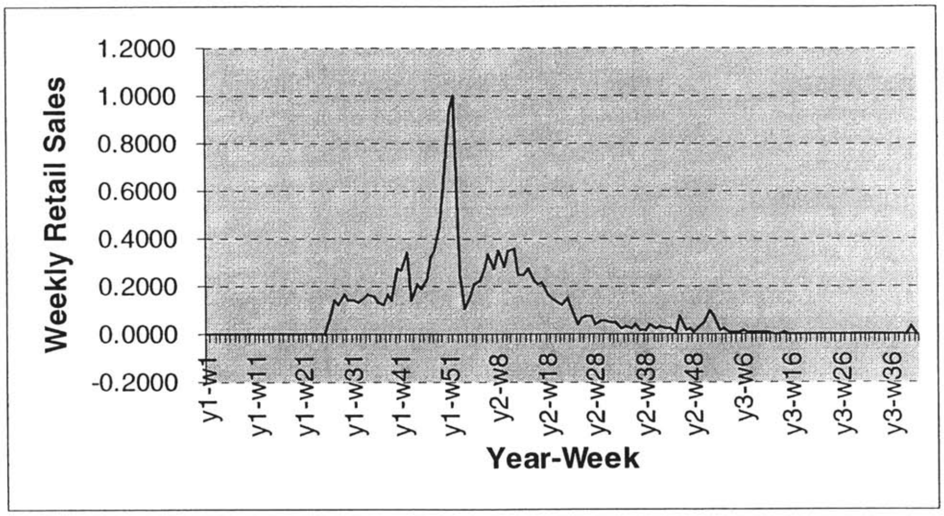
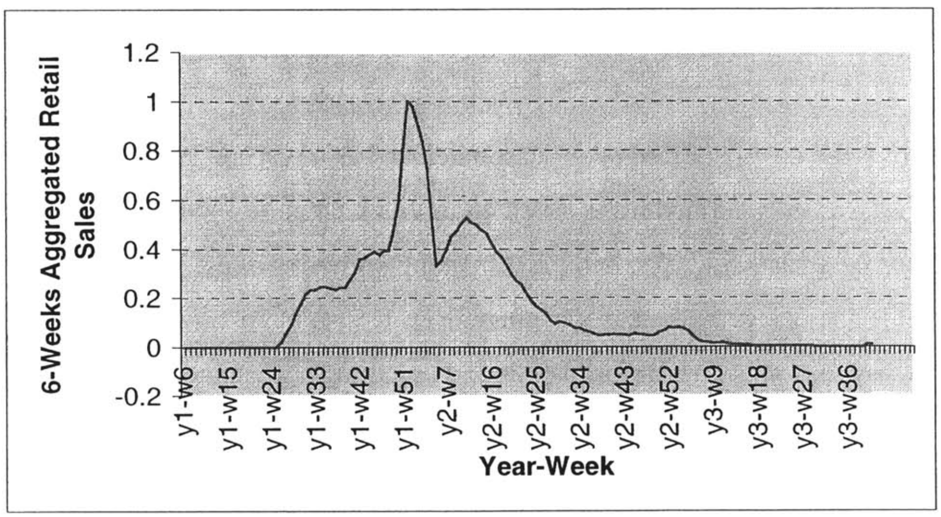


Figure 3.3 Time Pattern of 6-Week Aggregated Retail Sales



Note: The vertical axis is the total retail sales in the 6-week period until the current week. (e.g. the data point for Y1-W26 is the total retail sales from Y1-W21 to Y1-W26.)

Quantitative analysis of the demand pattern also indicated the possibility of a more systematic approach to demand forecasting and capacity planning. In particular, I quantified the demand variation property and the peak demand characteristics.

Table 3-2 shows the average weekly demand (μ_D) and the standard deviation of weekly demand (σ_D) and their relationship. I used the weekly retail sales data for six different products in my calculation. Data series are for the first year after product introduction. The six-week peak season demands are excluded. Results show that the σ_D/μ_D parameters for different products fall in a reasonable range of 39%-62%. These measures can be used to determine inventory and capacity requirements for the supply chain. In **Appendix B**, I present the analysis for base stocks and required capacities using a σ_D/μ_D range of 40%-60%.

Table 3-2 Standard Deviation over Mean Demand
(For a one-year period after product launch excluding peak season)

	Average Weekly Demand μ_D	Standard Deviation of Demand σ_D	Standard Deviation /Mean σ_D/μ_D
Product 1	5000	3119	62%
Product 2	204	82	40%
Product 3	1351	640	47%
Product 4	1052	426	41%
Product 5	1416	635	45%
Product 6	891	346	39%

Table 3-3 shows the calculation of peak season demand as a percentage of yearly demand for six products. Peak season is defined to be Week 48 to Week 53 in the year that the product is launched. This peak lasts 6 weeks, and the remaining 46 weeks of the year are defined to be the regular season. The percentage measures range from 18%-28%. Knowing the percentage demand for the Christmas season is crucial for planning. For example, if annual financial forecasting expects 10,000 unit sales on a camera product, combined with a 25% estimated percentage for the 6-week peak season, the implied average demand rate is 10,000*(1-25%)/(52-6) = 163 cameras per week for the rest of the year. The average weekly demand in Christmas season is 10,000*25%/6 = 417 cameras. These are important planning parameters.

Table 3-3 Total Demand in Peak Season vs. Total Demand in the First Year

	Total Demand for Peak Season	Total Demand for the Year	Percentage of Yearly Demand in Peak Season
Product 1	51474	281474	18%
Product 2	3690	13053	28%
Product 3	22731	84883	27%
Product 4	17317	65703	26%
Product 5	15996	81130	20%
Product 6	11307	52314	22%

Table 3-4 compares the peak and non-peak demand. For example, 2.0 weeks of excess demand means that the average weekly demand for the Christmas season is three times that for the regular season. The excess demand numbers are good indications of the required overtime production for peak season. Assume that the factory capacity of one shift corresponds to the average demand of the regular season. A 2-week excess demand for the Christmas season requires extra production that equals 12 weeks of regular season demand. It can be completed by running two extra shifts if the production lead time is 6 weeks, or by running one extra shift if the production lead time is 12 weeks.

Table 3-4 Average Weekly Demands in Peak Season vs. Rest of the Year

	Average Weekly Demand (Peak Season)	Average Weekly Demand (Regular Season)	Excess Demand (in weeks of non-peak demand)
Product 1	8579	5000	0.7
Product 2	615	204	2.0
Product 3	3789	1351	1.8
Product 4	2886	1052	1.7
Product 5	2666	1416	0.9
Product 6	1885	891	1.1

3.5 Forecasting of Peak Season Demand

The quantitative analysis in Section 3.4 provides the general characteristics of the demand process. In this section, I will explore the possibility of better forecasting of demand. In particular, I introduce a method for forecasting the cumulative demand for the 6-week peak season (from week 48 to week 53).

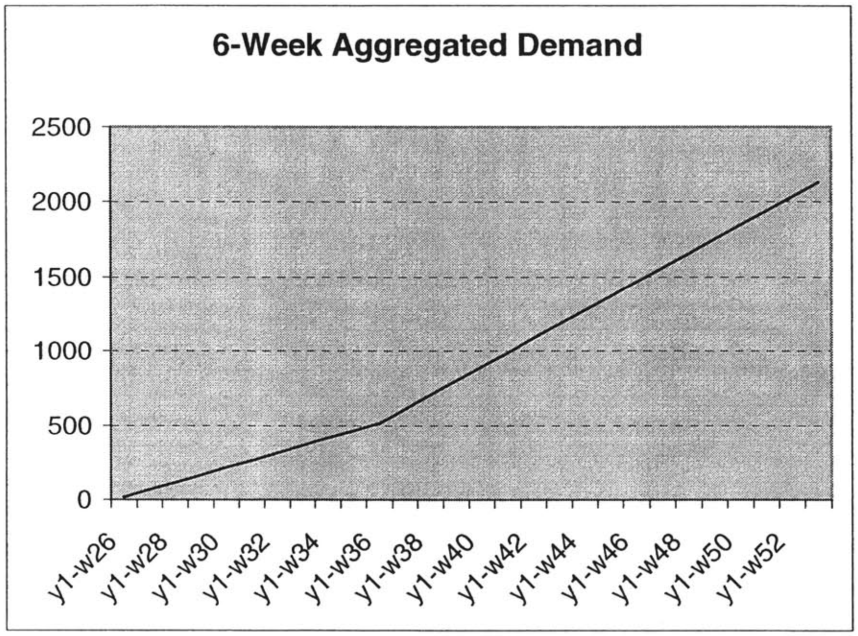
The following observation from multiple demand patterns is the basis for my forecasting method:

- Starting in Week 48, the retail sales sharply increase. Retail sales usually peak in Week 52 and sharply decrease in Week 53. After Week 53, sales volume bounces back to a normal level. I define Week 48-53 to be the Christmas season.

- After initial product introduction, average demand increases from week to week. The increase accelerates approaching Christmas season.

I assumed a simple pattern of two linear ramps for demand prediction as shown in **Figure 3.4**.

Figure 3.4 Model for 6-Week Aggregated Demand Forecasting



To accommodate longer distribution times and lead times for adding manufacturing capacity, I attempted to forecast the total demand for the 6-week peak season in Week 36 (12 weeks prior to the beginning of the peak season). Historic data for 6-week aggregated demands are used for the forecast. The forecasting model is developed as follows:

1. Perform linear regression to obtain the slope of increase (S1) until Week 36.
2. Assume a slope of increase equaling S2=C*S1 for Week 36 – Week 53.
3. Predict the cumulative demand of Week 48 – Week 53 using S2 and the cumulative demand of Week 31- Week 36.
4. Use the same C to predict the cumulative demands for different products.

5. Choose C to minimize mean square error of prediction for all products.

Data for four different products are used in this analysis with optimal C=1.9. For practical purposes one can use C=2, which simply means that the slope doubles after Week 36. Knowing C, Step 1-3 can be followed to predict cumulative demand of Week 48 to Week 53 in Week 36. The result is shown in **Table 3-5** with reasonable error range of 1% - 21%. See **Appendix C** for detailed computations.

Table 3-5 Forecast Results for Total Peak Season Demand

	Product 1	Product 2	Product 3	Product 4
Actual Total Demand (Wk 48-53)	3690	22731	17317	15996
Predicted Total Demand (Wk 48-53)	3722	18066	19830	16802
Prediction Error	1%	21%	15%	5%

3.6 Indications from the Demand Pattern

The analysis of demand patterns illustrates similarity among different products. These general characteristics can help Kodak in making decisions about supply chains. In particular, demand variation, peak season characteristics, and the ability to predict peak season demand early on add tremendous value for management decision making.

The retail demand patterns for digital cameras are not just random noises. Different demand periods (i.e. pre-Christmas, Christmas peak, post-Christmas) have different trends. The general demand properties and trends in these periods can help the company to make proper decisions. The Christmas peak season, due to its large percentage volume, usually stretches the capability of different stages in the supply chain. The ability to forecast the total peak season months in advance will help alleviate some of the operation difficulties.

Although the time patterns of retail demand shows consistency across various products, the bullwhip effect is likely to destroy such patterns in upstream demands as proven by historic data. Therefore, close monitoring of the retail demand data is extremely important.

4 Supply Chain Management for Digital Cameras

The digital camera supply chain consists of camera manufacturers, packaging facilities, distribution sites, and retail stores. Effective management of such a supply chain requires the cooperation of all players. Because the supply chain expands beyond Kodak's corporate boundary, a collaborative effort is needed for establishing an optimal supply chain strategy.

Internally, the different business units within Kodak have different supply chain objectives. To the extent there are shared resources, the existing procedures may be at odds with D&AI's business goals. The company's financial condition may also present special challenges, pressuring D&AI to make sub-optimal decisions. Therefore, it is essential for D&AI to manage according to the principles of a responsive supply chain.

This chapter introduces frameworks and concepts that can be used for the supply chain reengineering effort.

4.1 Replacing the Push System with a Pull System

The existing digital camera supply chain can be characterized as a push system. Manufacturers make long-term production plans at the outset of product introduction. These plans usually incorporate steady output rates, allowing only slow changes. At the other end of the supply chain, retail demands fluctuate considerably from week to week. In this process, the manufacturers push products into the supply chain at one end; the customers take product out at the other end. The mismatch between input and output rates results in excess inventory or stockout, both undesirable outcomes.

In a pull system, consumer purchases trigger supply chain reactions. Each period, retail stores order from distribution centers the amount of cameras consumed in the last period. The distribution centers then order the same amount from packaging facilities, and the retail demand signal continues to move upstream. If rapid response is needed from one stage to another, safety stock is used to satisfy demand while the stage waits to be replenished. The whole pull system marches at the beat of the demand signal. A pull system implementation has the following advantages:

- The supply chain can respond quickly to market changes since the end-customer demand signal moves up the supply chain without significant delay. With current information technology, it is possible to make the retail sales data available to all supply stages immediately, allowing them to anticipate downstream demand and plan for it.

- Appropriate inventory levels in a pull system can be calculated based on demand variation, service times and customer satisfaction levels. Companies can make conscious decisions about the tradeoffs between these variables.

- A pull system is a good remedy for the bullwhip effect since the same demand signal travels through the supply chain.

However, the successful implementation of a pull system puts certain requirements on the supply chain stages. The requirements include:

- Reliable service lead times

- Sufficient capacity to handle demand variation

- Different contract terms between Kodak and the subcontractors to allow flexible manufacturing

- Processes and infrastructures to allow communication of the demand signal

In summary, a pull system can improve the supply chain performance for digital cameras. Implementing it will require changes to existing processes and collaborative relationships with other players. See **Appendix A** for a step-by-step description of the operation of a pull system.

4.2 An Integrated Supply Chain Approach

Many problems in a supply chain result from the fact that each stage makes decisions according to its local needs, and without adequate information from other stages. Such decisions can adversely affect the performance of other stages, and more importantly, the overall performance of the supply chain. An integrated supply chain requires the partnership of all stages. Decision making in such a supply chain will take into account needs and constraints of various players and attempts to optimize the overall system performance.

Kodak's digital camera supply chain can benefit considerably from an integrated strategy. Since Kodak sits in the middle of the supply chain, it can easily be blind-sided by changes in supply and demand conditions. Integration will help the information flow. Kodak's ability to sell digital cameras is largely constrained by the manufacturers' ability to supply them and the distributors' ability to deliver them. An integrated strategy will minimize the mismatch between supply and demand.

Based on Kodak's existing relationship with manufacturers, distributors, and retailers, I propose three stages of the integrated supply chain implementation:

1. Kodak should setup systems to obtain sales and inventory information from distributors and retailers periodically. There is already partial implementation of the system in US. Kodak can use these data as indications for market movement and constantly update the manufacturers about changes. This allows both the manufacturers and Kodak to improve planning. Historical data show that, on average, demand variation doubles when the signal propagates from retailer to packaging center. (i.e. σ_D/μ_D[packaging center] = $2*\sigma_D/\mu_D$[retailer]) Safety stocks and slack capacity can be reduced if end-customer demand is used for planning. See **Appendix D** for details.

2. Kodak should work with the distributors and retailers on their inventory replenishment policy to eliminate bullwhip effect. A pull system using the retail demand as pull signal can be a good target. Kodak should also negotiate with manufacturers to have more flexible terms regarding production capacity.

3. If manufacturing flexibility is sufficiently improved such that factories can handle demand variation with short lead times, Kodak could implement Vendor Managed Inventory (VMI). This will allow the company to optimize inventory placement in the whole supply chain. (Tradeoff between cost and benefit of flexible manufacturing will be discussed in next chapter.)

These three steps will move the company towards an integrated supply chain strategy. Implementation should be phased to allow adequate time for relationship building.

4.3 Using Separate Processes for Different Demand Periods

Digital camera products generally have life cycles of 12–18 months. In this short period of time, customer demand will go through a pre-Christmas season, a Christmas peak season, and a post-Christmas season. Different demand characteristics in the three periods require different supply processes.

In pre-Christmas and post-Christmas season, there is considerable weekly demand variation. Such variation can be handled using the safety stocks in the system. **Appendix B** presents the analysis of capacity and factory inventory requirement based on a range of demand variation consistent with existing products. Supply chain operation during these two periods should be a basic pull system using the Base Stock Inventory Model. Prior to product launch, capacities and inventories at different stages of the supply chain should be determined according to a generous estimate of demand rate, demand variation, and lead time. As long as the observed demand and lead time are in line with the estimate, there is no need to expedite products even if the stocks are low at certain stages. Panic reactions to occasional low stocks can be detrimental to combating the bullwhip effect. But significant change in the demand process or consistent delay of service should trigger a rebalance of the supply chain. Further improvement can be made by taking into account the systematic ramp-up and ramp-down in the two periods. Acknowledging the change in demand rate will allow Kodak to time phase inventory installment and further reduce inventory.

The Christmas peak season can have average demand three times the average for the rest of the year. Sizing factories based on peak season demand properties will lead to either excess capacity or excess inventory. But the production rates for the regular season are insufficient for Christmas demand. The season poses extra difficulties, as distribution lead times are longer around holidays. Therefore, peak-season demand in excess of the regular-season average should be handled by adding shift operations, using faster transportation, and adopting other special processes. Lead time is required for setting up the special Christmas operation. As shown in Section 3.5, the historic data of 6-week aggregated demand can be used to roughly estimate the total peak season demand 12 weeks prior. The estimates can guide the decision making for Christmas operation. However, such ability is limited by the availability of data. Products introduced close to Christmas will not enjoy the benefits of this approach, though overproduction at that time may not be too great a risk.

4.4 Supply Chain Decisions for Specific Products

Each year, Kodak launches a series of products; each has specific supply chain settings. Supply chain decisions are made prior to product launch, during the product commercialization process. Lacking the integrated supply chain approach, many decisions that impact supply chain performance are made without considering the whole system. In this section, I propose a guideline for making such decisions. The following steps can be followed to resolve supply-chain-related issues for specific products:

1. Estimate the total consumer demand in the first year using financial projections, market intelligence, etc.

2. Estimate the percentage of the yearly retail sales occurring in peak season.

3. Compute the average peak-season weekly demand and the average regular-season weekly demand. Take the ratio of the two.

4. Based on the ratio, determine the number of extra shifts required for Christmas production. Also determine a timeline for the extra shifts to be started. Decisions should be made according to the estimate of peak-season distribution lead time.

5. Estimate the demand variation for the regular season.

6. Use the average regular-season weekly demand and the demand variation to determine the factory capacity.

7. Calculate the expected inventory levels based on demand characteristics and estimated service times. In the case that different shipping modes and packaging options are available, calculate the inventory levels for all scenarios.

8. Select the appropriate shipping mode and packaging option based on inventory projection and other cost factors.

9. Setup the information flow such that retail demand data are visible to all upstream stages.

The following is an example of using the framework for specific demand characteristic, following the step numbers given above:

1. Assume the total demand in the first year is D=10,000.

2. Historic data show a range of 18% - 28% for peak season fraction of annual sales. I choose 25% percent for the analysis.

3. average peak-season weekly demand D_P = 10,000*25%/6 = 416
   average regular-season weekly demand D_R = 10,000*(1-25%)/(52-6) = 163.
   ratio between the two R_D = 416/163 = 2.6

4. The above estimate shows weekly excess demand of 1.6 times average in the peak season. It will take about 9 weeks to produce the excess demand for the 6-week peak with one extra shift. Leaving about 3 weeks for distribution, one extra shift is needed 12 weeks prior to the peak season. (Remember that it is possible to roughly estimate the peak season demand at the 12-week mark if there are enough data!)

5. Historic data show a range of 40%-60% of weekly demand. I choose 50% percent for the analysis.

6. For σ_D/μ_D = 50%, **Appendix B** shows that slack capacity of 50% (χ/μ_D = 50%) corresponds to a 3.1 week planned production lead time. The factory inventory will be 4.7 weeks of demand. Slack capacity of 50% seems appropriate in this situation.

7. Using the formulas in **Appendix B,** I can calculate the base stock inventory for σ_D/μ_D = 50% in different distribution options. The following tables show the result for two different scenarios:

With four stages in the supply chain: manufacturer, packaging center, distribution center and retailer:

	Retailer	Distribution Center	Packaging Center
Upstream Service Time	2	2	3
Production Lead Time	0	2	2
Downstream Service Time	0	2	2
Customer Service Factor (k)	2.3	2.3	2.3
Base Stock Inventory (in weeks of demand)	**3.6**	**3.6**	**5.0**

With only two stages in the supply chain: manufacturer packages the cameras and serves retailer directly:

	Retailer
Upstream Service Time	3
Production Lead Time	0
Downstream Service Time	0
Customer Service Factor (k)	2.3
Base Stock Inventory (weeks of demand)	**5.0**

5 Recommendations and Conclusion

In this chapter, I give overall recommendations based on my analysis. I present improvement opportunities using the suggested model. Finally, I give specific recommendations regarding the operational issues for implementing the target supply chain strategy.

5.1 The Target Supply Chain

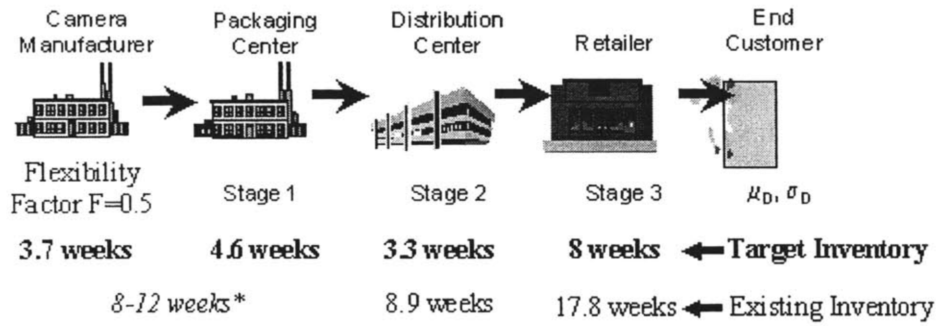
The focus of my research at Kodak was to establish a supply chain framework for digital camera products. The optimal supply chain should be responsive, flexible, cost effective and consistent with business objectives.

I propose a pull system using the Base Stock Inventory Model for the regular season fulfillment. Such a system closely couples supply chain stages with end-customer demand, allowing quicker reaction to changes in market conditions. Safety stocks are used in the system to combat demand variation and improve customer satisfaction. These interstage inventories allow reliable service time from one stage to another. Slack capacity of up to 50% average demand is suggested for camera manufacturers to offer reasonable service time to the downstream stages. A 3-week service time is achievable with demand variation (σ_D/μ_D) of 40%.

I also recommend building ahead for the Christmas season. The simple forecasting method shown in Section 3.5 gives reasonable estimates of the total demand during peak season 12 weeks prior to the start of the season, providing sufficient lead times for companies to setup extra shifts for camera production.

Figure 5.1 shows the inventories in the target supply chain and the existing one. Using the new supply chain framework, inventories in the system can be reduced from 35-39 to about 20 weeks. Inventory turns can be more than doubled. Shortening the inventory pipeline in the system will greatly improve the system responsiveness.

Figure 5.1 Comparison of Existing and Target Inventories



- The combined inventory measure for manufacturers and packaging centers are from Kodak internal estimates.

5.2 Establish Close Collaboration with Retailers and Distributors

Analysis in previous chapters argues that an integrated supply chain is essential to the implementation of a pull system. In particular, end-customer demand signals have to propagate directly to upstream suppliers without amplification of demand variation (the bullwhip effect). One of the key steps towards integration is to establish collaborative relationships with retailers and distributors. Collaborations allow Kodak to access valuable demand information and influence the downstream inventory replenishment process. I propose three areas for collaboration in an attempt to improve overall supply chain performance:

- **Information Link** – Shared information systems across different stages in a supply chain enable seamless and reliable exchange of demand and inventory data. Systems can be further improved to interface with order entry, operation planning, demand forecast, and other enterprise systems. The integration with other systems will help the companies gain more operational efficiency, though implementation can be time consuming.

- **Policy Collaboration** – As shown with the bullwhip effect, inventory management, capacity planning and other types of policies at one stage of the supply chain affect the performance of other stages, hence the whole network. The ability to form consensus on a set of consistent and complementary policies will lead to significant improvement.

- **Building Trust** – Trust is the basic element in a partnership. Collaboration aims to change the behavior of sub-optimizing based on local requirements. However, only an open and trusting supply chain partnership can result in mutual gains. Therefore, building trust should be an ongoing effort.

5.3 Improve Manufacturing Flexibility

One of the big obstacles for Kodak in moving from a push system to a pull system is the manufacturing capacity constraint. The existing supply contracts only allow very slow change of production rates. This is optimum strategy for the manufacturers since it facilitates a long, steady production runs. The pull system will require a very different strategy. Although production smoothing can be used to average out demand, which results in less variation experienced by manufacturers, it is still necessary to have slack capacity on a weekly basis. In other words, production rate should be able to increase by up to 50% from the long-run average from one week to the next. The factories will not be able to enjoy steady long runs since low demand periods will force a reduction in production rates.

However, manufacturing flexibility is costly. Having slack capacity requires extra labor force and machine time. Machine time is usually not a binding constraint, especially in second and third shifts. Therefore the cost of slack capacity is mostly determined by cost of labor. Increase in labor cost should be tradeoff against saving of inventory carrying cost. For example, I assume that 20% of the cost for producing a camera is labor cost. Adding 50% slack capacity will then increase the manufacturing cost by about 10%. If this strategy reduces inventory by 4 months with an annual carrying cost of 30%, the saving is also 10% of the manufacturing cost, equivalent to added labor cost. As a result, improving manufacturing flexibility for high-material-cost, low-labor-cost camera models will yield more benefit. In the long run, manufacturing process can be improved for flexibility.

To improve manufacturing flexibility with external suppliers, Kodak needs to negotiate different types of supply contracts, giving supplier incentives to develop flexible production capability. Such incentives may include profit sharing, long-term business partnership, etc.

Alternatively, Kodak can develop its internal digital camera supplies and initiate a lean manufacturing process. This gives Kodak more control over the factories, thus greater powers to make changes in production flow. Low labor-cost production could also be investigated. Such a strategy may open more grounds for supply chain improvement.

It is essential that the manufacturing constraints be lifted to accommodate the pull system. If capacity stays flat, the supply chain will revert back to a push system.

5.4 Use Direct Ship When Appropriate

There have been various direct ship implementations within D&AI. Direct ship refers to the distribution mode where a third-party vendor picks up digital camera shipments and delivers them to Kodak customers. The shipments can originate either from a Kodak facility or from subcontractors in Far East. Various premium rates are charged based on the origin and destination. The alternative is to use Kodak's existing distribution system where digital camera shipments are consolidated with other Kodak shipments on their way to the customers. The advantage of direct ship is the reduction in distribution time. The savings range from a few days to two weeks.

Pipeline inventories are directly proportional to distribution lead time. Safety stock can also be reduced if lead time is shortened. Therefore, reducing distribution lead time will reduce inventory. But the cost of few weeks of inventory can be offset by the increase in shipping cost. To the extent that products are shipped into inventory buckets, direct ship is not always a cost saver.

On the other hand, direct ship serves other important functions:

- Direct ship shortens the information lead time and closely links the customer and the supplier.
- Direct ship provides an alternative distribution channel. It can be an easy way to expedite product delivery in special circumstances. To the extent that market volatility in the digital camera industry is attributable to planning errors, an option for speedy delivery is always valuable.

- If safety stocks are eliminated from certain stages of the supply chain, direct ship can be used to guarantee the service time.[1] This strategy is particularly attractive if direct ship permits part or all of the manufacturing to start after receiving orders for the products (The Dell Model), allowing the company to hold cheaper materials and increase flexibility.

In general, it is beneficial for D&AI to setup the infrastructure to facilitate direct ship for various products. It can be used to improve supply chain performance in certain situations.

5.5 Consolidate Camera Manufacturing and Packaging

One of the decisions to be made prior to product launch is where to package the cameras. The packaging operation is a manual process that places camera bodies and accessory items into retail boxes. Most camera manufacturers are willing to provide packaging service as part of the supply contract with extra cost. It makes packaging a simple manufacturing step, eliminating that stage entirely from the supply chain. The camera supply pipeline is therefore shortened, creating opportunities for inventory reduction. The elimination of a stage will also bring camera producers closer to their customers. The alternative is to ship camera bodies to different sales regions and perform the packaging operation there. With obvious advantages of the combined option, several concerns have prevented D&AI from fully committing to it. These include:

- Regional packaging gives local the sales group more control over the product configuration. With market conditions changing rapidly, it allows the regional sales group to have more flexibility in making changes to retail configuration.

- Identical camera bodies can be packaged in a variety of retail boxes. It is sometimes difficult for the manufacturers to manage the mix in their packaging operation. In particular, they may have trouble procuring all the accessory items and managing the inventories. As a result, they may limit the number of configurations or require a considerable lead time for selecting the configuration mix.

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[1] Remember Safety Stock = σ*sqrt($S_{i-1} + L_i - S_i$). Direct ship reduces distribution lead time L. When $S_{i-1} + L_i - S_i$ is reduced to zero, there's no need for safety stock.

- With regional packaging, common accessory items across different products enjoy inventory pooling. As the packaging operation moves to the manufacturer location associated with specific products, this benefit will go away. However, camera bodies are significantly more expensive than accessory items. Therefore the benefit of reducing camera inventories in the supply chain is likely to overweigh the lack of inventory pooling for accessory items.

In general, I propose that the company work towards a consolidated strategy. Several things can be done to alleviate some of the concerns:

- A virtual inventory management system using information technology can be established to allow Kodak to manage the inventories at manufacturing locations.

- Future retail box designs should focus on reduction in variety. Whenever possible, make retail configurations that serve multiple regions and markets.

- The retail box should be designed such that it contains camera bodies and generic accessories with space to add in configuration-specific items. Such items can be added when the specific demand materializes or after reaching the sales regions.

5.6 Organizational Recommendations

At Kodak, multiple managers: manufacturing, operations, planning, logistics, sales and marketing, have responsibilities for different parts of the supply chain. Without a clear metric to measure the overall supply chain performance, managers make decisions to optimize their functional metric. Such decisions can be detrimental to improving supply chain performance.

D&AI's organizational structure at the time was more focused on functional tasks than on product flows. By changing the organizational structure to emphasize product flow, decision making will become a collaborative effort. Different groups will better align their objectives. Since my departure, a cross-functional supply chain reengineering team has been established to improve the digital camera supply chain. Different roles associated with various stages of the product flow were identified and assigned to appropriate people. A key role was defined for a flow manager who controls the product flow.

I would further recommend that members of the reengineering team include a set of supply chain measures (i.e. total supply chain cost, product availability, etc.) in their personal performance metrics in addition to their existing ones. Sharing the same set of performance metrics will ensure collaboration.

5.7 Conclusion

As a final note, Kodak has started implementing the pull-based supply chain using principles and concepts described in this thesis. Although market conditions and demand characteristics for digital cameras may continue to change, establishing organizational process and infrastructure to facilitate supply chain improvement will be a big step towards final success. Continuous learning can then add to existing knowledge base.

Appendix A: Simulation of Base Stock Models Using Historic Data

Supply Chain Characteristics:

	Retailer	Distribution Center	Packaging Center
Mean Demand	100		
Demand Standard Deviation	40		
Upstream Service Time	2	2	3
Production Lead Time	0	2	2
Downstream Service Time	0	2	2
Customer Service Factor (k)	2.3	2.3	2.3
Expected Total Base Stock	330	330	460

Simulation Model:

Initial inventories equal to the expected base stock levels.

Demands for Y1-W48 to Y1-W53 are replaced with randomly generated data with mean=100, standard deviation = 40.

In Wi: Retail Sales = Si

In Wi+1: Retailer orders Si from distributors. Distributor ships Si. It will take two weeks to get to retailer.

In Wi+2: Distributor orders Si from packaging centers. Packaging centers ships Si. It will take two weeks to get to distributor.

In Wi+3: Distributor orders Si from factory. Factory ships Si. It will take three weeks to get to packaging center.

Simulation Table:

YR_WK	*Retail Sales*	*Retail Inventory*	*Product Shipped by Distributors*	*Distributors Inventory*	*Product Shipped by Packaging Center*	*Packaging Center Inventory*	*Product Shipped by Factory*
y1-w26	35	330		330		460	
y1-w27	72	295	35	330		460	
y1-w28	60	223	72	295	35	460	
y1-w29	82	199	60	223	72	425	35

y1-w30	70	188	82	199	60	353	72
y1-w31	72	178	70	188	82	293	60
y1-w32	66	189	72	178	70	246	82
y1-w33	75	193	66	189	72	248	70
y1-w34	80	189	75	193	66	236	72
y1-w35	78	175	80	189	75	253	66
y1-w36	64	172	78	175	80	248	75
y1-w37	61	188	64	172	78	239	80
y1-w38	82	205	61	188	64	227	78
y1-w39	72	188	82	205	61	238	64
y1-w40	136	177	72	188	82	257	61
y1-w41	131	122	136	177	72	254	82
y1-w42	167	62	131	122	136	246	72
y1-w43	71	32	167	62	131	170	136
y1-w44	104	93	71	32	167	121	131
y1-w45	94	156	104	93	71	26	167
y1-w46	114	132	94	156	104	91	71
y1-w47	160	122	114	132	94	119	104
y1-w48	106	56	160	122	114	191	94
y1-w49	125	64	106	56	160	149	114
y1-w50	65	99	125	64	106	92	160
y1-w51	227	140	65	99	125	81	106
y1-w52	69	38	227	140	65	69	125
y1-w53	103	34	69	38	227	164	65
y2-w1	53	158	103	34	69	43	227
y2-w2	77	174	53	158	103	99	69
y2-w3	102	200	77	174	53	61	103
y2-w4	111	152	102	200	77	235	53
y2-w5	133	117	111	152	102	227	77
y2-w6	163	86	133	117	111	229	102
y2-w7	137	34	163	86	133	170	111
y2-w8	172	29	137	34	163	114	133
y2-w9	138	21	172	29	137	53	163
y2-w10	171	20	138	21	172	26	137
y2-w11	177	21	171	20	138	-12	172
y2-w12	123	-18	177	21	171	13	138
y2-w13	123	30	123	-18	177	-21	171
y2-w14	137	84	123	30	123	-26	177
y2-w15	109	70	137	84	123	-11	123
y2-w16	104	83	109	70	137	37	123
y2-w17	107	117	104	83	109	77	137
y2-w18	81	120	107	117	104	90	109
y2-w19	73	142	81	120	107	110	104
y2-w20	67	176	73	142	81	140	107
y2-w21	60	190	67	176	73	169	81
y2-w22	73	204	60	190	67	199	73
y2-w23	53	197	73	204	60	239	67
y2-w24	19	204	53	197	73	260	60

Simulated Inventory and Stockout Frequencies:

	Retailers	Distributors	Packaging Centers
Expected Safety Stock	130	130	160
Average Safety Stock	132	134	172
Average Safety Stock (weeks of demand)	1.3	1.3	1.7
Stockout Frequency	1.92%	1.92%	7.69%

Stockout Frequencies for Similar Simulations:

	Retailers	Distributors	Packaging Centers
Product 1	3.85%	3.85%	5.77%
Product 2	1.92%	1.92%	3.85%
Product 3	3.85%	3.85%	7.69%
Product 4	1.92%	1.92%	1.92%
Product 5	1.92%	1.92%	3.85%

Appendix B: Base Stock and Capacity for Different Demand Variation

Base Stock Formula:

$$B_i = \mu_D * (S_{i-1} + L_i - S_i) + k * \sigma_D * \sqrt{S_{i-1} + L_i - S_i}$$

in weeks of demand:

$$B_i / \mu_D = (S_{i-1} + L_i - S_i) + k * \sigma_D / \mu_D * \sqrt{S_{i-1} + L_i - S_i}$$

Base Stock Calculation for σ_D/μ_D = 40% - 60%:

Assumptions:

	Retailer	Distribution Center	Packaging Center
Upstream Service Time	2	2	3
Production Lead Time	0	2	2
Downstream Service Time	0	2	2
Customer Service Factor (k)	2.3	2.3	2.3

Base Stock in Weeks of Demand:

	Retailers	Distributors	Packaging Centers
σ_D/μ_D = 40%	3.3	3.3	4.6
σ_D/μ_D = 45%	3.5	3.5	4.8
σ_D/μ_D = 50%	3.6	3.6	5.0
σ_D/μ_D = 55%	3.8	3.8	5.2
σ_D/μ_D = 60%	4.0	4.0	5.4

Capacity Formulas:

$$F = \frac{\chi}{k\sigma_D} = \frac{\chi}{\mu_D} \cdot \frac{1}{k} \cdot \frac{\mu_D}{\sigma_D}$$

$$n = (1 + F^2) / 2F^2$$

$$B = n\mu_D + k[n\sigma_D / \sqrt{(2n-1)}]$$

In weeks of demand:

$$B / \mu_D = n + k[n\sigma_D / \mu_D / \sqrt{(2n-1)}]$$

Calculation of Planned Lead Time n (in weeks):

	$\chi/\mu_D = 25\%$	$\chi/\mu_D = 50\%$	$\chi/\mu_D = 75\%$
$\sigma_D/\mu_D = 40\%$	7.3	***2.2***	1.3
$\sigma_D/\mu_D = 45\%$	9.1	***2.6***	1.5
$\sigma_D/\mu_D = 50\%$	11.1	***3.1***	1.7
$\sigma_D/\mu_D = 55\%$	13.3	***3.7***	1.9
$\sigma_D/\mu_D = 60\%$	15.7	***4.3***	2.2

Based on the required planned lead time, slack capacity of 50% is chosen.

Calculation of Factory Inventory (in weeks of demand) with Slack Capacity of 50%:

	Planned Lead Time n	Factory Inventory
$\sigma_D/\mu_D = 40\%$	2.2	3.3
$\sigma_D/\mu_D = 45\%$	2.6	4.0
$\sigma_D/\mu_D = 50\%$	3.1	4.7
$\sigma_D/\mu_D = 55\%$	3.7	5.6
$\sigma_D/\mu_D = 60\%$	4.3	6.5

Appendix C: Peak Demand Forecasting

1. Perform regression on 6-week cumulative demand vs. week number with data up to Week 36. The purpose is to find the slope. The following is a sample data series.

Week	Cumulative Demand
26	73
27	222
28	346
29	518
30	663
31	812
32	875
33	882
34	924
35	915
36	903

⇨ Slope = 87.2.

Perform the regression on all available data sets. Four sets of data were found with the following slopes for the four different products:

S1 = 87.2
S2 = 318.9
S3 = 456.5
S4 = 419.0

2. Use the last available data point for the 6-week cumulative demand (Week 31- Week 36) and a linearly scaled slope (assuming scale factor C) to predict the 6-week cumulative demand for Week 48 – Week 53.

D1(48-53) = D1(31-36) + C*S1*17 = 903 + C*87.2*17[1]
D2(48-53) = D2(31-36) + C*S2*17 = 7754 + C*318.9*17
D3(48-53) = D3(31-36) + C*S3*17 = 5068 + C*456.5*17
D4(48-53) = D4(31-36) + C*S4*17 = 2189 + C*419.0*17

1 17 is the time difference between the two demand periods: Week 31-36 and Week 48-53. Using a linear model, the predicted demand in Week 48-53 equals to the demand in Week 31-36 plus 17 times the scaled slope.

3. Determine C such that the mean square error between the prediction (above calculation) and the actual data is minimized.

=> C= 1.9

The forecasted demand for Week 48-53 is compared with the actual ones along with percentage error.

	Product 1	Product 2	Product 3	Product 4
Actual D(48-53)	3690	22731	17317	15996
Forecast for D(48-53)	**3722**	**18066**	**19830**	**16802**
Percentage Error	0.9%	20.5%	14.5%	5.0%

Similar procedure can be used to forecast peak demand for new products. For simplicity, use C=2 since we are only trying to roughly estimate the demand.

Appendix D: Benefit of Information Sharing

The following table compares the base stock inventory and slack capacity requirement for different demand variation levels using the example in Section 2.6:

	Base Stock Inventories at Packaging Center (weeks of demand)	Planned Lead Time (weeks)	Required Slack Capacity (χ/μ_D)	Factory Inventory (weeks of demand)
$\sigma_D/\mu_D = 40\%$ (retailer demand)	4.6	2.2	50%	3.3
$\sigma_D/\mu_D = 80\%$ (packaging center demand)	7.7	4.0	70%	6.7

Monitoring the demand at retailers and distributors and collaborating with them will allow Kodak to ultimately set smaller inventory buffers and use less slack capacity. Getting the demand information is the first step towards the final goal.

Bibliography

Barnett, William F., "Four Steps to Forecast Total Market Demand", Harvard Business Review, July-August 1988,

Black, Brian, "Utilizing the Principles and Implication of the Base Stock Model to Improve Supply Chain Performance", LFM Master's Thesis, Sloan School of Management, 1998

Colgan, James, "A Business Planning Model to Access the Tradeoff Between Inventory and Capacity for a Stage 1 Manufacturing Process", LFM Master's Thesis, Sloan School of Management, 1995

Coughlin, Lawrence R., "Optimization and Measurement of a World-Wide Supply Chain", LFM Master's Thesis, Sloan School of Management, 1998

"Eastman Kodak Co. – A Competitive Assessment Report" Global Industry Analysis, Inc. August 2000

"Eastman Kodak Company: Looking for Value Part 5 – Consumer Digital", Credit Suisse First Boston Equity Research Report, May 2000

Fisher, Marshall L., Hammond, Janice H., Obermeyer, Walter R., and Raman, Ananth "Making Supply Meet Demand in an Uncertain World" Harvard Business Review, May-June 1994

Fisher, Marshall L. "What is the Right Supply Chain for Your Product?" Harvard Business Review, March-April 1997

Gilpin, Bryan C. "Management of the Supply Chain in a Rapid Product Development Environment", LFM Master's Thesis, Sloan School of Management, 1995

Grave, Stephen C., "A Tactical Planning Model for a Job Shop", Operations Research 34(4): 522-33, 1986

Graves, Stephen C. "Safety Stocks in Manufacturing Systems" Journal of Manufacturing and Operations Management, 1988, Vol. 1, No. 1, 67-101

Graves, Stephen C. and Sean P. Willems "Optimizing Strategic Safety Stock Placement in Supply Chains", Manufacturing & Service Operations Management, Winter 2000, Vol. 2, No. 1, pp. 68-83.

Lee, Hau L., Billington, and Corey "Managing Supply Chain Inventory: Pitfalls and Opportunities", Sloan Management Review, Spring 1992

Lee, H. L., V. Padmanabhan, and S. Whang, "Information Distortion in s Supply Chain: The Bullwhip Effect," Management Science, Vol. 36, No. 6, June 1990, pp724-738.

Silver, E.A., and R. Peterson, "Decision Systems for Inventory Management and Production Planning", 1985, 2nd Edition, New York: John Wiley & Sons

Silver, E.A."A Tutorial on Production Smoothing and Work Force Balancing", Operations Research 15(6): 985-1010,1967

Wala, Tomasz P., "Integrating the Value Chain: A Step-by-Step Apporach for Creating a World-Class Supply Chain for Kodak Professional Digital Cameras", LFM Master's Thesis, Sloan School of Management, 1999

Wheeler Daniel, H., "Pulling a Job Shop into Supply Chain Management", LFM Master's Thesis, Sloan School of Management, 2000