

Lean Principles Applied to a Supply Chain with Demand Uncertainty

by

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and

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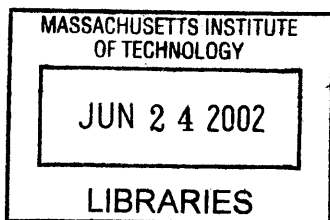
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Abstract

This thesis describes the work performed over a six and a half month internship at Eastman Kodak Company in Rochester, NY. The thesis focuses on the implementation of a lean manufacturing system, modeled after the Toyota Production System, in the Kodak color film business. The goal of the system is to systematically eliminate all forms of waste from the production process in an attempt to reduce costs and inventory.

This thesis approaches the problem from two different points of view. On the one hand, it takes a high level view of the entire supply chain and describes how material and information should flow through the supply chain. It highlights where inventory buffers should be located and which operations should be improved in order to reduce the size of these buffers. Finally, this thesis highlights the importance of leveling the customer demand signal in order to implement a true pull system using Kanbans. On the other hand, this thesis describes the implementation of lean manufacturing tools such as Kanban systems and Heijunka boards in some Kodak operations. This work includes the use of tools such as visual signals, cellular manufacturing, Kanbans, Heijunka boards, etc.

The work performed over the internship sets the foundation for the transformation of the Kodak supply chain into a lean supply chain capable of dealing with uncertain demand. Additionally, the work can easily be transferred and applied to other Kodak businesses such as paper and photochemicals.

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1. Introduction and Overview

1.1. Company Background and Business Challenges

In 1880 George Eastman began commercial manufacturing of dry plates. From this original venture, of which Eastman was the sole proprietor, evolved Eastman Kodak Company. For the reader interested in the history of the company, Collins (1990) tells the story of Kodak in great detail. Over its 120 year history, Kodak has evolved into a multi-billion dollar, multinational company whose name is recognized all over the world. This thesis will focus on the color film business. Specifically, it will focus on how Kodak is dealing with a rapidly changing economic environment and the emergence of a disruptive technology.

1.1.1. Evolution of the Color Film Business

The color film business presents an excellent example of an industry going through a

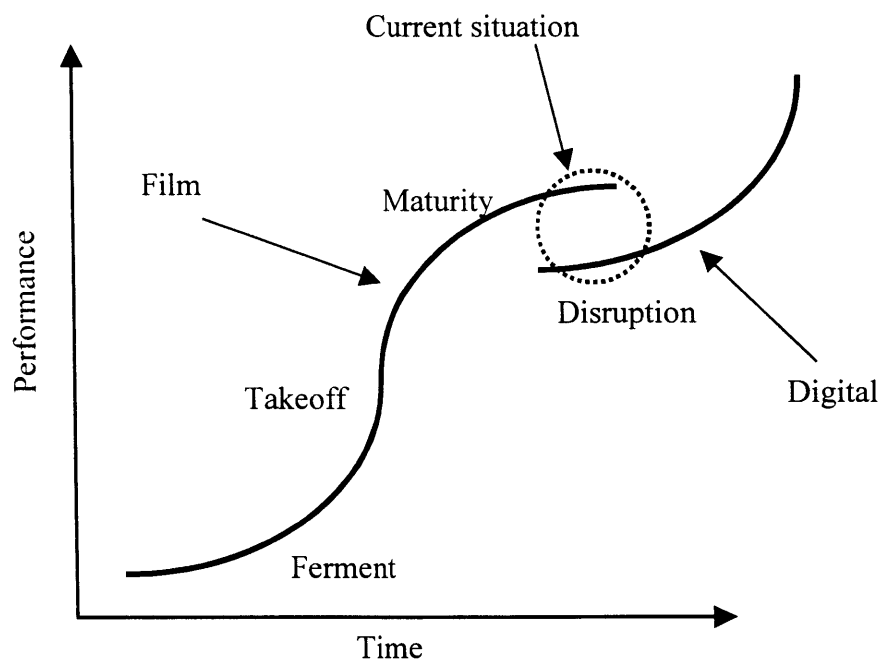


Figure 1: Evolution of the Color Film Business

complete life cycle (Figure 1). In the 20th and 21st centuries, the film industry has gone through various stages: from periods of ferment when it was an expensive and exclusive

product, until the takeoff stage, when film started to be used by the millions of people all over the world, to maturity, when the market is no longer growing and profit margins are shrinking. Additionally, while color film is in a state of maturity, a disruptive technology (i.e. digital) is emerging which is threatening the very existence of this product. (Henderson, 2002)

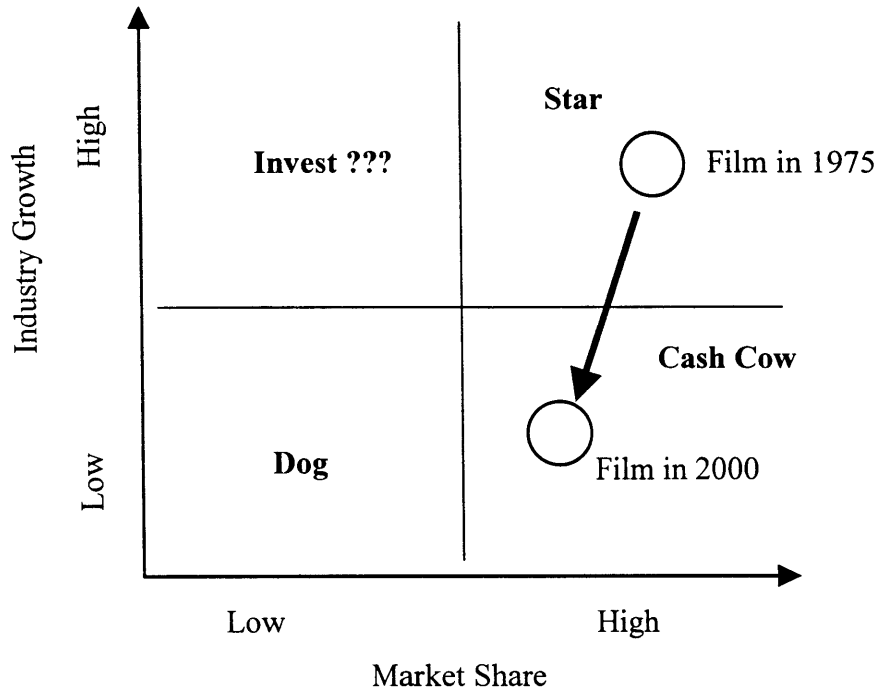


Figure 2: Growth-Share Matrix

In a similar way, we can use the BCG Growth-Share Matrix (Oster, 1999) to further understand what is happening to this business (Figure 2). In 1975 Kodak film was a “star” product. Kodak enjoyed very high market share in the US and throughout most of the world and the film business was growing. However, over the last two decades the product has slowly become more mature, growth rates have slowed and competition from Fuji has taken some market share away from Kodak. Competition from Fuji has also placed price pressure on Kodak, which has had to slowly, but constantly reduce its prices.

1.1.2. The Emergence of Large Retailers

In the 1990s, a second phenomenon brought about a major change in the film business: the emergence of large retail chains. These retailers, such as Wal-Mart and Target, are now by far the major customers in the US. This has shifted some of the market power

from Kodak to the retailers. In essence, because the retailers require additional services and significant volume discounts, Kodak profit margins are being reduced. In fact, the packaging work-center, in which film and one-time-use-cameras (OTUC) are packaged into cardboard merchandisers, exists in large part to serve retailers. This is a major additional cost for Kodak.

1.1.3. The Effect of Digital Technology

Digital technology has entered the consumer market place over the last five years. While it is clear that digital will dramatically change the business and that color film sales will eventually decline, it is difficult to exactly understand the timing and exact way this will happen. Looking back at figure 1, it is unclear how far along the maturity part of the S-curve we are for film and how far along the digital curve we are for the disruptive technology. We know reasonably well what the curves look like qualitatively but not quantitatively.

Kodak has embraced digital technology completely because Kodak realizes that the long-term future will be dominated by digital technology. Dan Palumbo, president of Kodak Consumer Imaging business, best summarizes the situation: "For Kodak, digital technology and the Internet were good news and bad news. We realized they threatened products we've been putting out for 120 years, namely film and cameras. At the same time, we understood they presented perhaps our greatest opportunity since George Eastman produced his first camera." (Palumbo, 2001)

As proof of the fact that Kodak is embracing digital technology and the Internet is the recent success of Kodak Easyshare digital cameras. Kodak has been rapidly gaining market share in digital cameras. In December 2001, 50% of major retailers listed Kodak as the best selling digital cameras. Along these lines, Kodak also acquired Ofoto, a web site that offers photo printing services. It currently has over two million members and expects double-digit yearly growth. Finally, Kodak has also been aggressively pushing printing kiosks in which customers can upload their digital images from a variety of sources and obtain prints. Over 24,000 kiosks have been installed in many large retail

chains. These activities are proof not only that Kodak understands the importance of digital technology but also that it is committed to it. (Smith and Keenan, 2002)

1.2. Lean Manufacturing

This thesis focuses on the implementation of lean manufacturing in Kodak color film manufacturing operations. The goal is to implement the Toyota Production System (TPS), which is called the Kodak Operating System(KOS) at Kodak. Clearly, there are some major differences between making automobiles and making film. However, the Toyota Production System is a way of thinking and therefore it can be applied to extremely diverse products. In an attempt to familiarize the reader with TPS and with some of the terminology associated with it, the following is a brief introduction to this production system. The reader interested in learning more about TPS should consult Ohno (1988), Shingo (1989) and Monden (1998).

1.2.1. The Toyota Production System, What is it?

The Toyota Production System (TPS) was developed over a 30-year span at Toyota Motor Company. It was created and it evolved out of the need to compete with western automobile companies whose production volumes were dramatically larger. Because of the tremendous success that Toyota Motor Company has enjoyed over the last 20 years, gaining market share in virtually every continent, many have looked at and studied Toyota to determine the roots of its success. Particularly, Toyota has made production its core competence and has consistently delivered outstanding quality products at the lowest cost. In fact, it is rumored that Toyota plans to market its manufacturing capabilities to non-car companies creating a separate manufacturing consulting business. (Drucker, 2001)

Many people have studied and attempted to copy TPS and tried to apply it to their own production system. Yet, few companies have succeeded. Because Kodak is attempting to do the same, it is useful to briefly describe why people have failed, in an attempt to understand the fundamental reasons of failure and avoid repeating them. The failure of

companies to implement TPS is particularly surprising in light of the fact that Toyota has allowed thousand of people to visit Toyota factories and see their manufacturing operations. In fact, Toyota gives public tours every day in some of its factories. So why is it so difficult to implement TPS?

There are a number of reasons why TPS is difficult to implement. Spear and Bowen (1999) write: “ ... observers confuse the tools and practices they see on their plant visits with the system itself.” This is certainly a key factor. All of the practices we routinely associate with TPS, such as Kanban or Heijunka, are just tools. They were developed because at the time they were the best way to achieve a certain objective. If Toyota could figure out a better way to achieve the goal then certainly it would stop using these tools and move on to a better solution.

So what is the ultimate goal? The goal of TPS is the elimination of waste in order to produce the highest quality product with the least resources possible. Several people, including Suzaki (1987) have identified seven types of waste:

- Overproduction: producing more than what the customer is buying
- Transportation: excessive handling and unnecessary material movement
- Defects: producing defective parts, scrapping parts, etc.
- Inventory: unnecessary holding costs, additional storage and handling costs
- Overprocessing: processing material in such a way that no value is added to it
- Waiting: workers having to sit idle because of material or machines being unavailable
- Motion: unnecessary motion by workers

Through continuous improvement, companies must work at systematically identifying and eliminating their waste. To successfully implement TPS, everybody in the organization must understand this philosophy in order to work toward the waste elimination goal. Clearly, this takes a significant amount of time and effort because the entire organization needs to be trained. This leads us to a second factor: implementing lean takes time to do it correctly. Not all companies are willing to embark in a multi-year

program that spans virtually every department in the company. This represents an additional obstacle to implementation.

A third factor that often arises and that is difficult to overcome is that in many companies lean results in job reductions. This is not the purpose of lean, but lean does increase productivity, which subsequently allows us to produce more with less. Therefore, if sales are flat or declining for extended periods of time companies have difficulty in finding areas where to re-deploy employees. So far, this has not been an issue with Toyota because their sales have slowly but constantly increased. Yet, it remains to be seen what Toyota itself will do if sales flatten for extended periods of time.

The internship project that is the basis for this thesis focused on developing a lean value stream map for the entire color film supply chain. Additionally, it focused on implementing lean on the shop floor. A number of “tools” and methods were used to achieve these goals. Following is a brief description of some of these tools.

1.2.2. Value Stream Maps

Value stream maps entail mapping out the flow of material and information along the supply chain. By looking at a value stream map, the reader can see where inventory is stored along the production flow and how each step in the production flow sends and receives information. But most importantly, value stream maps allow the reader to understand and quantify the time spent adding value to a product. For example, in a value stream map of color film, from wide-roll storage to the finished product entering distribution, the product was going through value-added time approximately 2-3% of the time. In other words, for every 100 minutes, the film was being processed 2 or 3 minutes, the remaining 97 minutes were spent in work-in-process (WIP). So for 97% of the time no value is being added to the product. Value Stream Maps allow us to see this and allow us to design a better supply chain where product will “flow.” This was a critical tool in designing the color film supply chain from a macro-perspective. Rother and Shook (1999) present details on the value stream mapping process.

1.2.3. Kaizen

At the heart of lean manufacturing are Kaizen events. A Kaizen event is best described as a short, energetic, focused effort by a team of people to solve a specific problem. In a Kaizen event a team of approximately ten people including operators and management work together for four to five days to resolve specific manufacturing problem. As an example, the team might focus on transforming a production line into a group of cells, or focus on reducing the set-up time required for a changeover on a piece of equipment. Kaizen events are at the heart of the lean culture for a number of reasons. First and foremost, independently from the results they bring people together on the shop floor to look at a process and try to improve it. Additionally, through Kaizen events a company can develop the lean culture because personnel from all departments work together at eliminating waste and understand the meaning of focusing on value-added operations. Finally, Kaizen events generally result in dramatic productivity improvements in production.

1.2.4. Heijunka

Heijunka focuses on “leveling” or “smoothing”¹ production with regards to volume and mix. This concept is fundamental to the work presented in this thesis and will be discussed in detail throughout. Leveling is a basic component of TPS, because without production smoothing it is not possible to reduce inventory and use the Kanban system. The first fundamental step is to determine total customer demand over a given period, for example one month. Subsequently, the goal is to produce the average every day to meet this quantity. For example, if we forecast that consumers will buy 22 million rolls of film in the month of May and there are 22 working days, then we must produce 1 million spools of film a day.

At this point production is smoothed in terms of quantity but not in terms of mix. If the forecast says we expect to sell 50% 400-speed film, 25% 200 speed film and 25% 800-speed then we should make 2 lots of 400 speed, 1 lot of 200 speed and 1 lot of 800 speed.

¹ The words leveling and smoothing will be used interchangeably throughout this thesis.

Then we should start over with 2 lots of 400 and on through the sequence again. This assumes the lot sizes are all the same and relatively small. This leveling is not necessary for the operation doing the leveling but for the upstream operations which will receive production signals through Kanbans and need to receive their signals as level as possible to avoid needing excess capacity or inventory to meet the needs of the downstream operation. All this will be examined in detail in the next chapter.

1.2.5. Kanbans

A Kanban is a visual signal used to communicate with the upstream operation. Generally, there are two types of Kanbans: a production Kanban and a withdrawal Kanban. A production Kanban instructs the operation to produce a certain amount of a certain product. A withdrawal Kanban requests the withdrawal of material from some kind of inventory storage location generally defined as a supermarket.

1.3. Motivation for This Work

The evolving of film from a “star” to a “cash cow” brings about changes in how the business should be managed. As growth slows significantly, and as investments must be made in new emerging technologies, it is necessary to focus on reducing costs and increasing positive cash flow. Robert Brust, Kodak Chief Financial Officer, said in a presentation to the Philadelphia Securities Association: “We see our future as a blend of the cash rich traditional products with new digital technology moving into the mix, and ultimately providing lower margined, but much higher growth business.” Managing a mature business for cash entails two things: reducing costs to maintain margins and reducing inventory to free up cash. These two objectives were at the heart of the work performed over a six and a half month internship at Eastman Kodak Company in Rochester, New York.

1.3.1. Cost and Inventory Reduction

As discussed in the previous sections, film prices have declined as a result of competition, large retailers and new disruptive technology. Consequently, Kodak must

develop a way to produce high quality, low cost film to maintain margins. To do this, Kodak formed the Kodak Operating System (KOS) office. KOS is tasked with leading the company through the implementation of lean manufacturing. Later sections will discuss in more details the fundamental concepts of lean and the tools used to achieve cost reduction. However, what is important to note is that KOS is not simply trying to help implement certain specific lean tools. On the contrary, KOS is trying to change the culture of Kodak. It is trying to systematically analyze every single part of the Kodak supply chain and eliminate waste and non-value-added operations. This is not simply a production problem, it is an enterprise wide problem. Many functions including manufacturing, planning, supply chain, customer service, sales and marketing, finance and accounting must embrace this new culture and contribute to the elimination of waste. As non-value added operations are identified and eliminated, the cost of film will decline.

KOS waste elimination initiative also leads to eliminating unnecessary inventory, which is a form of waste. This is fundamental as the film business is being managed as a “cash cow.” In fact, Kodak CFO points out that to manage for cash it is fundamental to reduce inventories, which leads to higher inventory turns, which improves cash flow. (Brust, 2001) This concept of developing a lean culture to learn how to use lean tools will be a recurring theme throughout this thesis.

1.4. History of LFM Internships in Color Film

Eastman Kodak Company and the Leaders for Manufacturing (LFM) program at MIT have been long-time partners. Several internships have been performed on the color film flow. Hetzel (1993) and Homsy (1995) observed the presence of the “Beer Game” effect on the color film supply chain at Kodak. In particular, Homsy (1995) observed the need to improve the fundamental processes across the supply chain in order to achieve cycle time and inventory reductions together with improved customer service. Subsequently, a number of projects focused on specific areas along the supply chain. Miller (1997) and Horn (2000) focused on sensitizing. Pagendarm (2000) focused on the finishing (i.e. slitting, perforating, spooling and packaging) part of the supply chain. More recently, Street (2001) and Wong (2001) focused directly on the customer and on obtaining point

of sale data. Finally, Kandare (1999) describes the efforts to convert Kodak color film supply chain from a push system to a pull system. His effort focused primarily on the work-centers, which in this thesis are referred to as “support” (i.e. acetate and Kodak Estar base). Popoola (2000) describes the implementation of lean manufacturing concepts at Kodak Canada, Inc. Kodak Canada, Inc. was the first location to implement lean within Kodak. Following all these theses in specific flow areas, this thesis takes a step back and looks once more at the entire supply chain for color film.

1.5. Thesis Overview

The work in this thesis was conducted as part of the KOS office initiative. The work focuses on two main areas. On the one side this thesis will take a macro-level look at the color film supply chain to design a lean supply chain. This will mean answering a number of basic questions such as: how should information flow through the supply chain? Where and how much inventory should be in the supply chain? Which operations in the supply chain must be improved to achieve specific cost and inventory goals?

The second area of focus will be the micro-level design of the production system and will focus on the actual implementation of the lean supply chain design. This will include issues such as how to teach lean to the workforce, how to blend lean with existing MRP/ERP systems and how to approach different business models inside the same supply chain (i.e. build-to-order vs build-to-stock).

Chapter 2 gives an overview of the color film supply chain, the product portfolio and the current state value stream map. Chapter 3 describes how the lean supply chain should be designed from a macro-level. This chapter will explain when, what and how much each operation should produce. Chapter 4 will take a more quantitative look at the lean supply chain design. It will use historical data to understand how this design will affect production throughout the supply chain and subsequently it will use a blend of forecasting and historical data to determine exactly where and how much inventory to hold. Finally, this chapter will answer a fundamental questions of what operations along the supply chain require improvements such as lot size or lead time reductions, in order to

achieve the desired inventory reductions. Chapter 5 will describe in greater detail the actual implementation of this process on the shop floor. Two different variations of the production system will be presented: one for a build-to-order business and the other for a build-to-stock business. Finally, Chapter 6 will draw some conclusions and discuss the remaining work that needs to be completed.

2. Color Film Manufacturing Supply Chain

2.1. The Color Film Supply Chain

With regards to film manufacturing, Kodak is vertically integrated. This is in part due to historical reasons and in part due to the extremely specialized nature of the manufacturing process. The color film supply chain is shown in Figure 3. As will be clear from the discussion that follows, we can generally assume that as we move upstream in the supply chain, the process becomes more capital intensive with larger lot sizes and longer lead times. Additionally, it is important to note that the chemical part of the procedure is performed in a chemical/batch process type environment. While the down stream part of the supply chain takes on the form of discrete manufacturing.

2.1.1. Emulsions

This is the “chemical” part of the supply chain where hundreds of chemicals, including light sensitive chemicals, are mixed together. The type and quantity of chemicals will determine the type of film produced and the speed of the film. This is a batch processing type of operation. It is characterized by relatively long lead times and complicated changeovers, which require cleaning of all the equipment to make sure no chemicals from the previous batch are left over. The raw chemicals are mostly supplied by outside chemical companies.

2.1.2. Sensitizing

Sensitizing is the heart of the film making business. In sensitizing, the chemicals from emulsions are coated on top of a thin plastic sheet (i.e. support). Kodak also manufactures this plastic sheet, which is generally referred to as the support. The support is manufactured in large rolls. In the sensitizing operation, a thin coating of the chemicals from emulsions is placed on the plastic sheet to form a wide-roll of film. This operation is done in a large building on multiple floors. The equipment was designed for large batches and, therefore, the changeovers are not easy and often lead to significant amounts of wasted chemicals. The entire operation takes place in the dark.

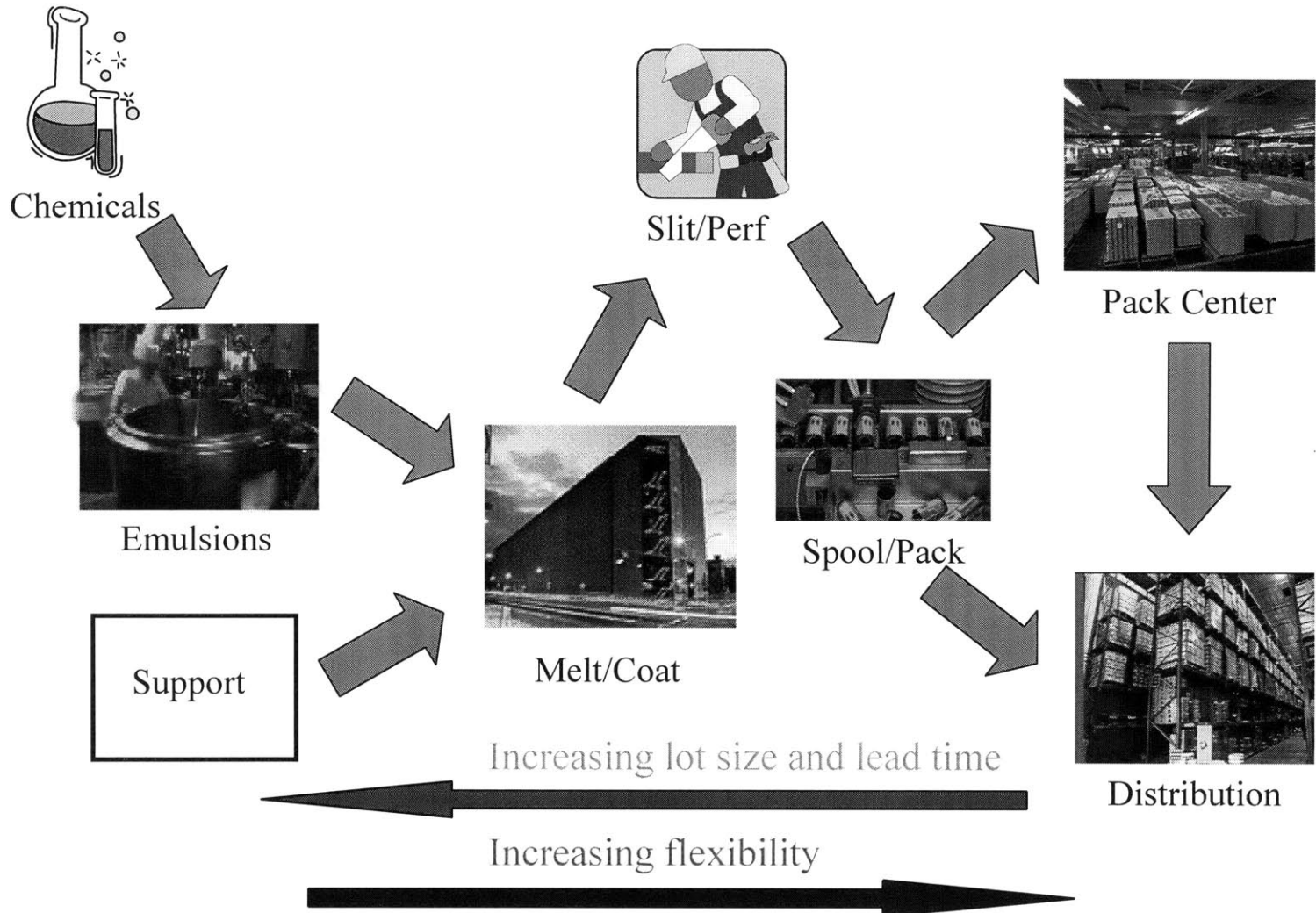


Figure 3: The Color Film Supply Chain

2.1.3. Slitting and Perforating

Once the wide-rolls are completely coated they are moved to the slitting and perforating operation. In this operation, the wide-rolls are slit into 35 mm wide rolls and the edges of the film are perforated. This operation is also conducted in the dark with automated equipment. The minimum lot size is currently one wide roll because it is not practical to slit partial rolls. Throughout the thesis this operation is referred to as slit/perf.

2.1.4. Spooling and Packaging

Once the perforated, 35 mm roll is completed it can be transferred to spooling and packaging. In this operation, the long rolls are cut into 12, 24 or 36 exposure lengths and each length is attached to a plastic spool and then enclosed in a metal case. This is now the typical roll of film that the consumer uses in their camera. At this point the spool is packaged into the appropriate packaging. Over time, the type and formats of different packages has ballooned to over 500 different configurations. Packaging can differ in quantity of spools, shape, colors on the package, special promotional logos, store specific packaging, etc. Additionally, not every piece of equipment can package every kind of product. Therefore, at this point in the flow we start to have product specific equipment. This is in general not true in the previous operations. Throughout the thesis this operation is referred to as spool/pack.

2.1.5. The Pack Center

With the emergence of large retailers, the “pack center” has gained significant importance. The “pack center” takes various types of products (i.e. 35 mm film, Advanced Photo System (APS) film, one-time-use cameras, etc.) and packages them in cardboard displays called “merchandisers. Stores place these units in the aisles, near the cash registers, etc. This is strictly a build-to-order business. No merchandisers are stored in distribution for future delivery. These merchandisers fall into three major categories: standards, towers and clips and tubes. Standards are small, stand alone display units, towers are larger displays, which typically are placed on the floor in large aisles of major

retail chains. Finally, clips and tubes are small strips with product hanging from them which can be hung anywhere in a store.

Merchandisers can contain one or more different forms of film and/or one-time-use cameras. For example, a tower might contain 200-speed film, 400-speed film and one-time-use cameras. The idea is that this is more convenient for the customer, because the merchandisers contain multiple products. Additionally, the display is very colorful and is placed in strategic locations in the retail stores to attract attention from the consumer.

2.1.6. Distribution

Most Kodak customers expect product to be available when they order it. Therefore, Kodak has an extensive warehouse and distribution system to help deliver product on time and efficiently to its customers. Almost all products, with the exception of merchandisers, are stocked in regional distribution centers (RDCs). Customer orders are shipped from the distribution center to the customer and product is re-ordered via a traditional re-order point methodology.

2.1.7. Supporting Operations

The previous sections have described the path of film along the supply chain because this is the focus of this thesis. However, there are a lot of other operations that take place at Kodak or at suppliers to support production. The most important operations are: metals, cartons, cans-caps-spools and cardboard. In metals, large sheets of metal are cut into small squares and then rolled to form the individual casing of each spool. In cartons, the graphics for all the boxes are printed on the appropriate material. In cans-caps-spools the spools for the film, the caps and the cans to store the individual rolls of film are produced. An external supplier supplies cardboard for the pack center.

2.2. The Product Portfolio in 35 mm Film

Figure 4 shows the product architecture to give the reader an idea of how the product changes along the supply chain previously described. (Homs, 1995) In essence, a large

number of chemicals are mixed and combined to form a relatively small number of film codes. Film codes differ in speed, color and general quality. One film code can then be spooled in different length spools (i.e. 24 exposure, 36 exposure, etc.). At this point the number of options balloons dramatically as there are many different ways to package film as previously described. Once in distribution, product is distinguished not only by catalog number but also by warehouse location through the use of Stock Keeping Units (SKUs).

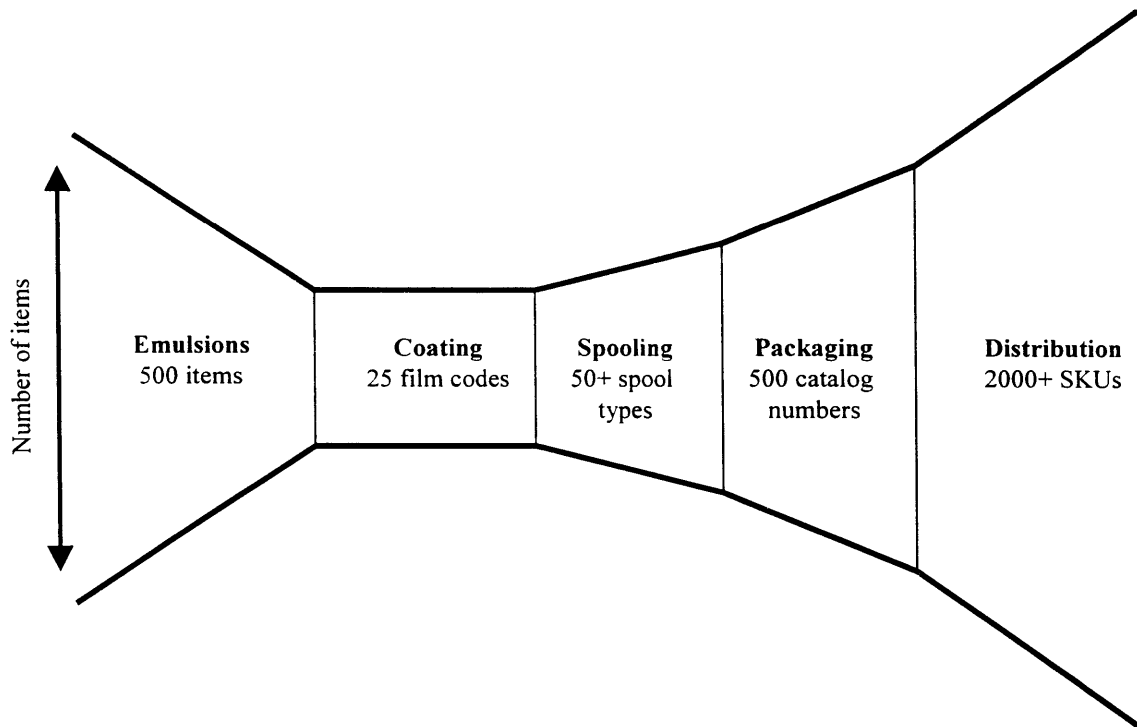


Figure 4: Product Architecture

2.3. Current State Value Stream Map

Figure 5 shows the current value stream map of the color film supply chain. Kandare (1999) describes a supply chain wide initiative entitled Integrated Demand Flow (IDF). IDF's goal was to convert the supply chain from a push system based on forecasts to a pull system based on consumption. The current state of the Kodak supply chain reflects this initiative started in late 1997. The entire supply chain is still controlled by an MRP

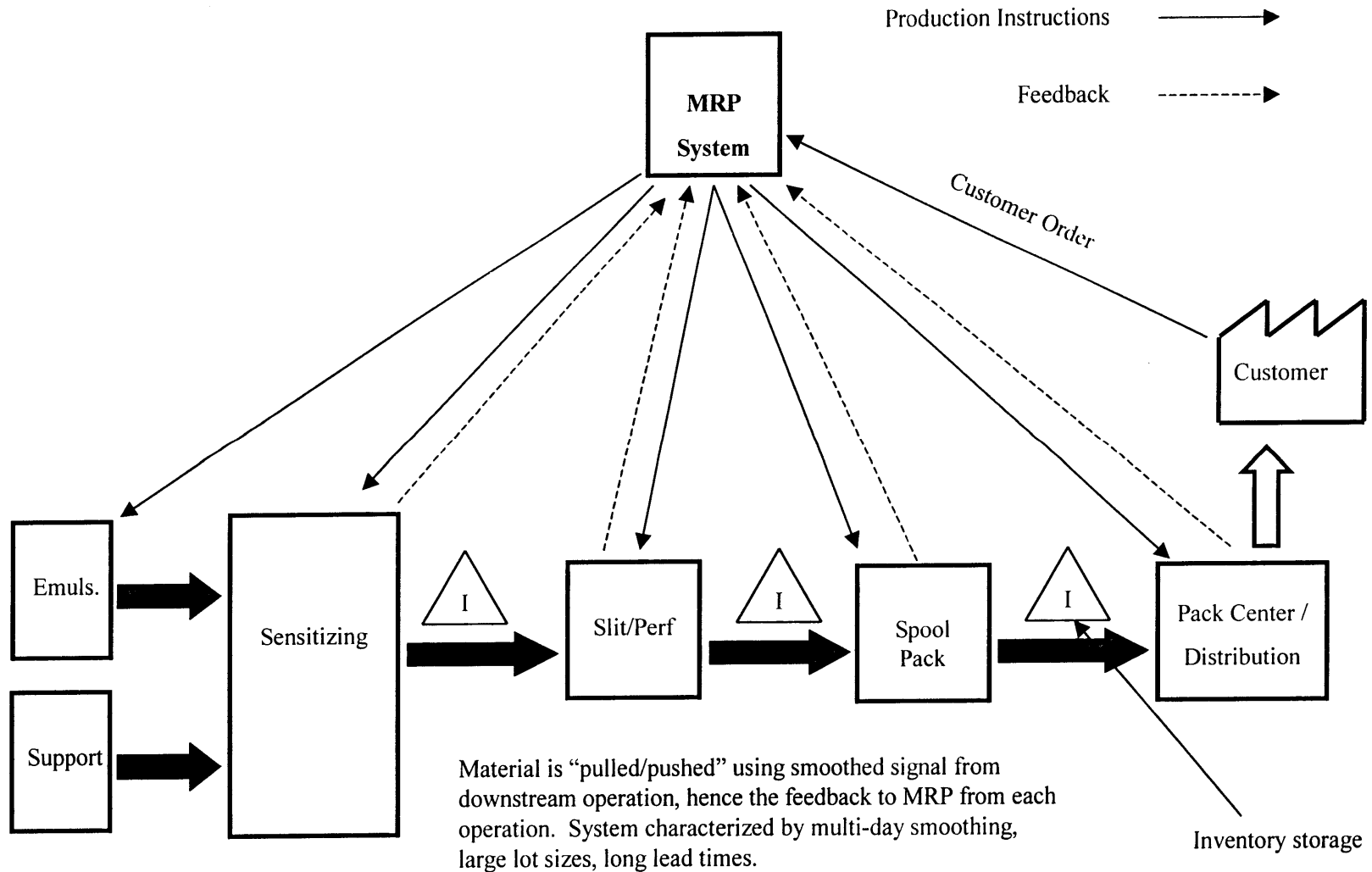


Figure 5: Current State Value Stream Map

type system. However, the signal sent upstream is not based on a forecast but based on the consumption of the downstream operation smoothed over a number of days. Therefore, it is a pull system in that the production upstream is being driven by downstream consumption, rather than by a forecast. Two important distinctions are large lot sizes and long lead times. These factors result in the presence of large amounts of Work-In-Process inventory virtually everywhere in the supply chain.

2.3.1. Characteristics of the Supply Chain: Lead Times, Lot Sizes, Etc.

In general, the supply chain is characterized by increasing lead times and lot sizes as we move upstream. Distribution is set-up to carry virtually all products so that they can be available to the customer for immediate delivery. The “pack center” is a build-to-order work-center that had a five-day lead time for most orders at the beginning of this internship. The five days were necessary to secure the materials required to assemble the merchandisers. The actual production time was rarely more than one day except for extremely large orders. Additionally, this work-center faced extremely seasonal business, particularly in certain product lines and the work force is comprised almost entirely of contract workforce. Finally, both distribution and the pack center had lot sizes of one.

Moving upstream, most of the operations in the finishing department had lead times in the order of one-day or less. Lot sizes range, depending on the products, from 8 to 16 pallets of film. The lot sizes were dictated mainly by the equipment set-up time as well as by the size of the incoming wide rolls. In particular, because the operations take place in the dark and are significantly automated, whenever a wide-roll entered slitting, the entire wide-roll was slit independent of demand.

Sensitizing posed an entirely different set of issues. The sensitizing “equipment” occupies an entire building made up of multiple floors. It is at the same time a chemical batch manufacturing operation as well as a discrete manufacturing operation. Due to the large number of raw material needed for the “coating,” it is necessary to plan ahead for a coating run to take place. Weekly schedules are generally used and are “frozen” a couple

days before they start effectively making the lead-time at least nine days. Additionally, because this is a chemical batch operation, a significant amount of waste is involved in changeovers, forcing lot sizes to be relatively large, generally between four and ten wide rolls.

Following this brief overview of the various stages of the supply chain, it should be obvious how the end close to the customer is extremely flexible while the back end is not. The result is that the extremely variable customer signal is passed on from the downstream operations to the upstream operations. While this might seem the right thing to do in a pull system, it is not. In a pull system, especially one in which lead times and lot sizes vary so dramatically along the supply chain, it is fundamental to level the demand signal in order to avoid the “Beer Game” effect and to reduce inventories. This concept will be further discussed in chapter 4.

2.4. Information Flow: Scheduling and Planning

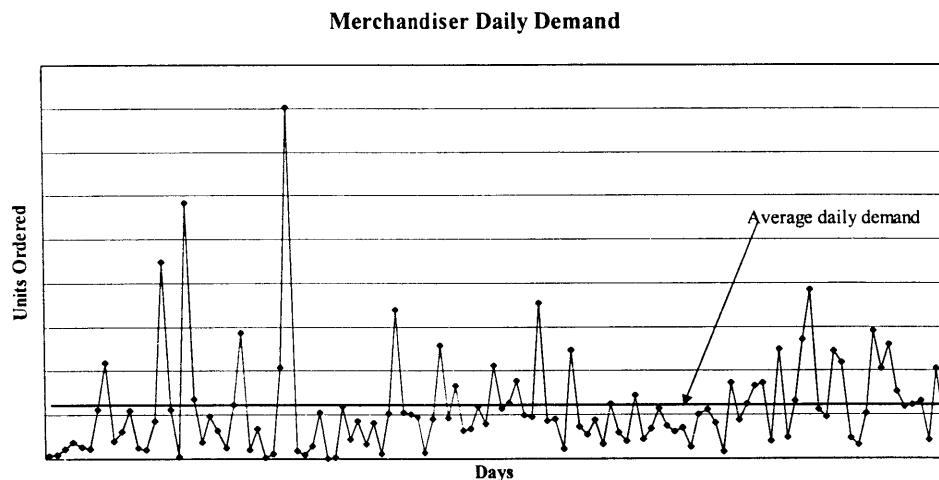


Figure 6: Daily Demand for a Family of Merchandisers

To better illustrate the kind of signal faced by this supply chain, figure 6 shows the demand signal over 6 months of a family of merchandisers produced in the “Pack Center.” This demand shows significant variation on a day to day basis and some seasonality. Yet, the pack center, because of its extremely flexible operations and workforce can almost follow this demand with the exception of some of the peak days.

However, if this signal is passed on to the rest of the supply chain, the other operations cannot follow this signal. In practice, this means that the upstream operation would be required to produce the necessary supplies but would be unable to do so and therefore would have to hold inventory. To avoid this problem, Integrated Demand Flow (see section 2.3) smoothed the signal between each step. In other words, it based the demand signal not on the actual daily signal but on the signal over an average number of days, usually between three and seven days. Therefore, it is not a pure pull system as significant inventory is being held between the operations and the demand signal is continuously smoothed. Yet, it is not a push system as it is not based entirely on forecasts but on the incoming consumption signal from distribution based on a reorder point methodology.

2.4.1. The role of MRP/ERP

Kodak uses a number of MRP-type systems to monitor production and associated functions, primarily it uses SAP and Manugistics. The purpose of these software packages is threefold. First, they allow all the supporting functions such as finance, accounting and logistics to keep track of the data they require. Secondly, they simplify the planning job by keeping track of what inventory is available, matching customer orders with available inventory, placing production orders when reorder points are reached, etc. Finally, these software packages help issue production orders so that the various operations along the supply chain can produce the correct product at the right time. This last function is somewhat in contrast with the concepts of lean manufacturing and will be discussed later on in the thesis.

3. Future State Map

3.1. The Lean Supply Chain

Developing a lean supply chain is a continuous process without an end. The supply chain will continue to evolve and become “leaner” as we improve process capabilities, reduce lot sizes, reduce changeover times, reduce lead times, increase productivity and so on. Following the philosophy of continuous improvement takes time. Therefore, the initial goal was to develop a vision of what the lean supply chain should look like. Subsequently, the focus was on highlighting what steps needed to be taken to achieve the lean supply chain.

What makes a supply chain lean? While there is no such thing as a complete lean supply chain, there are some fundamental guidelines to follow in order to make the supply chain lean. The goal of all these guidelines is to help eliminate waste from the production floor. The following guidelines should be used to design a lean supply chain: (Rother and Shook, 1999)

3.1.1. Pacing the Operation

The supply chain must be set-up to operate at a certain pace, which is generally referred to as a takt time. This takt time can be reset periodically based on changing demand and supply patterns, but it should generally be adhered to as close as possible. Takt time refers to the pace at which consumers are purchasing our product. For example, if consumers purchase color film at a rate of 1000 rolls/day, 7 days/week, our supply chain should be set-up to reliably produce 7000 rolls/week. Assuming the plant runs 5 days/week, we need to produce 1400 rolls/day. If the operation runs 24 hours/day, the takt time will be available time divided by customer demand. Based on the assumptions described above, we have 1440 minutes available in a day and we must produce 1400 rolls. Therefore, takt time is just over 1 minute/roll. This means having the right amount of people, machines and material to meet the production takt time.

Clearly, it is extremely difficult to predict how many rolls of film consumers will buy over the next year to set up the correct takt time. Therefore, a takt time is selected based on forecast and historical data and can sometimes be a range rather than a specific number. Section 3.3 will describe how a takt time was selected and monitored given the demand volatility and seasonality of color film demand.

3.1.2. One Piece Flow

Upstream processes and down-stream processes should operate on a continuous flow system whenever possible. Continuous flow, or one-piece flow, refers to the fact that each operation will only produce one part for the downstream process, and will not produce any more until the one part produced is being used. The flow of material is one of the major goals of a lean supply chain. When material moves continuously more value is added to it in less time than would happen otherwise. However, to achieve one piece flow the operations must be perfectly balanced and must be physically linked. This is not always possible to achieve.

3.1.3. The use of Supermarkets to Control Production

In practice, one-piece flow is often difficult to achieve so “supermarkets” are used between operations. A supermarket is simply inventory organized by product type, which is stored between two operations. The quantity of material in a supermarket is strictly limited. As the downstream operations needs material it goes to the supermarket and pulls material from it. When this happens, the upstream operation replenishes the inventory that was used. This inventory buffer is necessary because of lot size mismatches, lead times, process reliability and transportation time.

For example, if the upstream operation has a lot size of three and the down stream operation pulls one part, then two parts are left in the supermarket until they are consumed later on. Similarly, if the downstream operation pulls parts at a rate that is faster than the upstream operation can produce, the supermarket inventory helps cover the lead time difference. In a similar fashion, the supermarket covers transportation lead

times and unscheduled equipment down time. The supermarket inventory belongs to the upstream operation and serves as a reminder that the inventory is due to its inability to meet the demand it faces.

3.1.4. Customer Demand Signal

How and where the customer demand signal is sent is the single most important aspect of setting up a lean supply chain. This is where the fundamental difference arises with MRP-driven production systems. In a lean supply chain, the customer signal is sent only to one place in the supply chain. From that point on material is pushed downstream and pulled from the upstream. Where the customer signal is sent depends on the nature of the production process (job shop vs medium and high volumes). In color film, the signal goes to the packaging or pack center lines. From here material is either pushed into distribution strictly to replenish customer consumption or sent directly to the customer.

The steps involved in handling customer demand are the fundamental part of this thesis and discussed in section 3.3. However, important guidelines to follow are the need to level the volume of the demand in order for production to be able to run to the prescribed takt, and to level the mix. Leveling the mix means making every part as often as possible. This will differ dramatically depending on the product portfolio and the process capability. For example, in sensitizing this might mean making every part every week, while in finishing this might mean making every part every day or every shift.

3.2. Future State of the Color Film Supply Chain

Figure 7 shows a simplified version of the future state of the color film supply chain. While a simplified version, it is sufficient to explain how lean concepts are being applied to this supply chain. Following the guidelines described above, the vision is to have a supply chain in which the customer orders are sent to the end of the supply chain, and material is pulled from the upstream operations as needed. The exact process of how the customer signal is manipulated will be analyzed in the next

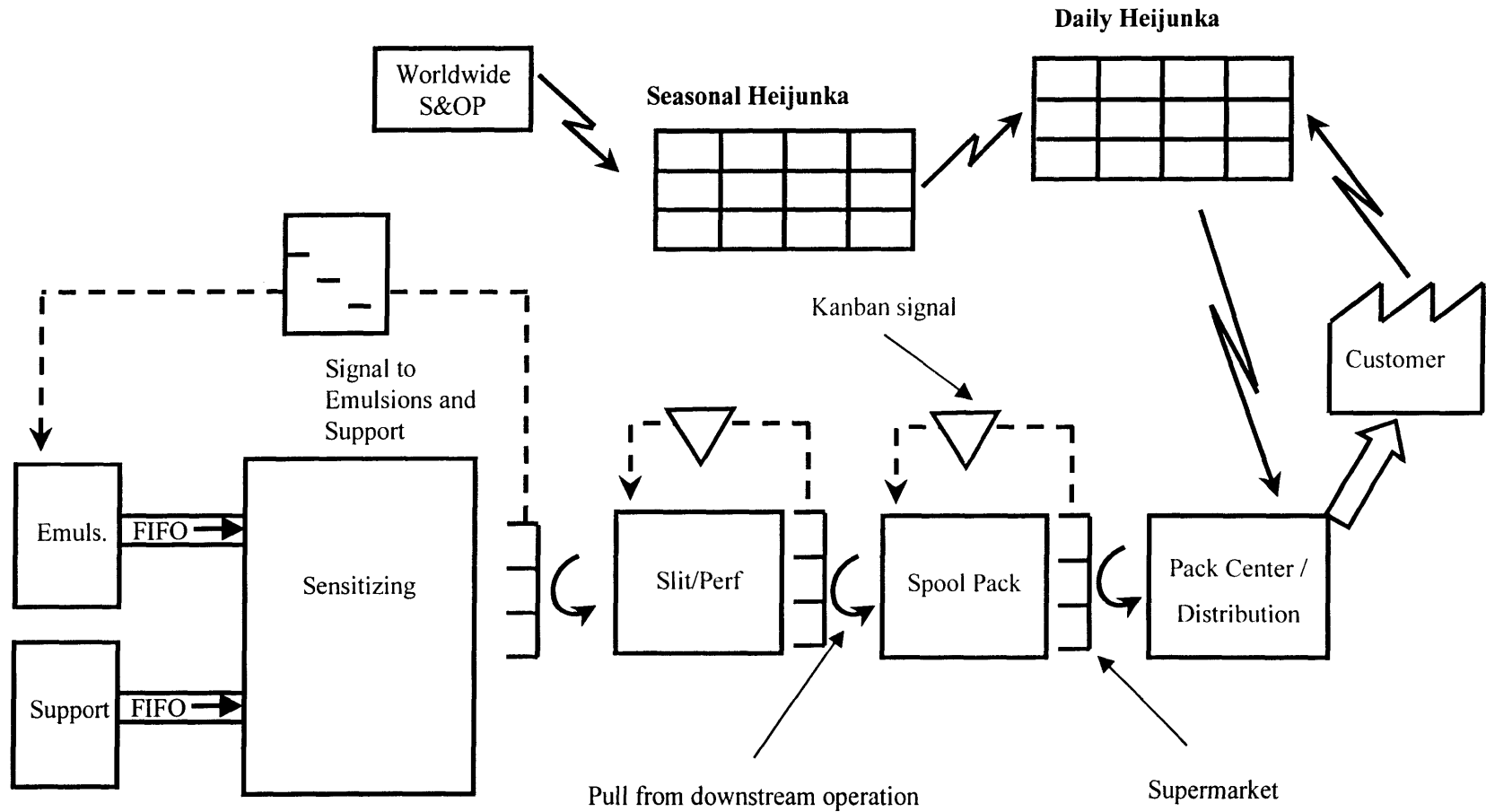


Figure 7: Future State Value Stream Map

couple of sections. Once the daily orders for each work-center are chosen, they are displayed on a board using cards. In the Toyota Production System this is referred to as the Heijunka board. The goal of the board is to pace the operation, therefore it indicates what must be shipped and at what time it should be shipped.

Starting from the pack center, the daily orders are displayed on a board and are produced throughout the day. To produce the orders, packaged film (i.e. product) from spool/pack is consumed as well as other supplies from outside vendors. The pack center has some material on site, as this material is used Kanban cards are sent to the spool/pack operation so that the product used can be replenished. The supermarket between spool/pack and the pack center serves three major purposes. It covers the transportation time from one operation to the other. It accounts for lot size mismatches, in other words the pack center might consume only one pallet but the spool/pack operation has a minimum lot size of four to eight pallets, therefore it produces more than what is needed, ships what the pack center wants and stores the rest in the supermarket for future use. Finally, the supermarket covers lead time; when spool pack receives order to produce a certain product the order is placed in queue behind other orders and is produced after those orders.

To manufacture product, spool/pack pulls film from the slit/perf supermarket. This occurs in the same fashion as described above. As in the previous case, the supermarket covers lead-time, lot size mismatches and transportation time. Once again, slit/perf will require wide rolls to produce to demand and these wide rolls are available in the sensitizing supermarket. As these wide rolls are used, the consumption is recorded on a visual board and the operation is scheduled in multi-day time slots. This board is a sequence board on which the wide rolls consumed are identified and a production sequence is scheduled. The product architecture shown in section 2.2 explains how hundreds of chemicals need to be prepared for a coating event. Consequently the schedule is sent to emulsions and support in advance of the coating event so that they can prepare the necessary materials for the coating procedures. The sensitizing equipment was designed for large batches. Therefore, it is the focus of significant work to reduce

set-up times, reduce waste during changeovers and reduce lead times. The vision is to go from coating every product every week to every product twice a week and eventually coating three times a week.

The following sections will explain in greater detail how customer demand is handled and smoothed in order to meet the daily takt time.

3.3. The Seasonal Heijunka

The key element of the production system developed at Kodak is the Seasonal Heijunka. The goal of the Seasonal Heijunka is to set rules around how the entire supply chain should run. Monden (1998) best explains what the Seasonal Heijunka does in comparison to an MRP-driven system: “The master schedule is very important in MRP

Work center	Pack Center			
Time period	2/1 to 4/1			
Supermarket Items	Daily Max	Aim	Ahead	Behind
Item A	30	10	30	0
Item B	50	15	50	0
Item C	70	22	70	0
MTO Items				
Item D	19			
Item E	17			
Item F	30			
Item G	25			
Item H	42			
System Takt	50			
System Ahead/Behind			150	0

Table 1: Seasonal Heijunka

because it is a target to be rigorously maintained. In the Kanban system, the overall plan [equivalent to the Seasonal Heijunka] does not strictly target production, but merely sets up a loose framework that prepares the plant-wide arrangement of materials and workers at each process.” Therefore, the Seasonal Heijunka allows us to set-up the supply chain to operate most efficiently at a certain production rate. It is referred to as seasonal

because demand will likely change seasonally and the supply chain might need to be resized to operate at a different rate. The Seasonal Heijunka specifically sets certain parameters: the daily takt time, the supermarket items, the item-level daily max production quantities, and the ahead/behind rules for the supermarket items. An example of what the Seasonal Heijunka for a work center looks like is shown in Table 1.

3.3.1. System Takt Time

Based on a blend of forecast and historical data, the planning community identifies the daily takt time necessary over a certain period of time to meet customer demand. The daily takt time indicates the production rate of each work-center. For example, 4-packs (i.e. cartons containing 4 rolls of film) are packaged on the same equipment and form a work-center. The takt time will indicate how many 4-packs must be produced in a day.² This takt time is set only for the final operations, all other operations will receive pull signals from the downstream operations. However, if the final operation runs at a fixed takt time with limits on item level production (i.e. Daily Max production levels), then the pull signals to the upstream operations will be inherently constant. The takt time allows each operation to decide how many people and how many machines are necessary to run efficiently at the given rate. Excess capacity or excess inventory are a form of waste and should, therefore, be eliminated.

3.3.2. Supermarket Items

Supermarket items in the Seasonal Heijunka refer to “high-running” items, which are ordered very frequently. Some items are very popular and are high runners year round like 400 speed, 24-exposure film. Other items, might be selected as supermarket items only for a specific season. For example items packaged specifically for a promotional event like the Olympics. The supermarket items play a key role in this production system because they are used to fill in the “valleys” in the demand signal. Every day Kodak

² Technically takt time indicates the amount of time allotted to produce one piece. For example, one minute to produce one 4-pack. However, since the production hours are known and fixed, throughout the thesis the term takt time will often be used to indicate production quantity by shift or by day, for example 1440 4-packs/day.

receives customer orders for certain items, some days the orders exceed the takt time, other days they are below the takt time. When the orders are below takt time, the rest of the production will be filled with supermarket items. This allows production to run level. The general concept is illustrated in Figure 8. The customer demand signal shows significant demand variability. The supermarket items make up the inventory to buffer demand variability. Production runs level at a pre-determined takt time, when orders are higher than takt time, product is shipped from the inventory. When orders are below takt time, the extra product produced is placed in the inventory. This allows variability to be absorbed by the inventory fluctuation while the production runs at a constant rate (i.e. takt time).

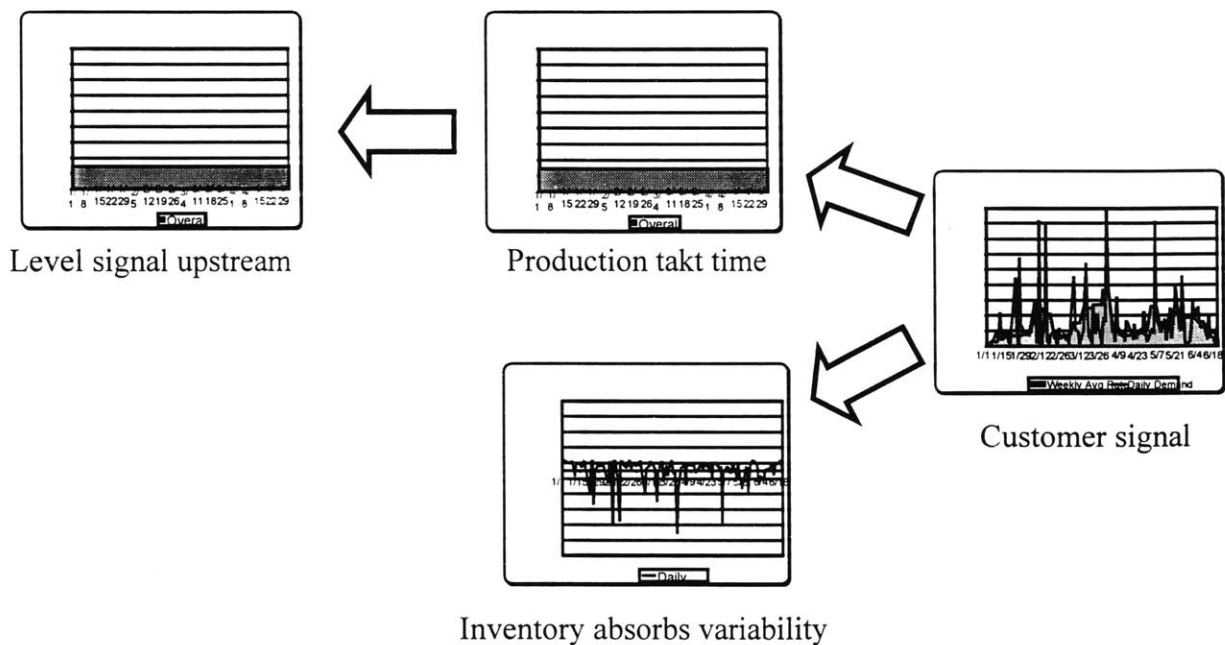


Figure 8: Use of Inventory to Absorb Variability in Demand

Additionally, every supermarket item has an “aim” rate associated with it. The “aim” is the daily average production of that item. The goal is to level not just the overall quantity but also the mix of products. Together with a work-center forecast, planning must develop an item level forecast for the supermarket items. This allows us to identify the daily amount that should be produced if we were able to perfectly level demand at the item level. For example, if among all 4-packs one of the supermarket items is a 4-pack of 200 speed, 24 exposure rolls, planning identifies the average daily demand for this item.

If, over the period of this Seasonal Heijunka, Kodak expects to sell 150,000 of these 4-packs and there are 100 working days, the daily takt will be 1500, 4 packs/day. Clearly, achieving this level of accuracy with the forecast can be challenging for certain items but the “aim” quantity serves as a useful guideline for production.

3.3.3. Daily Max Production

The Seasonal Heijunka also identifies the daily max production for each item in each work-center. This item is extremely important for two reasons. First of all, limiting the max value of any item produced allows us to limit sudden increases in demand of a certain particular subcomponent. Secondly, the daily max determines the size of the Kanbans in the upstream operation. For example, if the daily takt is 3000 4-packs/day and the max for a 200 speed, 24 exposure 4-pack is 1000, only 1000 cartons to produce this specific type of 4 pack must be available from the cartons department. If the daily max did not exist then the packaging department could potentially run 3000 of these 4 packs in a day creating a sudden demand for these specific cartons. As a consequence, the cartons department would be forced to hold 3000 cartons for this item. Therefore, the daily max is a fundamental part of the smoothing strategy because it contributes to item level smoothing which, as we will prove later, is fundamental to reducing inventories. The daily max is generally set by taking the 95th percentile of the orders over a period of time. In addition, the daily max should always be less than the takt time because we do not want to produce only one item in a day.

3.3.4. Ahead and Behind Rules

So far the rules in the Seasonal Heijunka have been based on forecasts and historical data. What if the forecasts are incorrect? When should we intervene? To address these issues the Seasonal Heijunka contains “ahead and behind rules.” These rules allow us to understand when the system is running ahead of or behind of demand and to make the necessary adjustments. If inventory increases to the ahead level, then production is producing more than customers are buying. Vice versa, if inventory hits a behind level, production is making less than the customers are buying. It is important to note that the

ahead/behind inventory for all work centers, except the pack center, is located in distribution. Distribution is the inventory due to demand variability; therefore, it reflects whether production is ahead or behind demand. In general, the ahead level is the re-order point set in distribution using the base stock model. The behind level is generally set as a percentage of the re-order point which ranges between 30% and 60% and is set by the planning community based on their knowledge of demand. This will be further discussed in Chapter 5.

Each supermarket item will have two inventory numbers associated with it: an ahead number and a behind number. The sum of all these number for all the supermarket items will be the work center's ahead and behind numbers. The ahead number indicates the maximum amount of inventory Kodak is willing to accumulate of each item without having orders. The behind number indicates the minimum inventory Kodak is willing to carry of a specific item. Let's return to our 200 speed, 24-exposure 4-pack example. Let's assume for several days in a row orders received are below takt. To reach production takt we produce our supermarket items and place them in the finished goods supermarket or in distribution. As we do this, we keep track of how many 4-packs we have. When we reach the prescribed ahead number, we stop producing this specific supermarket item. When all the supermarket items are at the ahead number we must stop and re-evaluate our takt time. What is happening is that customers are buying less than forecasted and, consequently, we are building inventory.

Similarly, the behind number is the minimum amount of inventory we are willing to carry, when we reach the minimum for all or most of the supermarket items, we must increase our takt because customers are buying more than we are producing. In essence, the ahead and behind numbers allow us to achieve two goals: make sure our forecast is accurate and avoid building unnecessary inventory. They serve as "reality checks" for the system.

3.4. The Daily Heijunka

At this point we are ready to understand the Daily Heijunka. The daily Heijunka takes the daily customer orders, “filters” them through the Seasonal Heijunka and decides the pulls from production for the day. The Daily Heijunka plays a fundamental role in lean manufacturing. It is where the information and materials meet. The daily Heijunka tells production what to ship, when to ship it and how much to ship. It represents actual customer demand, with some smoothing based on the Seasonal Heijunka rules previously discussed. Finally, the Daily Heijunka paces the operation at a constant rate, the takt time.

3.5. The Role of Visual Signaling

Probably the single most evident change made on the shop floor is a shift from IT based signals to visual signals. Chapter 5 will explain in detail the work performed to set-up visual controls. The goal of these visual controls is for anybody on the shop floor to be able to understand what is going on in production. This means that at any time one can look at a pallet of material and understand where it came from, why it is located where it is and what it’s purpose is. Similarly, anybody should be able to look at a Heijunka board and determine at what pace the operation is running, whether it is ahead or behind schedule and so on. The importance of all this is that we can only improve what we see. If the operators see material on the shop floor with specific labels and they understand why it is there, they can easily develop ways to improve the system. This is not true of IT-driven systems. If an operator sees a pallet in a certain spot he assumes that it is where it should be and has no way of telling otherwise. Only by seeing and understanding can a process be improved.

Over the course of the internship, the author participated in multiple Kaizen events and all involved introducing visual signaling in order to make the process self evident and subsequently improve the process. Finally, visual signaling offers another major advantage over IT-based systems, namely it is easy to improve. ERP-based systems have fixed lead times, lot sizes, etc. Therefore, these parameters are taken as a given by everybody and nobody tries to improve them. Furthermore, these systems often prevent operators from making improvements because only select people have the knowledge and

understanding to change these parameters in the system and understand their effect on production. Undoubtedly, out of all the improvements the author witnessed at Kodak, visual signaling is by far the most powerful and effective.

4. Future State Value Stream Map Analysis

This purpose of this chapter is to gain a better understanding of how material and information flow will be affected by the Seasonal Heijunka production system described in the previous chapters. To help understand these affects we take two different approaches. In the first part of this chapter, we use historical data to simulate how one section of the Pack Center would have run over a 6 month period if the Seasonal Heijunka method were used for production. In the second part of this chapter, starting with section 4.2, we take a more complete look at the color film supply chain and try to understand where supermarkets will be located and where we should focus Kaizen events to improve operations and reduce lead times and inventories.

4.1. Standard Merchandisers Pack Center Analysis

Before applying the new production system to the Kodak color film supply chain, a series of tasks had to be completed. Some were operations type tasks such as developing effective ways to display information visually and finding the best way to pass Kanban cards (i.e. information) between operations located in separate buildings. But the most important issue was teaching people how the system would function and what their role would become as part of this new production system. In order to help convince everybody that this system would work, a small simulation was developed using historical data. This proved that the system would work with the demand pattern normally faced by the Pack Center.

4.1.1. Six Month Daily Heijunka Study

Sales data were selected for a specific family of merchandisers called “standards” in the pack center. The data covered approximately 6 months. The data showed daily customer orders by item for this family of merchandisers. Because this is a build-to-order business, the orders come directly from the customer and are not filtered through distribution. Based on the customer demand, a Seasonal Heijunka was developed with a system takt time, high running supermarket items, max daily production quantities for each item, aim

quantities for the supermarket items and ahead/behind rules for the inventory. Chapter 3 describes how the various levels were selected. The initial inventory in the supermarket was arbitrarily set at 50% of the ahead value. The amount of inventory initially in the supermarket does not affect the final result. This system works on an ongoing basis so clearly we must start with some inventory in case the first order of the simulation is greater than takt time and we need to ship more than we can produce. However, once the system is running it is independent of the initial inventory. The goal is to end a period with the same amount of inventory that the period started with; this would mean the amount produced is exactly the amount purchased by the customers. One final important assumption should be noted: any order for any item above the max level was assumed to have a five-day advance notice. This is realistic since the daily max numbers are selected so that they cover the majority of orders and sales representatives generally are aware in advance when one of the large retailers places large orders.

At this point six months of production were simulated by loading the Daily Heijunka, based on daily customer orders and subject to the rules of the Seasonal Heijunka. This simulation was performed using an Excel spreadsheet. On a daily basis the spreadsheet compared orders to available inventory in the supermarket. Subsequently, daily production was set in order to meet the daily orders; any excess capacity was dedicated to supermarket items, which were placed in the supermarket for future orders. The simulation consisted in the following steps:

- Customer Orders for the day were received
- Supermarket items available from the supermarket were deployed immediately
- The balance, if any, of these items was scheduled to be produced
- All other items (i.e. Make-To-Order) were scheduled to be produced
- Supermarket items were added to reach the necessary daily takt time

In the event that there was not enough capacity between supermarket inventory and daily capacity, some orders were delayed until the next day. This happened on approximately 1% of the orders received over this six-month period. There are two reasons for this; the

primary cause is the arrival of an extremely large order for which five days advance notice was not enough. The second cause was the simultaneous arrival of small orders, the sum of which exceeded the takt time. However, if we consider that today's lead time is five days, this system was able to reduce lead time from five days to one day for 99% of the orders while helping production run level. Because the supermarket inventory is made up of high running items and is limited by the ahead rule, the risk to Kodak is extremely small.

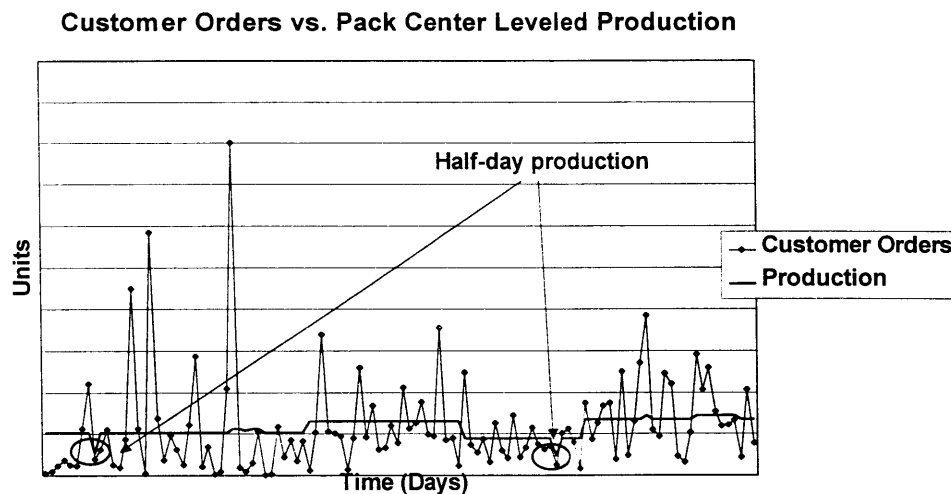


Figure 9: Daily Orders Versus Level Production

Figure 9 shows the orders versus the production level over the 6 months. It is important to note a number of things. First of all production is smooth over selected periods of time in which the takt time was the same. During this time, a 10% overtime factor was allowed in order to increase flexibility and avoid carrying additional inventory in the supermarket. Twice, we reached the ahead levels in the supermarket and both times production was stopped. Since the workers must be employed eight hours/day, when production was stopped, half-day Kaizen events were held to improve the operation and to avoid producing more product. This is consistent with trying to eliminate overproduction, which is a form of waste. Considering the extreme variability in the customer signal, the improvement shown is quite dramatic.

4.1.2. Reductions in Variability Along the Supply Chain

The results of this simulation were presented to the planning community as proof that the Seasonal Heijunka production system could be used to run the production floor and that it could handle real customer orders. However, we recall that the Heijunka process is not done for the operation that actually uses the Heijunka but rather for all the upstream operations that must react to the pull signals. These upstream operations are less flexible and can therefore benefit from receiving demand signals with less variability.

Recalling Figure 7 on page 31, we observe that the Pack Center “pulls” product (i.e. film) from the packaging work center. Therefore, it is useful to look at some of the most common products and see how the variability in the signal changed between a build-to-order scheme and the new process. This data is obtained by using the bill of material of the merchandisers used in this simulation and “exploding” daily product consumption. Table 2 shows the change in variability, as measured by standard deviation from the mean, for the most commonly used products. This is an appropriate way to look at the data because our goal is to produce the mean every day. This is what allows us to minimize

Product	Standard Deviation for Build-to-Order Strategy	Standard Deviation for Leveled Process	Improvement
Product A	180	118	34%
Product B	139	91	35%
Product C	197	115	42%
Product D	189	72	62%

Table 2: Demand Variability Reduction Due to the Seasonal Heijunka Process

inventory and helps improve productivity. Therefore, the lower the standard deviation of the signal, the better. All numbers have been normalized to protect Kodak confidential information. The Seasonal Heijunka production scheme allowed a reduction in variability of the pulls on the packaging department of 30% to 60%.

Following the same logic, as these products (i.e. film) are produced they consume film and consequently the pull signal is passed further up the supply chain to sensitizing. Using the bill of materials, the daily film consumption was converted to daily wide roll consumption by adding up all the rolls of film that use the same wide roll. This method was used to understand how wide roll was being “pulled” by the downstream operations on a daily basis. Table 3, below, shows the decrease in variability of the pull signals on sensitizing is extremely significant.

The purpose of this exercise is to help employees understand, through a simple simulation, the power of leveling the demand signal downstream and using a pull method on all the upstream operations. In fact, this is just a first step. As the following supply chain analysis will show, leveling (i.e. reducing variability from the mean) at the item level will yield significant inventory savings through the entire supply chain. Since the supermarkets are sized based on the daily max values of each item, reducing the daily max (i.e. leveling) will help reduce inventory. This simulation proved that the overall production system based on the Seasonal Heijunka can be successfully applied today to Kodak operations.

Wide-roll	Standard Deviation for Build-to-Order Strategy	Standard Deviation for New Process	Improvement
Wide-roll A	183	67	63%
Wide-roll B	173	74	57%
Wide-roll C	128	46	64%

Table 3: Decrease in Variability on Sensitizing

This simulation also highlights the fundamental importance of working with Kodak customers to get frequent, smaller orders and fewer large orders. Small orders allow the daily max levels to be set lower and allow the ahead/behind levels to be tighter since they are proportional to customer demand variability. Both of these factors help reduce inventory and variability in the supply chain. To better understand this scenario, the reader can think of the extreme situation in which the retailer would order the average consumption every day with a perfect forecast, this would allow Kodak to plan

production with the absolute minimum waste as there would be no variability. While this is clearly impossible, receiving frequent small orders rather than large infrequent ones helps get closer to this ideal. In this regard, the initial work is extremely encouraging; towards the end of the internship one of the major retail customers was shifting from placing a few large seasonal orders to giving monthly forecasts and weekly orders. This kind of improvement will be critical to the success of this production system and it will also allow the retailer to dramatically reduce its own inventory of Kodak products.

4.2. Kodak Kodacolor Supply Chain Analysis

A second analysis that was performed looked at the entire Kodak Kodacolor supply chain from the packaging lines to sensitizing and included all products. The purpose of this analysis was to understand the impact on inventory of this new system as well as to understand where to focus process improvement efforts (i.e. Kaizen events). In other words, in this analysis certain parameters such as lead time and demand variability, were varied to understand what impact they had on inventory. This gave us an understanding of which of these parameters was most critical to inventory reduction.

4.2.1. Supermarket Sizing

Inventory in the supermarkets is determined by the max demand over the lead-time plus one lot size. For example, assume that the max demand is 1000 spools/hour, lot size is 1000 spools and lead-time is 10 hours. Therefore, the supermarket size is 11,000 spools (1000 spools/hour times 10 hours plus 1000 spools/lot). Let's examine the dynamics of what happens to understand why the supermarkets are sized using this technique. The worst-case scenario is that demand comes in at max demand and that no demand has come-in for the entire previous lead-time. In other words, no spools have been pulled from this supermarket over the last 10 hours, but over the next 10 hours pull signals will be 1000 spools/hour. As spools are pulled, when 1000 are pulled (after 1 hour) the first batch is placed in queue for production. We expect it will take 10 hours to receive this material based on the given lead-time. Over the next 10 hours the 10,000 remaining spools will be consumed and production signals will be sent every 1000 spools (i.e. every

lot size). When the 10 hours are completed, the first batch, ordered 10 hours ago, is received and the supermarket is replenished with 1000 spools. If max demand continues, this will be consumed as well, but when this is consumed completely, the next batch will arrive and so on. This is the fundamental thought process behind the supermarket sizing.

4.2.2. Modeling Approach for All Kodak Kodacolor Products

In order to determine the size of the supermarket along the supply chain it would be ideal to have developed a Seasonal Heijunka for every single packaging work center and subsequently cascade demand upstream based on the bill of materials and on the max daily values. However, at the time this model was developed only a couple work centers were operating with this production system. Therefore, a different approach was used. The data available consisted in monthly sale quantities by item for one year. Using this data the steps shown below were followed:

- A yearly takt time for the entire Kodacolor production was identified. This was obtained by dividing the total yearly sales (in spools) by the number of working days.
- Based on the product architecture shown in figure 4, products were organized by film code (i.e. 400-speed color, 100-speed black and white, etc.), in other words all products using the same film were grouped together.
- The demand was reduced from product to spool quantity (again see figure 4). For example, if the sales data showed that Kodak sold 1000 4-packs and 400 2-packs of 200-speed film 24 exposures, then the sales were reduced to 4800 spools (i.e. 4 times 1000 plus 2 times 400) of 200-speed film with 24 exposures. This gave us demand in spools grouped by film code and by number of exposure.
- If Seasonal Heijunkas were in place, it would be possible to derive daily max values for each spool type. However, because the Seasonal Heijunkas are not available, an assumption was made that max daily values are a percentage of average. As a base case this percentage was set at 300%. In other words, if on

average Kodak sells 3000 200-speed, 24 exposure spools a day, we assume that any day this value can be somewhere between 0 and 9000 spools.

- The daily demand was further reduced into slit rolls demand (again see figure 4 to see how the supermarket are located along the supply chain). Slit rolls are stored in the supermarket downstream from slit/perf and they are wide rolls that have been slit to 35 mm wide and have been perforated along the sides. To calculate the pull signals as well as the takt time for slit/perf the same methodology was used. The demand in spools was translated into demand in slit rolls based on the number of exposures, which determines the length of film used, and the film code. The daily max values were also obtained in the same way. It is important to note that at this stage in the supply chain major lot size mismatches start to arise, especially for those film codes that have low demand. This happens because when slit/perf receives a pull signal, the operation slits an entire wide roll independent of how small the demand signal is. This is due to the fact that once a wide roll enters the slitting and perforating equipment it goes through a lot of automated equipment operating in the dark. With the current equipment, it is not practical to slit only half a wide roll. Clearly, this presents a potential for improvement if necessary.
- Now that demand was available in slit wide rolls, based on the number of slits in a wide-roll, the pull signals on sensitizing were identified. These pull signals are not replenished directly by sensitizing on a daily basis but rather the signals are collected over the multi-day lead-time. Next they are aggregated and a schedule is developed and frozen a couple days prior to production. The planned schedule is sent to emulsions and support and the correct supplies prepared for the production run. Lot sizes in sensitizing are multiple wide rolls. The combination of large lot sizes and multi-day lead times makes the wide-roll inventory by far the largest of all the supermarkets.

4.2.3. Key Assumptions and Other Considerations

In general the analysis assumes a worse case scenario. In other words, it assumes that inventory or capacity must be available to cover multiple days at max demand for every

single item, in every single operation with the exception of sensitizing. Based on historical demand patterns, this is unlikely to happen. But as a first pass analysis it was the best approach possible. Some other important assumptions to consider are the following:

- One takt time is used for the entire year. In reality, there is some seasonality in Kodak demand and most likely Kodak would run somewhere between two and four takt times each year.
- The demand data covers 98% of the spools sold, the other 2% is made up of extremely small runners, which were excluded to simplify the analysis.
- Spooling and packaging, referred to as spool/pack, are considered one operation with negligible inventory between them. The same applies to slitting and perforating, referred to as slit/perf.
- Sensitizing is assumed to run as many days as all other operations. In reality sensitizing goes through significant shutdown periods. The impact of these are not considered in the analysis.
- The pack center is not included in the model, however all the demand that comes from the pack center is included. This is because the pack center operates the only build-to-order model in the supply chain and was analyzed separately.
- Last year's demand data is used. Promotions and changes in the economic environment could cause some changes in the demand. However, since this is a very mature business, these changes can be safely assumed to be minimal.
- As we move further up the supply chain equipment is shared with other product lines outside Kodacolor or some products are used for exports. To account for this factor, capacity in these operations was reduced by a fixed % value.
- For sensitizing, demand is aggregated over the lead-time before the production schedule is set. As daily demand is aggregated, the probability that consecutive days will be at the daily max for any item decreases. It is assumed that the variability decreases with the square root of the lead-time. In other words, if we aggregate demand over 3.5 days the max daily value is reduced by the square root of 3.5. So let's say that average wide roll consumption of 400 speed film is 3 per

day, with a daily max of 7 per day. The average over 3.5 days is simply 3.5 days times 3 per day. However, the max value is 3.5 days times 7 rolls/day divided by the square root of 3.5. So aggregating multiple days together reduces the variability of the signal. This makes intuitive sense since it is less and less likely to have consecutive days at the max value.

Setting up the supply chain in the way described above adds one more major change to the supply chain which is not captured in the model. The lead-time from the factory to the distribution centers is reduced to one day plus transportation time for orders below the max level of each item. This reduction in lead-time will allow Kodak to reduce the inventories in the distribution system because these are calculated using the base-stock model.

4.2.4. Effect of Lead Times and Lot Sizes on Inventory Buffers

To analyze the entire supply chain an Excel spreadsheet was set-up to calculate the size of each supermarket along the supply chain. These supermarkets, shown in Figure 7 on page 31, are a supermarket of packaged spools after spool/pack, a supermarket of slit rolls after slit/perf and a supermarket of wide rolls after sensitizing. Each one of the three operations (i.e. slit/perf, spool pack and sensitizing) has a lead-time and lot size associated with it. Based on these capacities and on the pull signals expected from the downstream operation it is possible to calculate the size of these supermarkets using the methodology described in section 4.2.1. The supermarket after spool/pack is made up of the same items as distribution. However, this supermarket serves to absorb supply variability. In other words, if we were to ask production to manufacture the same amount every day (i.e. the same volume daily) it would not be able to meet this production goal due to lot size and lead time mismatches. Therefore, this supermarket aids production in meeting leveled orders.

After setting up the analysis, a number of scenarios were analyzed by varying lead times and demand variability. These scenarios were used to evaluate the size of the supermarkets following spool/pack, slit/perf and sensitizing. Table 4 summarizes the

results as a function of a base case scenario. The table shows the frequency of the coatings in sensitizing, which is equivalent to the lead-time, as well as the lead-time for slit/perf and spool/pack. The “demand variability” column refers to the value used for the daily max. As discussed in section 4.2.2, in the base case, the max daily value was equal to 300% of the average value. Finally, the last three columns indicate the size of the three supermarkets. However, the supermarkets are significantly different in size with wide-roll being by far the largest one. Therefore, a 10% reduction in wide-roll is significantly better than a 10% reduction in any of the other two supermarkets.

It should be noted that to protect Kodak confidential information everything has been normalized compared to a base case, which is roughly equivalent to the state of the supply chain in the summer of 2001. The base case is the first row in Table 4. This base case was also used to verify the accuracy of the model. In general, inventories along the supply chain fluctuate wildly due to the frequency of coating events and to the fact that a planner with extensive experience, who tends to make decisions based on her knowledge of the business, manages the system. However, the base case yielded supermarket sizes roughly equal to the ones in June 2001.

Coatings /week	Slit/Perf Lead-Time	Spool/Pack Lead-Time	Demand Variability	Wide-Rolls	Slit-Rolls	Spools (supply-side)
100%	100%	100%	100%	100%	100%	100%
100%	50%	50%	100%	100%	62%	52%
50%	50%	50%	100%	62%	62%	52%
33%	50%	50%	100%	53%	62%	52%
33%	50%	50%	167%	90%	65%	59%

Table 4: Effects of Various Process Improvements on Supermarket Sizes

Subsequently, a number of cases are analyzed. In the second case, improvements are made on the lead-time for slit/perf and spool/pack. These improvements result in inventory savings of 48% in the spool supermarket and of 38% in the slit-roll supermarket. Intuitively, this makes sense, as the inventory must cover less lead-time. Note that there is not a one to one relationship due to lot size mismatches and timing of the replenishment signal from the supermarket. Along the same lines the third scenario

looks at coating film twice as often, effectively reducing the lead-time in half. This yields an additional savings of 38% in the wide-roll inventory. The fourth scenario further looks at improving coating frequency, reducing the lead time by two thirds compared to the base case. However, this further improvement only leads to an additional 9% inventory savings in wide roll inventory. Given the extreme operational difficulty in reducing lead time by two thirds compared to the base case scenario and the limited additional savings, this does not appear to be an attractive option.

The last scenarios prove an extremely important point. The scenario is identical to the fourth one except that demand variability is higher in the last scenario. This demand variability difference represents higher max values at the item level. Recalling that all supermarkets must cover max demand over the lead time, it makes sense that as this increases, supermarket sizes must increase. What is notable is the significant increase in wide roll inventory. Yet again this makes sense because sensitizing lead-time is in the order of days, compared to hours for the other operations. Therefore, demand variability increase will have a bigger impact on this inventory. Additionally, lot sizes for sensitizing are significantly bigger also causing the supermarket size to be particularly sensitive to variation in the max demand.

4.3. The Effect of Leveling High Running Items.

One of the goals of the KOS lean system is to focus on material flow. When material is flowing through the production process value is being added to it and less time is spent sitting idle. In theory, if we could achieve one-piece flow and a perfectly balanced line than we would have no Work-In-Process inventory and all material would flow continuously. While this is unachievable, the new production system can move closer to this ideal by reducing inventory, lot sizes and lead times as discussed above. A key component to eliminating this kind of waste is leveling production.

The concept of leveling consists in two distinct parts previously discussed. First we want to level volume so that every day we produce the same amount of product. Level production allows us to reduce inventory and eliminate unnecessary excess capacity, both

of which are a form of waste. Secondly, leveling attempts to level mix. In other words, if the goal is to produce 10,000 spools of 400 speed and 10,000 spools of 200 speed with lot sizes of 1,000, traditional production methods would suggest that we produce two large lot sizes of 10,000 to avoid changeovers. On the contrary, lean suggest that we alternate lots of 1,000, or smaller, to level the mix. The rest of this section will explain how this production criteria affects inventory.

Over the long run, say a couple months, it is difficult to know exactly what item to produce and when due to the poor forecast reliability. However, there are a few very high running film codes in Kodacolor, which account for the majority of production volumes. In the system described so far, these items' production ranges any day from 0 to the daily max. This forces production to hold a considerable amount of inventory to be prepared for periods of demand at the max level. However, it is possible to set tighter ranges on these items because they are by far the highest running and are purchased consistently.

The approach taken is as follows: a daily minimum is introduced on selected high running items. Returning to our previous example, if for film code A we set the max to 1,000 spools/hour, it is advantageous to introduce a minimum quantity to get material to flow, rather than getting orders for 1,000 spools/hour for the first 10 hours in a day and no orders for the subsequent 10 hours. Let's further assume that the average daily demand is 500 spools/hour. In the ideal case, we could predict average daily demand with enough accuracy to simply produce this amount each day. As this is very difficult, we set a minimum and a maximum. For example, we set the minimum to 40% of average daily demand, which in this example is 200 spools/hour. This means that every day we will "pull" from the supermarket to distribution at least 200 spools/hour independent of what demand really is.

Let us observe how we would calculate the size of the supermarket downstream from one of the operations in this new case where we have established minimum and maximum production limits. Section 4.2.1 described how to size supermarkets given a max demand

level. However, if there is a minimum demand level the supermarket size must cover the max demand over the lead-time, plus one lot size, minus the minimum amount produced over the lead-time. Figure 10 & 11 show a comparison of the two scenarios, in one case there is no minimum production amount, in the other case there is a minimum production amount. Let's analyze the two cases separately.

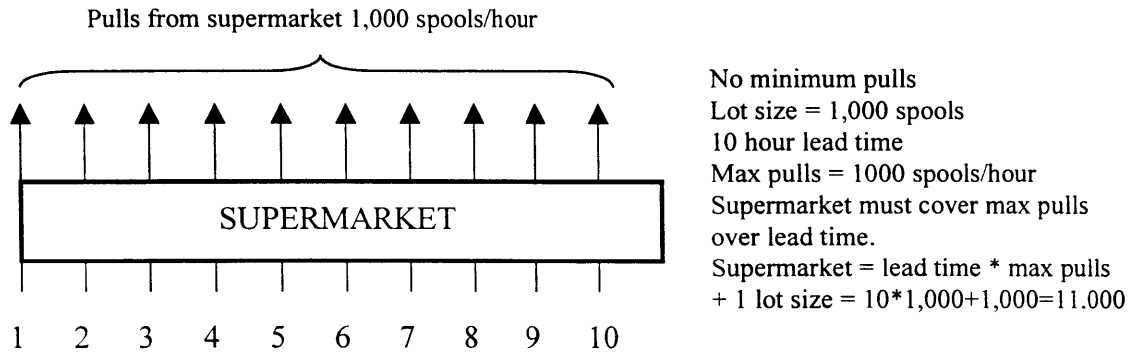


Figure 10: Supermarket Sizing With No Item Leveling

In the first case (Figure 10) demand can vary from 0 to 1,000 spools/hour. If we consider the worst-case scenario, that we get 10 consecutive hours of max demand, the supermarket must contain 11,000 spools as calculated in section 4.2.1.

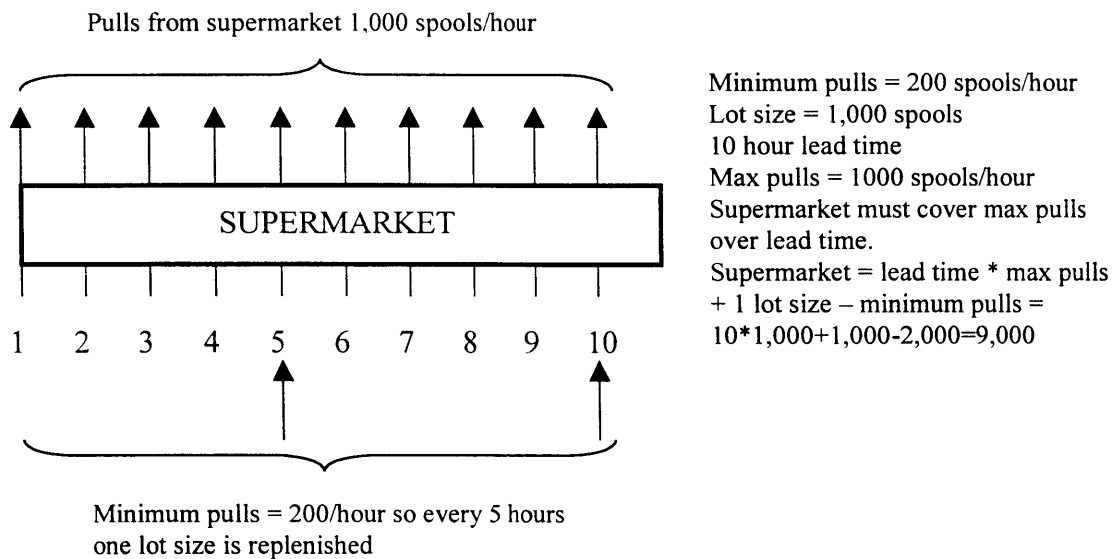


Figure 11: Supermarket Sizing With Item Leveling (i.e. minimum pulls)

In the second case (Figure 11), we face the same demand of 1,000 spools/hour and the same lot size and lead times. However, we know that for the ten hours before the first pull, we pulled a minimum of 200 spools/hour. Consequently, during this 10-hour period of high demand we will be receiving 2,000 spools. Therefore, the supermarket can now be sized by the max demand over the lead-time, plus one lot size, minus the minimum expected pulls, which will be replenished. In our case, the minimum pulls that will be replenished is 2,000 spools, so the supermarket size will be $11,000 - 2,000 = 9,000$. We were able to reduce inventory without any changes to lead-time or lot sizes but simply by leveling the demand on the operation. At this point it is easy to see that in the extreme case where we could get a perfect forecast we could run one lot every 2 hours and hold almost no inventory. However, since we do not have a perfect forecast, we approach the problem by developing a range of minimum pulls to maximum pulls and then try to tighten this range. This is the approach that was taken in the second part of this simulation to see how inventory could be reduced by tightening the ranges on the highest running items in Kodacolor. The decision to work only on the high running items is because these are the easiest items to forecast, it would be difficult to do this on some of the lower running products.

Returning to our supply chain analysis, Table 5 shows the impact of leveling on the supermarket sizes for a given set of supply chain lead times and lot sizes. The minimum and maximum numbers are shown as a percentage of the daily average. Therefore, the first line is equivalent to the case discussed in table 4 where there was no minimum (i.e. minimum = 0), and the daily max was equal to 300% of the daily average.

Minimum Production	Maximum Production	Wide-Rolls	Slit-Rolls	Spools
0%	300%	100%	100%	100%
20%	260%	89%	88%	90%
40%	220%	78%	72%	74%
60%	180%	59%	50%	57%
80%	140%	49%	38%	32%
100%	100%	38%	19%	14%

Table 5: Effects of Leveling on Supermarket Sizes

The reductions in inventory in the three supermarkets are achieved strictly by managing the pull signal in the downstream operation. In the six scenarios shown below, no changes have been made to lead times or lot sizes in any of the operations.

It is useful to observe again that the numbers make intuitive sense. In the last case, where the 4 high running film codes are run at average every day, inventory is decreased significantly but not completely because there are still film codes that are not leveled and there are still significant lot size mismatches especially in sensitizing. Note how without making absolutely any changes to the supply chain characteristics or the process (i.e. lead time, lot sizes, etc) but by simply leveling at the item level, it is possible to significantly reduce inventory. Even without going to the last extreme case, which would require a very accurate forecast, it is easily possible to reduce inventory 30% to 40% by simply leveling around a smaller range.

4.4. Where Do We Focus the Next Kaizen?

In the sections above we analyzed the effects of improving lead times on the supply chain as well as the effects of leveling and changes in demand variability. Therefore, using the results above we can identify key areas where improvements will yield the most benefit to the supply chain. From strictly a process perspective, the most important improvement area is sensitizing, specifically cutting lead-time in half. This is primarily due to the fact that the wide roll inventory is by far the largest inventory in the supply chain and a reduction in this inventory of 38% as shown in table 4 would be a major improvement. Further lead time reduction in sensitizing do not yield as large an inventory savings. However, given the nature of the sensitizing operation, reducing the lead-time in half is a significant challenge. Additional efforts in this area would focus on reducing waste during changeovers and reducing lot sizes.

The reader will note that in table 4, lead times are also cut in half for slit/perf and spool/pack. These results were achieved in most work centers over the internship period through separate work from the one described in this internship. Consequently, the lead-

time has been reduced by 50% in those areas; the challenge is now to make it repeatable and sustainable as this was not the case when the author left Kodak in December 2001.

The second most important area of improvement is in the packaging operations. These are all the operations that will have a daily Heijunka scheduling the leveled pulls onto the supply chain. The pulls experienced by all the upstream operations are strictly a function of these pulls. Therefore, the only leveling occurs at the packaging operations and in the pack center. Section 4.3 showed in detail the power of leveling these operations.

Leveling these operations will yield dramatic inventory reductions and will have many additional benefits in productivity and quality improvements.

The third and most difficult area of improvement is sales and marketing. Sales and marketing must be educated so that they understand the dynamics that take place in the supply chain and how making every part every day helps reduce inventory and improve quality. Once they understand these concepts, sales and marketing must work with the customers to help reduce demand variability and obtain accurate forecasts. The better the demand can be forecasted, the tighter the min-max production levels can be set, the less inventory will be in the supply chain. This also highlights another important factor that will be discussed later, specifically that lean is an enterprise wide initiative and to truly reap the benefits of this production system everybody from manufacturing, to planning, to sales and marketing must be involved.

5. Case Study: The Pack Center vs 4-Pack

The previous chapters have focused on the production system and on how it would affect inventory and response times along the entire supply chain. In essence, the previous chapters analyzed the macro-picture. This chapter will focus in more detail on what actually needs to be done on the production floor. Two different models will be presented: the pack center model and the 4-pack model. Though guided by the same fundamental principles, the two differ slightly and will serve as a way to explain how continuous improvement should help all these systems evolve. Since we have identified the key to this production system as the leveling of the demand, this implementation part will focus primarily on implementation in the processes further downstream where the demand signal is being sent.

5.1. The Role of the Pack Center in the Supply Chain

The pack center operation assembles merchandisers for retail stores. Merchandisers are displays, generally made of cardboard, which contain Kodak products and can be placed in the aisles of retail stores to give Kodak products more visibility. Generally they contain multiple products such as one time use cameras, and various types of film. There are mainly three kinds of merchandisers: standards, towers and clips and tubes.

Standards are smaller units which have a cardboard base to raise them to eye level when they are displayed. Towers are very large displays, which are often placed on a pallet and displayed in the aisles of large retail stores like Wal-Mart. Towers can contain hundreds of rolls of film. Clips and tubes are small strips with generally about 10 items on them which can be hung almost anywhere inside a store. This is a build to order business that assembles the merchandisers only once they are ordered. There is no inventory of merchandisers in distribution.

As the importance of major retail chains has grown, so has the role of the pack center. Being the last operation before the customer, the pack center is a key to this new production system. It receives a customer signal (i.e. orders) and must pull all the

products (i.e. 35 mm film, APS film and One-Time-Use-Cameras) from various Kodak locations and assemble the merchandisers. The merchandisers are made of cardboard supplied by a local vendor.

The pack center faces significant demand variability as well as seasonality. Over the year the contract work force varies by a factor of four between high season and low season. In addition, on a day-to-day basis order variability varies dramatically as observed in chapter 4 and shown in Figure 6 on page 26. It is absolutely necessary to find a way to level demand or it is virtually impossible to implement any kind of pull production system. If demand is not leveled, the upstream operations will see dramatic demand swings and will have to either have excess capacity or excess inventory. Both of these options represent forms of waste and should be eliminated. Therefore, the pack center is a critical spot to level demand. The following sections will describe the work done to implement a leveling board on the production floor.

5.1.1. Cellular Manufacturing and Kanbans

The first step in being able to implement a pull production system based on KOS is to have flexibility on the production floor. Specifically, the ability for quick changeovers is key to meeting customer demands and reducing inventory. Through weeklong Kaizen events, the pack center was converted from a mass production type environment with long production lines to cellular manufacturing. For example, standard merchandisers were produced on production lines with ten to fifteen people in which each person performed one step in the process. However, these lines presented a number of problems:

- Too many people on the line tended to interfere with each others' work
- It was difficult to balance the operations and consequently workers spent a lot of time waiting for product to flow to them.
- Accountability was generally very poor, some workers worked very hard, others could hide in the crowd.

- Line changeovers were time consuming since a line required a lot of material for a specific merchandiser.

The pack center had 4 lines to produce standards. This was in part due to the fact that the orders were not leveled and therefore the same workers would run all standards one day and none the next. So in the “peak” days they required a lot of capacity, which was unutilized in the “off” days. Clearly, all the excess capacity is a form of waste that lean aims at eliminating.



Figure 12: Cellular Manufacturing in the Pack Center

The 4 lines were replaced with 8 cells. The cells were operated by two or three operators, which built the entire merchandisers. The layout of the cells was such that adjacent cells could share supplies. One material handler was assigned to two cells in order to replenish supplies. After a brief learning curve the productivity of the cells was double that of the lines, mainly due to the fact that operators did not spend any idle time. Cellular manufacturing offered the following advantages:

- Smaller production groups (i.e. two or three people per group) could more easily implement one-piece flow.

- Changeovers in a cell are significantly faster than for an entire production line because the amount of material needed is much less.
- Small groups of operators take more ownership of the finished product.
- Cellular manufacturing allowed for increased flexibility in scheduling since the four cells, which replaced one production line, could produce 4 different merchandisers simultaneously.

The cells were supplied of all necessary material from on-the-floor Kanbans. Figure 12 shows a cell operating during normal production. This cell is staffed with two operators working together to produce merchandisers. The product and supplies necessary are placed all around them and are replenished by material handlers. A visual indicator is used to signal the material handlers and the team leader if there are any problems. A green light indicates production is proceeding on takt, a yellow light indicates the cell is



Figure 13: Kanbans

running low on material and needs replenishment and a red light indicates the cell has stopped for some reason (i.e. missing materials or some other problem). Particular attention is placed on ergonomic issues to avoid bending, reaching and twisting. The

wood tables were built specifically for these cells. They hold the cardboard parts right in front of the operator to minimize motion (i.e. waste).

Figure 13 shows the Kanbans from which the material handlers pick the required materials and delivers them to the cells. Each pallet space is dedicated to a specific material and is labeled accordingly. Each pallet contains a Kanban card, when the material handler consumes all the material on top of the card; the card is taken to a collection box. This card is used to order product from the supplier. Two daily deliveries are scheduled from the supplier. The Kanban is sized to cover max demand over replenishment interval. Members of the supplier team were involved in the Kaizen event and helped develop this pull replenishment signal. Product (i.e. film and cameras) is also supplied using similar Kanbans for replenishment.

5.1.2. Heijunka Process Implementation

Figure 14 shows a schematic of the set-up of the production system in the pack center.

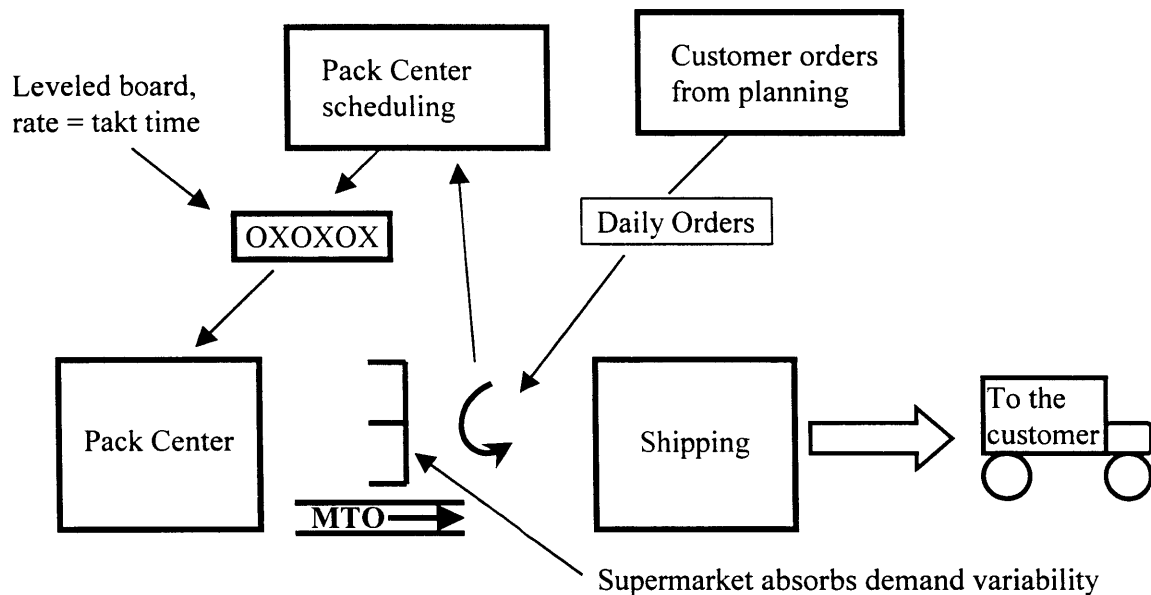


Figure 14: Build-To-Order Production Model

Customer orders come in unlevelled every day. Planning processes the orders and tells the pack center what the daily orders are. The goal is to take orders today and ship them tomorrow. Consequently, once a day (either late evening or early morning) planning

sends the customer orders. Orders are made up of two types of items (i.e. merchandisers): supermarket items and Make-To-Order (MTO) items. The supermarket items are withdrawn from the supermarket, the MTOs are made within 24 hours in the exact quantity needed. Once the daily orders (i.e. pulls) are in from planning, the pack center scheduling group schedules the shop floor based on the rules in the seasonal Heijunka (i.e. takt time, item level max, etc.) and the pulls requested by planning.

A number of things are critical to this model. First, the pack center always produces at a level rate as prescribed by the Seasonal Heijunka, this will ensure level pulls on the upstream operations. Second, the customer pulls are unlevelled and therefore some inventory (i.e. supermarket) is necessary to level demand. Third, the pack center is capable of lot sizes of one on any item and has 100% reliability that it will meet takt time. This is crucial to this model. There is no inventory buffer for supply variability; the sole purpose of the supermarket is to absorb customer demand variability.

5.1.3. The Heijunka Board

Figure 15 shows the Heijunka board used to schedule the production of merchandisers. Each card identifies one pallet, or partial pallet, of a certain type of merchandisers. Cards are color-coded based on the products contained in the merchandisers. Additionally, the red line on the bottom of the card identifies supermarket items. Each card instructs the operators on what to produce, how much to produce and where to send it. Once a pallet is produced, the card is placed on the pallet. By limiting the number of cards in the system, we are able to limit both production and, for the supermarket items, inventory. In other words, say there are 30 cards for supermarket item A in the system. If a card is placed on every completed pallet, then once there are 30 completed pallets there are no more cards and no more production can be scheduled on the board. With this method it is possible to keep track of both inventory ahead as well as daily max quantities. Leveling out the cards by color will help level the pulls on the upstream operations. Each row is

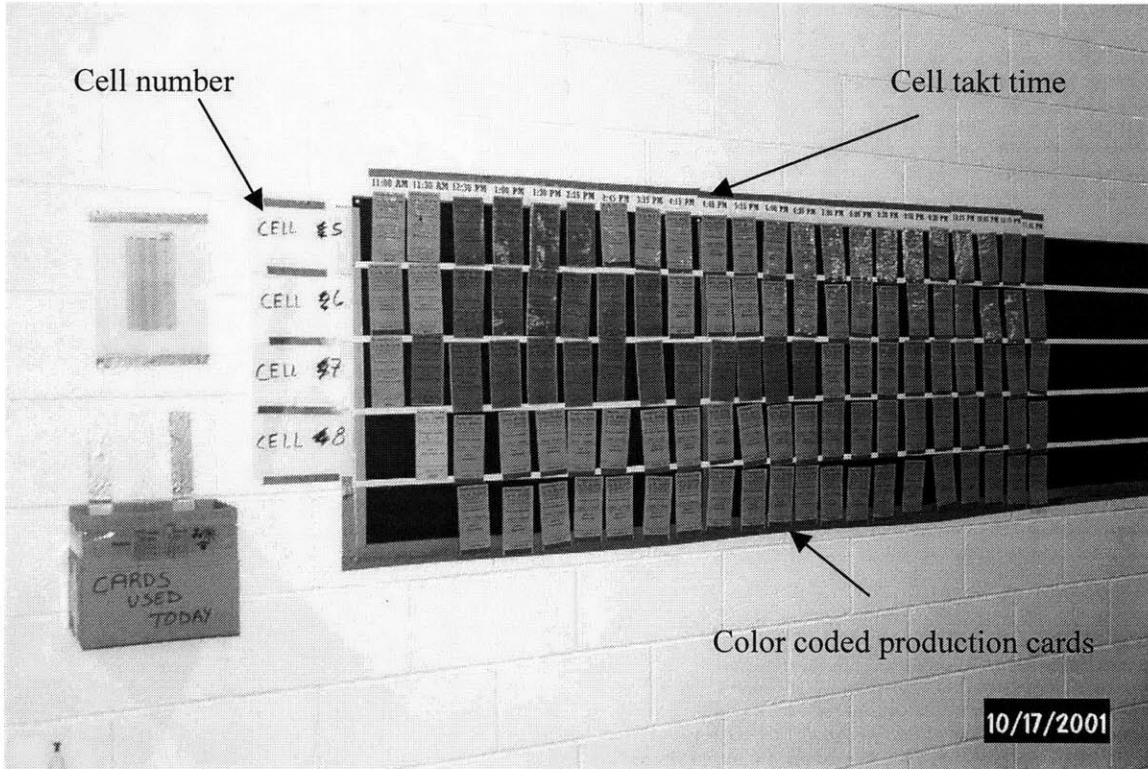


Figure 15: Daily Heijunka Board in the Pack Center

the expected production of a cell. Each card is spaced based on the required takt time and taking into account breaks and shift changes for the work force.

5.1.4. Supermarket Visual Board

Figure 16 shows the inventory board. This board is located next to the Heijunka board and serves as a visual indicator for the amount of material stored in the supermarket. Since in the pack center the supermarket is used to absorb demand variability, the inventory in the supermarket reflects the pack's center ahead or behind situation. Whenever a pallet of material is placed in the supermarket, a tag is placed on this board to reflect that. Similarly, when a pallet is removed, a tag is removed. The tags form a bar chart of inventory in the supermarket. By simply looking at this control chart, it is easy to tell how full or empty the supermarket is. The max level of each bar in the bar chart is easily recognizable. In Figure 16 the supermarket is full.

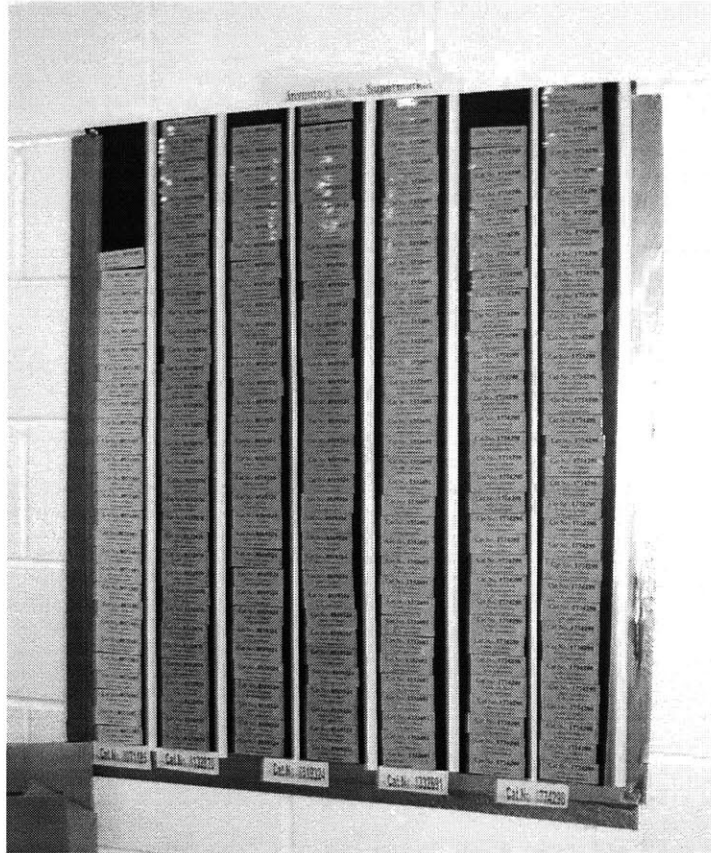


Figure 16: Supermarket Inventory Bar Chart

5.1.5. The Effect of Smoothing on Our Suppliers

Prior to the implementation of this system, large inventories were required between the supplying operations (i.e. 35 mm film, APS film and OTUC) and the pack center. The reason is quite simple. While the pack center has a huge capacity and extreme flexibility, the upstream operations do not. Upstream operations are constrained by lot size, lead-time and machine reliability. Therefore, these operations cannot follow customer demand.

Once this production system is in place the demand on the upstream operation is leveled. Consequently, these operations can get closer to following the pull signals and much of the inventory between the two operations can be eliminated. We will revisit this discussion after analyzing the 4-pack model.

5.2. The 4-Pack Model

4-packs are packages of 4 rolls of film. Generally, the four rolls are the same but their can be combinations in which they are different. 4-packs are assembled on high speed lines which take the rolls of film from spooling and group them 4 at a time, insert them in a cardboard box and seal the box. It is important to analyze the 4-pack scenario for two reasons. First, it is one of the main suppliers to the pack center and it will be helpful to understand how leveling the pack center helps 4-pack. Second, it is a build-to-stock model like all other finishing work centers. Consequently, the production system used in 4-pack is applicable to virtually all other work-centers at Kodak that receive a customer signal.

5.2.1. The Build-to-Stock Scenario

Most Kodak customers want product available immediately as soon as their order is placed. Consequently, Kodak has an extensive distribution network with regional warehouses in order to serve its customers. When a customer places an order, the order is routed to the closest Regional Distribution Center (RDC), which ships the product from the available stock. Internally, these RDCs operate on re-order points. When inventory falls below a pre-determined re-order point, an order is placed on the factory to replenish the product consumed. The amount of inventory held in the RDC is proportional to the lead-time necessary to replenish it and the variability of customer demand.

5.2.2. The Supply Variability Inventory vs Demand Variability Inventory

Probably the single most important change made by the new production system is to divide inventory into two separate “supermarkets.” The distribution center holds the inventory as a result of demand variability. The supermarket next to the production lines protects from supply variability. Figure 17 shows a schematic of how the production system in 4-pack will work. Orders from the customer go to the distribution system and are shipped directly to the customer on a daily basis. When inventory falls below the re-order point, an order is sent to the factory. In order to allow the factory to see a pull

signal as close as possible to customer demand, the minimum order size was set to one pallet. Therefore, any order of one pallet or more will be passed directly to production.

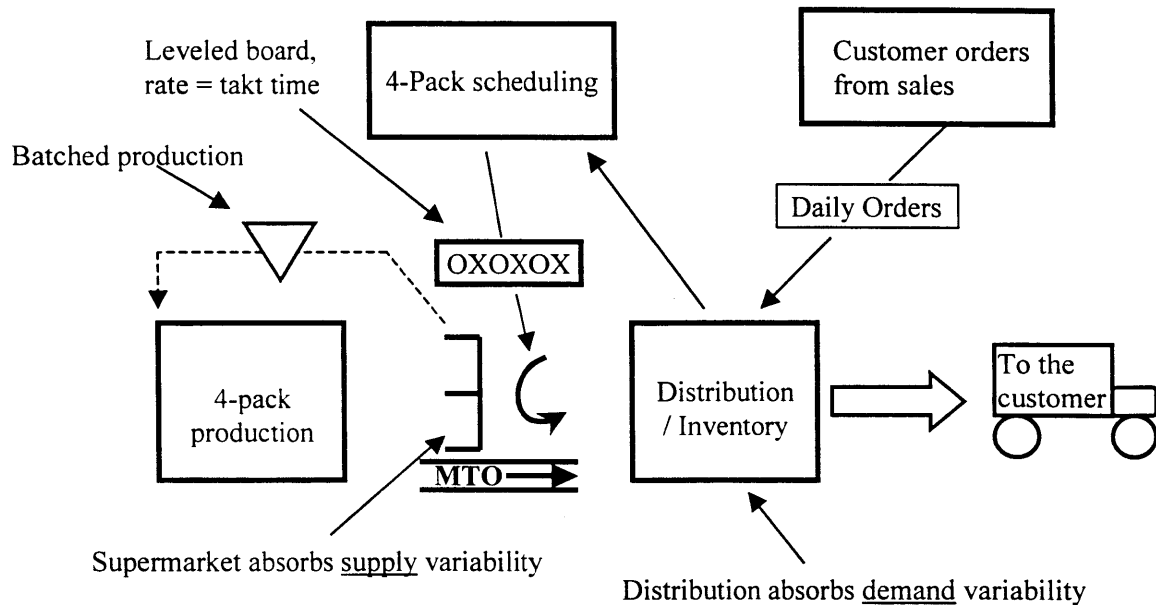


Figure 17: Build-To-Stock Production Model

5.2.3. Effects of the Process on Lot Size, Lead-Time, Etc.

The scheduling group looks at 4-pack orders coming from distribution and schedules leveled pulls at a fixed takt time based on 4-pack's Seasonal Heijunka. Therefore, the pulls conform to all the Seasonal Heijunka rules such as fixed takt time, daily item level max, etc. This is a fundamental difference from the pack center. In the pack center, the board schedules production because there is no supply variability. In 4-pack, as in all other work centers in Kodacolor, there is supply variability, in other words even if we pull at a constant takt time, production cannot meet this demand. This is due to the fundamental difference in the production process. The pack center is completely driven by manual labor, there is no real equipment necessary to assemble a merchandiser. In all of the packaging work centers, spools of film are packaged into cartons at high speeds on highly automated equipment. These work centers package well over one million spools per day of film. Therefore, there are multiple reasons why the packaging work centers have demand variability. First, lot sizes are larger than one pallet due to the way

equipment was designed and due to the difficulty of performing changeovers. Second, production has unexpected down time due to machine breakdowns. This is a common problem and packaging routinely has trouble meeting its scheduled takt time. Third, lead-time for a product is several hours. Because of all these factors, production must have a supply supermarket to help meet the daily pulls. This inventory is next to the production line to serve as a constant reminder that production is unable to meet level pulls.

The ahead and behind rules in a build to stock scenario are based on the inventory in distribution. In other words, the distribution inventory reflects whether the takt time is ahead or behind demand. Ahead and behind rules can therefore be explained as a percentage of reorder point. For example, if inventory is at or above reorder point for all supermarket items, then the system is ahead because there is enough inventory in distribution to meet demand. If inventory is at 40%³ of reorder point or below, the system is behind.

This division of inventory based on its cause is a major breakthrough to achieve inventory reduction. Prior to this, most personnel in production associated the presence of inventory to uncertain customer demand. Now, there are no excuses. The inventory in this supermarket is completely production's responsibility. When production will be capable of running small lot sizes with no down time, large inventory will be unnecessary.

5.3. MRP vs Lean or Macro vs Micro

One of the major issues encountered during the implementation process was how to coordinate lean with the existing ERP/MRP systems. The difference is that MRP sets the production schedule based on a forecast, while the Seasonal Heijunka process sets up the capacity of the supply chain based on forecast but operates on customer demand on a day-to-day basis.

³ The 40% value is picked arbitrarily in this case. Generally the behind value will be somewhere between 30% and 70% of the reorder point.

The transition from one system to the other can be somewhat difficult. ERP/MRP systems were originally designed to help operate at the macro level and to keep track of inventory throughout the supply chain. However, these have evolved to control virtually every phase of the production. For example, MRP is used to schedule production, force pre-determined lot sizes and lead times at each process step and identify inventory for specific customers or uses. On the surface this all sounds like a good idea, however a series of problems arise on the shop floor:

- There is little to no incentive to reduce lot size and lead-time because these values are fixed in the system.
- MRP encourages employees, particularly the planning community, to use the system instead of actually seeing what is taking place on the shop floor. It is difficult to make improvements to a process while sitting in front of a computer screen.
- Even though MRP vendors claim that these software packages can be customized to virtually any scenario, the reality is that very few people have the knowledge and understanding to change the system. Consequently, these systems encourage the “this is the way we have always done it” type behavior and discourage improvements and innovation.
- As a result of the difficulty of learning the entire system, employees tend to work only in their specific area developing little or no knowledge of the entire process. For example, a planner might be in charge of scheduling product A in work center C. The planner most likely only knows the screens in MRP that he/she needs for his/her task and being completely separate from the production floor he/she tends not to understand how their decisions may affect the rest of production.

For these reasons, MRP/ERP use should be limited to high level planning and forecasting and for transmitting information between separate sites. For example, it is used to pass on customer orders from the distribution centers. In essence, it should be used for the inputs and outputs to the shop floor. However, the shop floor must run on simple visual

signals so that production methods and systems can be constantly modified and improved.

5.4. Continuous Improvement

The two models presented in this chapter, the pack center and 4-pack, are two different stages of the evolution of the production system. Once the Seasonal Heijunka production system is in place, the goal is to slowly eliminate the inventories in the supply chain through continuous improvement of the operations. For example, 4-pack's goal is to become a reliable supplier with short lead-time and small lot size. When this goal is achieved the "supply variability" supermarket can be eliminated and inventory reduced. At this stage, 4-pack will operate similarly to the pack center. In a similar fashion, all the other operations: sensitizing, slit/perf, the cardboard supplier, etc. need to improve their processes to reduce inventory. Sales and marketing must work with the customers to help reduce demand variability and encourage them to purchase small quantities at high frequency. This will result in lower inventories for everybody. It is easy to see how this system permeates the entire organization. The more commitment and involvement from all parts of the organization, the more successful this system will be.

6. Conclusions and Future Work

6.1. Lean Manufacturing at Kodak

Through its involvement with the Leaders for Manufacturing Program and other similar initiatives, Kodak has been working on lean for quite some time. The formation of the Kodak Operating System Office has been a major step towards implementing lean manufacturing in the color film division. Additionally, other divisions are also starting to follow the same path.

The fundamental purpose of lean is to reduce the cost of color film. This is accomplished by eliminating all forms of waste. In particular, eliminating inventory will free up cash to invest in growing businesses and will accelerate the cash flow cycle and ultimately improving cash flow. Additionally, the elimination of waste will reduce the cost of color film, which will help Kodak maintain its margins as retail prices decline.

6.1.1. The Seasonal Heijunka Production System

The production system described in this thesis will allow Kodak to systematically identify and eliminate waste from its production while remaining customer focused. The system adapts the fundamental philosophy of the Toyota Production System to a business with significant demand uncertainty and more pronounced seasonality than the automotive industry for which TPS was originally developed. The system emphasizes some key concepts:

- The importance of developing a lean culture, which focuses on waste elimination.
- The use of lean tools to eliminate waste in the production processes.
- The use of small lot sizes, short lead times and short changeovers to reduce inventory.
- Sizing the supply chain based on a seasonally adjusted forecast.
- Operating the production on a pull system based on daily customer demand.

6.1.2. Supply Chain Analysis Results

The analysis of the supply chain proves that the combination of shorter lead times and faster changeovers can lead to significant inventory reduction from the current state. These improvements can be achieved through the application of Kaizen events and other lean tools at various operations in the supply chain. The analysis shows that, as a result of the current large lot sizes and weekly schedules, sensitizing is an area where Kaizen events can be particularly effective.

Additionally, the analysis shows that before being able to implement any of the typical lean techniques such as Kanbans, it is fundamental to run at a level takt time. Because of the variability and seasonality of Kodak orders this takt time will be adjusted seasonally. However, only by running at a constant takt time can a pull-system be implemented with reasonable inventory. For these reasons, initial implementation efforts must focus on the finishing work centers so that all pull signals to the upstream operations can be leveled. The finishing work centers are the ones at the end of the supply chain closest to the customer. They are all the packaging work centers, like 4-pack, and the pack center.

Finally, the analysis shows that the leveling concept of trying to run every product every day as close as possible to the average daily demand can yield significant inventory savings. In the analysis, the idea of introducing a range (i.e. a minimum and a maximum) and then working continuously on tightening this range gives a practical way of approaching production at the average daily value. Sales and marketing, in coordination with the planning community, must play a crucial role to help improve leveling. The savings from film code leveling can be very significant and are quantified in detail in chapter 4.

However, by far the biggest benefit of the work performed in this internship and of introducing lean in general is to refocus people's attention on the shop floor. The enormous benefits of level production on productivity and quality are simply immeasurable and are probably the main reason why so many companies struggle to

understand why Toyota is so successful. Only with stable, level production can workers dedicate their efforts to productivity and quality improvements.

6.2. Future Work

There is no such thing as a “lean company.” Every company has extensive areas of improvement and waste elimination. The work described in this thesis sets up production in a way that it can now operate more efficiently. The production system forces accountability for every parameter in the system. However, there are still significant improvements that must be made to reduce costs and inventory. Primarily, before a successful pull system can be implemented, all the finishing work centers must have a well developed Seasonal Heijunka which levels their production so that all the upstream operations will face less variable pull signals. Without this leveling, the pull system will simply not work.

Once the Seasonal Heijunkas are in place, all efforts will have to focus on reducing lot sizes and lead times in all the operations to get material to flow through the supply chain. In this respect the, value stream mapping will prove an invaluable tool to map the progress of the supply chain. Finally, Kodak must realize that lean is a long journey. It took over 6 months to implement seasonal Heijunka’s in two work centers and both are still not operating completely correctly. Therefore, it will take some years to get the entire supply chain to work on a true pull system with leveled demand.

6.2.1. “Squeezing” the Supply Chain

Once the production system is in place it becomes critical to “squeeze” waste out of the supply chain. In other words, operators and managers must work together to systematically identify and eliminate waste. This will slowly eliminate inventory from the supply chain. On the one hand, this process becomes harder every day because the “low hanging fruit” is easily identified, but hidden waste is harder to find. At the same time, these tasks become easier every day because Kodak employees will slowly develop a “waste elimination” culture.

6.2.2. Applying Lean to Other Operations

Lean is already being passed on to other operations such as paper manufacturing and photochemicals. Color film, through the KOS office, has taken the lead in applying lean within the company. It will serve as a benchmark for all other businesses at Kodak. As we discussed, the lean concepts go beyond the manufacturing floor. The challenge for Kodak is to educate its workforce on lean so that employees are not simply applying tools as a black box, but actually understand the thought process and the philosophy behind these tools. It is this culture, not the production system nor the tools applied that will make Kodak a world class manufacturing company. The tools and systems will continuously evolve and change while the culture will get stronger and widespread among the workforce.

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