The Impact of High-Mix, Low Volume Products in Semiconductor Manufacturing

By

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Submitted to the MIT Sloan School of Management and the Department of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration
and
Master of Science in Civil and Environmental Engineering

In Conjunction with the Leaders for Manufacturing Program at the
Massachusetts Institute of Technology
June 2003

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Abstract

The communications industry is a market with phenomenal growth opportunity. Companies such as Intel Corporation are using this potential market expansion to build upon their core business in semiconductor manufacturing. There are 2 key differences between current semiconductor products, such as memory and microprocessors, and the integrated circuits required in the communications industry: volume and product mix. Very high volume products with little variety characterize the current products, whereas communications products are traditionally made up of a high-mix of low volume products.

This thesis examines the high-level manufacturing question of how Intel's high volume manufacturing will be impacted by the addition of high-mix, low volume products. A framework was developed to analyze any change in manufacturing strategy. The 4-step process includes:

1) Understanding production systems relation to product composition
2) Relating business drivers to production systems
3) Completing a competitive analysis to determine key business drivers
4) Adjusting manufacturing procedures to match the new system requirements

The manufacturing procedures are analyzed comparing how each behaves in low-mix, high volume product environments versus high-mix, low volume product environments. Finally, the thesis concludes with recommendations for future research on this issue.

Thesis Supervisors: Charlie Fine
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Acknowledgements

I would like to express my sincere appreciation to everyone who has supported me throughout my journey at MIT. The Leaders for Manufacturing (LFM) Program has provided me with a wonderful opportunity to develop academically, professionally, and personally. I would like to thank all my classmates and the staff for making these last two years truly amazing.

To my colleagues and champions at Dell, I appreciate your faith in my ability and generous sponsorship of me to the LFM Program. I am grateful for the opportunity and look forward to returning to Dell and working with such a dynamic group of people.

To Intel Corporation who sponsored the work for this thesis, I am appreciative for the experience. I hope this is only the beginning of fostering collaboration between Dell and Intel through the LFM Program. Specifically to the ICG Manufacturing Ops Group; Chris Richard, Brian Kelly, Mark Scott, Jon Frommelt, Eric Simpson, and Dave Fanger, I thank you for your encouragement and insights into the Intel culture. And to my supervisor, David Knudsen, I also thank you for always being there with a pep talk, right when I needed it.

Thank you to my MIT advisors, David Simchi-Levi and Charlie Fine, for their guidance and advice throughout the work of this thesis.

To my Smoothie Leadership Team: Strawberry, Kiwi, Mango, Ravioli, Chorizo, and honorary member Lemon-Lime, I am a better person because of your help and advice throughout this process. I look forward to continued friendships, professional relationships, and lots of laughs in the future.

I would like to thank my parents and brother and sisters for their encouragement to enter graduate school. The precedent you have set helped paved the way for me to undertake this wonderful opportunity. Your constant support of my endeavors is appreciated more than you will ever know.

And most importantly, this thesis is dedicated to my husband, Rob. You continue to amaze me everyday with your love and creativity. Thank you for encouraging me to follow my dreams and then supporting me throughout these crazy 2 years! I look forward to continuing this life of adventure that we have started together.

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Chapter 1 – Introduction and Overview

This introduction and overview chapter provides background on the high-level manufacturing strategy question raised in this thesis. A background on Intel Corporation is presented as it provides the foundation of this study. The last section provides the thesis structure and framework used throughout the remaining chapters.

1.1 Problem Statement

Production systems have evolved over time according to product mix and process structure. From initial welding and craft shops to Henry Ford's mass production of the Model T to the evolution of Lean manufacturing in Japan, different systems have been created. Hayes and Wheelwright created the Process/Product Matrix in 1979 that links the appropriate process structure with product mix [1]. The premise of the diagram below is that companies should match products and processes by staying on the diagonal. Any move off the diagonal should only be taken consciously with a strategic plan in tact.

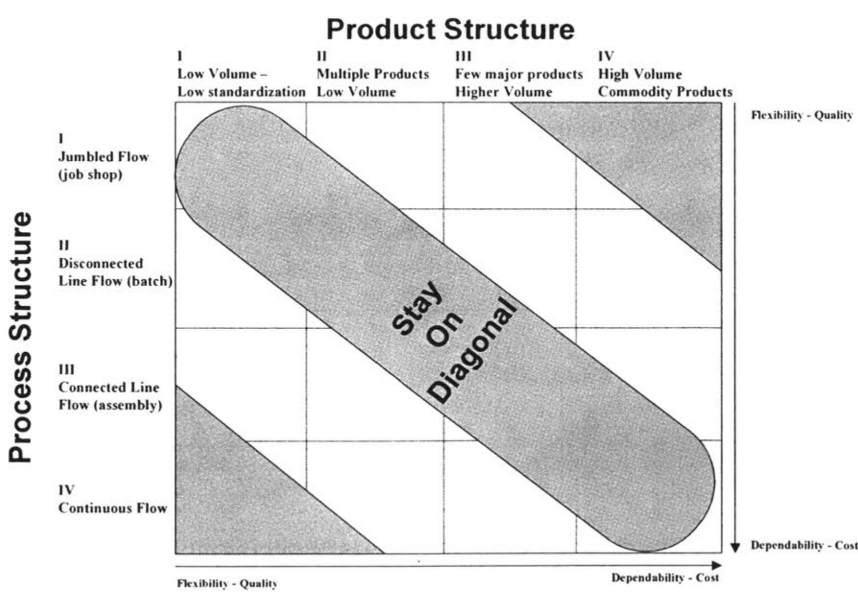

Figure 1.1 Hayes/Wheelwright Product/Process Matrix [1]

The dilemma Intel is currently facing is that their current manufacturing system does not match their prospective new market growth. Microprocessor manufacturing is optimized for very high volume with a relatively small product mix. Intel's growth into the communications market brings a new product mix requiring a different production system. The communications industry is characterized by a high-mix of low volume products. A manufacturing strategy needs to be formed to include these new products in Intel's manufacturing. This new market either moves them to a new production system "up" the Hayes/Wheelwright diagonal or requires them to utilize their current process and venture "off the diagonal." Either situation should not be entered into lightly. Figure 1.2 shows the potential move options for Intel in the communications market.

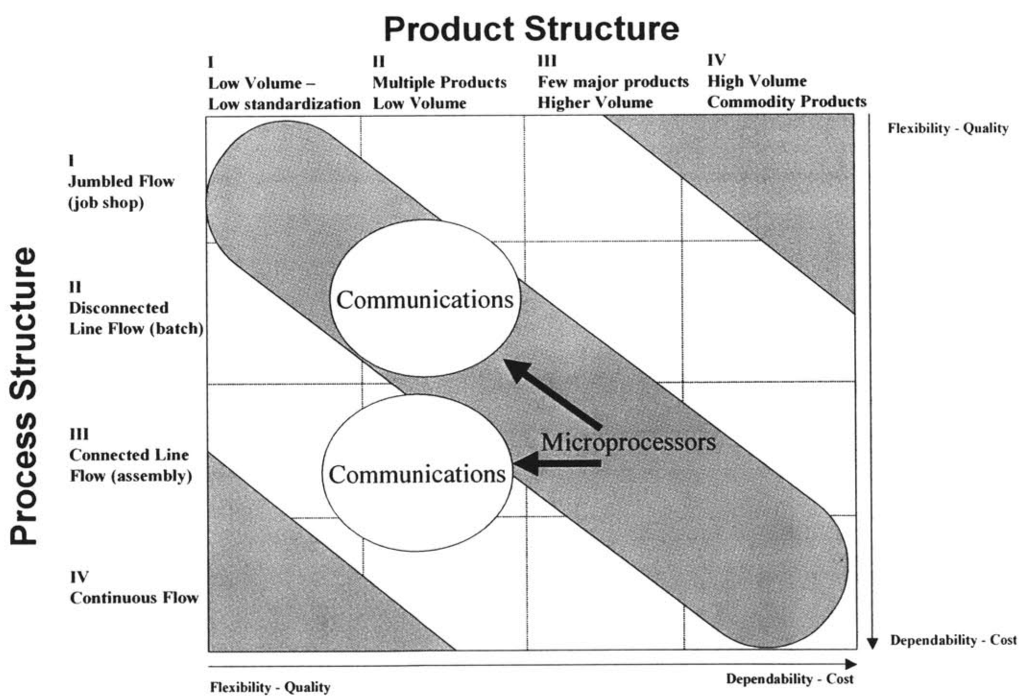

Figure 1.2 Potential Movements along the Hayes/Wheelwright Matrix for Intel

1.2 Intel Corporation Background

Intel Corporation is a leader in semiconductor technology and manufacturing. Founded in 1968, Intel began as a memory producer before introducing the first microprocessor in 1971. Today, Intel supplies chips, boards, and systems for the computing and communications industries. Intel's mission is "to be the preeminent building block supplier to the Internet economy" [7].

1.2.1 Moore's Law

Gordon Moore, one of the co-founders of Intel with Robert Noyce, forecasted the rapid pace of technology innovation in 1965. This forecast has since earned the name, Moore's Law. The foundation of Moore's Law is an empirical relationship between time and the number of transistors that could be placed on an integrated circuit. As shown in Figure 1.3 below, Moore's Law states the transistor density on integrated circuits doubles every couple of years.

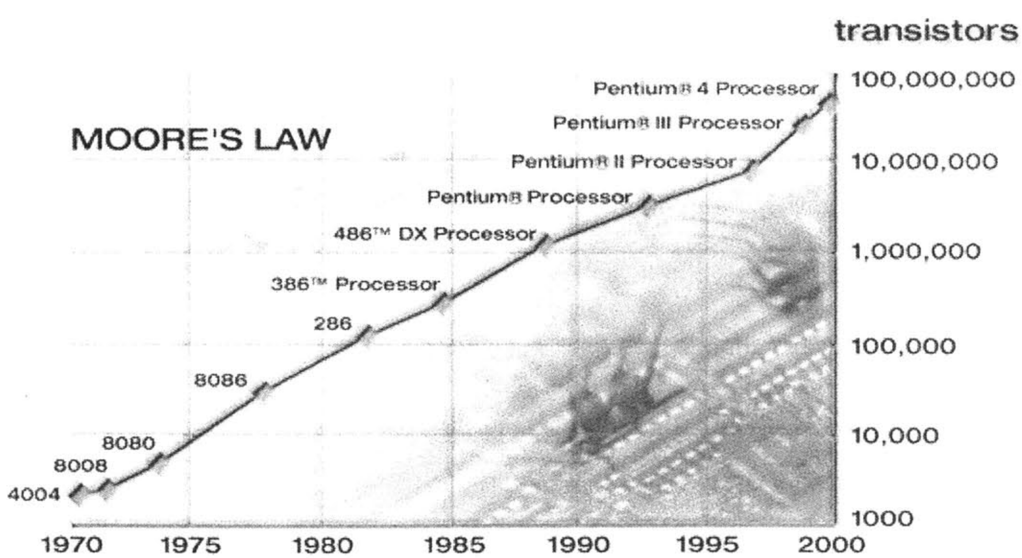

Figure 1.3 Moore's Law (http://www.intel.com/research/silicon/mooreslaw.htm)

This phenomenon has held true for over 30 years, and with current advances in technology being investigated, there appears to be no end in sight. Gordon Moore, in referring to his law described above, has been quoted as saying, "More than anything, once something like this becomes established, it becomes more or less a self-fulfilling policy" [7].

1.2.2 Historical Competitive Advantage

It is through Intel's consistent dedication to technological advances that the company has stayed ahead of the competition. Intel is a $26 billion company and invested $3.8 billion in R&D in 2001. In the same year, Intel spent $7.3 billion on capital investments to expand and improve its manufacture capabilities [7]. It currently commands approximately 80% share of the microprocessor market [8].

This incredible lead is established through its unique competitive advantages of economies of scale and fast and efficient execution worldwide. Intel has a parallel product and process development. The company then incorporates its rapid transition program from development to full volume production. Intel uses a "Copy Exactly!" (CE!) methodology to decrease time to market and increase yields [7]. The foundation of CE! is the ability to quickly ramp products into production. Each step of the development process is exactly duplicated when the product moves into the factory. And each Intel factory is nearly identical so that products and processes may be shared through a Virtual Factory and brought up to speed quickly. This method is in stark contrast to most companies in the semiconductor industry who rely on different development equipment before handing off the products to the factory.

1.2.3 Intel's Communications Group

Intel has been entering the communications market such as Ethernet and wireless in the last few years. The plan is to find areas of growth for integrated circuits as the market for computer microprocessors has slowed. Communications is currently a relatively small market with an uncertain future, but the growth potential is phenomenal.

Business Week magazine reported that Intel invested in more than 30 acquisitions in the past three years at a cost of greater than $10 billion. CEO Craig Barrett expects communications and wireless business units to grow 50% annually [10]. Intel's goal is to bring "flexibility, cost savings, and faster time-to-market" to the communications industry [7].

With a historical competitive advantage of bringing leading edge products on leading edge processes, Intel plans to continue this methodology into its new markets. Outsourcing, while it has been done in the past, is not the preferred option for future growth. Therefore, Intel must adapt its current strategy in manufacturing to incorporate these new products.

A key difference between traditional Intel products and the newer communications products is the product life cycle. Microprocessors in general have historically had a 12-18 month life. The communications products on average have a five-year life cycle. The shorter life cycle of microprocessors forces the manufacturing system to quickly ramp the new products to high volume. When a new product comes on line, the older product volume is rapidly decreased as well. In contrast, the large mix of communications products does not have such a well-defined product growth and life cycle. The volumes can vary significantly over the five years.

Another key differentiator is that the relationship between product mix and volume within the communications sector is not consistent. Forecasted demand is measured in wafer starts per week (wspw) which is an industry metric used throughout semiconductor manufacturing. Graphing the number of products or line items against the annual demand volume shows the variety within the industry. Figure 1.4 below shows three categories that can be used to identify groups within Intel's communications product line: Commodity, Mainstream, and Specialty.

The Commodity group is relatively high volume with only a small number of line items. Mainstream products have a larger variety with much lower volume. And Specialty products are on the far end of the spectrum with extremely low volume and a high mix of products. While all of these products represent high-mix, low volume, there is not a one size fits all solution to this situation.

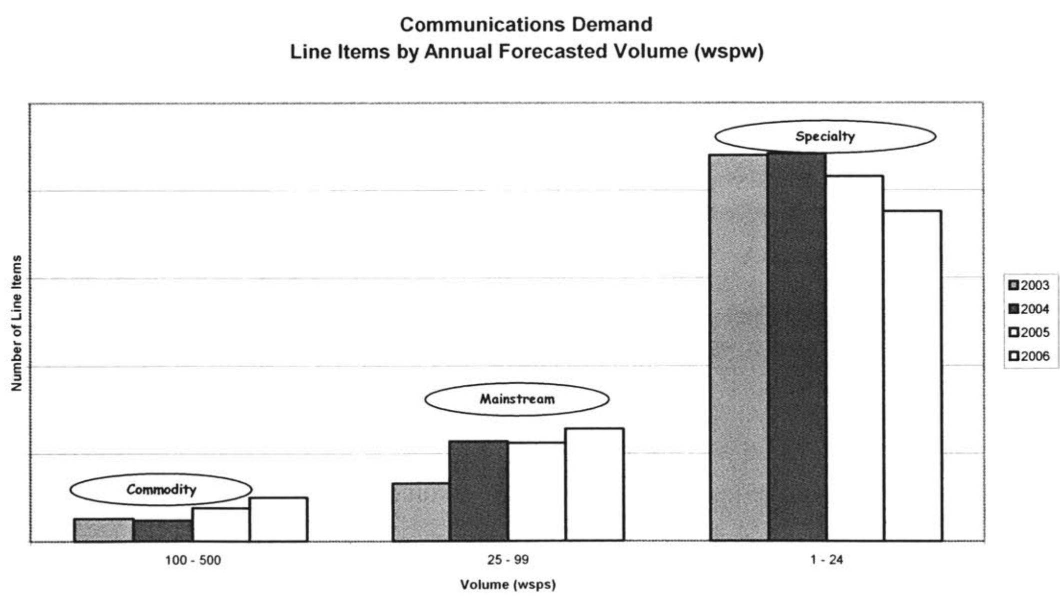

Figure 1.4 Product Breakdown by Line Items and Volume

1.3 Thesis Structure

This thesis is divided into 10 chapters. Chapter 2 discusses the problem Intel is facing from an outside perspective. Benchmarking is done from other companies, as well as, industry research on the transition from low-mix, high volume (LMHV) to high-mix, low volume (HMLV). Chapter 3 introduces an overall manufacturing strategy framework that starts with a modified version of the Hayes/Wheelwright product and process matrix and carries through to business drivers, competitive analysis, and manufacturing procedure adjustments. Chapters 4-8 analyze how each manufacturing procedure varies from a LMHV environment to a HMLV one. Each chapter includes the challenge Intel faces on the corresponding manufacturing procedure. Finally, Chapter 9 summarizes the key learnings of HMLV, provides recommendations for Intel, and considers topics for further research.

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Chapter 2 – HMLV Research

This chapter focuses on outside research in high-mix, low volume manufacturing. First will be a historical look at high-mix manufacturing. This is followed by an analysis on the balance between mix and complexity and cost. And lastly will be a look at benchmarking of other companies with examples of how one company adapted to changes in product mix and volume.

2.1 Historical Evolution of HMLV

High-mix, low volume production has evolved from the advent of mass production with Henry Ford's Model T to the advances made by Japanese manufacturers in the 1970's and 1980's to meet customers desires for more choices.

2.1.1 Henry Ford and the Model T

Henry Ford is often credited with revolutionizing the manufacturing industry. He did not invent the automobile or the assembly line, but he did change the process so that cars could be mass-produced and enjoyed by many at a reasonable cost. The advancements made with the application of a moving assembly line reduced the amount of time it took to produce an automobile. For example, in 1914, Ford produced 300,000 cars with 13,000 employees, while the other 299 auto companies together produced 280,000 cars with over 66,000 employees.

Henry Ford is often credited with saying the buying public could purchase a Model T "in any color, so long as it's black." Whether or not this is a true statement, Ford optimized his production system and used black paint because of its faster drying time. Ford created an efficient production system focusing on low-cost automobiles so that automobiles could be purchased by more of the general public. The addition of different body colors was added later in response to customer demand.

Michael Porter claims that competitive advantage comes fundamentally from a value that a firm creates above and beyond the cost a buyer is willing to pay. There are two distinctive types of advantages: cost leadership and differentiation [4]. Since the inception of mass production, manufacturing companies have been trying to achieve an advantage over the competition using these values.

2.1.2 Introducing Mix into High Volume

Many companies now understand that customers not only desire product variety, but also that they have come to expect it across many industries. However, a business cannot simply introduce this variety into a volume-focused manufacturing environment without affecting other business metrics. Mahoney outlines the flaws in this strategy with an explanation of the Honda-Yamaha (H-Y) war in Japan [3]. The intense competition began with Yamaha announcing its plans to invest as necessary to become the largest motorcycle producer in the world. Honda's response to this threat was to increase product offerings by introducing 113 new products over the next 18 months. Customers chose the variety offered by Honda and left Yamaha financially devastated. When the war ended, both companies suffered through increased costs and inventories.

2.1.3 Japanese Evolution of Manufacturing Principles

Since the H-Y war of the 1960's, the Japanese have been the leaders in incorporating economies of scale to increased product mix. The thrust behind their evolution of manufacturing strategy has been intense competition within Japan and not the external world. For example, while the U.S. has three major automobile manufacturers, Japan has 10 viable and competitive manufacturers.

Japanese manufacturers introduced the concepts of Group Technology, Design for Manufacturability, Just-In-Time, and Design of Experiments from 1975 to 1985. In particular, the Toyota Production System (TPS) and its focus on Just-In-Time cost reduction was introduced in the 1970's, and its continuing evolution is still recognized as a competitive advantage for producers today [3]. TPS remains the ultimate benchmark for successful HMLV manufacturing.

2.2 Balancing Costs with Customer Needs

The most important thing for customers is receiving the product they want; in the time they want it, at a low cost, with high quality. However, a company cannot offer infinite variety and expect infinite growth. A balance must be made between cost and mix. The company must determine the extent of variety that customers truly value and analyze the complexity involved in that increased variety. According to the Boston Consulting Group, the cost of complexity (i.e. inventory, material handling, set-up, test, overhead) increases in proportion to the logarithm of variety increases.

In Figure 2.1 below, the Total Cost curve is calculated from the costs related to scale and those related to mix.

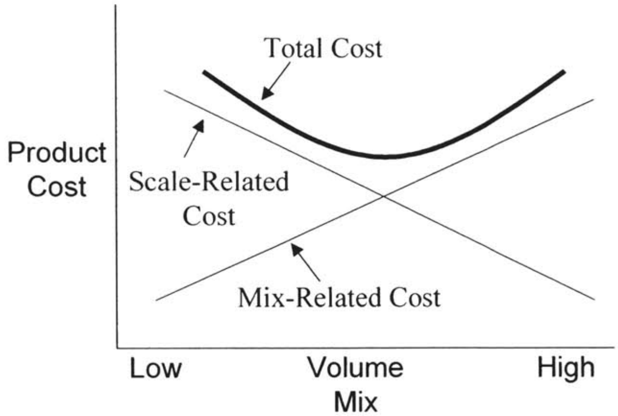

Figure 2.1 Strategic Cost Drivers [3]

In order to increase the firm's competitive advantage in a high-mix environment, the firm must decrease the cost of complexity. Decreased complexity results in increased flexibility and an overall decrease in total cost needed to supply higher-mix products. Determining how and where the complexity costs can be decreased is one step toward efficient HMLV manufacturing.

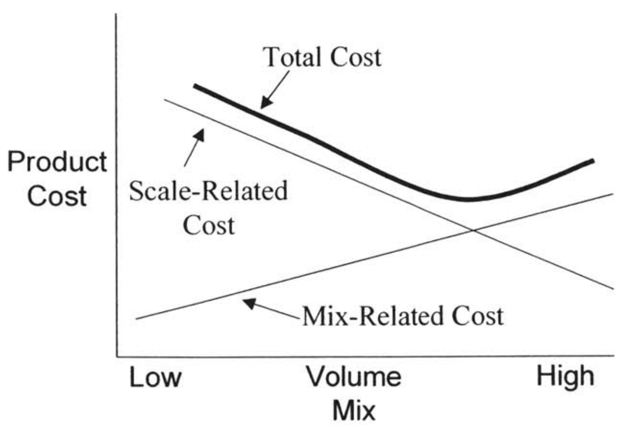

Figure 2.2 Complexity affect on Strategic Cost Drivers [3]

2.3 Benchmarking Examples

Many companies have faced the transition from LMHV to HMLV. The auto industry in particular has been affected by the desires of customers for more variety and personalized vehicles. Over time, consumers have become more finicky about what kind of car they want. This includes everything from color to upholstery to engine size and cup holders. Auto manufacturers have historically followed the same steps of many mass producers in achieving economies of scale by producing in large volumes. This method creates a repetitive environment that allows the same product to be produced consistently at the lowest possible cost. Having a "one size fits all" manufacturing system is no longer an option to remain competitive.

The following sections will detail the way one major car manufacturer (referred to as Company X) has approached this request. In the first example, the manufacturer became more flexible in its current system. And in the second example, the same company created a new system to support a different market segment with increased variety at lower volumes.

2.3.1 Adapting the Current Production System

The first method Company X chose to follow in order to "stay in the game" was to adjust its current system to add in flexibility. In other words, as described in the H-Y war previously, the company could not simply add mix to its current high volume production system. The system needed to change in order to support the new mix. This was done through the inclusion of lean manufacturing principles and added automation for a more flexible manufacturing system. Lean manufacturing is defined as the elimination of waste throughout the manufacturing process. This concept will be explored further in subsequent chapters. These adjustments moved the company off the Hayes/Wheelwright diagonal while still employing the same basic, line assembly system.

2.3.2 Creating a New HMLV Production System

As time has progressed, Company X is still seeking new market areas for growth. A potential niche market for auto manufacturers is low volume, specialty vehicles. The premise behind these cars is the ability to bring them from concept to production in a short time, while only selling a limited number. The volume on these niche cars is approximately $1/5^{th}$ of a regular, high volume vehicle. Yet, it is not as low as a 500-unit vehicle volume that would be hand crafted in a job shop.

Realizing this market has different needs, the company decided not to "adjust" its current production system to include this product. While the new production system has already been made flexible, it is not flexible enough to accommodate these new needs. Thus, Company X has created a new production system. The factory is located in a different area and is being set up with a completely new mindset, that of low volume and customer requirements. The new system also employs a batch process as opposed to a line flow process normally used in auto production. The batch concept allows the company to produce multiple low-volume vehicles while not jeopardizing the business drivers of flexibility and performance [5]. An example of this case study and different strategies pursued is presented in Chapter 3 as part of the Manufacturing Strategy Framework.

Chapter 3 – Manufacturing Strategy Framework

This chapter presents on an overall framework that can be followed when evaluating a new manufacturing strategy. The framework begins with an updated and more detailed version of the previously mentioned Hayes/Wheelwright matrix. This matrix is then extended to relate each production system with the business drivers. The third step is to understand the business drivers by performing a competitive analysis. And finally, once all these things are understood, any changes to the manufacturing procedures can be made. These adjustments will be explored in depth in the following chapters.

3.1 Production Systems

There are two main categories of production systems: product-focused and process-focused. A product-focused system is based on continuous or repetitive demand on a dedicated production line. The specialization of this line is volume-focusing production. The risk associated with product-focused production is inflexibility to meet changes in product demand or life cycle. A process-focused production system can be applied to a broad spectrum of products utilizing the same technology. Ideally, multipurpose equipment is used that can be quickly changed over, is highly reliable, and easy to maintain [3].

3.1.1 Product Volume – Layout Flow Matrix

Hayes and Wheelwright created their product/process matrix in 1979. Since that time, many advances have been made in production capabilities. John Miltenburg created an updated version of this matrix by incorporating systems such as lean and flexible manufacturing systems [6]. See Figure 3.1 below.

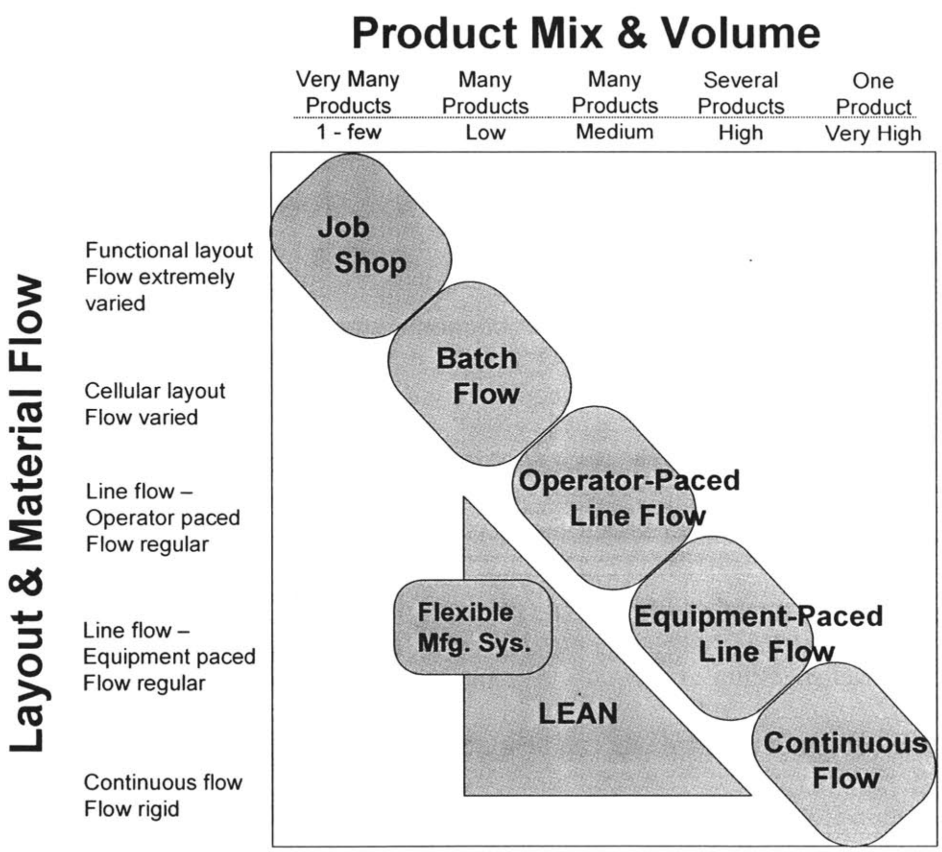

Figure 3.1 Product Volume – Layout Flow Matrix [6]

In this Product Volume – Layout Flow (PV-LF) matrix, each production system is named and given further details on the volumes and line layout. Each system is described briefly below, followed by Table 3.1 that outlines the characteristics of each production system [6].

- Job Shop

  A job shop production system produces many products in volumes ranging from one to just a few. The layout is functional such that material flows through each department. Within each department is general-purpose equipment with operators that are highly skilled in that area.

- Batch Flow

  A batch flow system produces fewer products in higher volumes than the job shop. The layout is functional and/or cellular. Flow may be varied according to product, but a batch of material flows together in the same pattern.

- Operator-Paced Line Flow

  A line flow production system is one in which the equipment and processes are arranged in a line and specialized to produce a relatively small number of products or product families. The product design is stable and the volume is high enough to justify a dedicated line.

  The operator-paced line flow incorporates a highly flexible line system with variable volume and a high degree of product mix. The output of the line depends on the product, the number of resources on the line, and the degree of teamwork between operators.

- Equipment-Paced Line Flow

  An equipment-paced line flow produces a smaller number of products with higher volumes than the operator-paced. The equipment is more specialized and operators normally perform simpler tasks as determined by the speed of the line and the equipment. The output of the line is limited by the speed of the line.

- Lean

  Lean manufacturing is a system of eliminating waste from a production system. It is generally a line flow system that produces several products in low to medium volumes. There are many tools and techniques within lean production, such as statistical process control (SPC), Just-in-Time inventory, Kanban, set-up time reduction, pull production, standardization, kaizen, and problem solving. However, lean is more of a production philosophy than a collection of techniques.

- Flexible Manufacturing System (FMS)

  The FMS production system consists of a variety computer controlled machines linked through an automated material delivery system. The system is highly flexible allowing it to produce many products in low volumes. The system is also very expensive and used when other, simpler line flow systems will not suffice.

- Continuous Flow

A continuous flow production system is similar to a line flow system. However, it is more automated and less flexible. It is designed to produce one product or a few similar products at very high volumes. The equipment is specialized and very capital expensive. The equipment runs with little operator assistance and is used to produce standard products at the lowest possible costs.

Production System	**Product**		**Material Flow**	**Layout**	**Equipment**	**Costs**	
	Variety	**Volumes**				**Fixed**	**Variable**
Job Shop	Major Differences	Very Low	Random	Functional	General Purpose	Low	High
Batch Flow	Large Variety	Low	Random w/ patterns	Cells & Functional	General Purpose	Moderate	Moderate
Operator-Paced Line	Some Variation	Medium	Regular	Line	Specialized	High	Low
Equipment-Paced Line	Standard	High	Regular	Line	Special Purpose	Very High	Low
Continuous Flow	Standard	Very High	Rigid	Line	Special Purpose	Extremely High	Very Low
Flexible Mfg. System	Major Differences	Very Low	Regular	Line & Cells	Flexible, automated	Extremely High	Very Low
Lean	Large Variety	Medium to Low	Regular	Line	General Purpose	Moderate	Low

Table 3.1 Production Systems Characteristics

3.1.2 Example using PV-LF Matrix

Using the Company X case presented in Chapter 2, application of the PV-LF Matrix is shown below in Figure 3.2. In the first situation, Company X migrated off the traditional Hayes/Wheelwright diagonal utilizing Lean Manufacturing principles. In the second case, Company X changed from a traditional equipment-paced line flow to a Batch Flow system. Both moves represent responses to increased product mix and lower volumes.

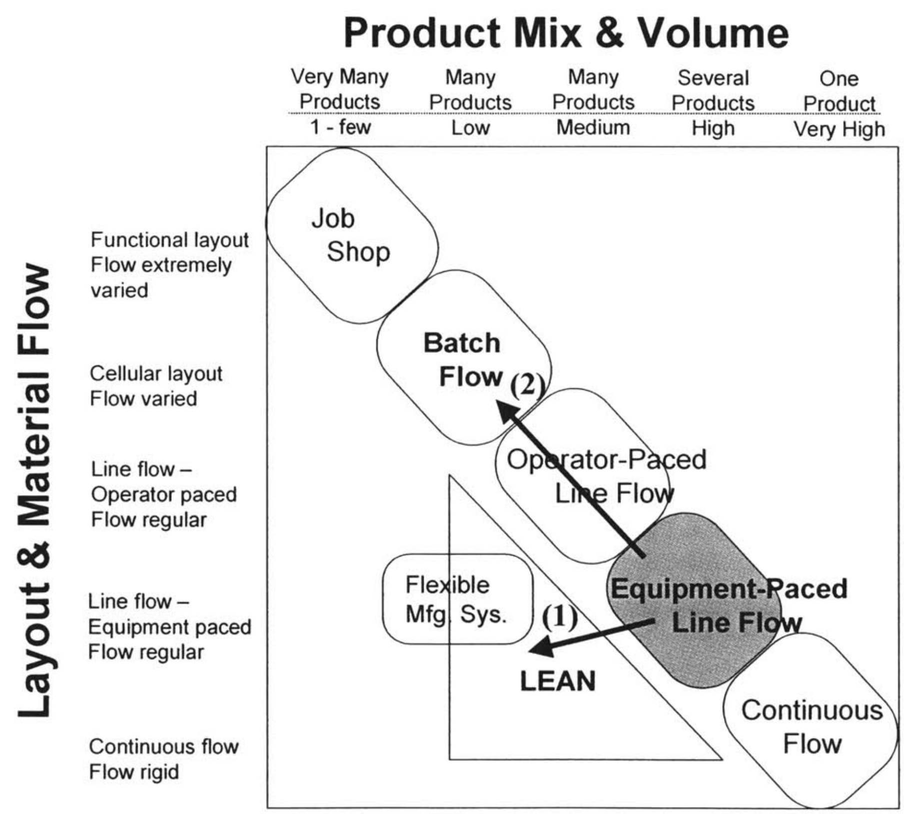

Figure 3.2 Company X Moves along PV-LF Matrix

3.2 Business Drivers

How a company chooses to manufacture its products depends not only on the product volume and mix, but also on the drivers behind the business itself. For example, one company's competitive advantage may be low cost. Another company may excel on delivery. Yet another may win over competitors with higher performance and quality. The advantage a firm has over another determines the business drivers. And different production systems perform better on different drivers.

The six key business drivers are described below:

- Market Responsiveness – Ability to bring new products to the customer quickly (i.e. – new product introduction).
- Flexibility – Ability to respond quickly to changing customer demands on existing products (i.e. – product changeover).
- Performance – Extent to which the products features permit the product to do things other products cannot.
- Quality – Extent to which the product meets the customer specifications.
- Cost – Material, labor, overhead, and resources required to produce a product.
- Delivery – Time between order and delivery to the customer.

Figure 3.2 below shows how each production system performs in regards to each business driver relative to the other business drivers. The initials down the center of the figure represent the different production systems. On the right half of the graph, the longer the black bar, the better performing the production system is in regards to that business driver. A long white bar indicates poorer performance against that metric relative to the other production systems. The key point from this figure is that not all production systems perform the same against different metrics or drivers. Another key take-away from this figure is that there are different degrees of difficulty in implementing each production system. Even if a production system looks ideal, other factors need to be considered such as time, resources, and commitment.

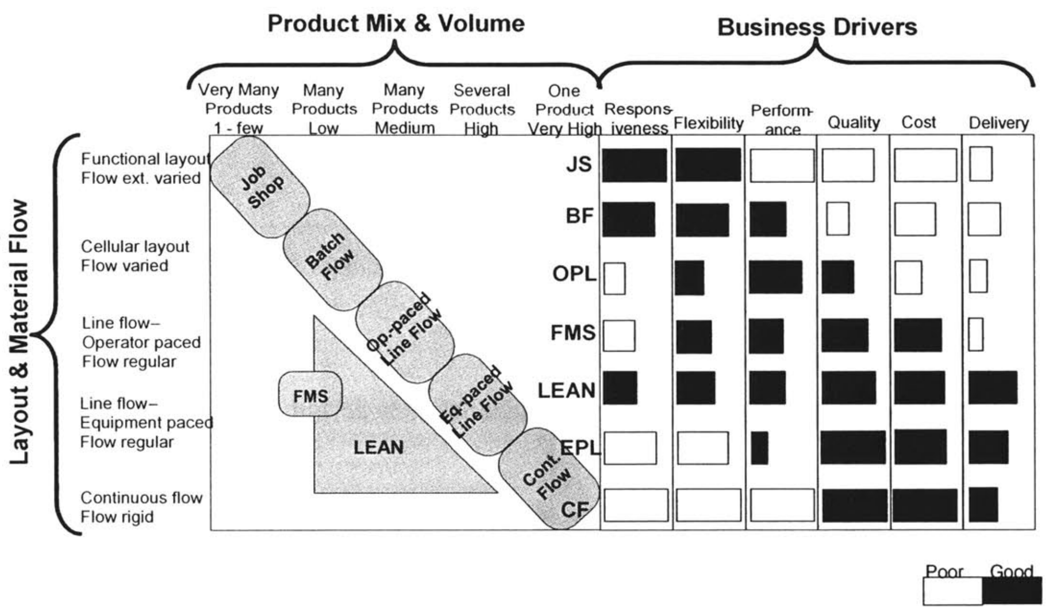

Figure 3.3 Relating Production Systems to Business Drivers

3.3 Competitive Analysis

A company must firmly understand what its business drivers are before creating a new production system. Any drastic changes made without this knowledge may cause a company to head down the wrong path.

A process used to define the business drivers, especially when entering a new market, is competitive analysis. The level of detail involved in this analysis may vary from a high-level overview down to an intense, detailed investigation requiring many resources over an extended period of time. Whichever path a company chooses depends on the needs and maturity of the business.

The basic framework of a competitive analysis is the same regardless of the level of detail. The first step is to choose metrics in each category of business drivers. These metrics serve as the base to compare the following four items:

1) Where is the company currently?
2) What is the market qualifying level?
3) Where is a strong competitor currently?
4) What should the new target level be for the company?

Once each of these metrics is determined, a company better understands where it is and where it needs to be. This process will also highlight the importance of each business driver. The importance level can vary from not a factor, to a market qualifying level, to a competitive advantage. Normally, only one to two drivers stand out as creating a competitive advantage. It is these drivers that a business must focus on when creating a new manufacturing strategy or production system.

This competitive analysis can be applied at a high level to the product categories identified in Figure 1.4. The key business drivers for each communications product category are listed below:

- Specialty - Responsiveness, Flexibility, Performance
- Mainstream - Flexibility, Performance, Quality, Cost
- Commodity - Performance, Quality, Cost, Delivery

Figure 3.4 below shows an application of relating these key business drivers to corresponding production systems.

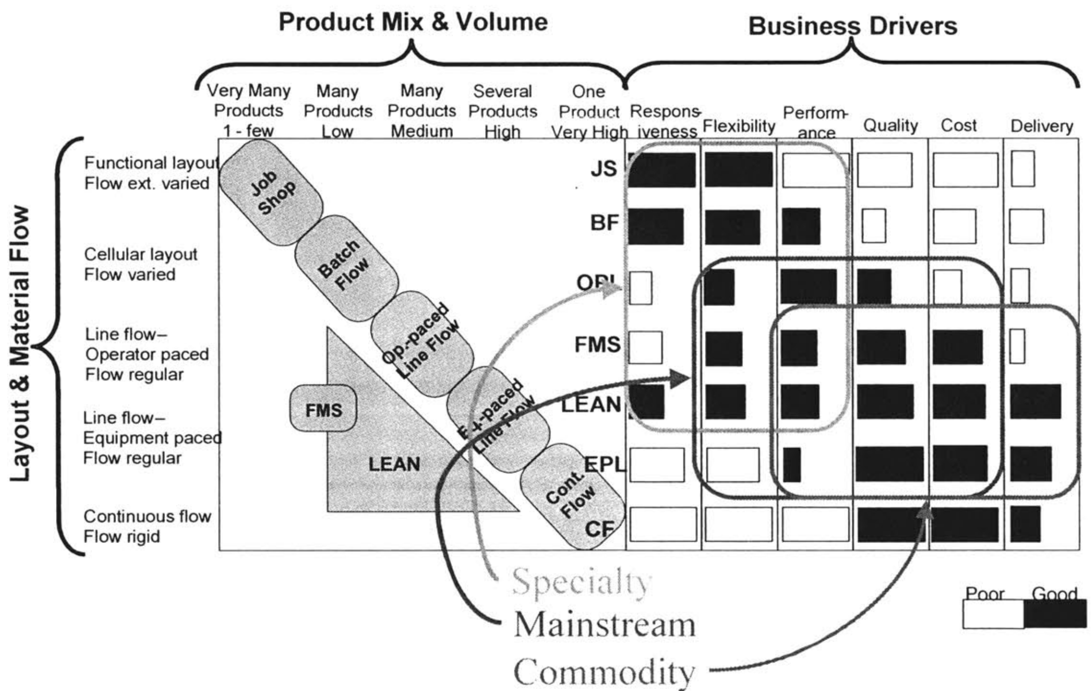

Figure 3.4 Application of Competitive Analysis to Intel's Communications Products

3.4 Manufacturing Procedures

After a firm understands its current production system and related business drivers, and completes a competitive analysis to understand any changes in business drivers, it must then make decisions on any adjustments it chooses to make in the control it has over production. There are five key areas in which a company has control over manufacturing procedures: production control, capacity planning, sourcing, process improvement, and organizational structure. The next five chapters will compare the differences of each of these controls between a LMHV focused company and a HMLV focused company. Examples of how Intel is affected by each procedure are also included at the end of each chapter.

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Chapter 4 – Production Planning and Control

Production planning and control is the mechanism used to determine when and how products are built in a manufacturing facility. This function is separated into two segments: strategic and tactical. The strategic part incorporates the planning phase or the philosophy behind the system. The tactical part is where the business takes control over the chosen strategy. Control is the decisions made regarding scheduling of products, along with inventory and demand management. Those goals may be vastly different from LMHV to HMLV and this chapter highlights the dichotomy between these systems for both the strategic and tactical areas. The challenges Intel faces in its move from LMHV to HMLV are also included at the end of the chapter.

4.1 Strategic Drivers

As discussed previously in this thesis, business drivers relate to the production system a company uses. Similarly, those business drivers also determine the strategic direction of the planning system within the overall production system. Different planning strategies are employed whether the business is focusing on flexibility, cost, quality, performance, or delivery. The decision on what type of planning system will be used, whether it is push, pull, or a combination of both, must be made prior to implementing any control over that system as will be discussed in section 4.2.

4.1.1 Push Production Systems

A push system is one where production decisions are based on long-term forecasts and raw materials are consistently introduced to the process, usually through a Materials Replenishment Planning (MRP) system. When a machine is available, it processes the work-in-process (WIP) that is waiting in front of it. The push system, therefore, starts with a master schedule and products are moved from raw materials through manufacturing to finished goods inventory and finally to the customer.

A push system is often referred to as a build-to-stock system. High equipment utilization and high inventory levels are often indications of a push system. The system often does not have the ability to react to and meet changing demand patterns. Thus, when the demand for certain products disappear, there is an obsolescence of inventory already built [15]. Figure 4.1 below shows the flow of information for orders for a push system.

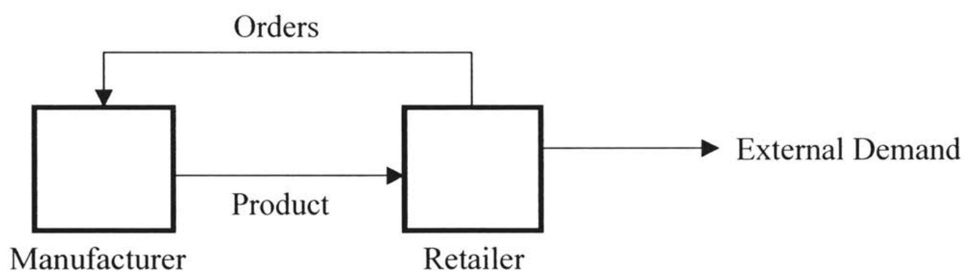

Figure 4.1 Push Production System [15]

4.1.2 Pull Production Systems

A pull system, on the other hand, is one where materials are only introduced as machines become available. Production is demand driven so that it is coordinated with customer demand instead of a long-term forecast [15]. When a product is needed by either the final consumer or to fill an inventory location at a customer, only then is the signal sent upstream to manufacturing that a product is needed. This signal passes through manufacturing back to raw materials and production control, such that, material is introduced into manufacturing only as space allows.

Pull systems are designed through tools such as Kanban and Just in Time (JIT) to reduce inventory levels so a large accumulation of work-in-process (WIP) inventory will not occur before or after a machine. Pull systems are often indicative of a lean manufacturing system. Typically, pull systems have much lower inventory, enhanced ability to manage resources, and a reduction in system costs when compared with push systems [15]. Figure 4.2 below shows the flow of information from the demand base back to the manufacturer.

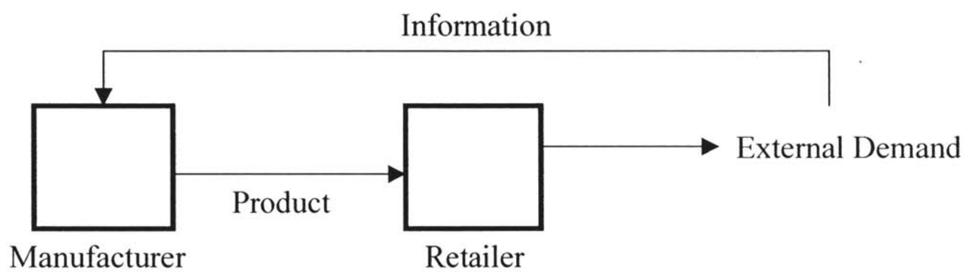

Figure 4.2 Pull Production System [15]

4.1.3 Push-Pull Production System

A production system does not necessarily have to be entirely push or entirely pull. Often times a combination of push and pull is the optimal system. For example, MRP may be used to push material to a certain point in the production line. This may be, but is not required to be, the bottleneck. It may also be a point in the system where all products are the same. In this sense, product customization will occur following this step. This delayed differentiation allows the company to use an aggregate forecast, which are more accurate, up to a designated point. After which, a pull system is used to build orders, either to stock or to order as discussed in the next section. The interface between the push stages and the pull stages is known as the *push-pull boundary* [15].

4.1.4 Overall Planning Strategy

There is often no clear definition for a strategy to be purely push or pull or a combination of push and pull. However, there are general guidelines and most efficient options. Typically, LMHV is indicative of a push system. As a small mix of high volume products are made, the manufacturing environment is repetitive and thus, set up to consistently produce material. HMLV can either be a pull system or a push/pull system, depending on the flexibility of the system, the lead-time, and forecast accuracy. The increase in product mix or customization leads to a greater need to rely on a customer order before beginning production.

4.2 Tactical Controls

After a strategy is formed to determine where on the gradient of push or pull the production system will be, the company can then begin the tactical steps needed to coordinate production throughout the factory. The main criteria for analysis are scheduling, demand management, and equipment utilization.

4.2.1 Scheduling

Scheduling is concerned with resource allocation and sequencing decisions for products to be manufactured. The primary factors in scheduling include delivery goals, processing time, resource utilization, and inventory levels. These objectives are often in conflict with each other in HMLV systems as shown in Figure 4.2 below.

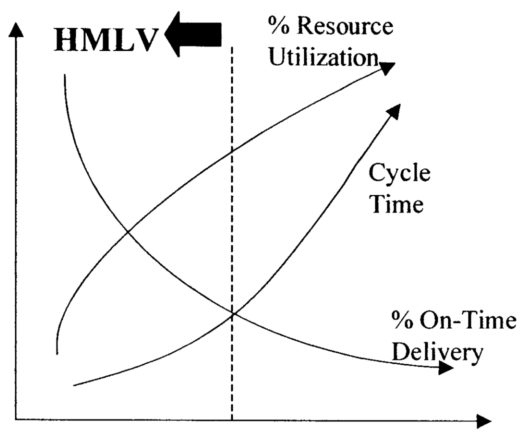

Figure 4.3 Trade-offs between Resource Utilization, Cycle Time, and Delivery [3]

As resource utilization and cycle time increase, on-time delivery decreases. This is common in LMHV environments where delivery time is not as important in most push or build-to-stock systems. When cycle time decreases to minimize total processing times, the machine utilization is reduced as well. HMLV manufacturing is optimized towards the left side of the chart meaning that maximizing resource utilization is not a core competency in HMLV [3].

Sequencing of products is a key factor in determining the efficiency of a process. Whether the goal is product delivery, machine utilization, or cycle time, meeting the goal depends on the order the products are built. In LMHV environments, scheduling is less of an issue since there are not many products to choose from and most are being built in high enough volumes that there is a large safety stock on inventory. Sequencing is key for HMLV products. Depending on the variety of the mix, considerations need to be made for equipment downtime needed for changeover to new products, priority level on the orders going to customers, and overall cycle time of the factory.

4.2.2 Demand Management

Demand management is the process used for understanding the demand from the customer base. This is highly dependent on how close the manufacturer is to the customer. If there is a relationship directly between the customer and the manufacturer, it is expected that the manufacturer has a good handle on the product expectations and volumes. An example of this would be Dell Computer Corporation that sells customized computers directly to the customers. The more common situation is when the manufacturer is removed from the customer by a few steps. An example of this would be Axcelis Corporation. Axcelis makes the capital equipment for the semiconductor industry, such as Intel, who makes the chips that are put into the computers that are sold to the customer, either directly or through a retail chain.

As the distance from the customer increase so does the uncertainty in the forecast. Even if the product demand remains fairly stable, the inventory and back-order levels fluctuate considerably across the supply chain. The increase in variability up the supply chain is a phenomenon commonly referred to as the Bull Whip effect [15].

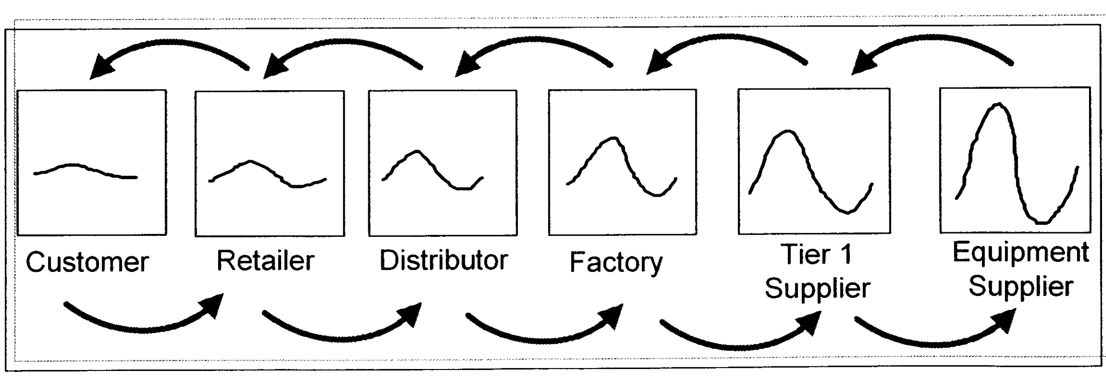

Figure 4.4 The Bull Whip Effect

Demand volatility is another factor to take into consideration. The more volatile an industry, the more flexible the manufacturer needs to be to respond to changes. Some volatility is expected and predictable, such as seasonal volatility. An example is the spike in sales at Amazon.com in the 4^{th} quarter due to the holiday season. Other types of volatility are more difficult to predict. Factors affecting this include information and delivery lags, chain accumulations, order batching, price fluctuations, and gaming.

4.2.3 Equipment Utilization

Equipment utilization is measured as the percentage uptime or the percentage of time a piece of machinery is used to generate product. Downtime, or the time when equipment is not being utilized to produce product, can be either scheduled, such as preventative maintenance or product changeover, or unscheduled due to breakdowns or lack of raw materials. Factors that affect utilization are equipment flexibility, cost, and reliability. A dedicated piece of equipment may be specific to a particular product line. A general-purpose piece of equipment may be used on a variety of products as will be discussed in the next chapter.

Changeover time is the major factor in equipment utilization. HMLV systems require flexible production lines. Long equipment set-up or changeover time greatly reduces the flexibility of the whole system and inhibits the ability to produce a high product mix. LMHV systems do not require frequent equipment changeovers and thus are typically focused on high equipment utilization.

4.3 Trade-offs between LMHV and HMLV

In summary, there is no clear answer on how a factory should schedule and run its products based on volume and mix. There are guidelines on which systems are more efficient for LMHV and HMLV, but the company needs to take into account the trade-offs. The basic premise is that the business needs to understand the relationship between the demand, product lead-time, and production flexibility and create a system that balances those things with the customers needs.

Regardless of what a company chooses to do with its schedule and resources, the path must be clearly communicated. Chapter 8 on Organizational Structure will highlight the importance of this clear communication and corresponding metrics.

4.4 Production Planning at Intel

Intel faces a major challenge with production planning and scheduling as it transitions to also produce HMLV products. Intel currently has a very successful model in its LMHV microprocessor production. The key issues that need to be addressed for HMLV communications products are lot size, scheduling, and demand management.

4.4.1 Lot Size

Lot or batch size is the number of products manufactured together at one time in the factory. At Intel and most semiconductor manufacturers, the lot size is 25 wafers. One wafer will translate into many microprocessors, depending on the size of the final product. The lot size of 25 was determined to be optimal many years ago. Since that time, all the processing equipment is built to accommodate this lot size.

While lot size is not a primary factor in the LMHV microprocessor business, it becomes a major factor when running HMLV products. As shown in Figure 1.4, there are a great number of specialty products whose demand is less than 25 wafers/week. This translates into less efficiency on the equipment and a higher machine set-up or changeover rate. This goes against the grain of Intel's traditional LMHV system, which is constantly focused on high machine utilization.

4.4.2 Product Scheduling

Regardless of the lot size, scheduling orders in the factory is a key concern for Intel. The current strategy is to use a push system with products that are built-to-stock. As mentioned earlier in this chapter, this results in high resource utilization and a long cycle time. The resource utilization will be discussed further in Chapter 5. The long cycle time decreases the flexibility of the factory to change products as needed.

Orders sent to the factory as lots are assigned a priority. The priority determines which products are produced first on each of the machines. The operators and supervisors are given the control to best utilize their equipment and meet the demands of the lot priorities as determined by production control. As the variety of lots increases with a higher product mix, the complexity associated with assigning priority and optimizing machine capability increases tremendously. Intel will need to view the global optimization of production planning. If each area is locally trying to optimize itself according to machine time and available lots, there will be further delays in manufacturing.

4.4.3 Demand Management

Intel commands an 80% share in the microprocessor market. This dominant position gives them a great deal of leverage in determining and understanding the demand. This, in conjunction with the current build-to-stock and inventory policies, enables Intel to smooth the demand as they send orders to the factory floor.

The HMLV communications market is in its infancy. No one currently has a large market share and many companies are trying to enter and determine the different opportunities. Forecasting becomes next to impossible and a build-to-order system makes the most sense. There are many hurdles in this area for Intel to overcome, as it must understand the customer needs, the trade-offs between forecasting and cycle time, and lot prioritization in the factory.

Chapter 5 – Capacity Planning

A manufacturing procedure that works together with production planning is capacity planning. There are two major views in capacity planning, long-term and short-term. Long-term capacity planning must be done initially as it determines the type of equipment purchased and manufacturing line set-up. The cost and flexibility of the equipment choices are major factors in determining what equipment will be purchased and where and how it will be utilized. Once demand and long-term capacity planning are complete, a factory must translate the demand into daily capacity requirements. The considerations for short-term capacity planning include resource and equipment utilization done in concert with production planning. All of the above capacity planning requirements depend on the nature of the product mix and vary greatly from LMHV to HMLV, as this chapter will explore.

5.1 Long-term Capacity Planning

As a company plans for its long-term production, it needs to consider the equipment that will be needed. The product make-up over the expected life of the equipment will determine whether general-use or dedicated machines are more applicable. This equipment also determines whether the manufacturing lines are dedicated to a certain product line or are shared across a variety of products. The different manufacturing lines may be within the same factory, or an entire factory may be dedicated to certain types of products.

5.1.1 General Use Equipment vs. Dedicated Equipment

General use equipment includes machines that are adaptable to a variety of products. Characteristics of general use equipment include flexibility, low efficiency, and are generally more expensive. The machines set-ups can be changed easily to accommodate new products.

Conversely, dedicated equipment is highly specialized and each piece of equipment is committed to a certain product or product line. It is very efficient and normally has high utilization. It is difficult and sometimes impossible to produce new products on these machines.

5.1.2 Trade-offs Between Shared and Dedicated Manufacturing Plants or Lines

Once the decision is made between general use and dedicated equipment, how those machines are put together determines where the different products are made. The more flexible the equipment, the more products can be produced on that line.

A LMHV situation will predominantly have dedicated equipment and the entire line is optimized to continually and efficiently produce the high volume products. When the equipment needs to be switched over for a new product, the changeover time is rather long and results in a loss of productivity.

A HMLV plant will normally have general use equipment that can be used across the great variety of products. The equipment is flexible and can be quickly changed or adjusted from one product to another. The utilization rates are lower than those of dedicated equipment and this factor needs to therefore be considered when calculating the capacity requirements.

5.2 Short-term Capacity Planning

Short-term capacity planning is done after the equipment is already purchased. The decisions have already been made as to what equipment will be used and the short-term planning is what is used to determine the most effective uses of those resources. This includes understanding the theory of constraints and level loading the plant.

5.2.1 Theory of Constraints

Eliyahu Goldratt developed the theory of constraints, which recognizes constraints determine the overall performance of a manufacturing system. A constraint is defined as anything that limits performance relative to the goal of making money. His manufacturing model says that improving or mitigating constraints will improve the overall system [13].

Understanding of system constraints is critical in short-term capacity planning. The output is completely limited by the constraint. Improvements at the constraint, such as set-up time, improved preventative maintenance, and more efficient equipment, will result in improvements in the entire system. Conversely, machine breakdown or starvation of material at the constraint results in reduced throughput [3].

Theory of constraints becomes a critical factor in HMLV manufacturing. For most LMHV plants, the constraint remains fairly stable and the work and capacity can be scheduled around that. This is not true in HMLV environments, as the constraint will continually move across different pieces of equipment. Different products have different needs and which one is currently prohibiting throughput is the one that needs to be considered in capacity planning.

5.2.2 Load Leveling Strategy

Capacity is defined as the rate in which work is output by the production system. Load leveling is the balancing of load with capacity, as opposed to scheduling which is used to smooth demand. A level load is the result of proper short-term capacity planning.

The first step in load leveling is calculating the available capacity on each piece of equipment in the process. Available capacity is defined as follows:

Available capacity = Time available x efficiency x availability x activation

Only a constraint should have an activation value equal to one [3]. The other factors can be adjusted according to product mix, maintenance schedules, and resource allocation. Based on this calculation, short-term capacity planning can be used to determine the company's ability to meet demand.

The strategy a firm employs in response to demand can be one of the following three kinds [3]:

1) **Lead:** Proactive capacity planning where capacity is increased based on anticipated demand.
2) **Lag:** A reactive strategy where capacity is increased based on a demonstrated increase in demand.
3) **Tracking:** A proactive or reactive strategy where capacity is increased or decreased based on an anticipated or demonstrated increase or decrease in demand. The changes are incremental and relatively small compared to lead or lag capacity changes.

5.3 LMHV vs. HMLV

LMHV situations are flexible to use a combination of any of these strategies. Although a lag strategy is generally not a good idea, LMHV production may be able to employ this if the safety stock is high enough and extra capacity is costly compared to inventory. The lag strategy is cost-based and thus the safety stock is necessary to offset the risk of poor delivery performance for a lack of response to demand changes.

HMLV environments should generally use a combination of lead and tracking strategies. This will allow the system to effectively respond to changes in demand. The lead strategy is high-risk from a cost perspective, as the company will have to carry the burden of extra capacity if the forecasted demand does not pan out. However, this is the best option for handling changes in product demand, which is necessary in high-mix production. Including a tracking strategy allows the inclusion of overtime, outsourcing, and a temporary workforce to handle the small changes as needed.

5.4 Capacity Planning at Intel

Both long-term and short-term capacity planning at Intel is critical. Semiconductor manufacturing is a high fixed cost, capital-intensive industry. This situation leads to a general theory that idle capacity is bad and high equipment utilization is good. There is also a very long lead-time in equipment purchases. The key challenges for Intel are long-term planning and short-term utilization given the product mix, flow and constraints.

5.4.1 Long-term Capacity Planning

The long lead-time and high costs of semiconductor equipment are major challenges in long-term capacity planning. A low estimate in capacity needs results in lost sales. An over estimate is costly and leads to either idle capacity or over production and excess inventory. While still extremely challenging, Intel's history and dominant place in the microprocessor market gives it an advantage in determining the capacity needs for those products. Intel's entrance into the communications market presents an entirely new challenge.

The first decision that needs to be made is whether communications products will be produced on equipment dedicated to those products, or whether it will be shared across product lines. The semiconductor equipment or tools are the same for both product groups. The low and uncertain demand of the communications product line diminishes the possibility of creating an entire manufacturing line just to serve those products. Also important to note is that the communications products will utilize the latest technology level in Intel. This eliminates the possibility of using older, retired, or excess equipment located throughout Intel. Thus, the general equipment purchased will most likely be shared between HMLV and LMHV products.

5.4.2 Semiconductor Product Flow

Product flow in semiconductor manufacturing is not linear. Due to the many layers and different types of processing needs, the flow can be characterized as re-entrant. This means that an activity will be performed on the product on one machine or tool, move to the next machine, and return to the initial tool for further processing. This happens multiple times and each product has a unique requirement for process steps.

This constant movement of product makes the scheduling of products and equipment more complex. The constraint or bottleneck in the factory is never constant and is always moving. One way in which Intel handles this issue today is with a large amount of inventory in the factory. Work-in-process (WIP) is constantly available before each machine. This decreases the risk of starving a machine, especially if that machine becomes the bottleneck. It also increases machine utilization, which, as mentioned before, is a key metric at Intel.

5.4.3 Short-term Capacity Planning

Given the long-term strategy of sharing equipment across product lines and the challenges associated with moving constraints, short-term capacity utilization and load leveling become even greater challenges. In order for Intel to be successful in communications, they must be able to minimize the cost in the factory while maximizing the flexibility of the manufacturing environment to respond to the new product mix. With flexibility comes more equipment set-ups and an increase in downtime. While the technical analysis is important, the change process and incentive system is even more important. As long as employees are judged on throughput and equipment uptime, there will not be any improvements to the process that allow a higher mix of products. Chapters 7 and 8 further discuss the impact of metrics and organizational structure on change management.

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Chapter 6 – Sourcing

Sourcing is a term used to understand a company's relationships with suppliers and distributors. This chapter focuses on both ends of the supply chain. First is a look at how LMHV and HMLV companies view the number of suppliers and their interaction with them. On the opposite side of supply is how a company distributes its material to customers and the way in which a customer receives and expects service from the company. Finally, Intel must re-evaluate both ends of the supply chain with their new manufacturing strategy.

6.1 Procuring Materials from Suppliers

The relationship between suppliers and customers is an ever-changing situation. In the past, most of these relationships were one-sided. The customer needed a part of a certain specification and the purchasing department would see what was available in the market and make decisions based on cost. In today's world, many companies are collaborating with suppliers to develop more efficient and cost-effective materials. This relationship becomes even more crucial as the requirements for parts become more specific with increasing product mix.

6.1.1 Basis of the Supplier Relationship

The basic premise of the supplier relationship is changing. In high volume, commodity markets, customers can look to a variety of suppliers to find what they need. Given that most of their parts will be similar and in high volume, they have an advantage to look for economies of scale in their ordering and focus primarily on the cost.

Suppliers have little more involvement other than meeting the needs of the given specification.

In HMLV environments, there is likely to be a higher level of customization in the input materials. This may require suppliers to work more closely with the customer to understand exactly what is needed. A closer working relationship can evolve over time such that the supplier gains more insight into the firm's operating needs. This may include being involved in the design phase of a new product or having direct insight into the inventory level of supplied parts so that parts may be replenished on a more frequent basis.

6.2 Distributing Product to Customers

Just as a company must work together with its suppliers to reach an agreement on product performance and delivery, the company must act as the role of supplier in dealing with its customers. A similar contract is developed in this relationship as the company has to serve its customers needs. Distributing a high mix of products versus a low mix requires different relationships and requirements.

6.2.1 Distribution Channel

Once again, the customer determines the variety of products in the market. As customers demand more variety, firms must change the distribution channel of their products. For LMHV products, a single distribution channel may be all that is needed. Since the products are all the same, the main factor is getting the product out and into the hands of the customer. The requirements have been pre-set and determined before mass production. A safety stock level can be set so that there is always an ample supply of product available to meet demand.

In HMLV environments, a variety of distribution channels may be possible or required. Since the customers are requiring more specific information on the products, a firm may choose to have a direct model and sell directly to the customer. If some sort of distribution channel is used, forecasting and safety stock levels because even more important.

6.2.2 Delivery

Delivery of product to a customer involves two main criteria: how and when. Often times the "how" of delivery is determined by the manufacturer based upon the "when" of delivery preferred by the customer. A customer that needs a certain product tomorrow is treated differently than a customer who needs a regular shipment of product every week. A LMHV market generally consists of the latter situation. The customers know what the options are and therefore give advance notice of what is needed and when. The manufacturer can then determine when it will be produced and how it will be delivered.

Most generalities and rules are discarded in the HMLV market. The added variety gives the customer more power in determining their specific needs. The manufacturer then faces the dilemma between early production and forecasting customer demand or creating a system flexible enough to meet the delivery window required by the customer. This strategy is determined during the capacity planning and strategic production planning phases. Once determined, any changes in customer delivery requirements require a change in the upfront process.

6.3 Sourcing at Intel

Entrance into the HMLV communications market will affect Intel's sourcing strategy. On the supplier side, Intel must understand its equipment and raw material needs. However, most changes will be on the distribution side. Considerations include new customer needs, the distribution channel, and inventory policies.

6.3.1 Intel's Supplier Relationships

There are two categories of suppliers for Intel: equipment and raw material. Intel works closely with its equipment suppliers in procuring all the tools necessary in semiconductor manufacturing. As shown in Moore's Law in Chapter 1, there is a trend in the industry for more and more transistors on integrated circuits. This phenomenon has required newer technology and greater capabilities in the manufacturing tools. Because Intel is using the newest technology on their communications products, the addition of these products will be only a small factor in their relationships with suppliers for new tools capable to produce these products. This relationship is already established and would continue with or without the new products.

The raw materials required on integrated circuits are also evolving over time. Silicon is the primary base of a wafer, but other materials are being identified. However, there is less variation in what materials are needed, and more variation in how they are put together. Because the forecast is aggregated across all products, the addition of HMLV products is not likely to be a key factor in supplier relationships.

6.3.2 Intel's Distribution Channel

Although changes in sourcing materials from suppliers is not likely to be strongly affected by this change, Intel's distribution channel will definitely be affected. Intel will now be a supplier to a new set of customers and these customers will have different needs and demands from Intel.

Intel currently has a distribution channel that includes warehouses carrying a significant amount of inventory. Because of the nature of LMHV, this strategy is successful because the safety stock levels can be set such that product is always available to the customers. Another key point is that there are a limited amount of customers needing these products and each probably has a set reorder policy and relationship with Intel.

The communications customers will be different than the current microprocessor customers. Intel will need to work with these customers closely upfront to determine their product needs. The distribution process will thus also be affected. Delivery time and method will most likely be unique to each customer such that a single strategy of inventory level and safety stock will not be possible. If a build-to-order policy is created, another option includes delivering directly to the customer.

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Chapter 7 – Process Improvement: Metrics and Incentives

The nature of the production process, along with factors such as capacity constraints and resource utilization, influence the way in which improvements are dispersed throughout the organization. All of these factors are affected by product make-up, current measurement systems, and employees' incentives. This chapter begins with a discussion of firms' metrics and incentive systems. General statements about process changes in LMHV and HMLV follow this. Finally, Intel's Copy Exactly! methodology is highlighted and the risks associated with including HMLV in a Copy Exactly! environment.

7.1 Company Metrics and Incentives

People will perform according to how they are measured. If a manufacturing manager is rewarded based solely on output, other factors such as quality or inventory may be ignored in order to increase output. Similarly, if different employees are measured on different outputs, there could be some fighting or manipulating within the company to improve one person's own metric.

A company must determine reasonable metrics to measure status and improvements in the organization. And to force improvement, there must be incentives aligned to the proper metrics. A change in focus or strategic direction must be accompanied by a change in incentives, if not also metrics. A failure to change the requirements and rewards will result in a failure of the organization to fully make the change.

7.1.1 LMHV Metrics and Incentives

LMHV manufacturing organizations typically have throughput as a key metric. The efficiency and uptime of the equipment are vital in mass-producing product. Quality will also be a key metric, as the firm will be focusing on the yield achieved.

Assuming the employees are incentivized to maximize these metrics, the culture and processes will cause employees to make the process as efficient as possible. This will go back as far as the capacity planning stage. Dedicated equipment that does not need to be set up will be purchased. The planning department will work closely with the operations team to reduce changeover and equipment downtime.

7.1.2 HMLV Metrics and Incentives

HMLV manufacturing organizations are focused on getting the right product to the customer at the right time. Flexibility is important so that equipment can be quickly changed over in order to respond to a new demand for new products.

The employees' incentives will likely be tracked with sales and delivery requirements. Inventory levels will be key so that there is never a stock out situation, nor a large amount of inventory taking up space in a distribution center. This will track back to the capacity and demand planning stages to ensure the plant is set up to succeed. The appropriate equipment and line set up are critical to product mix. Everyone will work closely with the marketing and sales department to enable the plant to produce the right products at the right time.

7.1.3 Intel Metrics and Incentives

Intel's metric and incentive system is based on the high volume nature of their core business. The development fabs are primarily concerned with yields and information. When they have enough information and high enough yields, the product can be moved into full production. The key metric for production fabs is referred to as WIP turns. This basically measures throughput by calculating the number of value added steps divided by average inventory.

The operations team is measured against these metrics and thus, incentivized to maximize the output. There is a clear focus in Intel's high volume facilities to meet throughput targets and run the fab as efficiently as possible. The WIP turn metric becomes less meaningful in low volume manufacturing because the entire inventory will be at one process step at a time. The situation becomes feast or famine, as the metric will look bad one day and good the next after the inventory moves through the process.

7.2 Process Improvements in LMHV and HMLV

Every company has their own method of making continuous improvements. Some of these include six sigma methods, phase reviews, and unique business process improvement programs. Along with the formal programs, there are often informal ways of getting things done. These could include use a suggestion box or changes made on the fly by engineers, operators, and supervisors.

In general, the more products produced on the manufacturing line, the more ownership is given to the employees that work on those lines. Standards are created for the overall process, but changes are often needed and time is usually of the essence in making those changes to produce valuable product. A line that is set up to produce only a few products is more likely to be optimized to produce efficiently. Any changes usually require a higher degree of authorization and possible experimentation before implementing a new method.

7.3 Intel's Copy Exactly! (CE!)

As mentioned in Chapter 1, Intel employs a Copy Exactly! method for process improvements. Due to the intricacies and detailed technology in Intel's processes, any minor change can make a major impact on the final product characteristics and quality. Intel has many fabs, located throughout the world. The products in each of the fabs are based on certain technologies. The fabs and technologies are connected together through a virtual fab. This virtual fab allows people from all over the company work with others and shares "best known methods" or BKMs and allows people to make more informed decisions on process improvements.

The CE! process has evolved over time and is now ingrained into the Intel culture. The method also includes the start up of a new facility. Any new production fab is designed so as to copy exactly the fabs running similar technologies. By doing this, Intel minimizes the variation in production. As Intel has dominated the LMHV microprocessor market, this strategy has been extremely successful. It allows Intel to ramp products more quickly than its competitors and achieve higher yields in the process. Early introduction of products in the microprocessor market has been key driver in the success of this business.

7.4 Risk of CE! in HMLV

The power of CE! is deeply imbedded in the fact that Intel produces primarily high volume products. The terms Copy Exactly and HVM (high volume manufacturing) are used consistently at Intel. This is another indication that the culture is focused on maximizing throughput, performance, and quality. All procedures and standards are prepared for HVM and must be followed throughout the affected organizations in order to be effective.

The primary quality for HMLV is flexibility. A process must be able to respond to changes in demand, as well as, be amenable to process changes. Flexibility necessitates the process owner to make process improvements and/or changes in a short time frame. In other words, as the product mix varies, other factors in the process such as equipment set-up, product flow, and operating conditions may require adjustments as well. The process owner cannot wait to test and experiment and gain lengthy approvals in order to make the changes.

The dichotomy between CE! and process flexibility is the largest cultural barrier for Intel to overcome. For Intel to blindly introduce HMLV products in fabs and plants that have traditionally been LMHV is a recipe for failure. People are creatures of habit and for many years the employees at Intel fabs have been focusing on HVM and the associated metrics. Unfortunately, the answer is not as easy as changing the metrics or incentives, and is only one factor. People need to understand where ownership lies and change their mindset on how they work and make process improvements.

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Chapter 8 – Organizational Structure

For an organization to be effective, its structure must match its goals. Every organization has different processes and structures that define how the organization works. One method of evaluating and understanding how the organization works is to view it through different perspectives. This gains insight into the true motivations for the employees and management team. A three-lens analysis is an academic organizational process tool used to guide a richer picture of an organization [14]. The three different lenses are: strategic design, political, and cultural. Within these lenses is the overall direction of the company, formal and informal relationships between groups, and underlying company culture that affects change management.

This chapter focuses less on the differences and similarities in these areas between LMHV and HMLV systems, but more on analyzing how an organization reacts during a change from one to the other. A look into Intel's structure and potential effects from a change in product mix is also examined through the three-lens analysis.

8.1 Strategic Design Lens

The strategic design lens looks at the flow of tasks, the formal structure that sorts people into different roles, how the roles are related, and how the organization can achieve its goals [14]. Relationships within the company often determine how works gets done. Whether a company is hierarchical or horizontal, there are written and unwritten rules on how to accomplish goals and create change. Managers can make their firm successful by understanding the basic principles of organizational design and the company's current environment and by then aligning the design with the strategy [14].

Product mix plays a key role in the strategic design of a business. Whether a company sells 1 item or 1,000,000 items, it must set up systems to support those products. This strategy plays a key role in setting the direction of a business. For example a company with only a few products (LMHV) may set up the strategic focus to be solely on the process used to create the products. All departments from marketing and sales to purchasing to manufacturing and distribution will be focused on how to make the current products "better" whether better means smaller, bigger, faster, cheaper, or prettier.

Conversely, a company with a high variety of products is more likely to set the strategic design around new products. The technology, customer, or service requirements will be the focus of all departments in the company. The company is most likely to be interested in the future capabilities of the company to create new products and enter new markets rather than focus on its current products.

Any change from LMHV to HMLV requires a review and understanding of the strategic design lens. The reasons for the shift are incorporated into the company's overall strategy. The task flow and formal structure must be aligned to meet the new goals. The transformation will only be successful if the path is clearly communicated.

8.2 Political Lens

The political lens is used to understand the different interests and goals that guide both individuals and groups inside and outside of the organization. This often involves the amount of bureaucracy required to make things happen in an organization. Finding the right person or people necessary to agree is a key step in creating change. Other factors include how power is distributed, location and views of stakeholders, and how conflicts are resolved [14].

The formal structure of a firm is not the only consideration for understanding the political perspective. Relationships within a business are not one-time events, but instead are built over time. No specific organizational interaction is independent of the past or dependent on expectations for the future [14]. This is especially important when considering major changes that impact an entire organization.

While there are not many general political rules according to LMHV and HMLV systems, this is once again something that needs to be considered and evaluated in any company. The biggest impact a political system will have on a manufacturing environment is when there is a large change from LMHV to HMLV, for example. People will inherently resist change. Understanding the interests and motivations of the different groups, as well as, the key players will help make any transition go much more smoothly.

8.3 Cultural Lens

The cultural lens looks at the informal relationships and foundation of the organization and views how work is accomplished. This perspective looks at how history has shaped assumptions, how special practices become rituals, and how stories shape the feel of an organization [14]. There is not a more important characteristic in understanding how a company works than embracing the culture. A culture is developed over many years and it is ingrained in the people and the processes.

As with the political lens, the cultural lens is critical when formulating change in an organization. People in LMHV manufacturing environments have a culture that has sustained that capability to become very successful. They have developed standards and procedures to be effective in that arena. A change from LMHV to HMLV means that those procedures that have worked so well over time are probably not going to work in the new setting. People will resist this due to the feeling that these processes have always worked in the past.

8.4 Three Lens Analysis at Intel

Intel is a technology and process-oriented company. The formal structure is aligned via a matrix such that employees report both through a product group and a process organization. Within these reporting structures lies a company that is dedicated to a meritocracy system. There is not a strong hierarchy such that employees are rewarded on their merit and encouraged to speak their concerns at all levels of the organization.

This meritocracy is coupled with a very strong, process-oriented culture. Intel has survived many economic downturns and advancing competitors by focusing on its strengths and competitive advantages. The culture within Intel has evolved over the years to make it deeply imbedded in the way Intel conducts business. Andy Grove, founder and former CEO of Intel, has documented much of Intel's success and culture in his book, "Only the Paranoid Survive" [2].

The introduction of communications products will be a major shift for Intel. While many may see that the new products are still semiconductor-based products, they may not be able to see the full ramifications of what these HMLV products will mean to Intel. These products will affect all groups from Marketing and Sales to Development to all the manufacturing steps from the fabs to assembly and test, and finally to the distribution system used to send the products to the customers.

An overall strategy must be created that understands the needs of all groups involved. The political system and powers and needs of all stakeholders are important to the success of the change. And most importantly, the change will drastically affect the culture of the organization. This barrier cannot be underestimated as the success relies on the employees to make it happen.

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Chapter 9 – Conclusions and Recommendations

This thesis does not provide a quantitative analysis about how Intel will be affected by changes in product mix. Nor does it give any direct implementation paths for Intel to follow as it enters upon this expedition into the communications market and high-mix, low volume manufacturing. It does, however, provide a framework for how Intel should evaluate the change and provides examples of areas that need to be considered. This chapter summarizes the thesis, as well as, provides the author's recommendations for future projects at Intel as the company proceeds on this journey.

9.1 Project Conclusions

Intel's venture into the communications market is an exciting opportunity for the company to expand its prowess in semiconductor manufacturing to new areas. This document has highlighted the magnitude of this change by including benchmarking of other firms in similar situations, a framework for evaluating manufacturing strategy, and the impact that such a change will have on a variety of manufacturing procedures. The conclusions can be summarized in three key areas: business drivers, manufacturing alignment, and change management.

9.1.1 Business Drivers

The evolution of Intel as a technology driven company has created a powerhouse of a company to live on the cutting edge, takes risks in new marketplaces, and dominate the microprocessor market. The company has faced numerous challenges in participating in an industry that is not fully defined. They face a similar challenge with their entrance into the new communications industry.

A key message for Intel is to understand the business drivers as the business and markets change. The effectiveness of Intel in microprocessors does not automatically mean they will be effective in communications. The industry is different and therefore, the business needs are different. Using the framework presented in this thesis, and specifically the competitive analysis, will allow Intel to fully understand the new needs of the business and help steer the company in the right direction with the right goals and targets.

9.1.2 Manufacturing Alignment

Manufacturing is part of the heartbeat of Intel. The company prides itself on its technology and ability to execute that technology effectively and in high volume. Any new opportunity for Intel will affect its manufacturing operations.

New business drivers will not mean anything to Intel without systems in place to execute those drivers in manufacturing. As explored in chapters 4 through 8, there is a large dichotomy in expectations and methods when comparing manufacturing procedures in LMHV and HMLV situations. Creating alignment between the business direction and manufacturing systems is crucial for Intel to be successful in new markets.

9.1.3 Change Management

Intel is a large company with an extremely strong culture. The nuances within the culture cannot always be defined, but they are embedded in the employees at Intel. The impact of a change of this magnitude will affect a large portion of the employees and should not be taken lightly. Change management will be critical to the success and should be considered holistically, and not as an isolated event in any one sector of the company.

Change management involves employees from the bottom to the top. Top management cannot simply dictate or force new ideas into the organization. Similarly, any major change such as the one being discussed here cannot evolve solely from a grass roots effort within pockets of Intel. Both groups need to buy-in to the change and understand the needs of all facets of the organization. The strategy of the organization must understand the political structure and cultural norms to effectively implement any changes.

9.2 Future Recommendations

Intel's journey into communications and HMLV will not be a short one. The company must move rather swiftly so as to not miss the opportunity. At the same time, analysis is important and there are many opportunities for the company to keep moving forward. This final section gives some thoughts on areas requiring further analysis.

9.2.1 Lean Manufacturing Opportunities at Intel

Although not highlighted here, this project brought about many discussions on the opportunities for implementing a lean production system at Intel. Further analysis is needed and there are a lot of opportunities for Intel to embrace it. This cannot be a grassroots effort by a few people and needs to be an all-encompassing look at Intel and their manufacturing procedures.

9.2.2 Pilot Program for HMLV

The full impact of HMLV can only be understood if it is tested in manufacturing. As the analysis work is being done about where to build the products and how to incorporate them into manufacturing, a small pilot of specially chosen products will help identify areas that might not be otherwise considered.

9.2.3 Complete Manufacturing Framework

The manufacturing framework presented in chapter 3 provides the outline for understanding business drivers and organizations needs. An in-depth analysis using a cross-functional team applying these tools would provide valuable insight into how the change will impact the different organizations.

9.2.4 Organizational Alignment

An organizational assessment is another opportunity for Intel to identify the key affects of HMLV. Many of the design groups have come to Intel through acquisitions. Although they have been incorporated into Intel, the drive to build these products at Intel and not outsource is a relatively new concept. Eliminating outsourcing as an option can change the way in which these teams work within Intel. An assessment of the organization and goals would be a valuable exercise to ensure everyone is following the same path.

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