

Improving the Flexibility of the Desktop PC Supply Chain

By

Johnson Wu

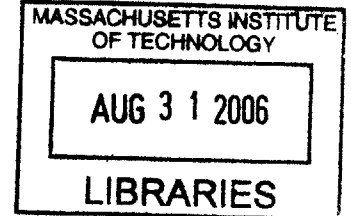
B.S. Industrial Engineering & Operations Research, University of California, Berkeley (2000)

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

Master of Business Administration
and

Master of Science in Civil & Environmental Engineering

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Abstract

Dell Inc. is a company headquartered in Round Rock, TX founded by entrepreneur Michael Dell in 1984. In its 20+ years of history, Dell has revolutionized the PC industry by deploying the “Dell Direct” model—eliminating the “middleman” retailers in the PC supply chain—and achieved the Number 1 market share in the PC market. In managing its supply chain, Dell also utilizes its direct model and owns strategic relationships with many of the contract manufacturers, most of which have factories in China. For desktop PCs, these contract manufacturers produce semi-completed products and ship these products to Dell’s U.S. and Ireland factories, and then Dell factory workers complete the remainder of the desktop PC assembly process by installing the components that are customized by Dell’s customers. In order for Dell to remain low-cost and readily respond to customer demand, Dell’s suppliers maintain a minimum amount of semi-completed goods inventory in a hub near each of Dell’s manufacturing facilities.

Foxconn (Hon Hai Precision Industry Co., Ltd.) was founded in 1974 by Taiwanese entrepreneur Tai-ming Terry Gou. Besides its home base in Taiwan, Foxconn has major manufacturing operations in mainland China, U.S., and Europe. Originally a maker of plastic parts, connectors and cable assemblies, Foxconn has since established manufacturing facilities worldwide that produce a variety of high-tech products, including electrical and mechanical components, modules and sub-systems for PCs, consumer electronics, handsets, networking, and display products. Foxconn’s eCMMS (e-enabled components, modules, move and service) model and its high degree of vertical integration in supply chain allow Foxconn to address clients’ needs from a single source. Foxconn services name-brand clients, such as Dell. Similar to Dell’s inventory management strategies, Foxconn also requires its suppliers to keep a minimum amount of raw materials at its inbound warehouse.

Dell and Foxconn’s shared strategy is to maintain a minimum level of inventory while balancing it with a continuity of supply, in order to maximize sales and minimize the inventory-holding cost. However, this inventory management policy has been disrupted by a continuous shortage of chipset supply from Dell’s chipset manufacturer since July 2004. A chipset is a critical component of the desktop motherboard manufactured by Foxconn in China. After manufacturing the motherboard, Foxconn is also responsible for installing the motherboard into the desktop chassis before shipping the motherboard-inside chassis from China to U.S. or Ireland

by ocean. The chipset supply shortage has caused Foxconn not to be able to procure chipsets in order to manufacture the motherboards in China. As a result, some chassis are shipped empty by ocean first, and motherboards are air-freighted later. This leads Dell to utilize Third-Party Integrators (3PI) in the U.S. to install the motherboards into the chassis. The continuous shortfall of chipset supply increases the volume of motherboard-chassis integration in the U.S. and further increases Dell's overall manufacturing costs.

Thus, the goal of this thesis is to create a framework for improving the flexibility of the Desktop PC Supply Chain. This framework examines how the various players contribute to the supply chain, the dynamics among these players that led to the current supply chain design, and how Dell can work with its suppliers and other strategic partners to more effectively balance demand and supply. This thesis will explain the symptoms as well as the root causes of the problem, present the original direction of my internship and the exogenous factors that caused the direction to change, and describe the renewed direction. It will also examine Dell's decision-making process, organizational processes, and leadership issues involved. In addition, it will discuss how other industries structure their manufacturing given a supply shortage and the importance of trust and innovating contracting in cultivating more collaborative relationships in a supply chain.

Thesis Supervisor: David Simchi-Levi
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Thank you!

Sincerely,

Johnson Wu

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1 Introduction

The personal computer (PC) supply chain has undergone a significant transformation in the last few decades. In the U.S. market, originally everything was manufactured and assembled in the U.S., the sourcing and manufacturing shifted to countries such as Taiwan in the late 1980s, and since a few years ago China has been dominating the procurement and manufacturing strategies of many PC makers.

With the supply chain becoming more global and diverse, new challenges have also surfaced. In order to deliver customized products to end users on a timely basis, speed and efficiency of a PC maker's operations define the company's success. This fast clockspeed, coupled with the ever-expanding product selections and decreasing product lifetime, makes it challenging to coordinate and balance all aspects of the supply chain. In addition, the long lead time between China and the U.S. (or other PC markets in the world) further increases the complexity of the supply chain coordination.

Contract manufacturers emerged as a key part of the PC supply chain in the late 1980s. Today, many of the PC makers, or Original Equipment Manufacturers (OEMs), partner with contract manufacturers in China to take advantage of their low labor cost and high product quality. Primarily, OEMs still own the design and development portion of the product lifecycle, as well as the overall selection and supply chain coordination of the PC components. Contract manufacturers own the responsibility of mass production, management of the sub-tier suppliers, and delivery to the OEMs' markets. In Dell's case, for desktop PC products, Dell's contract manufacturers (such as Foxconn) produce partially assembled products in China and ship to Dell's factories worldwide for final assembly.

The supply chain balance and the continuity of supply can be affected when a critical PC component experiences a shortage, which reduces a contract manufacturer's ability to provide the products up to the level of assembly desired by the OEM. When this occurs, the PC maker and its contract manufacturers need to re-evaluate their supply chain strategies and manufacturing process design. If the component shortage makes it infeasible to perform a particular assembly step in China, the same assembly step will need to be performed in an area closer to the final market. This postponement strategy will inevitably increase the overall cost of the product, and the PC maker and the contract manufacturer need to determine how to adopt their supply chain strategies and manufacturing process design to still provide an adequate level of service to the end users in this fast-clockspeed world.

This thesis discusses Dell's decision-making process concerning the management of the chipset supply shortage that affected the PC industry since July 2004. Moreover, the thesis explores the various options for improving the manufacturing capability of Dell and Foxconn, in light of the chipset supply shortage. This thesis defines a supply chain strategy of minimizing manufacturing cost and complexity, characterizes the issues associated with Dell's decision-making process, discusses benchmark practices from other industries, and suggests

recommendations and future opportunities for Dell and Foxconn to improve both the overarching desktop PC supply chain and their internal operations.

The thesis proceeds as follows:

Chapter 2, Dynamics of the Desktop PC Supply Chain provides an overview of the PC industry, an introduction of the manufacturing process of desktop PCs, and the supply chain process. The objective of this chapter is to provide the reader with a sufficient background in the dynamics among the major players in this industry to understand the remaining chapters of the thesis.

Chapter 3, Symptoms and Root Causes discusses the differences between Level 5 (L5) and Level 6 (L6) integration in desktop PC manufacturing. It then dives into the details of the symptoms and root causes of the problem identified in the Dell-Foxconn supply chain during my internship.

Chapter 4, Original Direction of the Internship proposes an approach to solve the problem described in Chapter 3. It explains the scope of the project, the purpose of the optimization model, its input variables and expected outputs. It also formulates the optimization model using the input variables.

Chapter 5, Renewed Internship Direction describes the business environment that leads to the directional change of the internship, followed by a discussion of the renewed focus and deliverables of the internship.

Chapter 6, Examples from Other Companies explores how two other companies, Nokia and Toyota, deal with the shortage of critical parts. Although Nokia and Dell have very different sets of products, both operate within the consumer electronics space, while Toyota is in a completely different industry. The goal of this chapter is to illustrate how each of these two companies deals with a critical part shortage to cast some light on how Dell could more effectively manage the chipset supply constraint.

Chapter 7, Organizational Processes in Making Decisions & Driving Changes describes the organizational processes and leadership issues involved in the determination of the optimal solution to manage the motherboard-chassis integration in the U.S. The discussion is organized into two parts: first, it explores how the Dell speed influenced the decision-making and change management processes; second, it compares the consensus-building process and discusses the differences of the leadership styles in a matrix organization vs. a functional organization.

Chapter 8, Recommendations and Conclusions concludes the thesis by offering some recommendations developed by the author based on the six-month internship.

2 Dynamics of the Desktop PC Supply Chain

This chapter provides an overview of the PC industry, an introduction of the manufacturing process of desktop PCs, and the supply chain process. The objective of this chapter is to provide the reader with a sufficient background in the dynamics among the major players in this industry to understand the remaining chapters of the thesis.

2.1 PC History

In the 1960s, the first personal computers (PCs) became available to the market as non-mainframe computers, such as the LINC and the PDP-8. They were expensive and cost around \$50,000 U.S. At the same time, they were also bulky, and many were about the size of a refrigerator. However, they were called “personal computers” because they were they were small and cheap enough for individual laboratories and research projects to use. These computers also had their own operating systems and therefore could allow the users to interact directly with the computers.

The first microcomputers hit the market in the mid-1970s. Usually, computer enthusiasts purchased them in order to learn how to program and used these computers to run simple office or productivity applications or play games. The emergence of single-chip microprocessor lowered the price of a computer and attracted many buyers from the general public. The first widely and successfully sold desktop computer was the Apple II introduced in 1977 by Apple Computer.

In the 1980s, computers became increasingly cheaper and gained great popularity among home and business users. This trend was partly driven by the launch of IBM PCs, which

combined spreadsheet, word processor, presentation graphics, and simple database application into one machine. In 1982, Time magazine named the personal computer its Man of the Year.¹

The 1980s is also when laptop computers became available. The first commercially available portable computer was the Osborne 1 in 1981, which used the CP/M operating system.²

Although it was large and heavy compared to today's laptops, with a tiny CRT monitor, it had a near-revolutionary impact on business, as professionals were able to take their computer and data with them for the first time. However, it was not possible to run the Osborne on batteries; it had to be plugged in.

The functionalities of personal computers became more powerful and capable of handling more complex tasks in the 1990s. This phenomenon led personal computers to become more equivalent multi-user computers or mainframes. During this decade, desktop computers were widely advertised for their amount of power available for graphics and multimedia, and this increased the usage of desktop computers by studios, universities, and governments.

By the end of the 1980s, laptop computers were becoming popular among business people. Truly the size of a notebook, they had hard drives and standard-resolution screens. Today, high-end PCs focus more on greater reliability and more powerful multi-tasking capability.

2.2 PC Makers

There is a clear distinction between the major PC makers supplying to the U.S. market and those servicing the global market.

¹ Wikipedia on "personal computer": http://en.wikipedia.org/wiki/Personal_computer

² Wikipedia on "laptop": <http://en.wikipedia.org/wiki/Laptop>

First of all, the U.S. PC market is about one third of the worldwide PC market:

According to Yahoo! Finance, 14 million units of PC were shipped in the U.S. in the 2nd quarter of 2005, and 43 million units were shipped worldwide.³ As of the 2nd quarter of 2005, in the U.S. alone, Dell has the Number 1 market share (32.0%); Hewlett-Packard (HP) has 17.4% of the market share; Gateway 5.7%.

2005 Q2 US PC Market Shares (Based on Units Shipped)

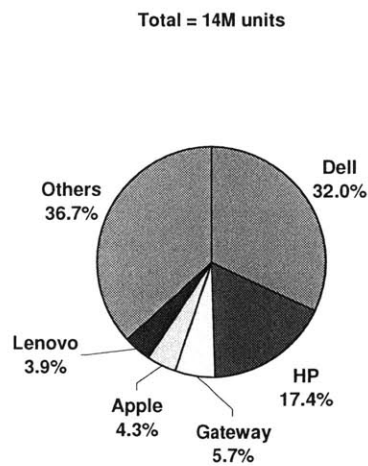


Figure 1. 2005 Q2 U.S. PC Market Shares (Based on Units Shipped)⁴

The major PC players in the U.S. have smaller market shares when it comes to the worldwide market. Although Dell and HP are still the largest players, Dell only owns 17.9% of the worldwide market, roughly half the percentage it occupies in the American market. In fact, the chart below show that Dell and HP combined only have one third of the global market.

³ Yahoo! Finance, 7/18/2005

⁴ Yahoo! Finance, 7/18/2005

2005 Q2 Worldwide PC Market Shares (Based on Units Shipped)

Total = 43M units

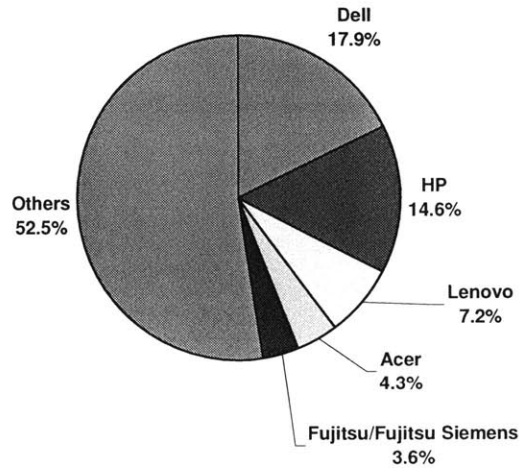


Figure 2. 2005 Q2 Worldwide PC Market Shares (Based on Units Shipped)⁵

The PC makers in the worldwide market are also more diverse. Non-American manufacturers such as Lenovo, Acer, and Fujitsu/Fujitsu Siemens show up as the third, fourth, and fifth largest PC makers in the world. In addition, as the chart above shows, there are many companies that each owns less than 4% of the worldwide market but all together make up more than half of the worldwide market. This shows that the worldwide PC market is more fragmented than the U.S. market.

The year-to-year market share % change is also a key indicator of the growth of the industry. In the U.S. market alone, from the 2nd quarter of 2004 to the 2nd quarter of 2005, Apple, Gateway, and Dell experienced the highest market share percentage growths. The total size of the U.S. market increased by 10% during the year.

⁵ Yahoo! Finance, 7/18/2005

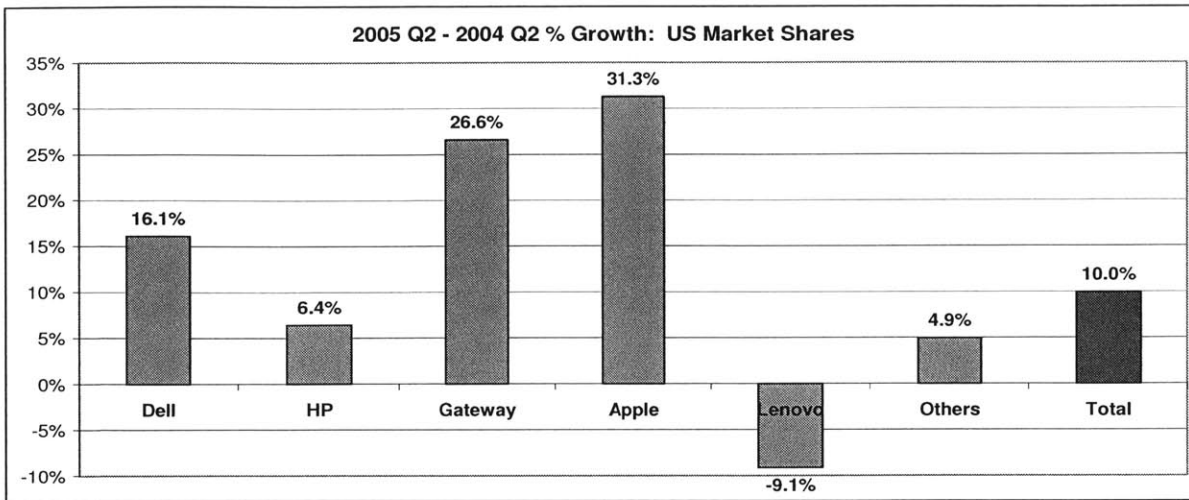


Figure 3. 2004 Q2 to 2005 Q2 Year-to-Year U.S. Market Share % Change by Company⁶

The picture looks very different when the global PC market is examined. The graph below shows that Acer had the highest market share percentage growth (67.7%) from the 2nd quarter of 2004 to the 2nd quarter of 2005. Dell came in as Number 2 (23.6%). The worldwide market size increased by ~15%.

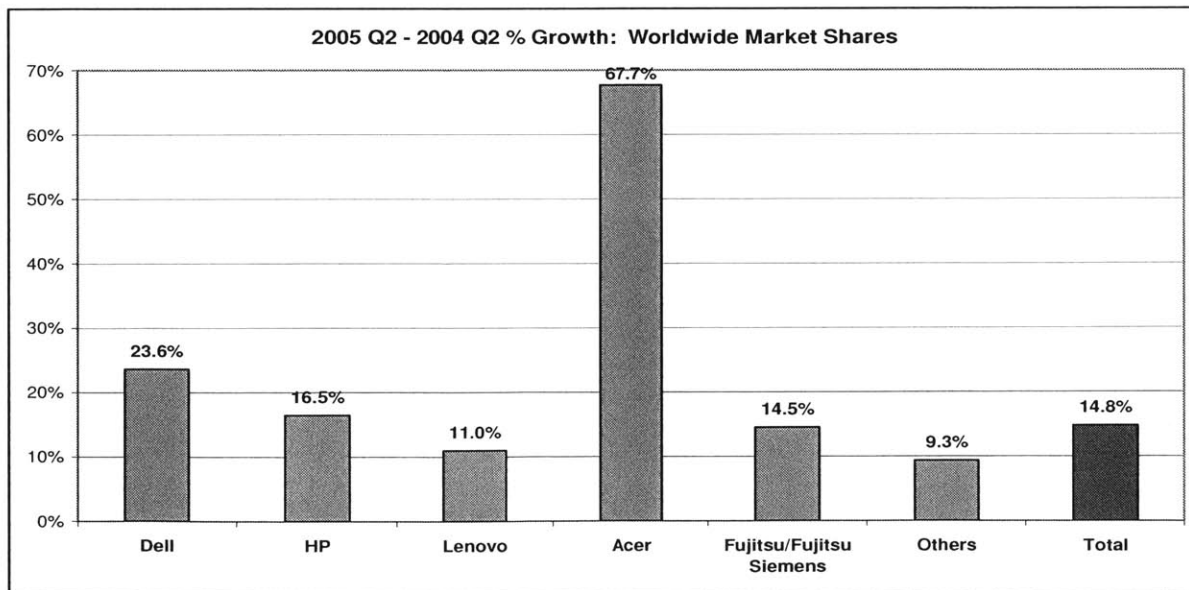


Figure 4. 2004 Q2 to 2005 Q2 Year-to-Year Worldwide Market Share % Change by Company⁷

⁶ Yahoo! Finance, 7/18/2005

It is important to note that although Apple experienced the highest U.S. growth and Acer experienced the highest worldwide growth, they remain as relatively small players, having only 4.3% of the U.S. market shares and 4.3% of the worldwide market shares, respectively.

Most PC makers today utilize contract manufacturers to produce high-tech electronic products. Typically, in the business model of contract manufacturing, the hiring firm approaches the contract manufacturer with a product design. The two negotiate and agree on the price, property of materials, sub-tier suppliers, and sometimes even the manufacturing process. The contract manufacturer then acts as the hiring firm's factory. Most contract manufacturers for both desktop and laptop PC products have factories in China or other parts of Asia. Depending on the degree of manufacturing competency and cost, some contract manufacturers do everything from manufacturing all the way to shipping fully assembled products on behalf of the hiring firms. Therefore, most American PC makers nowadays are "fabless". In fact, Dell is one of the few American companies that still retain manufacturing facilities in the U.S. In Dell's case, because customers can customize some components of their PCs on their orders, manufacturing a fully finished product and shipping it by ocean from the contract manufacturer's facility in China to the customers in the U.S. would be time-prohibitive, and manufacturing a finished product and air-freighting it would be too cost-prohibitive if it is a heavy or bulky desktop product. Therefore, for Dell's desktop products, contract manufacturers in China produce and ship (by ocean) half-assembled products to Dell's factories in the U.S. Once the supply arrives and the components preferred by a customer are known, Dell factory associates would perform further product fulfillment: build in the customized components (including the processor, memory, hard drive, speaker, etc.), install the necessary software application, perform

⁷ Yahoo! Finance, 7/18/2005

final unit testing, and then deliver the fully assembled and functional product to the customer in a timely fashion.

2.3 Dell's Company Background and Its Direct Model

Dell was founded by Michael Dell in his University of Texas, Austin dorm room in 1984 based on one simple business model: eliminating the retailers in a traditional computer systems sales channel and selling directly to customers. Based on this model to deliver customized systems to customers with lower-than-market-average prices, Dell soon started to enjoy business success and joined ranks of the top-five computer system makers worldwide in 1993 and became Number 1 in 2001. With three major manufacturing facilities in the U.S. (Austin, TX; Nashville, TN; Winston- Salem) and Brazil, China, Malaysia, and Ireland, Dell's revenue for the last four quarters totaled \$56 billion, and Dell employs 65,200 people worldwide.⁸

Besides personal computers, as the company grows, Dell's product offerings include a variety of consumer electronics: workstations, servers, storages, monitors, printers, handhelds, LCD TVs, projectors, etc. Some of these products are manufactured by Dell factory associates; other products are manufactured by other companies but sold under the Dell brand.

Throughout the company's history, Dell's fundamental business model has not changed: selling directly to customers has become Dell's key strategy and strength. The direct business model not only includes no retailers, but it also starts and ends with the customers: a customer order online or via phone a computer system according to his preferred configuration, Dell manufacturers this computer system, and Dell ships directly to the customer. Dell has been able

⁸ Dell Company Website, Company Facts:
<http://www1.us.dell.com/content/topics/global.aspx/corp/background/en/facts?c=us&l=en&s=corp&~section=000&~ck=mn>

to keep the manufacturing costs lower than its competitors because it not only saves money from shipping directly to customers, but it also only builds to order, so the raw material inventory is low. The direct model also reduces the time it takes between customer order and receipt of the system. Moreover, this direct model provide a single point of accountability so Dell can more easily design its customer service model in order to provide the necessary resources to satisfy its customers.

2.4 Contract Manufacturers

The phenomenon of contract manufacturing began in the 1980's. To take advantage of the labor cost differences, many Original Equipment Manufacturers (OEMs) began business engagements with contract manufacturers (CMs). At the beginning of the contract manufacturing business model, CMs were almost primarily only responsible for producing materials or unassembled components in the cheaper regions and shipping them to the OEMs' factories in the U.S. or Europe for product assembly.

However, this model began to shift dramatically in the late 1990's, as more and more contract manufacturers began to perform some level of manufacturing/assembly for their customers. This helped fuel the growth of contract manufacturing. According to Alameda, CA-based Technology Forecasters Inc., in 1998, the contract manufacturing industry was worth \$90 billion. By 2001, this figure almost doubled and reached \$178 billion.⁹ OEMs choose to let the contract manufacturers own part of the manufacturing processes for the following reasons:¹⁰

⁹ Wilson, Drew. "Contract Manufacturing Revs Up for 2000", *The Electronics Industry Yearbook/2000*, p. 88.

¹⁰ Fine, Charles H. and Dan Whitney. *Is the Make-Buy Decision Process a Core Competence?*, MIT CTPID Working Paper, 1996: http://imvp.mit.edu/imvpfree/Fine/Make_Buy.pdf.

1. Capability: The company cannot make the item or easily acquire such a capability and must seek a supplier.
2. Manufacturing competitiveness: The supplier has a lower cost, faster availability, etc. for what is presumably a direct substitutable item.
3. Technology: The supplier's version of the item is better.

Today, almost all the desktop PCs sold in the U.S. are initially produced by contract manufacturers in China. In Dell's case, since the time-to-customers factor plays a significant part of customer experience and satisfaction (as described in the previous chapter), the final assembly of desktop PCs is done in Dell's plants (Austin, TX; Nashville, TN; Winston-Salem, NC).

Traditionally, contract manufacturers produce products strictly for their OEM customers and do not produce products under their own brand names, in order not to compete directly with their customers. Hence, some people in the industry have called the contract manufacturing system a system of "stealth manufacturing"¹¹, and the names of these companies can be unfamiliar to people outside the industry. This dynamics is changing, however, as some contract manufacturers have begun to release products under their own brand names. Acer is a notable example.

Also, historically, contract manufacturers usually only perform mass production, not product design and development, for their OEM customers. The typical model is: The OEM develops and generates the design; the contract manufacturer manufacturers under the OEM's brand name. However, this industry has evolved to the point where distinctions between design

¹¹ Sturgeon, Tim. "Turn-key production networks: industry organization, economic development, and the globalization of electronic contract manufacturing, 1999.

and manufacturing services have blurred considerably. More and more contract manufacturers are working together with their OEM customers to co-develop the design. The patent of the design, however, usually still belongs to the OEM. Contract manufacturers also get involved in the design discussions to influence Design for Manufacturing (DFM) decisions. The easier it is for the contract manufacturer to produce a product, or the less capital expenditure a new product launch incurs, the more beneficial it is for both the OEM and the contract manufacturer. Attention to DFM also shortens the product lifecycle time and allows OEMs to deliver products to the market faster.

Outside the U.S., major OEMs from Asia, such as Japanese *keiretsu* and Korean *chaebol*, do not typically use contract manufacturers in their home markets. “Sales of major assembly operations to CM companies mostly occurred in foreign markets. The leader in outsourcing has been Sony, a company generally not considered a *keiretsu*.”¹² This example illustrates the difference between Western and Asian OEMs on how receptive they are in working with contract manufacturers.

2.5 Foxconn’s Company Background

Foxconn was founded by Tai-ming Terry Gou in 1974 in Taiwan. Originally established to produce plastic and connector products, it has now become one of the largest contract manufacturers in the world and produces high-tech and communication products for many name-brand companies. It has plants in China, U.S., and Europe. Since its listing on the Taiwan Stock

¹² Luthje, Boy. “Electronics contract manufacturing: Global production and the international division of labor in the age of the Internet”, *Journal of Industry Studies*, December 2002: http://www.findarticles.com/p/articles/mi_qa3913/is_200212/ai_n9159251/print

Exchange in 1991, Foxconn has grown significantly in terms of revenue. Its revenue reached \$27 billion USD in 2005, with over 200,000 employees worldwide.

Foxconn's objective is to maintain its position as one of the leading manufacturers of connectors, PC enclosures, and other precision components, and successfully develop products and market its products for use in network communication and consumer electronic products. To achieve this objective, Foxconn deploys the following strategies:¹³

- Develop strategic relationship with industry leaders: By working closely with top-tier PC and IC companies, Foxconn is able to predict market trends accurately and introduce new products ahead of its competitors.
- Focus on the development of global logistic capabilities: This enables Foxconn to respond quickly and efficiently to the customer's requirements around the world.
- Expansion of production capacity: Foxconn currently has production facilities in Asia, Europe, and the United States. Expanding its existing production capacity increases economics of scale.
- Achieve further vertical integration: Further integration of the production process allows Foxconn to exercise better control over the quality of its products.
- Maintain technologically advanced and flexible production capabilities: This increases Foxconn's competitiveness relative to its peers and allows it to stay one step ahead of the opposition.
- New products: Foxconn will leverage off its manufacturing expertise and continue to move tirelessly into new areas of related business

¹³ Foxconn Company Website, Strategy: <http://www.foxconn.com/about/strategy.asp>

In addition, Foxconn deploys an eCMMS (e-enabled Component, Modules, Moves, and Services) business model to provide its clients “total-package solutions” from one source, services ranging from molding, component sourcing, manufacturing, to after-sales warranty service. This business model has been successful as it generates loyalty and reliance from its clientele and reduces its clients from switching to other EMS players. In fact, most of Foxconn’s clients “accelerate outsourcing orders after placing a first order with Hon Hai/Foxconn.”¹⁴

2.6 Critical Components of a Desktop PC

The author will now describe the key components of a desktop PC and its assembly process. The discussion here is not meant to be exhaustive on all the components that make up a desktop PC. Rather, the focus of the discussion will be placed on the components that play a critical part of the project scope of this internship. Figure 5 illustrates the assembly of these components into a functional desktop PC.

¹⁴ Lu, Chialin. Yuanta Research Center Report on Hon Hai (2317.TW), February 14th, 2006.

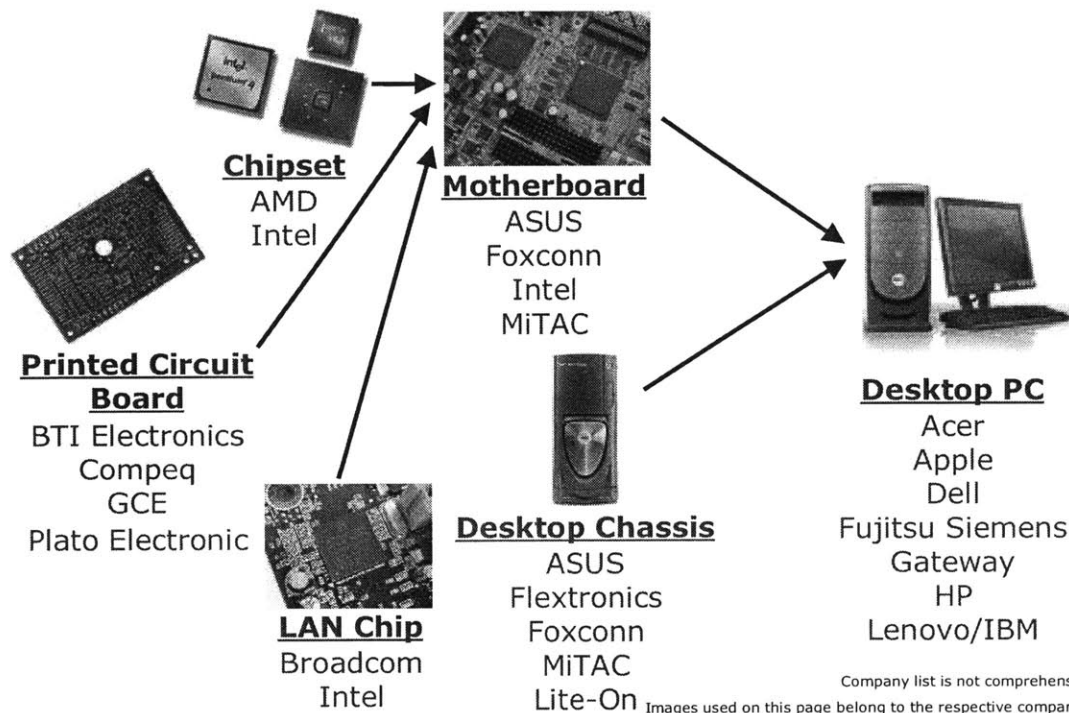


Figure 5. Critical Components of a Desktop PC & Major Component Manufacturers

Two major components of interest to this internship are the motherboard and the chassis.

A motherboard is the “nervous system” of a computer: it contains the circuitry for the central process unit (CPU), keyboard, and monitor and often has slots for accepting additional circuitry.

A chassis is the enclosure or framework case that contains and protects all the vital internal components from dust or moisture. Motherboards are typically screwed manually to the bottom of the chassis case, with the input/output (I/O) ports being exposed on the side of the chassis.

The chassis also contains the power supply unit.

A motherboard contains three critical components: chipset, printed circuit board (PCB), and Local Area Network (LAN) Chip. A PCB is the base of a motherboard; it consists of etched

conductors attached to a sheet of insulator. The circuit board is connected to other components that go on the board by soldering. A chipset is a group of integrated circuits that contains the northbridge and southbridge. The northbridge communicates with the CPU and memory; the southbridge communicates with the slower devices, such as the Peripheral Component Interconnect (PCI) bus, real-time clock, power management, etc. A LAN Chip enables a computer to communicate with the internet via Ethernet or Wi-Fi technology.

3 Symptoms and Root Causes

This chapter discusses the differences between Level 5 (L5) and Level 6 (L6) integration in desktop PC manufacturing. It then dives into the details of the symptoms and root causes of the problem identified in the Dell-Foxconn supply chain during my internship.

3.1 L5 vs. L6 Integration: The Mechanics

In desktop PC manufacturing, the degree of assembly can be broken down into 10 levels. The higher the level, the more fully integrated it is. The two figures below depict the 10 levels of desktop PC assembly. This scale can also apply to the manufacturing of servers and storages.

Desktop PC Assembly Levels

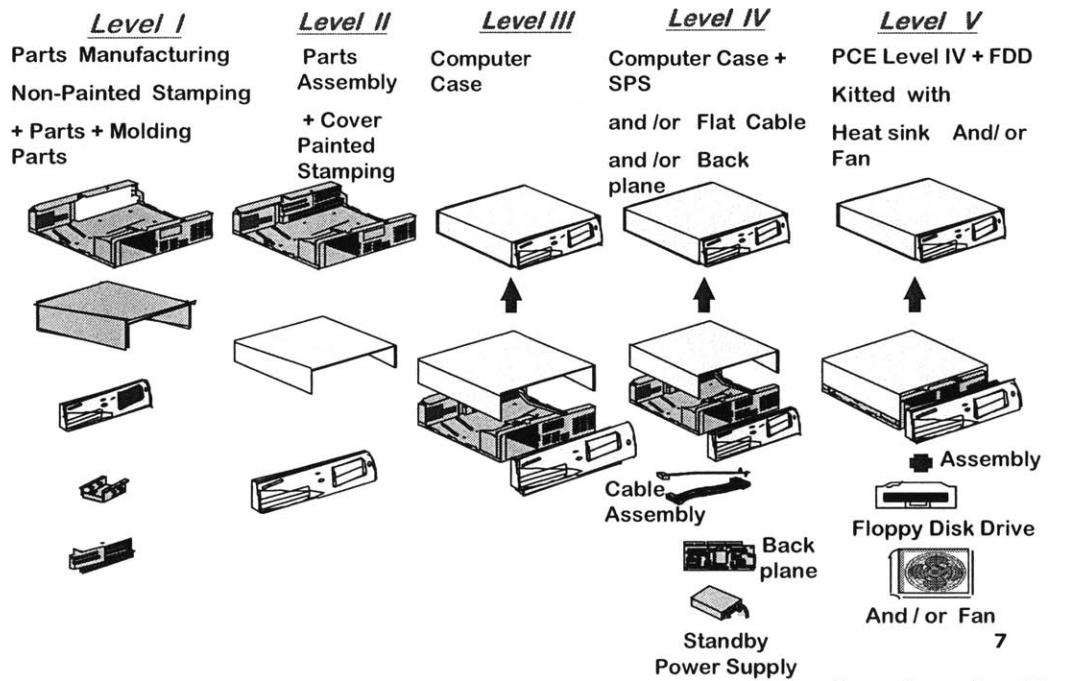
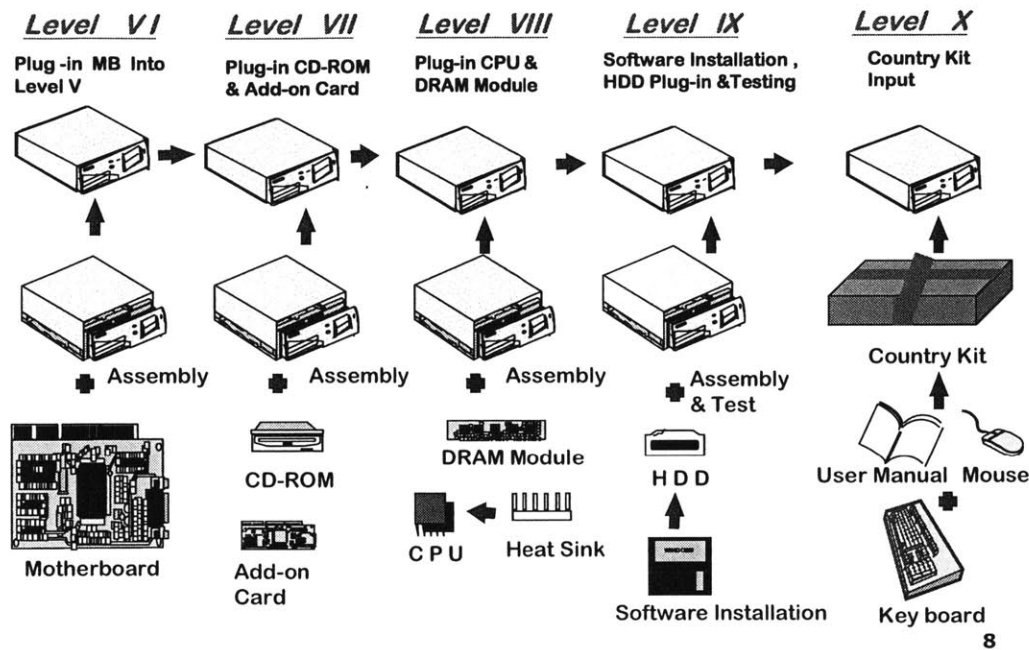


Figure 6. Levels 1 – 5 of Desktop PC Assembly¹⁵
Source: Foxconn Company Presentation

¹⁵ Foxconn Company Presentation, MIT LFM China Plant Tour, Shenzhen, China, 5/30/2005.

Desktop PC Assembly Levels



Source: Foxconn Company Presentation

Figure 7. Levels 6 – 10 of Desktop PC Assembly¹⁶

As illustrated by the two figures above, Level 5 includes the assembly of desktop PC chassis, floppy disk drive, and fan. Depending on the chassis configuration, it can also include the power supply in some cases. In Level 6, along with these components, the motherboard is also assembled into the chassis.

When a contract manufacturer in China produces a Level 6 desktop PC chassis, the chassis is not a functional unit yet and still requires customized parts such as the processor, memory, hard drive, speaker, etc. The contract manufacturer ships the Level 6 chassis from China to Dell's factories in the U.S. and Ireland, and then the Dell factory associates install these

¹⁶ Foxconn Company Presentation, MIT LFM China Plant Tour, Shenzhen, China, 5/30/2005.

customized parts to make the unit “Level 10”. A Level 10 product is a fully assembled and functional product and can be shipped to the customer.

Some of Dell’s products, such as handhelds and printers, are manufactured to Level 10 by the contract manufacturers. This means that Dell does not have dedicated manufacturing resources or capability to manufacture these products. Rather, the contract manufacturers produce these products and include the user manuals in the packaging and ship the products to Dell’s merge centers. These products are then “merged” with the PCs manufactured by Dell factory associates into the same shipment, so the customer can receive just one shipment with all the items in the order. Dell uses this shipping strategy in the hope of creating a more satisfying customer experience.

3.2 L5 vs. L6 Integration: Costs and Value Comparison

This section discusses the costs associated with Levels 5 and 6.

In Level 5 manufacturing, the motherboard is not installed into the chassis before the chassis is shipped from China to the U.S. by ocean. In Level 6 manufacturing, the motherboard is installed into the chassis in China.

Both Levels 5 and 6 share the following costs:

1. **Raw material costs:** Almost all of the raw materials used to make the components in a desktop PC, including sheet metal for the chassis, plastic parts inside the chassis, and the electronic parts of a motherboard, etc. are either produced by the contract manufacturers or their suppliers in China. The chipsets are manufactured in China, Malaysia, or the Philippines.

2. Materials transportation cost within China: To manufacture a motherboard, the chipset, printed circuit board (PCB), Local Area Network (LAN) Chip, and other critical components need to be transported to the motherboard manufacturer in China.
3. China assembly labor cost (the contract manufacturer performing Levels 1 to 5): Foxconn produces the chassis and assembles the chassis with the internal cables, plastic disk drive holders, etc.
4. Chassis ocean-shipping cost: This is part of the logistics cost to transport the chassis from China to the U.S. by ocean.
5. Chassis transportation cost within the U.S.: Once the chassis arrive in the U.S. port (typically Long Beach, CA), the chassis need to be transported by train or truck to Dell's Supplier Logistics Center (SLC).
6. Chassis inventory holding cost at the SLC: Once the chassis arrive at the SLC, they will stay there until the Dell manufacturing pulls the inventory into the factory. Although Dell officially only pays for the parts when it pulls the parts from the SLC into its factory, the inventory-holding cost and the SLC management cost still exist in the overall supply chain.
7. U.S. assembler's cost at Dell (Dell factory associates performing Level 7 to 10): Dell factory associates install the processor, memory, hard drive, speaker, and software to meet the customer's requirement.

In L6 manufacturing, a motherboard is installed into the chassis before the chassis is shipped by ocean to the U.S. Therefore, the only cost additional to the list above is the Chinese labor cost of assembling the motherboard into the chassis.

However, in L5 manufacturing (chassis without the motherboards are shipped by ocean to the U.S. first, and then motherboards are air-freighted to the U.S.), the list of costs is longer than L6:

1. Motherboard packaging cost: If the motherboard travels separately from the chassis, packaging is required to protect the motherboards from damaging during the freight. This is a cost that would be eliminated if the motherboard travels inside the chassis.
2. Motherboard air-freight/expedite cost: When the motherboard does not travel inside the chassis, separate transportation cost is required to air-freight the motherboards from China to the U.S.
3. Motherboard U.S. transportation cost: In L5 manufacturing, transportation cost is required to transport the motherboard from its arrival at the U.S. dock to the SLC and from the SLC to the 3rd-party integrator (3PI).
4. Motherboard inventory holding cost at the SLC: Since the motherboards are not inside the chassis in L5 manufacturing, separate SLC space is required to hold the inventory of motherboards.
5. Local/regional integration cost: When the motherboard and the chassis arrive in the U.S. as two separate components, local/regional laborers are required to integrate the two into one.
6. Chassis and motherboard U.S. transportation cost: Once the 3PI integrates the motherboard with the chassis, the chassis has to be transported back to the SLC.
7. Motherboard rework cost at Dell: Since the 3PI does not have the testing equipment to perform the functional testing on the L6 chassis, the chassis integrated by the 3PI naturally have a higher rate of quality defects. When a defect happens, resolution of the

defect is performed at Dell. Therefore, L5 incurs a higher quality defect resolution cost than L6.

8. Dell Level 5 management cost: L5 is more complex to manage than L6. Since more “work” has to be done when the chassis and the motherboard arrive as two separate units, Dell internally has to delegate more people to manage the 3PI integration activities and the quality defect resolution process. For Foxconn, this also represents a revenue drain, as the motherboard-chassis integration laborers have to sit idle due to the lack of motherboards.

The following diagram compares L6 with L5 manufacturing:

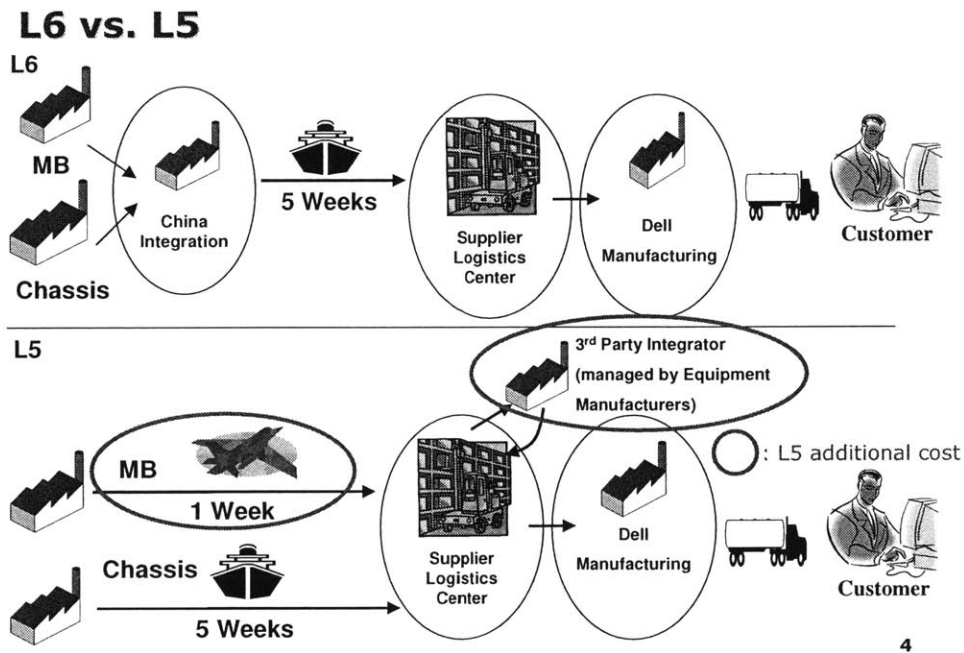


Figure 8. L6 vs. L5 Value Comparison

L5 has a higher overall manufacturing and logistics cost for two primary reasons:

1. Motherboard-airfreight cost: If motherboards cannot be manufactured in time to be integrated with the chassis before the chassis are transported by ship/ocean from China to the U.S., when the motherboards later become available, Dell incurs a cost to air-freight the motherboards in order for these boards to “catch up” with the empty chassis. Otherwise, if the empty chassis arrive in the U.S. without motherboards ready to be installed, the empty chassis would sit idle in Dell’s SLC and incur further cost by holding unnecessary inventory.
2. 3rd-party integration cost: For the motherboard-chassis integration work that takes place in the U.S., Dell currently outsources this task to a 3rd-party integrator. These integrators are located close to the Dell SLCs and factories, so the cost of transporting between the SLC, 3PI, and Dell factories can be minimized. However, since the U.S. labor rate is higher than the Chinese labor rate, the cost of integration is higher at a 3PI than at a Chinese contract manufacturer.

However, L5 manufacturing provides a more flexible supply chain for Dell and Foxconn since it is basically a postponement strategy. Since chipsets do not have to be delivered to the motherboard manufacturer’s facility before the chassis leaves the Chinese port, the supply chain enjoys a higher degree of flexibility since motherboards and chassis travel as two independent units. While the chassis are traveling on ocean, Dell and Foxconn can determine when and how many motherboards to manufacture in China and later air-freight to the U.S. L5 manufacturing allows more just-in-time production of chipsets and motherboards since the motherboard manufacturing process is not a pre-requisite of the chassis shipment schedule leaving the Chinese dock.

From a chipset supplier's perspective, L5 also ties less chipset inventory in the supply pipeline. Since the prices of electronic items depreciate over time, the chipset provider naturally prefers delivering the chipsets to Dell or Foxconn in a just-in-time fashion, instead of having a 5-week inventory of chipsets being tied in ocean containers in the Pacific Ocean.

3.3 Symptoms

Before July 2004, the majority (> 95%) of all desktop chassis Dell U.S. and Europe received from China were L6. However, since then, Dell and Foxconn have been seeing an increasing volume of L5 chassis from China. The chart below illustrates the expenses Dell has incurred to: 1.) air-freight motherboards from China, and 2.) integrate motherboards with chassis in the U.S. and Europe.

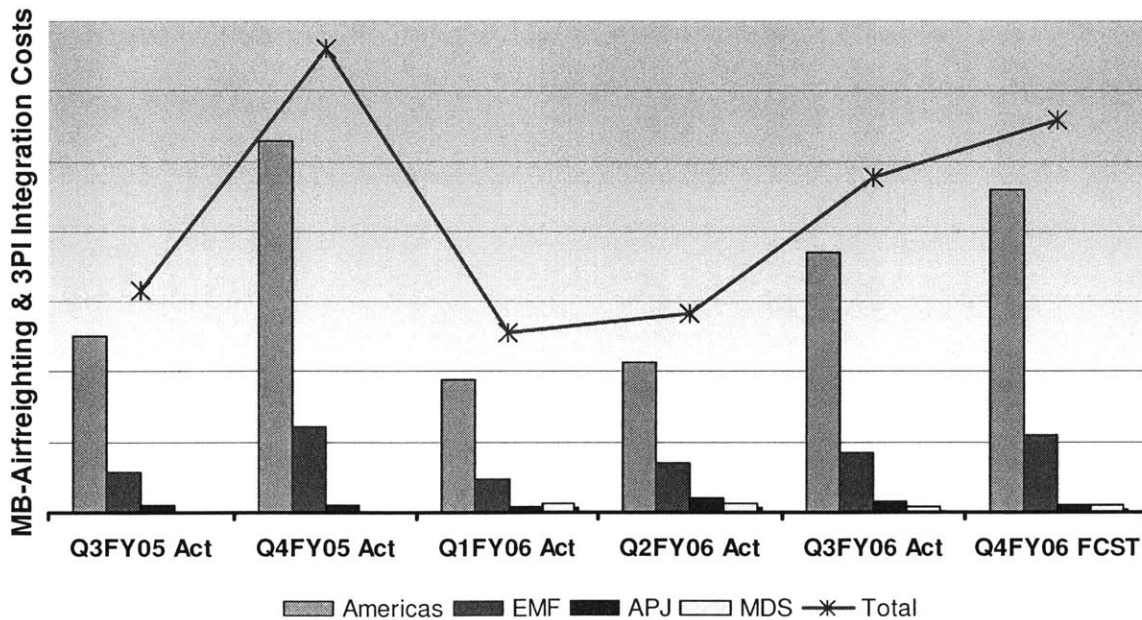


Figure 9. Motherboard Air-freighting and 3PI Integration Costs (Q3FY05 – Q4FY06)¹⁷

¹⁷ Data from Dell's Worldwide Procurement (WWP) organization. AMF includes 3PI integration cost. EMF and APJ don't as integration is done in Dell factory. In Dell's Financial Year, Q1FY05 is February – April 2004; Q4FY06 is November 2005 – January 2006.

The costs related to L5 manufacturing increased significantly from Q3 to Q4FY'05. As a way to control the skyrocketing costs, Dell's Worldwide Procurement (WWP) organization instituted an Expedite Council in Q1FY'06. Before the formation of the Expedite Council, Dell buyers had much freedom to expedite motherboards whenever they felt necessary without having to follow through an approval process. In Q1FY'06, the Expedite Council began to require any expedite cost to be reviewed and approved by the council first before a buyer can execute the expedite order. As a result, the cost declined in Q1FY'06. However, since the percentage of L5 manufacturing continued to increase, the cost beyond Q1FY'06 also continued to rise.

The chart below shows the percentage of L5 vs. L6 units over the 12-month period between July 2004 and June 2005, based on the worldwide Desktop PC units sent by Foxconn to Dell. As indicated by this chart, L5 manufacturing started to increase quite significantly in March 2005. The L5 % in June (27%) is more than 6 times the L5 % in March (4%), making the manufacturing cost per unit more expensive for Dell due to the increasing motherboard air-freighting cost and U.S. integration cost.

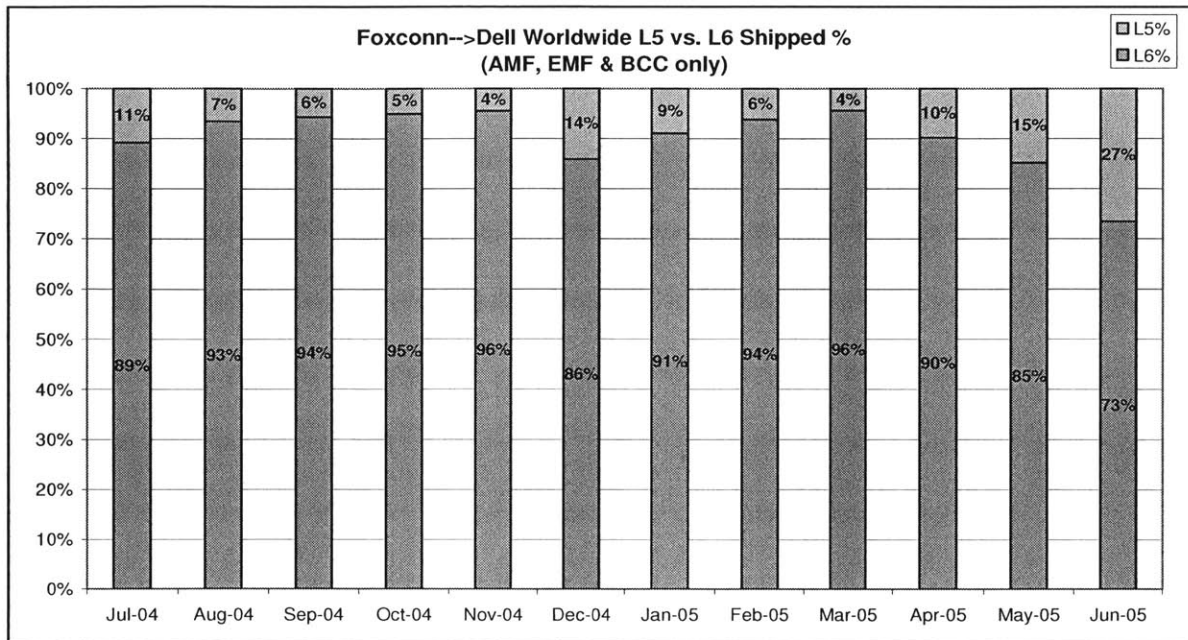


Figure 10. Percentage of L5 vs. L6 Production from July 2004 to June 2005¹⁸

3.4 Root Causes

At the initial period of my internship, it was unclear what driving forces actually contributed to the increase of L5 manufacturing in the Foxconn-Dell Desktop PC supply chain. Several reasons were speculated. Some of the people the author interviewed blamed the motherboard quality as the most important factor contributing to L5 manufacturing. Others cited the chipset shortage or Dell's forecasting ability as the number one root cause. However, no one seemed to know for sure what actually led to an increasing level of L5 manufacturing. An interview with a Global Supply Manager (GSM) at Dell reveals the following:

“The recent increase in L5 manufacturing is alarming to us. From Dell's perspective, this adds cost to our overall manufacturing process. We are not able to take as much advantage as we should of the lower cost structure of our contract manufacturers. Instead, we have to rely more heavily on the 3PI's. Not only do we get lower-quality products because we currently don't require 3PI's

¹⁸ Data from Foxconn Desktop (DT) II organization.

to perform integration unit testing, we also have difficulty forecasting for the 3PI's how much manufacturing capacity they should have available to support Dell's demand."¹⁹

Similarly, an interview with a Foxconn manager in its Shenzhen facility expressed similar sentiment:

“From a supplier's point of view, it would help us if we can deliver more value-added manufacturing steps for our customer Dell. Therefore, we prefer L6 over L5. However, whenever we don't receive enough chipsets from the chipset supplier, this halts our motherboard manufacturing in Shenzhen. In addition, our factory workers dedicated to L6 (motherboard-chassis assembly) also become idle. Since we have to find a different task for these laborers to work on whenever motherboards are not available, the staffing of these laborers and production scheduling become a constant headache that our management needs to deal with. It would be nice if we always had enough chipsets because these difficulties would disappear.”²⁰

Part of the internship was analyzing the root causes, and the author began to investigate whether data related to motherboard expedites was available. The investigation revealed that such data was available, but only on a limited fashion. Before the establishment of the Expedite Council, Dell buyers were expediting motherboards whenever they felt necessary without having to follow through a formal approval process, and the decisions to expedite were not captured. One of the positive effects the Expedite Council created within Dell was the documentation of expedite requests and related data. For each expedite request, the following information is now reviewed and documented:

1. Date of the request
2. Name of the requestor
3. Type of items required by the expedite request (motherboards or chassis)
4. Quantity of each item required by the expedite request

¹⁹ Interview with a Global Supply Manager at Dell WWP organization, June 2005.

²⁰ Interview with a Foxconn manager, July 2005.

5. Date when the request was reviewed and approved/rejected
6. Dollar amount required by the request
7. Name of the contract manufacturer

Based on the expedite data tracked by a Dell WWP analyst since the formation of the Expedite Council, the expedite cost can be broken into four categories:

1. Chipset supplier decommit or supply issues: When the chipset supplier is unable to deliver the previously agreed quantity of chipsets, it creates a disruption in the desktop PC supply chain. According to the data gathered in the first half of 2006, this accounted for more than 60% of the L5 manufacturing.
2. Quality/engineering issues: These issues lead to dysfunctional or problematic motherboards that need to be repaired or replaced by a new supply, which can subsequently create an additional unexpected demand of motherboards that were not part of the forecast agreed by Dell's chipset supplier Intel.
3. Dell forecast accuracy: When the actual demand surpasses the forecast, Dell would need to source extra chipsets or risk the possibility of not meeting customer demand. Since the lead time for manufacturing, assembling, testing, and delivering a chipset is on average 13 weeks, such a long lead time makes it difficult for Intel to provide the additional chipsets in order to meet Dell's demand schedule.
4. New Production Introduction (NPI): Since the actual demand of a newly released PC product can be especially volatile, the forecast uncertainty can create a need to expedite motherboards. However, as Figure 11 indicates, the amount Dell spends on expediting motherboards under this particular circumstance is small—only 3.8%.

The figure below shows the breakdown of expedite costs by root cause.

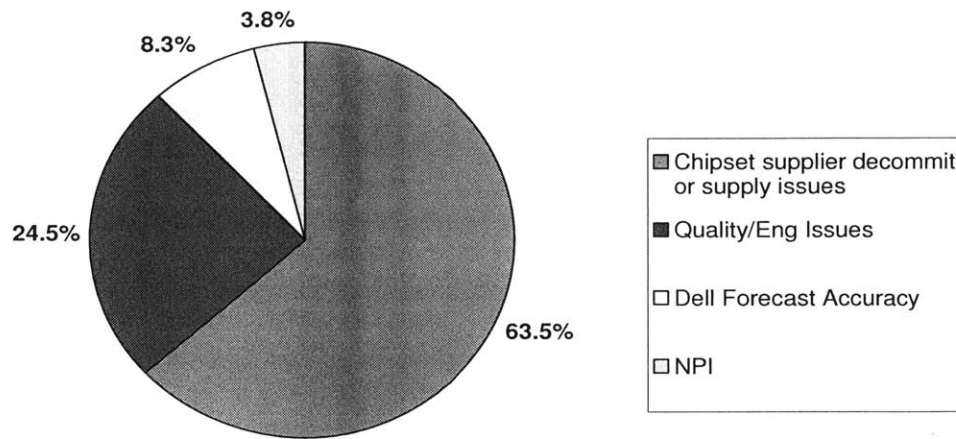


Figure 11. Dell AMF Expedite Expenses by Root Cause (January to June '05)²¹

The visibility to expedite-related data became possible after the establishment of the Expedite Council. This was helpful to the stakeholders involved because the data not only explained what the root causes were, but it also clarified to what degree each root cause contributed to the rising expedite expense. However, it should be noted that some of these root causes can be intertwined. For example, if Dell decides to order more chipsets than its previous forecast, and if Intel cannot provide the adequate quantity, it can be difficult to discern whether the root cause belongs to Dell's forecast inaccuracy or Intel's supply issue. Therefore, the data presented by Figure 11 should be treated not as absolute measures, but as relative weights of these root causes.

²¹ Data from Dell's Worldwide Procurement (WWP) organization.

On a more fundamental level, a chipset shortage can exist even when the chipset manufacturer has no capacity issue. The shortage could be caused by a sudden recall of defected chipsets, therefore creating a disruption in the supply chain. Therefore, a contingency plan (such as an optimization model pre-determining how many chipsets should be sent to China vs. the U.S.) becomes necessary to minimize the shock resulted by the supply disruption.

3.5 Impact on the Continuity of Supply

Continuity of Supply (CoS) is a phrase commonly used in Dell and Foxconn meetings. The concept of CoS is related to the inventory level at Dell's Supply Logistics Center (SLC) and is expressed as the number of Days of Supply Inventory (DSI). The DSI number is calculated based on the 4-week forecast in Dell's master production plan. For critical components, such as chipsets, Dell requires its suppliers to stock a higher DSI of inventory at the SLC. The DSI requirement is lower for less critical components. In fact, Dick Hunter, Vice President of Dell America Operations, describes CoS as Dell's primary focus with its suppliers:

“We organize around the concept [of the Continuity of Supply] and focus on the velocity of inventory throughout the entire supply chain. Virtual integration, rather than vertical, gives us the crucial ability to focus on our core competency and leverage those of our suppliers, such as their R&D investments. As such, we are able to keep operating expenses low while focusing resources on areas where we can truly add value for our customers.”²²

A chipset shortage has a direct impact on Dell's CoS. When the chipset supplier cannot provide enough DSI of chipsets to Foxconn to support the L6 manufacturing strategy, half-assembled L5 chassis will stock up in Foxconn's Shenzhen factory. If Dell and Foxconn choose to wait until the chipsets arrive in Shenzhen and Foxconn produces the motherboards before

²² Hunter, Dick. “Tying Supply Chain to Customers”, IndustryWeek, December 16th, 2005: <http://www.industryweek.com/ReadArticle.aspx?ArticleID=11124>.

shipping L6 chassis to Dell's factories in the U.S., a CoS gap will appear in the continuous shipments to Dell's factories and negatively impact Dell's ability to fulfill customer demand. In addition, this would also translate into a higher inventory-holding cost for Foxconn since the L5 chassis would be waiting at the Shenzhen factory for the motherboards to become available. To avoid this, Dell and Foxconn have chosen to ship L5 chassis in the event of chipset unavailability and air-freight motherboards later to be integrated with the chassis in the U.S. when the motherboards become available.

The CoS level also differs depending on which phase of the product lifecycle the product is in. When a product is in its NPI phase, the demand is more volatile, and regional L5 assembly in the U.S. can help meet the demand and prevent stockouts, which can translate into costly loss of sales for a company introducing a new product, from happening. When the product enters the mature phase, and the demand is greater but more predictable, L6 is more effective in reducing the manufacturing and logistics costs. Finally, when a product is about to become obsolete, and the demand again becomes less predictable, a balance should be achieved to both satisfy the volatile demand and minimize the motherboard expedites.

As discussed in the previous section of this chapter, according to Dell's internal data, 63.5% of all motherboard expedites was due to the chipset supplier decommit or supply issues. Why has there been such a shortage in the PC industry? The reason can be understood by analyzing the power of each player in the value chain illustrated by Figure 12.

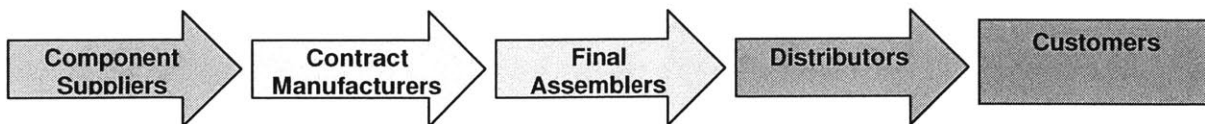


Figure 12. The Desktop PC Value Chain

In the PC value chain, the final assemblers (e.g. Dell) and contract manufacturers (e.g. Foxconn) rely on two parties: component suppliers that can provide the parts needed in building a PC, and distributors that can deliver the products to the customers. Dell's supply chain essentially eliminates the distributors as the middle-man between Dell and the customers and thus enables Dell to directly interface with its customers. However, on the upstream of the value chain, Dell still relies on the component suppliers to provide critical parts such as the chipset.

In 2005 and 2006, Intel's chipset production worldwide was unable to meet demand mostly due to production its capacity issues.²³ This, coupled with the fact that chipset manufacturing has a 13-week lead time, makes it difficult for Dell and its chipset supplier to forecast accurately. In the profession of forecasting, it is commonly known that the longer the time horizon, the lower the forecast accuracy.²⁴ Therefore, missing the committed quantity became more common, and the quantity under-delivered also became larger over time. As a result, and as illustrated by Figure 10, the percentage of L5 increased. Currently, unlike other PC makers such as HP that source chipsets from multiplier suppliers, Dell purchases chipsets exclusively from Intel. This means that Dell has to have strategies other than dual-sourcing to effectively deal with this issue.

Another factor that contributes to the chipset supply constraint is the lower margin of the desktop PCs. The trend in the future of the PC industry is that "portable PC demand will continue to drive growth in the U.S. while desktop growth will remain under pressure, eventually

²³ Channel Register, 12/1/2005: http://www.channelregister.co.uk/2005/12/01/intel_chipset_shortage/

²⁴ MIT 1.260J Logistics Systems course, Prof. Chris Caplice, lecture 2, fall 2004: <http://ocw.mit.edu/OcwWeb/Engineering-Systems-Division/ESD-260JFall2003/CourseHome/index.htm>

slipping to near zero from mid-single digits.”²⁵ In a capacity-constrained environment, Intel strategically allocates more of its production capacity to higher-margin goods, such as laptop PC chipsets. This is due to the fact that sales of a laptop PC typically generates a higher profit for Dell and Intel than a desktop PC. Therefore, although the lack of chipset availability hurts Dell on its desktop PC business, overall, Dell and Intel actually enjoy a higher profit through a higher availability of laptop PC chipsets. As a Dell laptop commodity manager described, “It’s not that the chipset supply shortage doesn’t affect us [in the laptop PC products]. We typically receive all the chipsets by the end of a quarter, but, throughout the quarter, our contract manufacturers don’t always receive the chipsets at the time they need the chipsets. Therefore, it becomes more difficult for them to determine the appropriate level of capacity to support Dell’s demand.”

In summary, the production capacity of Dell’s chipset supplier Intel was constrained in 2005 and 2006, forcing Intel to allocate more of its capacity to manufacture the higher-margin laptop PC chipsets. Strategically, this is also a policy deployed by Intel (and Dell) to capture higher profits in the midst of chipset production capacity constraint.

²⁵ InformationWeek, 6/16/2005, <http://www.informationweek.com/shared/printableArticle.jhtml?articleID=164900354>

4 Original Direction of the Internship

This chapter proposes an approach to solve the problem described in Chapter 3. It explains the scope of the project, the purpose of the optimization model, its input variables and expected outputs. It also formulates the optimization model using the input variables.

4.1 Scope of the project

1. *Desktop PCs only:* This project focused on desktop PC products only and did not involve laptops, servers, storages, or peripherals.
2. *Dell America Operations only:* In terms of geographic area, the problem described in Chapter 3 of this thesis impacted both Dell's operations in the U.S. (Dell America Operations, or DAO) and Europe (European Manufacturing Facility, or EMF). However, given the 6-month duration of this internship and the fact that the EMF procurement organization is organizationally independent from DAO, the scope of the project was limited to DAO only.
3. *Constrained by the chipset supply shortage:* Given the market dynamics, one major assumption of the project was that it would not address the opportunity to improve the chipset supply situation. The availability and allocation of chipsets were certainly hot issues constantly discussed by Dell's executives and its chipset provider Intel. However, for the purpose of this project, the chipset supply shortage was treated as a constraint.
4. *Focused on factory operational improvement:* Because the project was not to address the possibility of improving the chipset supply, the focus of the project was placed on examining Dell's internal operational improvement. In other words, the chipset supply

shortage posed a need for Dell to change its operational model in order to achieve its cost-saving target and manufacturing flexibility.

5. *Motherboard-chassis integration only:* This project focuses on the integration of two major components—motherboards and chassis. It does not involve fans, power supply, SPAMS (Speakers, Printers, Advanced Port Replicators, Monitors, Scanners), or other components. However, the lessons learned from this project can be applied to the other critical components as well.

4.2 Objective of the Optimization Model

Given the environment of chipset supply shortage Dell and Foxconn lived in, some questions needed to be answered:

1. *What quantity of L5 vs. L6 chassis should each factory receive every month?* Dell currently has 3 factories that manufacture desktop PCs: Austin, TX, Nashville, TN, and Winston-Salem, NC. Each factory has its own geographic demand and product mix it needs to satisfy. Under the condition that not all the desktop PC chassis will arrive in the U.S. as a L6 chassis, how many L5 vs. L6 chassis should each of these three factories receive? This question would be linked to understanding the production capacity and product mix strategy at each factory.
2. *Of all L5 units, what % should be integrated at Dell vs. 3PI?* Currently, Dell outsources all U.S. motherboard-chassis assembly work to the 3PI's, as it currently lacks the capability to integrate motherboards with the desktop chassis inside its factories. From a cost and flexibility standpoint, Dell needs to examine whether what portion of L5 units should be integrated in-house versus at a 3PI site.

3. *What should be the capacity of Dell's motherboard-chassis integration capability?*

Given the uncertainty of the chipset supply, Dell might need to consider whether the 3PI's have enough manufacturing capacity and what level of motherboard-chassis integration should be performed in each Dell factory.

4. *What should be each 3PI's motherboard-chassis integration capacity?* The capacity required at each 3PI can change if Dell decides to "insource" some of the motherboard-chassis assembly work.

5. *How many 3PI locations should there be in each region? Where should the 3PI's be located?* Currently, the Dell Austin factory is supported by two local 3PI's, and the 3PI located in Nashville supports the Dell Nashville and Winston-Salem factories. However, it is unknown whether this network would remain optimal once the Winston-Salem factory, opened in September 2005, ramps to its full capacity.

Overall, the project goal was to construct an optimization model to determine the optimal level of L5 integration volume in DAO to enable Dell & Foxconn to proactively plan for chipset supply shortage. As demonstrated by Figure 12, although the actual L5 integration volume needed in the U.S. fluctuates, the optimization model would compute the ideal constant level of L5 integration volume and the overall required integration capacity. Moreover, this model would take into account the following necessary conditions:

1. When a product is at the initial stage of its product lifecycle (aka. New Production Introduction), the demand is harder to predict, and therefore a higher % of L5 is desired to readily respond to the erratic nature of the demand. On the other hand, during the mature stage of the product lifecycle, when the demand is more stable, a higher % of L6 will help reduce cost.

2. Products that require more time to assemble should be assembled to the L6 level in China to take advantage of the lower cost of assembly.
3. Products that require fewer “touches” (for example, Dell’s “White Chassis” products of which the surface can be scratched easily) should be assembled to the L6 level in China in order to maximize the product quality, since assembling in the U.S. requires some components (such as a fan) in the L5 chassis to be removed first before the motherboard is assembled. The removal and re-insertion of these components introduce new “touches” otherwise not necessary if the assembly is performed in China.

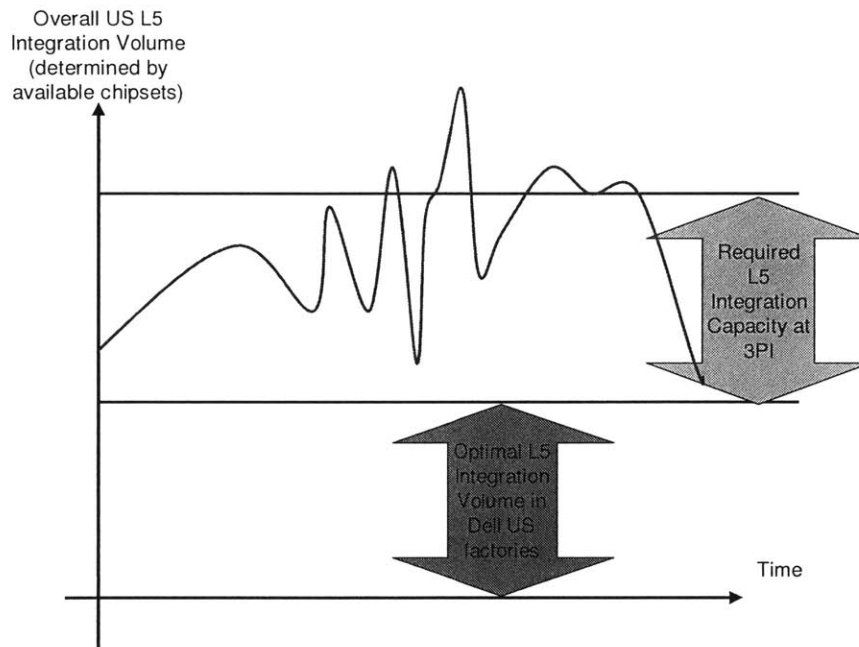


Figure 13. DAO and 3PI Integration Levels vs. Fluctuating Total US Volume

The optimization model would potentially be a linear programming model representing the manufacturing and supply chain system that exists between Foxconn and Dell. The model would consist of two major analytical components: the first part of the analysis would focus on

the quantity of Foxconn's weekly motherboard and chassis throughput; the second part of the analysis would focus on the actual weekly volumes of L5 and L6 desktop PCs and the quantity of motherboards required to perform motherboard-chassis integration in the U.S. Figure 13 illustrates all the input parameters and the expected outputs of the proposed optimization model.

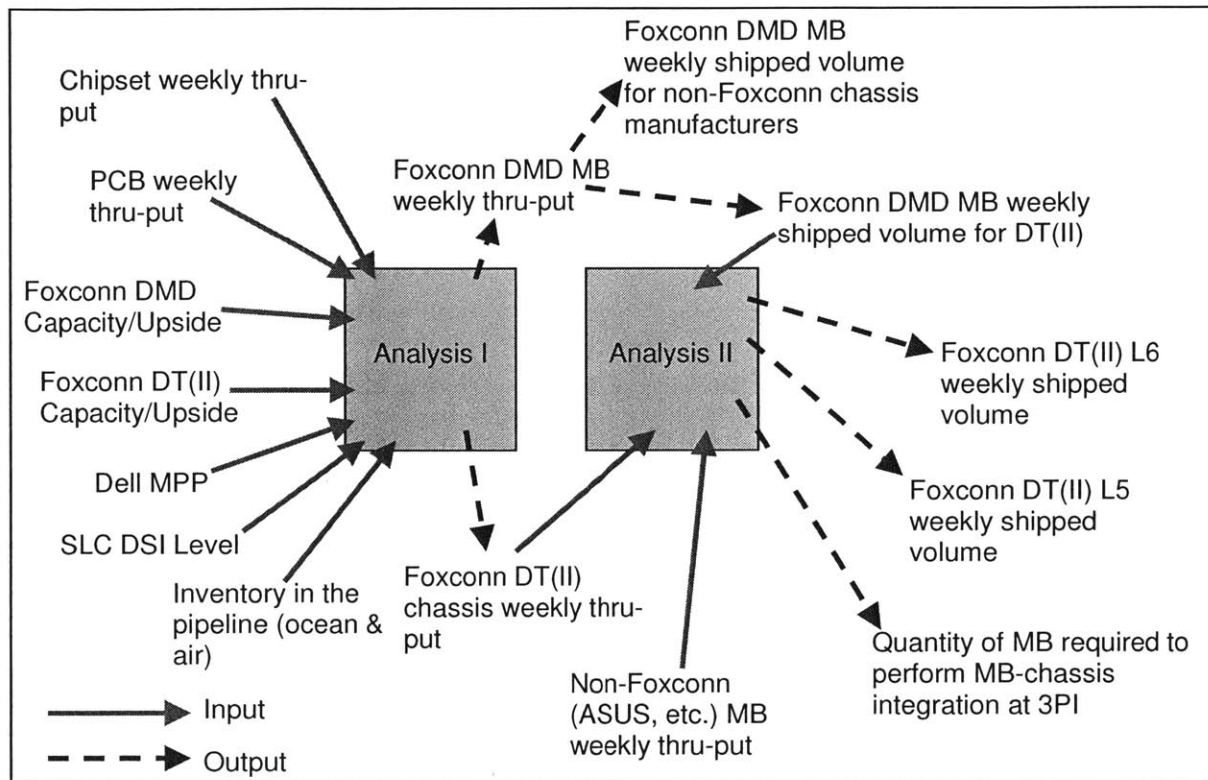


Figure 14. Structure of the Optimization Model originally proposed

4.3 Analysis I of the Optimization Model

In Analysis I of the model, the input parameters would be the following:

1. The quantity of chipsets (by type) the system will receive weekly: variable a_i , where i symbolizes a particular product type, assuming that n product types are considered in this optimization model.

2. The quantity of PCB boards the system will receive weekly: variable b_i
3. The capacity volume of motherboard production at the Foxconn DMD organization:
variable c_i
4. The capacity volume of chassis production at the Foxconn DT(II) organization: variable d_i
5. The required level of production based on Dell's Master Production Plan (MPP):
variable e_i
6. The number of Days of Supply Inventory (DSI) level that needs to be maintained in each
Supplier Logistics Center (SLC): variable f_i
7. The overall inventory level in the supply pipeline being transported by ocean or aircraft
carriers: variable g_i

In a nutshell, these input parameters provide the constraining variables based on the supply inputs and capacity in the system.

Analysis I of the optimization model would receive these inputs and perform the necessary capacity analysis to generate the following two outputs:

1. The quantity of motherboards the Foxconn DMD organization can produce weekly:
variable h_i
2. The quantity of chassis the Foxconn DT(II) organization can produce weekly: variable j_i

In other words, taking the input parameters described above, the optimization model would calculate and generate how many motherboards and chassis Foxconn can produce.

4.4 Intermediary Stage

Before going on to the second analysis stage, one crucial element to understand is the fact that sometimes Dell requires Foxconn to either send motherboards to or receive motherboards from other motherboard manufacturers—Foxconn’s very own competitors. Almost all of the contract manufacturers produce both chassis and motherboards; therefore, it would make better economic sense for the same supplier to be in charge of the assembly. Although this supply chain design might not seem intuitive at first because it would inevitably incur additional costs to transport motherboards from a motherboard manufacturer to a chassis manufacturer/assembler, it is a design engineered by Dell for the following reasons:

1. Spread the manufacturing risk: Designating the same contract manufacturer to be both the motherboard manufacturer and chassis manufacturer/assembler inherently bears a higher business risk than separating the motherboard manufacturing and chassis manufacturing/assembly into two different contract manufacturers. Dell’s current supply chain design lowers this risk. This way, if, for example, a natural disaster severely damages the production facility of one of the contract manufacturers, the same motherboard can still be produced by another manufacturer located elsewhere.
2. Increase competitiveness among the contract manufacturers: Since there is no guarantee that a chassis supplier will also win the bid of producing the motherboards that go into the chassis they produce, contract manufacturers have a greater incentive to compete on the basis of quality, delivery, and cost. This competition helps raise the overall product and process standard.
3. Cultivate the manufacturing capability of new contract manufacturers: Foxconn originally was only a chassis manufacturer but has since entered the business of

producing motherboards. This not only allows Foxconn to provide more value-added services to its client Dell, but it also gives Dell a greater degree of choices in developing collaborative relationships with its contract manufacturers.

In the intermediary stage of the optimization model, there are three variables:

1. The quantity of motherboards shipped to non-Foxconn chassis manufacturers: variable k_i
2. The quantity of motherboards received by Foxconn DT(II): variable l_i
3. The quantity of motherboards Foxconn DT(II) received from other motherboard manufacturers: variable m_i

Using these three variables, the quantity of chassis available for assembly could be generated.

Variables k_i , l_i , and m_i would then become the input parameters of Analysis II.

4.5 Analysis II of the Optimization Model

Analysis II takes the output parameters of the intermediary stage as the input and produces the outcome of the optimization model.

Based on the motherboards and chassis available at Foxconn, the optimization model is interested in generating the following outputs:

1. Weekly quantity of L5 chassis Foxconn will ship to Dell: variable p_i
2. Weekly quantity of L6 chassis Foxconn will ship to Dell: variable q_i
3. Weekly quantity of motherboards required to perform the motherboard-chassis integration at 3PI: variable r_i

The optimization model aims at providing a production plan that is clear for Foxconn and Dell and manageable in light of the chipset supply constraint.

4.6 Formulation the Optimization Model

Using the variables denoted above, the following formulation can be constructed. First, variable h_i (Foxconn DMD motherboard weekly throughput) depends on the weekly chipset and PCB through-put, as well as Dell's production goal and inventory. For $i = 1$ to n :

$$h_i \leq a_i$$

$$h_i \leq b_i$$

$$h_i \leq c_i$$

$$h_i \leq e_i + f_i - g_i$$

Similarly, variable j_i (Foxconn DT(II) chassis weekly throughput) depends on the capacity/upside at Foxconn DT(II), as well as Dell's production goal and inventory. For $i = 1$ to n :

$$j_i \leq d_i$$

$$j_i \leq e_i + f_i - g_i$$

Next, an equation needs to be established for the quantity of motherboards produced by Foxconn DMD weekly. The motherboards produced are either used by Foxconn DT(II) or sent to another chassis manufacturer. Therefore,

$$h_i = k_i + l_i$$

Subsequently, the L6 quantity produced weekly, variable p_i , will be constrained by the total number of motherboards available:

$$p_i = l_i + m_i$$

Finally, the L5 quantity produced weekly, variable q_i , will be the difference between the total number of chassis produced by Foxconn DT(II) and the number of chassis used only for L6.

This number should also equal to the quantity of motherboards required to perform the motherboard-chassis integration at the 3PI, variable r_i .

$$q_i = j_i - p_i$$

$$q_i = r_i$$

Naturally, all the variables in this optimization model would need to be either positive or 0:

$$a_i, b_i, c_i, d_i, e_i, f_i, g_i, h_i, j_i, k_i, l_i, m_i, p_i, q_i, r_i \geq 0$$

The objective of the optimization model is to maximize the L6 quantity in order to reduce cost, since L6 bears a lower manufacturing cost than L5:

$$\text{Max} \sum_{i=1}^n p_i$$

The formulation above is the basic formulation of the optimization model. In addition, more complexity can also be introduced into this model. For example, if, according to the forecast from the chipset supplier, the available chipsets are only 85% of the total desired for a given product type i , we can express the ratio between variables p_i and q_i as the following:

$$p_i / q_i = 85\% / 15\%$$

This model will provide Dell and Foxconn the flexibility to experiment with different ratios of p_i / q_i to examine what effect the increase or decrease of each input variable will affect the three output variables p_i , q_i , and r_i .

5 Renewed Internship Direction

This chapter describes the business environment that leads to the directional change of the internship, followed by a discussion of the renewed focus and deliverables of the internship.

5.1 Changing Business Environment

In September 2005, Dell's Worldwide Procurement was informed by Intel that the chipset shortage situation would become more severe going forward. In June 2005, the ratio of L5/L6 was 15%/85%. However, Dell was informed that, although the best estimate of L5/L6 would be 30%/70%, the L5 percentage could be foreseeably larger and unpredictable. In addition, Intel's capacity constraint would force Intel to only be able to provide a 3-month chipset forecast to Dell, as opposed to the 6-month forecast provided previously. The following diagram exemplifies the L5/L6 development over time.

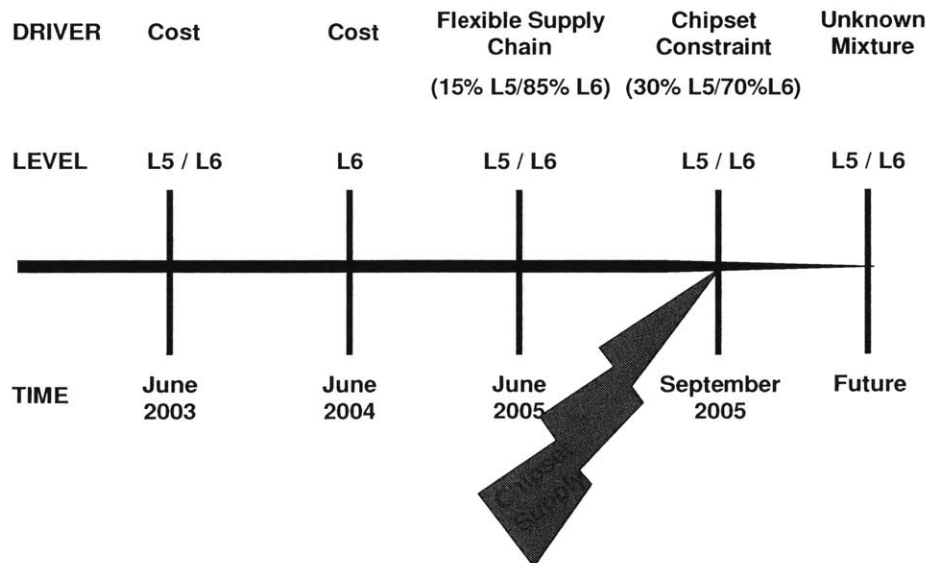


Figure 15. The Timeline of Chipset Supply Disruption & Its Impacts on the Uncertainty of L5/L6 mixture

This uncertainty had a profound impact on the internship. According to the author's internship manager at Dell,

“Originally, although we were already experiencing a fluctuating degree of L5 manufacturing in the U.S., if the chipset shortage situation stays within a reasonable range of upper and lower control limits, we could use an optimization model to determine what is the optimal level of L5 production that should take place at each Dell factory and each 3PI in the U.S. But the news announced by Intel indicated that the overall L5 amount would swing up and down too much thus making any sort of ‘optimal level’ of L5 irrelevant.”²⁶

Instead of an optimization model, a more immediate need posed by the chipset supply uncertainty was to identify ways to reduce this integration cost in the U.S., since it was generally thought that the 3rd-party integration was costing Dell more than it should. Therefore, identifying an alternative way of performing the motherboard-chassis integration became the new focus of the internship. Also, another objective of the internship was to balance this low-cost solution with the ease of managing the new process. The following sections described Dell's approach on identifying the most ideal manufacturing solution.

5.2 Dell's Approach on Reducing Cost

As described in Section 3.2, the two major costs associated with L5 are:

1. Motherboard air-freighting cost from China to the U.S.
2. Motherboard-chassis integration labor cost in the U.S.

The renewed direction of the internship focused on the second cost, rather than the first, since the first cost was entirely dependent on the availability of Intel's chipsets, which was a function of Intel's manufacturing capacity and was not in Dell's direct control. Dell would have a greater control over its motherboard-chassis assembly cost in the U.S.

²⁶ Interview with DAO Engineering/Quality Director Perry Noakes, September 2005

To identify the optimal way of motherboard-chassis assembly in the U.S., Dell initiated a Business Process Improvement (BPI) team. The team composed of members from various departments at Dell, including Worldwide Procurement, Regional Procurement (in Shanghai), Engineering/Quality, Production Control, Inventory Control, etc. The team jointly identified six manufacturing options for managing the assembly work in the U.S.:

1. Keep as current: 3rd-Party Integrator (3PI) managed by Equipment Manufacturers (e.g. Foxconn)
2. DAO Cellular Integration: Enable the Dell factory work cells to perform L5 to L10 mfg work
3. Offline Integration at the Supplier Logistics Center (SLC): Keep the current L6 to L10 manufacturing process unchanged; handle motherboard-chassis integration work at an SLC
4. Offline Integration at a Dell-leased building: Keep the current L6 to L10 manufacturing process unchanged; handle motherboard-chassis integration work at a separate building leased by Dell
5. 3PI managed directly by Dell
6. L6 from Equipment Manufacturers' Mexico plants: Many CMs have manufacturing facilities in which they produce for their other customers. Dell can potentially negotiate with the CMs to dedicate a portion of the CM's manufacturing capacity to support Dell's business.

5.3 *Quantitative Analysis*

Given that the development of the optimization model was no longer deemed suitable for the renewed direction of the internship, the BPI team determined that, besides cost, it would also be important to measure the complexity of each manufacturing cross-functionally. The team, consisting of members from the different organizations affected by the chipset supply shortage, initially could not easily determine the optimal manufacturing option. Therefore, the team discussed and concluded that it should generate a survey of the various departments impacted at Dell to quantify the difficulty of managing each of the six manufacturing options. The categories of the survey were established by the BPI team based on the attributes or business processes that would be impacted by the change of manufacturing method.

The survey was sent to the content expert within each affected department. These content experts were involved in the day-to-day business processes and planning and would be the best source to provide the score of the complexity induced on their departments under each manufacturing option. The following table illustrates the results:

	Option 1	Option 2 (original)	Option 2 (revised)	Option 3A	Option 3B	Option 4	Option 5
Worldwide Procurement	10	1	1	1	1	5	10
Regional Procurement	8	5	5	5	5	5	10
Master Scheduler	5	5	5	5	5	5	5
Production Control	5	10	10	7	7	7	5
Operations	1	10	10	5	5	1	1
DAO Quality	5	10	10	5	5	1	1
Processing Engineering	1	10	10	5	5	1	1
Supplier Quality Eng (Regional)	10	1	1	1	1	5	7
Supplier Quality Eng (Global)	1	1	1	1	1	1	10
Cost Accounting	5	1	1	10	10	10	1
Inventory Control	1	5	5	5	7	10	1
Logistics	5	1	1	5	5	5	10
Total:	57	60	60	55	57	56	62

Figure 16. Complexity and Cost Analysis of the 6 Potential Manufacturing Options²⁷

On the basis of manufacturing complexity, the original option (1) of having the contract manufacturers manage the 3PI had a medium complexity score. Option 3A received the lowest complexity score because overall Dell believed having its own factory associates assemble motherboards into L5 chassis in an SLC would only require Dell to install new equipment at the SLC, so the capital expenditure would be low and not impact the existing manufacturing process in the Dell factory. (Note that the complexity of Option 3A is only a point less than Option—Dell-managed 3PI. This will become important in the final decision.) At the other end of the complexity spectrum is Option 5. This option was the most complex because it would require Dell’s bi-regional procurement organization (in Austin, TX and Shanghai, China) to coordinate together and entirely revamp its business processes of managing the L6 chassis from Mexico. (Currently, all the L6 chassis come from only the Chinese factories of the contract

²⁷ Option 1: CM-managed 3PI (original baseline)
Option 3A: Integration at SLC/hub
Option 4: Dell-managed 3PI

Option 2: Integration at DAO work cells
Option 3B: Integration at Dell-leased bldg
Option 5: Integrated chassis from CM factories in Mexico

manufacturers.) The lack of a robust transportation and custom infrastructure in Mexico also contributed to the high complexity score.

On the basis of manufacturing cost, the original option (1) of motherboard-chassis assembly in a CM-managed 3PI has the highest manufacturing cost. (See Figure 16.) This high cost is driven by the process complexity involved: there are many changing hands handling the inventory from one part of the process to the next. As evidenced by the following testimony:

“In our current manufacturing option, the motherboards air-freighted from China are first stored in the SLC and then transported to the 3PI site for integration with the chassis. The chassis are then sent back to the SLC before being pulled into our Dell factories. There are many stakeholders that ‘touch’ the process: CMs, SLC management, 3PI staff, CM staff managing the 3PI production, and Dell factory associates and process engineers. There are just too many cooks in the kitchen trying to accomplish the same thing. We need a cleaner and more straight-forward process. This will not only make it easier to manage the process, but it will also improve our relationships with the CMs and 3PIs since the current process creates many confusing and frustrating situations, as well as last-minute fires related to motherboard quality issues.”²⁸

²⁸ Interview with an engineer in DAO Engineering/Quality organization, October 2005

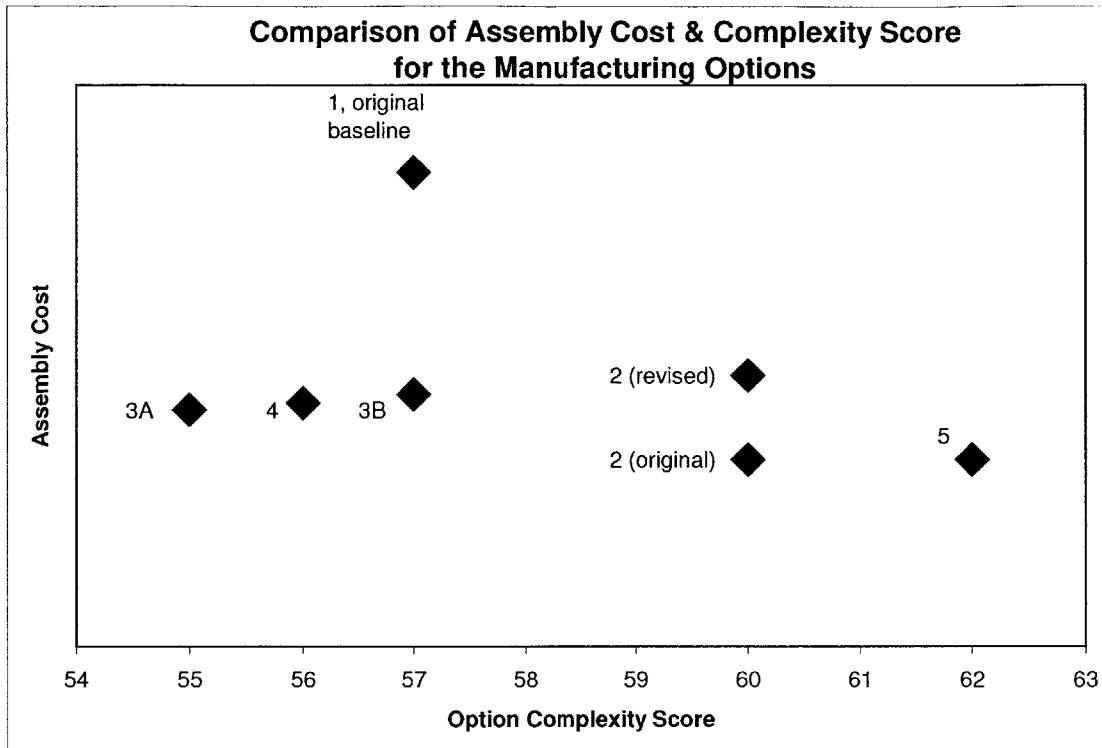


Figure 17. Complexity vs. Cost of the 6 Manufacturing Options

From the original data, it is evident that Dell believed that the lowest manufacturing cost could be achieved if: (a) Dell laborers manage the assembly process in-house, or (b) CMs perform the assembly from their Mexican factories because the Mexican labor rate is lower than the U.S. rate. However, these two lowest-cost options (2 original, and 5) also received the highest complexity scores. This is understandable because Option 2 would require Dell to develop its internal production control, operations, and quality management steps to manage the motherboard-chassis assembly. Since these steps did not exist in the original option, defining and executing them would add much complexity for Dell.

The cost of Option 2 was revised later when the project team re-calculated how much it would cost to expand the area of all work cells in the factory, install new equipment, and hold

additional inventory in the factory. The cost of Option 2, originally at par with Option 5, increased after the re-calculation.

When the six options are mapped on a complexity vs. cost chart (see Figure 16), it is clear that the original option (1) has the highest cost. Options 3A, 4, and 3B share have roughly the same assembly cost and complexity. One can further conclude that if the objective is only to decrease manufacturing cost, any of the other five options would be better than Option 1. However, when other factors are taken into consideration, it is less clear which of these five options would be the most optimal.

5.4 Qualitative Analysis

The following factors are less quantifiable but are also considered in this analysis.

1. Impact on employee morale: If Dell chooses to “insource” the motherboard-chassis assembly into the Dell factories, it would induce a negative impact on the throughput of the factory. Once the factory is upgraded to include the workstation space required for the assembly work, factory associates would also need to be trained on how to perform the assembly steps. The “insourcing” of these assembly steps would require the factory associates to be familiar with a more lengthy desktop PC build process. Consequently, the Dell management would need to evaluate the impact on employee morale and whether the factory associates would perceive the additional steps as “busy work” or value-added work.
2. Focus of competency: Since the chipset/motherboard is not a customizable part that can be selected by a customer, would it make better sense for Dell to outsource the motherboard-chassis assembly steps so it could focus on the more value-added steps

(installing the customizable parts into the desktop PC)? Or should Dell become more vertically integrated by incorporating the motherboard-chassis assembly steps into its factories?

3. Process smoothness & sustainability: How many additional laborers would be required to manage one of the six manufacturing options? How “clean” is the process for those who will be managing it?
4. Product quality: Would the option increase or reduce the number of “touches”? The more manufacturing or re-working steps are involved, the more the quality of a product suffers.
5. Material handling/cost-accounting: How easy or complex would it be to keep track of the cost of the materials from the beginning to the end of the manufacturing process? Whose “book” does the material/part belong to at each stage of the supply chain from China, the SLC, the 3PI, to the Dell factory?
6. Logistics: How easy is it for the existing transportation infrastructure to support the manufacturing selected? What are the custom issues of importing half-assembled products from China or Mexico?

5.5 Analysis Results and Decisions

The decision of how to handle the motherboard-chassis integration in the U.S. went through the following evolution:

1. The initial decision was to implement Option 3A (integration at the SLC) because it had the lowest complexity score (55) from the survey.

2. After realizing that none of the SLC had the capacity to handle the required integration volume, the decision was changed to Option 2 (integration at the DAO work cells) because it had the lowest cost. In addition, the opening of Dell's third U.S. factory in Winston-Salem, NC gave Dell the additional capacity to "insource" the motherboard-chassis assembly steps. This decision was reviewed and approved by the Dell management and agreed by Foxconn.
3. The Dell factory reviewed the decision and voiced concern about bringing additional manufacturing process steps into the factory, spending extra money on capital equipment, introducing supply disruption to the factory, and significantly changing the layout of the factory. After more analysis, it was determined that Option 4 (Dell-managed 3PI) would be implemented. The key reason is that the 3PIs operate in a progressive build process (similar to an automobile assembly line), in which each worker focuses on one specific task and therefore can be trained easily. The required capital investment is decreased because only a small number of assembly lines need to be upgraded, as supposed to every build cell in a Dell factory.

The next chapter of the thesis will discuss the organizational processes that led to this decision-making process. From a capability and resource management perspective, here are the reasons why Dell selected Option 4 as the final option:

1. This option required little capital expenditure because the 3PIs already had all the equipment in their facilities. Since the number of assembly lines in a 3PI was far less than the number of work cells in a Dell factory, it would require significantly less time, money, and planning to upgrade the 3PI assembly lines in order for the 3PIs to perform the motherboard-chassis assembly work.

2. The progressive build process at the 3PIs would allow each worker to specialize in a small range of tasks and therefore minimize the training time and associated cost. In other words, the ramp time at a 3PI would be shorter than at a Dell factory.
3. The Dell factories would continue to receive only L6 chassis, some assembled by Foxconn or other CMs in China and others assembled by the 3PIs. This would eliminate any supply disruption to Dell's existing L6 chassis-sourcing strategy and minimize the complexity for the Dell factories to manage its incoming chassis inventory.
4. This option would give Dell a greater opportunity to more effectively and efficiently manage product quality issues in the following ways:
 - a. By directly managing the 3PIs, Dell could establish more clearly defined metrics and escalation procedures to better measure a 3PI's quality performance.
 - b. CMs such as Foxconn can focus on their core competency of managing their operations in China without having to manage the 3PIs in the U.S.

On the other hand, this option also increased the complexity of Dell's internal cost accounting and inventory control processes. In the baseline Option 1 (CM-managed 3PI), until Dell "pulls" an L6 chassis from the SLC into its factory, CMs such as Foxconn own the inventory, including the motherboards and chassis being assembled at the 3PIs. However, in Option 4, Dell would start owning the inventory once the materials arrive at the 3PIs. From an overall system-wide view, the amount of inventory in the supply chain pipeline would not be higher or lower, as long as the chipset supply remains stable. However, Option 4 essentially transferred the 3PI inventory from the CMs to Dell, so Dell would need to establish a new process or system in order to accurately account the inventory level at the 3PIs, since neither Dell nor the CMs had a robust inventory-management system in place at the 3PIs before.

5.6 Issues with This Approach

Although the complexity and cost analysis served as a good attempt to gather data from the various departments in order to facilitate decision-making, there are three issues associated with this approach:

1. *The scoring process can be subjective or biased.*

Although a detailed explanation of the scoring scale was published to all the departments before they were asked to evaluate the complexity of each option, a 7 to one department might actually be more complex than a 7 to another department. Although each department produced their score based on the actual business hurdle each option would cause them, there is still subjectivity in the scoring process that was difficult to remove.

2. *No weight was placed to differentiate the more critical business processes from others.*

Is quality a more important measure than production control? From an overall systematic view, how does a complexity score of 5 in Operations compare relatively to a 5 in Logistics? These are some of the questions considered by the BPI project team. The team did discuss generating a weighted score for each option but decided not to adopt this idea because assigning a percentage of significance to each department would send the signal that some departments are treated more importantly or favorably than other departments. This would cause some political friction among the different departments. Consequently, the BPI team concluded the discussion by assigning an equal weight across all the departments.

3. *Another decision-making model might be more suitable.*

Although the team invested much efforts to capture the cost and complexity both quantitatively and qualitatively, the final result based on the team's analysis did not deliver a clear winning option. The BPI team selected this scoring model because it was easiest to collect and process data. This method seems suitable in an environment of the fast Dell clockspeed in generating a quick solution. However, the iterative nature of the project and the subjective nature of the scoring process made it difficult for the model to clearly yield an optimal solution. Although this model did deliver the benefit of eventually aligning the interests of all the stakeholders, another decision-making model that could more strikingly delineate the differences between these manufacturing options and deliver a more clear-cut solution may be more effective for the problem statement.

6 Examples from Other Industries

This chapter explores how two other companies, Nokia and Toyota, deal with the shortage of critical parts. Although Nokia and Dell have very different sets of products, both operate within the consumer electronics space, while Toyota is in a completely different industry. The goal of this chapter is to illustrate how each of these two companies deals with a critical part shortage to cast some light on how Dell could more effectively manage the chipset supply constraint.

6.1 *Nokia's Management of the Albuquerque Fire*²⁹

On March 17th, 2000, a thunderstorm lightning struck a Philips semiconductor fabrication plant in Albuquerque, Mexico and stopped its production. This fire initially led to only a one-week delay of some Philips chips that had been ordered by Nokia, and the delay could be easily covered by Nokia's safety stock. Although not yet a crisis, Nokia's executives decided that the situation needed closer examination and initiated a series of collaborative recovery efforts with Philips.

The examination helped Nokia realize that the fire not only destroyed the chips Philips had produced per Nokia's order, it also destroyed a significant portion of the manufacturing facility. The clean-up and re-start of production at the Philips Albuquerque plant would take weeks because the cleanroom environment of semiconductor fabrication cannot tolerate any dirt or the smallest articles. Nokia realized that the disrupted supply of chips would stop the production of four million cell phones—more than 5% of the company's annual production.

²⁹ Sheffi, Yossi. The Resilient Enterprise, The MIT Press, 2005, Chapter 1.

Nokia quickly organized a team of 30 executives and worked with Philips to understand the details about other Philips plants, and Nokia and Philips worked as if they were one company to address the chips supply shortage. The team discovered that the Philips plants in Eindhoven, the Netherlands and Shanghai have additional capacity and could be used to manufacture chips for Nokia. In addition, Nokia was able to source chips from its other suppliers to cover the chips shortage. Nokia's intensive collaborative efforts in working with Philips prevented a change in Nokia's manufacturing process and any delay of supplying cell phones to Nokia's customers.

This example is prudent for the chipset supply shortage faced by Dell. Both Philips and Intel (Dell's sole supplier of desktop PC chipsets) faced manufacturing capacity constraints and were not able to satisfy the demand of all of their customers. However, Nokia was able to aggressively channel all of Philips' available manufacturing capacity to meet Nokia's needs, whereas Dell has not been able to convince Intel to satisfy all of its chipset demand. In addition, Nokia was able to source chips from other suppliers, whereas Dell had no chipset suppliers other than Intel. Although the analysis of this internship did not pertain to Dell's multi-sourcing strategies, the Nokia case in this paragraph illustrates how multi-sourcing can be an effective strategy in reducing the risk of having to change the company's internal manufacturing design and process.

6.2 Toyota's Management of the Aisin Seiki Fire³⁰

On February 1st, 1997, a fire destroyed the Aisin Seiki factory, which produced P-valves and was located in Kariya, Japan. The P-valve was a critical component of the brake system in Toyota's cars, and it was used to prevent skidding on the rear brakes of cars. Unlike Philips'

³⁰ Sheffi, Yossi. The Resilient Enterprise, The MIT Press, 2005, Chapter 13.

relationship to Nokia, Aisin Seiki was the sole supplier to Toyota, as Toyota had come to rely on Aisin for 99% of the P-valves. (Toyota's other supplier Nisshin Kogyo produced merely the remaining 1% but was unable to boost its production 100 times of its existing production level to make up for the demand required by Toyota.) Having a very different supplier strategy from Nokia, was Toyota doom for failure?

The answer turned out to be no. Toyota and Aisin were both able to effectively utilize their *keiretsu*—a set of companies with interlocking business relationships and shareholdings—to combat the disruption of P-valves production. Immediately after the fire, both Toyota and Aisin started calling their suppliers in the *keiretsu*. 65 suppliers responded, and they were invited by Toyota and Aisin to the emergency war-room conference to plan the next steps.

Since the technology used in Aisin to make the P-valves was unique to Aisin, other suppliers did not have the equipment similar to Aisin's specialized machinery. These suppliers collaborated with each other to develop the technology. In addition, since the equipment was in short supply, the suppliers coordinated with each other to ensure that each would receive the equipment it needed. Moreover, many suppliers participated in the emergency recovery effort. For example, Taiho, a Toyota supplier since 1944, engaged 11 of its own suppliers in the effort. Brother Industries, a manufacturer of sewing and fax machines, spent 500 man-hours to convert its milling equipment to make P-valves for Toyota. 150 other companies provided machinery and fixtures to make P-valves and replace the equipment that Aisin had lost. The P-valves made by these suppliers were inspected and qualified by Aisin engineers, and these suppliers partook in this effort without any financial or legal negotiation. "We trusted them," said Masakazu Ishikawa, executive vice president of Somic Ishikawa, a Toyota auto parts supplier since 1937.

This story sounds almost incredible in an American business environment, since there is no alliance system in the U.S. similar to *keiretsu*. Since semiconductor fabrication is more technologically advanced than the manufacturing of P-valves, the duplicability of the P-valves manufacturing is significantly higher than semiconductor fabrication. However, since Intel is Dell's sole chipset supplier, it stands attested that if a disaster strikes one or more of Intel's fabs, Dell's chipset supply will become even more disrupted than the situation faced by Dell during my internship.

6.3 Lessons Learned

This chapter does not advocate that multi-sourcing is always better than single-sourcing. This depends on how vested or entrenched the relationships between a company and its suppliers are. Yossi Sheffi, in [The Resilient Enterprise](#), argues that single-sourcing requires deep relationships, whereas multi-sourcing requires the relationships to be "shallow" in order for these relationships to be manageable and sustainable. As illustrated by the following diagram, having shallow relationships in a single-sourcing setting puts danger in the supply chain, and investing deeply in the relationships when a company has many suppliers of the same type simply wastes money and energy. Since the Dell-Intel relationship belongs to the upper left corner quadrant, Intel, in its limited production capacity, has been able to dedicate its production to supply laptop PC chipsets, which yield a higher margin for both Dell and Intel. As a result, however, the desktop PC chipsets become de-prioritized and therefore generate the dilemma that became the focus of this internship.

Besides the chipset, CPU, and operating system, Dell actually adopts a multi-sourcing strategy for all other components. For chipsets, Dell uses only Intel for the following reasons:

1. Dell has a small R&D budget—roughly 1% of its net revenue. This small R&D budget makes it more suitable for Dell to focus on the R&D activities (such as setting the functional and technical specifications of a motherboard, etc.) with only one, but the most main-stream, chipset supplier. If Dell chooses to multi-source its chipsets, it could certainly alleviate the chipset supply shortage, but the R&D budget would most likely need to be increased to support Dell’s R&D activities with multiple chipset suppliers.
2. Dell has traditionally been able to respond to component shortages effectively. As proven by crises such as the West Coast longshoremen strike (which will be discussed in greater details in the next chapter), Dell has been able to manage its supply-demand scenarios dynamically based on its product availability. In other words, due to its real-time pricing on its internet website, even if it is constrained by the chipset supply from one supplier, Dell would be able to quickly shift the demand to higher-margin or higher-inventory products.

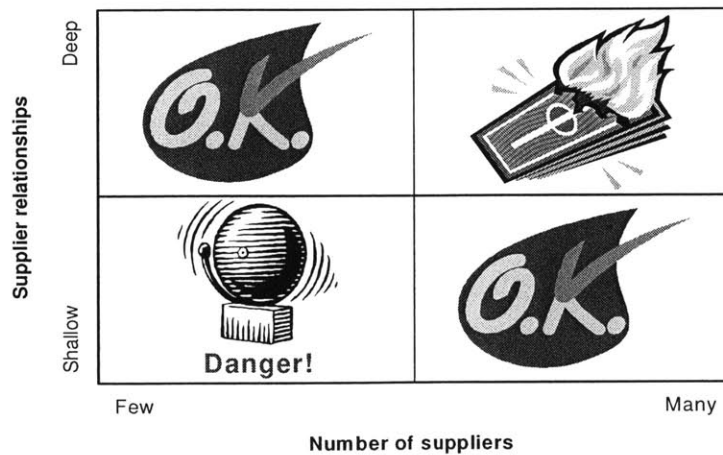


Figure 18. Procurement Alignment³¹

³¹ Sheffi, Yossi. *The Resilient Enterprise*, The MIT Press, 2005, P. 215.

7 Organizational Processes in Making Decisions & Driving Changes

This chapter describes the organizational processes and leadership issues involved in the determination of the optimal solution to manage the motherboard-chassis integration in the U.S. The discussion is organized into two parts: first, it explores how the Dell speed influenced the decision-making and change management processes; second, it compares the consensus-building process and discusses the differences of the leadership styles in a matrix organization vs. a functional organization.

7.1 *The Speed of Dell vs. Informed Decisions*

Dell is known to have a fast or short clockspeed. This is primarily driven by the nature of the consumer electronics industry. With the average product life cycle becoming shorter, the time to market or time to customers has also become shorter. The company's performance depends on how it can readily satisfy consumers' ever-changing tastes and fluctuating demand in a market with ever-expanding product selections. This is especially critical for a company like Dell that is ultra lean in its on-hand inventory. In an interview with Fast Company, Dick Hunter explained, "When a labor problem or an earthquake or a SARS epidemic breaks out, we've got to react quicker than anyone else. There's no other choice. We know these things are going to happen; we must move fast to fix them."³²

In fact, Dell responded with great speed to the West Coast longshoremen strike in September 2002. It was able to quickly understand what inventory was being held up at the various ports from Long Beach to Seattle. Dell quickly chartered 18 Boeing 747s from UPS,

³² Breen, Bill, and Michael Anciro. "Living in Dell Time", Fast Company, November 2004: <http://www.fastcompany.com/magazine/88/dell.html>

Northwest Airlines, China Airlines, and other carriers. A Boeing 747 holds the equivalent of 10 tractor-trailers—enough parts to manufacture 10,000 PCs. This helped ensure minimum disruption in Dell’s manufacturing. Also, Dell examined the amount of excess inventory it still owned and communicated real-time to its sales force to drop the prices of the products. In other words, Dell raises prices on high-demand items that are in short supply. If an item is unavailable, Dell hides the item from its website. If Dell has too much of an item, they will discount it. Using the internet technology, Dell is able to quickly adjust its prices on its website. The word “Dellocity” is frequently heard in company meetings and conversations, demonstrating the great significance of fast speed in the Dell culture. Hunter adds, “We just can't tolerate any kind of delay. Speed is at the core of everything we do [at Dell].”³³

The fast Dellocity, however, can sometimes be a hindrance, rather than an enabler, to a successful and sustainable business solution. Making a decision based on a quick analysis tends to be a common practice at Dell, but sometimes this could lead to hasty or uninformed decisions that need to be revised later.

In the example of my internship project, the Dell BPI project team also felt an urgency to quickly generate a solution. However, it took the due diligence to review all the options and gain stakeholders’ alignment. After generating six potential manufacturing options, the team embarked on the tasks of conducting the ROI analysis, evaluating the pros and cons of each option, and obtaining management approval to move the integration from the 3PIs to the SLCs.

After this initial analysis of how much it would cost to install new equipment at the SLC, the team then conducted a facility walk-through of the Austin SLC building. The walk-through

³³ Breen, Bill, and Michael Aneiro. “Living in Dell Time”, Fast Company, November 2004: <http://www.fastcompany.com/magazine/88/dell.html>

was helpful for the team because it allowed the team to learn that the SLC was not adequately spacious. This new information then became part of the cost re-evaluation. Other costs that surfaced from the facility walk-through included the cost of installing a new air-conditioning system, since there turned out to be no air-conditioning in the building. The team also realized that the building did not have enough parking spaces, break areas, and restrooms for the 150 associates who would be working there each shift.

Recognizing that the SLC was no longer a viable location, the project team then decided to evaluate the required cost and timeline of performing motherboard-chassis assembly in the Dell factory work cells. The team met with the industrial designers and first-level operations managers of the Austin factory to find out how significant of a change this would introduce to the factory. It was determined that all of the work cells inside the Austin factory would need to be upgraded in order to create enough desk space for each PC builder to perform the motherboard-chassis assembly task. The Nashville factory would also require the same upgrade. The newest Winton-Salem factory, however, would not modify its existing work cells since they are designed for a three-person build process, unlike the one-person build cells in the other two factories. Rather, in the Winston-Salem factory, a progressive build process of the motherboard-chassis assembly would be installed in order not to disrupt the existing three-person build cells. The team also determined that the upgrades would only start after the beginning of the following financial year (February 2006) in order to prevent capital expenditure from accumulating before the end of the current financial year. In addition, the feedback from the first-level operations supervisors indicated that the upgrades could be done easily as long as it is scheduled in advance and coordinated with production, over two or three phases.

Before arriving at the final recommendation, the team kept all the stakeholders informed and was conscious in gaining their alignment. In generating a recommendation to move the motherboard-chassis assembly into the Dell factories, the team conducted further analysis to come to the following conclusions:

- A. Because Dell's new factory in Winston-Salem, NC recently began its operations (in addition to the Austin and Nashville factories), it would have the additional capacity to support the "insourcing" of the motherboard-chassis assembly. There was a strong rationale to support this claim especially because the growth of desktop PC was expected to slow down in the U.S. in the next few years, as more consumers would switch to laptops.
- B. However, for the Dell factories to move their design from L6 back to L5, all the benefits gained when the factories were transformed to L6 would be lost. The complexity re-introduced to the Dell factories would be too costly for Dell to realize any significant gain. Also, the work required to upgrade each factory and the amount of employee training needed would not be a sound investment for Dell if someday the chipset supply situation actually improves and the level of L5 drops significantly.

After considering all the inputs described above, the project team selected Option 4 (motherboard-chassis assembly in the 3PI, managed by Dell) as the final recommendation. This decision required the Dell WWP organization to negotiate with the 3PI vendors for a lower assembly cost, which turned out to be 50% of the original cost Dell was paying. The entire evaluation process took five months to complete, longer than a typical project running on the Dellocity. Below are some of the author's observations in the organizational structure that are related to finalizing this decision and driving a sustainable change in the organization:

1. Making decisions at a fast clockspeed: Dell's focus on speed and velocity is a by-product of the fast pace of the PC industry. Decisions tend to be made with a fast turn-around time, and this culture also permeates to its supply base. "Because the landscape of our business changes so rapidly, we believe longer-term projects usually cannot deliver the ROI they originally promise because the environment would have changed before we even begin the actual implementation of these projects."³⁴ On this internship project, the analysis was also performed on a one-year ROI basis, and there was a strong emphasis in the team to complete the analysis and begin the execution as soon as possible. However, the team took more time than a typical Dell project team to obtain buy-in from the various departments involved by presenting at the stakeholders' forums and gaining feedback from the department managers and leaders. Although it took the team five months to arrive at the final decision, the decision was implementable because all the departments involved had started to develop the necessary business and operational processes to manage the complexity issues in implementing the solution. In other words, although the team operated in a speed slower than the Dell clockspeed, it generated a solution with a strong stakeholder and managerial alignment.
2. Gain of cross-functional knowledge: The team assigned to this project consisted of members from various organizations within Dell, most notably the factory/operations and WWP. However, most of the team members associated with the project were "functional experts". At the launch of the project, they were very knowledgeable of the business processes within their own organization but often did not understand the issues or business processes in other organizations. The cross-functional setup of the team allowed

³⁴ Interview with a Dell DAO employee, June 2005.

the team members to evaluate the problem statement from a global, multi-departmental, and systematic view. From working on this project, the team members gained knowledge about the business processes pertinent to other organizations. This exposure would not have been possible if the team operated on a solely functional basis. The understanding gained from this cross-functional setup allowed a team member to focus on generating a recommendation that would benefit to the entire team globally, not just one department locally.

In summary, making analysis at a fast clockspeed could lead to ineffective decisions and elongate the change implementation process. Taking the time out to evaluate the various options and gain stakeholders' alignment might seem counterintuitive to the fast Dellocity. However, time spent allows the team to develop cross-functional knowledge and build consensus. The knowledge and consensus are critical in building a foundation for the ultimate success of a project.

7.2 Matrix vs. Functional Organizations: Leadership & Consensus-Building

Foxconn is a highly vertically integrated organization. In its desktop PC business for Dell, Foxconn manufactures all the mechanical components (using sheet metal to produce computer chassis), some electronic components (such as the motherboards), and perform some assembly before shipping the computer units to Dell's U.S. factories. Decisions at Foxconn tend to be made using a top-down leadership approach. Managers review the data presented by their subordinates, make the decisions, and order the subordinates to execute the decisions. This way of leadership style is consistent with the Chinese culture, in which people follow orders from the authority and don't typically question the decisions. The result is a top-down decision-making

process. However, since managers make the majority of the decisions, employees tend not to report out problems, since doing so would be treated the same as questioning the authority. Therefore, managers in Foxconn have to do more active, hand-holding management of day-to-day business issues. This is evidenced by the frequency of the Foxconn managerial meetings: in the start-up meeting every morning, the managers at DT(II) meet in a conference room, review the business, make decisions, and after the meeting meet with their employees to communicate the decisions.

On the other hand, the Dell culture is an American business culture, a culture that promotes individual ownership. Dell is also a highly matrix-oriented organization. As a result, Dell's morning start-up meetings are run with a very different style from Foxconn's and include everyone from the shift manager all the way down to the first-level supervisors. Decisions are discussed among the meeting attendees before they are finalized, and there is a high degree of bottom-up participation in the decision-making process, as managers tend to rely more on their subordinates to make and execute the decisions. After the meeting, the first-level supervisors would approach their factory associates to educate them about the daily production goal and brainstorm with them on ways the associates can work together to meet the goal. In a matrix team, decisions are made at a slower pace than in a functional organization, but if inputs from all the stakeholders are considered and buy-in from everyone is received, the decisions are more effective and sustainable. The resulting culture also encourages employees themselves to generate a stronger ownership of the driving changes and a more innovative way of solving the issues they encounter at work.

In the Dell project team related to my internship, the decision-making process is also based on matrix consensus building. As argued in the previous paragraph, matrix organizations

require more time to build consensus; however, once built, the decisions will be more lasting. The Dell project team in this internship worked in a cross-functional fashion, and this allowed for a collaborative environment in which everyone was able to share his ideas or concerns from his home department. The team went through the process of validating all the assumptions and aligning interests from the different stakeholders, and this approach solidified the finally approved manufacturing option before the actual implementation.

In a cross-functional matrix team, leadership also plays an important role. Since a matrix team values all team members' opinions and requirements, strong leadership is critical in maintaining the course of the project. More importantly, leaders/managers from the various departments represented on the team need to establish agreement with each other in order to provide a consistent direction for the team. For the project team involved in my internship project, although there were managers from the different departments participating in the project team, not everyone was engaged with the project on the same level, as some managers attended all the weekly steering committee meetings; others were present only occasionally. This uneven engagement, however, did not create challenges in the decision-making process because the leaders/managers from the various departments would hold recurring formal or informal discussions to discuss the project progress and different views of the project. For example, Dell's Production Control department had a goal to minimize the complexity in the production plans of its factories. The WWP department, on the other hand, had a goal of reducing cost of the motherboard-assembly cost. If the lowest-cost solution was to have Dell's factories assemble motherboards into chassis, this would meet WWP's goal, but it would also increase the product mix/complexity in the Dell factories and would therefore inherently conflict with Production Control's goal. To make effective decisions that result in sustainable changes, leaders of a

matrix team aligned and established common goals to ensure that there is incentive for the different departments represented to strive for the success of the team.

Thus, leadership and consensus-building play a significant role in helping a matrix organization make decisions that will drive effective changes. It is crucial for the leaders of a matrix organization to establish a common objective for the various departments of the organization. This prevents “too many cooks in the kitchen” who want to add their own individual ingredients that will eventually lead to a distasteful outcome. Consensus in a matrix organization enables individuals in the organization to apply their energy and creativity into generating a well-orchestrated and sustainable change.

8 Recommendations & Conclusion

This chapter concludes the thesis by offering some recommendations developed by the author based on the six-month internship.

8.1 Recommendations

To drive effective changes that can mitigate the chipset supply shortage, Dell can consider the following:

1. Simplify the design of the desktop chassis to minimize the time required to install a motherboard into a chassis: Based on a pilot conducted at the Dell Austin factory, it was estimated that adding the motherboard-chassis assembly steps (L5 to L6) would require an additional third or half of the current (L6 to L10) manufacturing time. The extended amount of time required makes it uneconomical to perform the assembly steps in the U.S., where the labor rate is significantly higher than the rate in China. It is important to note that at the time when Dell was performing the L5 assembly inside the Dell factories, the chassis designs were actually much simpler, and it took less time for a Dell factory associate to assemble motherboards into chassis. However, when Dell made the decision to outsource the motherboard-chassis assembly to the contract manufacturers in China, the chassis designs became more complex to assemble, but the material cost of the chassis decreased. Since, on future chassis designs, it is important for designers to achieve a balance of both worlds: a chassis design that is both easy to assemble and low in material cost. If the design of the chassis can be modified to be low in material cost and at the same time also facilitate an easier and quicker motherboard-chassis assembly process, there would be little cost difference between assembling in China and

assembling in the U.S., and consequently the chipset supply shortage would have less impact on Dell and Foxconn as they can exercise a postponement strategy (integrate the motherboard into the chassis as late as possible) whenever necessary without incurring a higher cost.

2. Consider expanding Dell's chipset sources: By using Intel as the only desktop PC chipset supplier, Dell does not have the freedom to acquire additional chipsets from other sources when Intel experiences a manufacturing capacity constraint. The current supply chain design compels Dell and Foxconn to consider re-designing their current L6 manufacturing process. If Dell could procure enough chipsets from other chipset manufacturers or even Dell's competitors and supply to Foxconn's motherboard production plant in Shenzhen, all chassis manufactured and shipped by Foxconn China would be L6, and the need to re-design the current manufacturing process would be eliminated. However, in the evaluation to work with more chipset suppliers, the additional R&D cost and time required to overcome the experience ramp must also be considered.
3. Collaborate with Intel to expand the manufacturing capacity of its next-generation chipset: Dell could quantify the amount of money it is *losing* on an annual basis due to the chipset supply shortage. Using this data, Dell could potentially share a portion of this amount with Intel as an investment to boost the manufacturing capacity of Intel's next-generation desktop PC chipset. This collaboration would create a more flexible chipset supply between Intel and Dell.
4. Develop profit-sharing and risk-sharing contracts: Dell can consider setting up terms and conditions with Intel to manage the risk of supply shortage of a critical component like

the chipset. Companies can align their supply chain partners' interests with their own "by redefining the terms of their relationships so that firms share risks, costs, and rewards equitably."³⁵ For strategic components, it is "crucial that buyers and suppliers have a close relationship so that the contracts can satisfy the objectives of both sides. Buyers and suppliers can share price risks by using revenue-sharing or sales-rebate contracts."³⁶ Revenue-sharing allows buyers to share some revenue with suppliers in return for a discount on the sales price. In sales-rebate contracts, buyers get rebate from suppliers when purchasing targets are met. Smart contracting leads to trust between the supply chain partners, since trust is "predicated on doing things jointly and in an aligned fashion over a period of time with no major surprises."³⁷

In addition, the author has some broader recommendations for Dell and Foxconn from an organizational perspective:

1. Foxconn and Dell should consider continuing the construction of the optimization model: Although the direction of this internship changed half way, some work and formulation related to the optimization model was already started, as described in Chapter 4. For both Dell and Foxconn to enjoy the benefit, more requirements of the model need to be gathered before the optimization is actually built.
2. Develop a cross-organizational job rotation program at Dell and Foxconn: In both Dell and Foxconn, employees generally possess very deep functional expertise but much less interdisciplinary knowledge. In DAO's Engineering/Quality organization has initiated an

³⁵ Lee, Hua L. "The Triple-A Supply Chain", *Harvard Business Review*, Reprint R0410F, October 2004, P. 8.

³⁶ Simchi-Levi, David. "Innovative Supply Contracts", *The Missing Link: Designing Supply Chains for Growth, Profitability, and Resilience*, strategy+business Books, 2005, P. 104-109.

³⁷ "Supply Chain Challenges: Building Relationships: A Conversation with Scott Beth, David N. Burt, William Copacino, Chris Gopal, Hua L. Lee, Robert Porter Lynch, and Sandra Morris", *Harvard Business Review*, Reprint R0307E, July 2003, P. 5.

employee rotation program for its employees, but the rotations are only within Engineering/Quality. The program can be expanded so an Engineering/Quality employee can spend a few months learning the business processes in WWP, for example.

Employees who have working knowledge from multiple departments have a more strategic, systematic, and integrated mindset and are more empowered to make informed decisions for that achieve globally optimized solutions. “Besides keeping interest level and morale high [in a team], this system acts as an informal certification system for all employees and ensures that employees are cross-trained fully on a variety of functions.”³⁸

3. Consider structuring a joint Intel-Dell internship to dive deeper into chipset supply issue: The focus of the internship did not examine in great details the demand/supply imbalance between Dell and Foxconn. However, benefits can be derived by having both companies analyze the misbalancing phenomenon at the upstream of the supply chain and provide some ways to achieve better alignment between Dell and Intel.
4. A more structured problem-solving methodology can prevent process rework and lead to more effective change management: Making decisions at a Dell clockspeed does not always result in sound solutions. Dell should examine the way decisions are made in teams and evaluate the effectiveness of these decisions. Conducting analysis in a more structured and comprehensive manner would create a stronger pull from all members of the team to deliver a longer-lasting change.

³⁸ Gotschall, George W., manager of total quality management in Picker International. Teams that Click: the Results-Driven Manager, a Timesaving Guide, Harvard Business School Press, 2004, P. 106.

8.2 Conclusion

Today's globalized supply network often scatters material sourcing, pre-production, and final assembly into disparate locations around the world. To achieve an optimized supply network, companies need to step beyond the traditional customer-supplier relationships and treat each other as partners in an alliance. The Toyota example described in Chapter 6 illustrates the importance of such an alliance at a time of a crisis. Incentives should be constructed to achieve globally optimized solutions across the entire supply chain, instead of focusing on adjusting individual portions of the business processes to accomplish only incrementally improved, locally optimized results.

In this internship project, the author initiated gathering requirements of an optimization model that was aiming to address what level of motherboard-chassis assembly should be performed in the U.S. given a constant level of chipset supply shortage. The sudden decrease of the chipset supply changed the direction of the project mid-course, and the project team developed a renewed focus of analyzing and understanding how Dell and Foxconn could modify their existing manufacturing and supply chain setup to reduce cost and complexity. After three rounds of analysis, Dell selected the option to directly manage the 3PI, remove layers of complexity in the current CM-managed 3PI option, and reduce the assembly cost by 50%.

Modern organizations should recognize that cross-functional knowledge is becoming increasingly important in today's globally intertwined supply chain. Although change management still requires top-down leadership and guidance, having cross-functionally trained employees will lead to stronger bottom-up engagement and facilitate the coordination across organizations.

Moreover, in a world moving as fast as the PC industry, making fast analysis does not necessarily lead to the optimal solution. Although it requires time and efforts to define the appropriate problem-solving methodology up front, verify the assumptions, and ensure alignment from all stakeholders, these steps are necessary in delivering a solution that can be effectively implemented. Analyzing the complexity of managing the business processes requires both qualitative and quantitative data, but even the data provided by functional experts can still be subjective. This subjectivity can be reduced if the data providers have more cross-functional understanding of the entire supply chain.

In conclusion, determining, aligning, and optimizing all stakeholders and partners' incentives in a global supply chain is a challenge faced by any global corporation today. The success of one corporation comes from the success of the entire supply network, and the companies that can create a healthy network in which all partners are incentivized and benefit from will achieve sustainable business relationships with their partners.

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10 Author's Biography

The author, Johnson Wu, was born and raised in Kaohsiung, Taiwan and moved to Los Angeles with his family when he was almost 14 years old. He graduated from the University of California, Berkeley in May 2000 with a BS Industrial Engineering & Operations Research (IEOR) degree and a minor in Asian/Japanese Studies. From 2000 to 2004, he worked in the fabrication & lithography equipment acquisition organization at Intel Corporation in Santa Clara, California. During the first two years of his career at Intel, he worked as a Database Developer/Analyst, using his knowledge in database design to create information systems to support decisions and planning for Intel. From 2002 to 2004, he served as an e-Business Systems Project Manager, leading cross-functional project teams to create and implement new information systems and data-analysis capabilities for Intel. One of the information systems he delivered, eAcceptance, automated Intel's equipment acceptance process by transforming the process from 100% paper-based to 100% electronic and reduced Intel's aged payables from \$90 million to \$15 million. He and his eAcceptance project team were recognized the Intel Divisional Recognition Award—the highest award an Intel employee could receive within a division.

In 2004, he joined the Leaders for Manufacturing (LFM) program at MIT for his MBA and MS Civil & Environmental Engineering degrees, where this thesis was completed in 2006. Upon graduation from MIT in June 2006, the author will be joining Cisco Systems as a Global Supply Manager in the firm's San Jose, California office, managing the relationships between Cisco and its contract manufacturers. The author can be reached at his permanent email address – johnson_wu@sloan.mit.edu.