ANALYSIS OF A HIGH-END MEMORY SUPPLY CHAIN – DRAM VENDORS TO FINAL ASSEMBLY

by

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ABSTRACT

Compaq Computer Corporation's High Performance Systems Division (HPSD) manufactures servers for mid-range and high-end server markets. It has a complex supply chain that includes the use of supplier hubs, outsourced memory module manufacturers, and stacked memory devices (chips). For this memory module supply chain, Compaq faces two major planning challenges. First, it is very difficult to get an accurate forecast of memory requirements. Second, the cost of memory continues to decline, on the order of 1-4% per month, which results in a high inventory holding cost.

A set of standard software tools is developed to assist analysts with determining the supply plan for memory from multiple suppliers. The purpose of these tools is to determine the minimum cost supply plan with an acceptable level of forecast risk. Two separate tools individually address cost and forecast challenges. The Cost Tool can consider up to nine cost categories across the supply chain network upstream from the factory. The tool is flexible, transparent, easily disseminated and easy to use. The Forecast Tool can track current supply activity and can forecast the next week's and next quarter's supply plan. The tool consists of a main menu worksheet and another worksheet for each quarter of the year in Microsoft Excel. It can be used for any commodity. It is flexible, easy to use and easily disseminated. Use of these tools should lead to more expeditious analyses of supply plans and forecasts while yielding estimates of the supply chain costs for a particular supply plan.

A conceptual model for decreasing costs by combining supply chain costs with a standard purchasing price-parity point is presented. The purpose of this model is to provide purchasers another point of view based on total supply chain costs, including inventory write-offs due to decreasing memory prices and transportation costs.

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1 Introduction

1.1 Problem Statement

Compaq Computer Corporation's High Performance Systems Division (HPSD) wants a clearer understanding of their server's complex memory supply chain. HPSD manufactures mid-range and high-end servers with one-third of their costs in memory. The memory supply chain is complex with five Dynamic Random Access Memory (DRAM) suppliers around the world. Compaq, like other computer manufacturers, has influenced its suppliers to use hubs near their manufacturing sites, but HPSD management does not fully understand the costs associated with the hubs. HPSD wants to know where costs are incurred in the supply chain or the time memory spends in each supplier's part of the supply chain. Complicating matters, the price of memory historically falls over time, which causes the company holding memory inventory to write down their inventory valuation to the market valuation. HPSD wants to be clearer about which company records the loss if the memory is in the hub or when a price change is passed through the hub to HPSD. In addition, HPSD receives sales forecasts for memory that are consistently high. If HPSD produced to these forecasted levels, excess inventory costs would be extremely large. HPSD's Life Cycle Management (LCM) group has learned to adjust the sales forecast to determine memory supply plans. The process by which LCM develops supply plans is based on experience, load trends over time, and moving average calculations.

HPSD needs standard software tools that internal financial analysts and life cycle managers can use to assist them with determining quarterly supply plans. The purpose of these tools is to determine the minimum cost supply plan while maintaining acceptable flexibility in the forecasted supply plan to meet customer demand. The requirements for these tools are that they be flexible, easily disseminated, and easy to use. Use of these tools should lead to more expeditious analyses of supply plans and forecasts while yielding estimates of the supply chain costs for a particular supply plan.

1.2 Definition of Key Terms

For brevity's sake, a bulletized list of words and definitions will serve as explanation of acronyms and specific phrases/words:

- AlphaServer: name of mid-range and enterprise servers at DEC and Compaq
- DEC: Digital Equipment Corporation
- DIMM: Dual In-line Memory Module, has nine or 18 memory DRAM or SDRAM on it
- DRAM: Dynamic Random Access Memory; a memory device; a semiconductor chip
- FAB: manufacturing fabrication facility, where silicon wafers are manufactured into processors and memory devices
- HPSD: High Performance Systems Division, a division of Compaq that makes AlphaServers
- Hub: Regionally located stock point where suppliers hold contracted amounts of materials on a consignment basis until pulled by the customer (supplier owns stock until pulled by customer)
- JEDEC: Joint Electronic Device Engineering Council is the semiconductor engineering standardization body of the Electronic Industries Alliance (EIA).
- LCM: Life Cycle Management Group in HPSD
- Module: a name for a printed wire board with electronic components on it – like DRAM
- Monolithic: a single SDRAM (not stacked)

- Price-Parity Point: an intersection between two price curves
- Printed Wire Board: a board that is made in layers with circuits running in between and through the layers
- SDRAM: Synchronous Dynamic Random Access Memory, a distinct type of DRAM
- Stacking/Stacked/Stack: process that stacks one SDRAM directly on top of another SDRAM, effectively doubling the density of the memory capacity in the same footprint as a single SDRAM on a printed circuit board (PCB)
- Supply Chain: the set of business operations in which raw material and components are transformed through conversion processes, storage, distribution, and delivery into a finished product for use by an end customer

1.3 Justification for this Initiative

The primary goal of this initiative is to assist product life cycle managers and financial analysts in determining and limiting the costs associated with memory supply plans. HPSD management chose to model the memory supply chain for two reasons. First, the memory supply chain environment was changing so quickly that management did not have a clear picture of all the pieces and costs associated with them, and any identification of cost reductions would increase profit. Second, memory was one-third of the cost for a complete server system, and HPSD was planning to eliminate internal memory module manufacturing by completely outsourcing its production. This would significantly impact their flexibility of acquiring adequate memory supply because the external memory module manufacturers would be less willing than an internal supplier to respond to an unexpected increase in HPSD demand. This would place more emphasis on accurate memory forecasts. Furthermore, one expects that a decrease in supply flexibility would drive life cycle managers to increase forecasts, which they are already knowingly overforecasting, resulting in increased exposure (more inventory) to decreasing memory prices.

At Compaq, it is estimated that the industry trend for the price of DRAM decreases by approximately 40% per year. For instance, in May 1999, DRAM prices decreased 18%.[1] Compaq consumes 10-15% of the world's memory output, so Compaq is vulnerable to DRAM price fluctuations. Normally a decline in the cost of raw material is good, but since the cost of memory is such a large part of the cost of the server its immediate effect can be bad. To stay competitive, Compaq passes through decreases in memory prices to the customer. Even though Compaq has contract prices, it inevitably has millions of dollars of DRAM in inventory at any one time. Thus, if DRAM prices drop, Compaq has to write down the inventory valuation to the market valuation of the current inventory. For example, if Compaq has $20million worth of memory inventory and the price of memory decreases by 18%, then Compaq would have to write down its inventory valuation by $3.6million since their inventory lost that much value. Inaccurate forecasts, typically overforecasts, add inventory to the supply chain. Decreasing this inventory exposure would mean significant savings (see Section 3, The Cost Model).

1.4 Background of Project Sponsor

Compaq Computer Corporation, headquartered in Houston, Texas, is one of the largest computer manufacturers in the world. It offers a complete line of computer products covering the entire price spectrum: from digital assistants and personal computers to large enterprise servers.

[1] Conversation with Jackie Gross, Manager of Compaq's Corporate DRAM Procurement Group, June 28, 1999.

"Compaq derives most of its revenues from business customers but also has product offerings for the home user, government, and schools."[2]

The work associated with this project was conducted at Compaq's Maynard and Marlborough, Massachusetts facilities and was sponsored by the High Performance Systems Division (HPSD) which has life cycle management responsibility for Compaq's mid-range servers and enterprise servers. This group became part of Compaq after the 1998 acquisition of Digital Equipment Corporation (DEC) by Compaq.

1.5 Thesis Overview

Chapter two provides background on Compaq's memory supply chain, describes the problems and challenges they face, and provides information regarding the computer industry's memory market. Chapter three describes the conceptual model that underlies the Cost Tool, which captures the supply chain costs, as well as the time memory spends in the supply chain. Chapter four describes the conceptual framework that underlies the Forecast Tool. Chapter five describes a concept for determining the cost tradeoff point for purchasing stacked or monolithic DRAM. The sixth chapter concludes this document by providing general conclusions and learnings.

The appendices are a rich source of detailed information about the tools. Appendix 1 provides details about the cost tool. Appendix 2 provides details about the forecast tool.

[2] Hoover's Online, "Compaq Computer Corporation: Company Capsule." www.hoovers.com, (March 30, 1999).

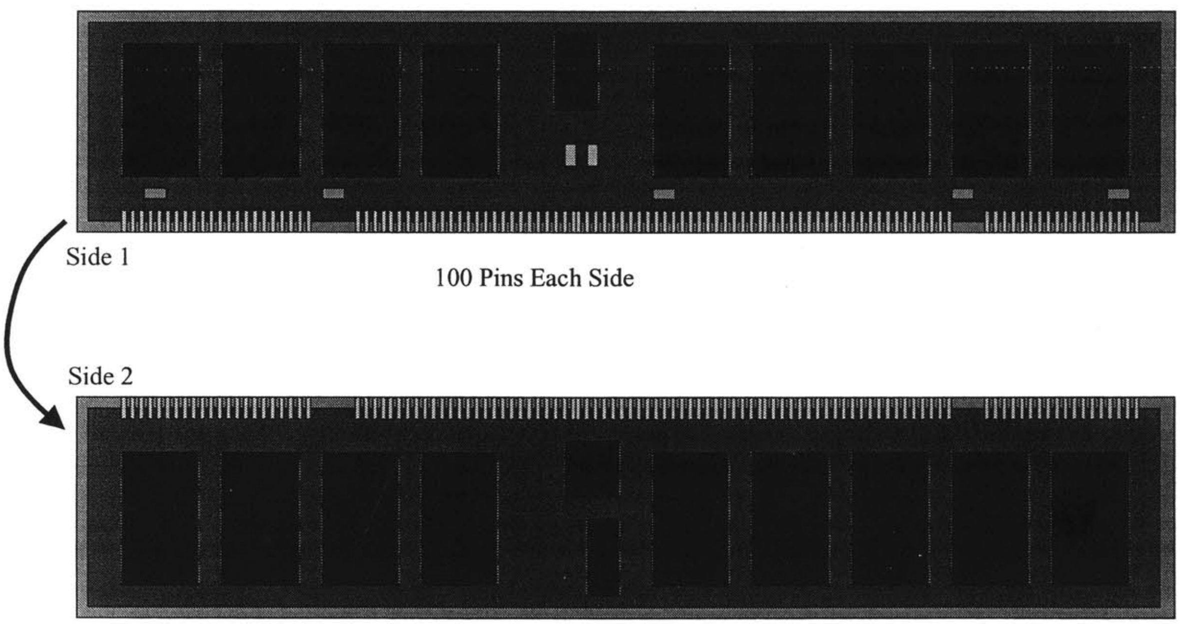
This thesis is written from the point of view that Compaq's suppliers' costs are in effect Compaq's costs too. That is, if a supplier is forced to incur additional supply chain costs, then these costs will be passed on to Compaq in terms of a higher price for the memory devices. For instance, requiring suppliers to hold memory in consignment (suppliers own material until customers pull material) at hubs forces them to integrate the cost of falling Dynamic Random Access Memory (DRAM) prices into their cost structures. This increased cost structure, caused by writing down memory inventory valuations to market valuations, will affect the DRAM price, thus not giving Compaq the full benefit of cost reductions resulting from continuous improvement efforts and higher yields from new technology implementations.

2 Background Research

2.1 The 200-pin Memory Module

The product in this study of Compaq's memory supply chain is HPSD's 200-pin Dual In-line Memory Module (DIMM). These DIMMs have a unique design in that they have 200 pins versus industry standard 168-pin DIMMs. The DIMM's primary components include Synchronous Dynamic Random Access Memory (SDRAM), printed wire board, transistors, resistors and a clock. Figure 1 shows a graphical representation of a 200-pin DIMM.

Figure 1. Representation of a 200-pin DIMM



The two large rectangles in Figure 1 above show the two sides of the 200-pin DIMM. The SDRAM are represented by the nine large dark, rectangles on each side of the DIMM. SDRAMs are memory devices, or semiconductor chips. The printed wire board is the largest rectangle in Figure 1. The SDRAM are physically "placed" onto the printed wire boards to make a memory module. The medium and small sized rectangles in Figure 1 are clocks, transistors, resistors, etc. Most 200-pin DIMMs have nine SDRAM on each side for a total of 18 per DIMM. For increased memory density, Compaq stacks one SDRAM exactly on top of another SDRAM, yielding double the memory density in the same physical area, or "footprint," on the board. A "stacked" DIMM has double the number of SDRAM, or 36 per board. DIMMs are manually inserted onto the server's main board in the designated slots which are located "physically" as close as possible to the processor (the goal is to have as much memory density as close to the processor as possible). The pins provide the electrical connection between the DIMM and its slot on the main board.

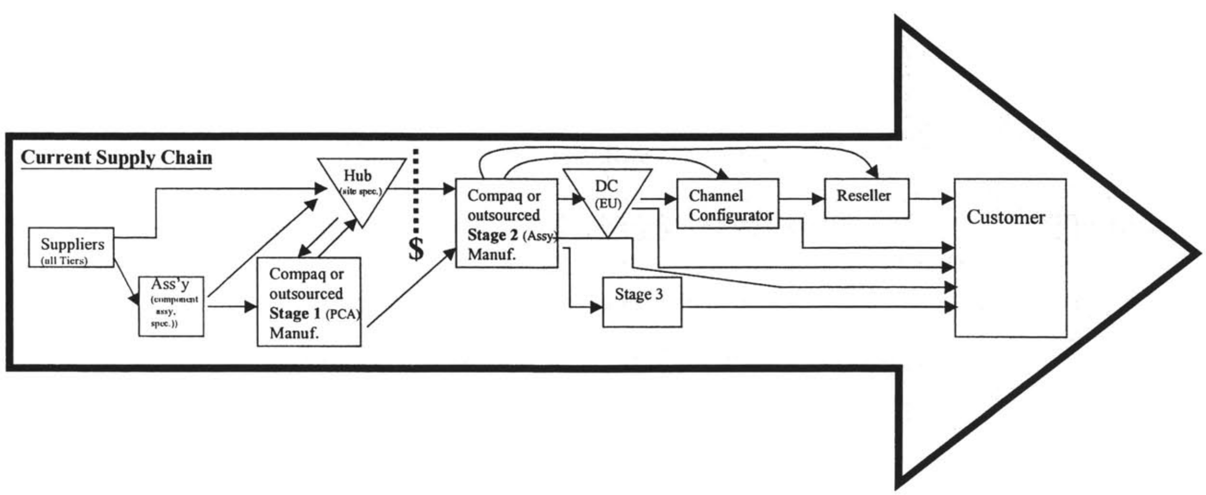
With the acquisition of DEC, Compaq not only gained its coveted worldwide services organization, but it also assumed control of HPSD's AlphaServer product lines. At the time, HPSD manufactured most memory modules internally. DEC had been developing a 200-pin DIMM for the new server products that it was going to introduce in 1998. No other company was using the DEC designed DIMM, but there were hopes at DEC of making it the new industry standard. It claimed higher performance than the standard 168-pin DIMM, allowing the 64-bit Alpha chip to perform at its maximum capacity. But, from Compaq's point of view, DEC had complicated the memory supply chain in the name of "technical elegance." Compaq required that HPSD start to treat memory like a commodity, and coordinate with its suppliers to manufacture memory modules externally.

With this initiative, HPSD looked to Compaq's five largest SDRAM suppliers for interest in developing manufacturing expertise in 200-pin DIMM production. A few early adopters were found, one of which used a contract manufacturer to manufacture DIMMs. In mid-1999, HPSD put into action a plan to completely outsource the 200-pin DIMM business, which was one-third of the cost of the AlphaServer platforms using 200-pin DIMMs, by the end of the year. This plan involved the use of five large SDRAM vendors around the world. These are the most cost effective producers and have the most aggressive FAB processes (aggressively increasing yields). Compaq is the initial user of the latest technology, and the Alpha chip's high performance always demands the latest, highest capacity memory devices for its customers.

2.2 Overview of Compaq's High-End Server Supply Chain

The Compaq Computer Corporation has an immense supply chain spanning the globe. It is a typical supply chain that starts with companies mining silicon and other substances from the ground and proceeds through the end customer who buys and uses the computers and servers Compaq manufactures. Figure 2 shows a high level view of Compaq's high-end server supply chain.

Figure 2. High Level View of Compaq's High-End Server Supply Chain



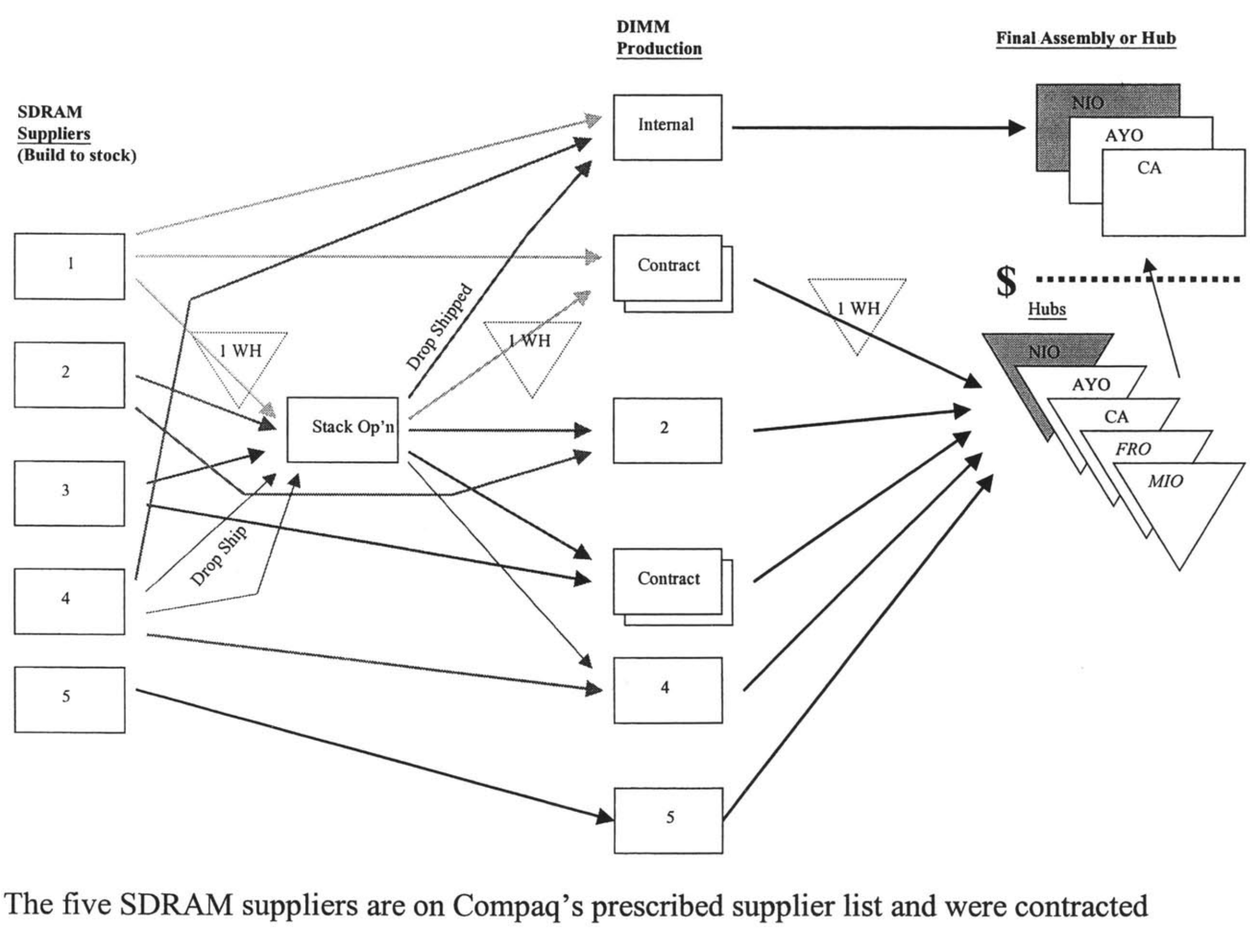
The "Suppliers" include all tiers. "Ass'y," short for assembly, are sites that manufacture or assemble parts such as printed circuit boards, power supplies, computer enclosures, computer frames, disk drives, cables, and peripheral devices. The "Hub" is a supply center where suppliers set up a consignment-based system (suppliers own material until the customer pulls the material) where Compaq pulls material. At the point of pull, Compaq accepts the material into its cost structure. Until that point, the supplier is holding the inventory in its cost structure. Contractual obligations between Compaq and suppliers ensure adequate amounts of parts and materials in the hub. "Stage 1" consists of the sites where Compaq manufactures PCAs, or printed circuit assemblies. HPSD is the primary user of these facilities where it manufactures custom and standard low-end and high-end memory modules for its mid-range and high-end servers. In 1999, Compaq started outsourcing the production of its 200-pin DIMMs with a goal of outsourcing all of them by the end of the year.[3] "Stage 2" consists of the assembly plants where Compaq manufactures computers and servers. The HPSD Stage 2 assembly plants are responsible for assembling, testing and shipping server computers. HPSD also has a facility where server orders are customized for special uses, "Stage 3" in Figure 2. The rest of the diagram details the many ways computers are distributed to "Distribution Centers," "Channel Configurators," and "Resellers." HPSD's servers are primarily built-to-order where some are shipped directly to customers while others spend a minimum amount of time at "Channel Configurators" and "Resellers." Typical HPSD final customers are stock market entities, research laboratories, banks, automobile companies, and aircraft companies.

[3] Conversation with Paul Sturgis, Memory LCM Group manager, June 21, 1999.

2.3 HPSD's Memory Module Supply Chain

This study involves an analysis of HPSD's global 200-pin DIMM supply chain from the SDRAM suppliers to the factories. The primary components of the supply chain include five SDRAM suppliers in five countries; a SDRAM stacking operation in Texas; module manufacturing sites in Scotland, Germany, East Asia, and California; and final assembly sites located in Singapore, Massachusetts, and Scotland. Figure 3 shows the supply chain diagram that is the basis for this discussion.

Figure 3. HPSD 200-Pin Memory Module Supply Chain



The five SDRAM suppliers are on Compaq's prescribed supplier list and were contracted through HPSD procurement. The SDRAM suppliers are companies aggressively pushing the technological limits to increase the memory capability of each chip. As mentioned earlier, to enhance the memory capability in its servers, HPSD utilizes a stacking method where one SDRAM chip is stacked directly on top of another SDRAM chip, effectively doubling the memory capability while preserving the standard placement space required by the chip on the module. Currently, approximately 20-30% of HPSD's SDRAM volume is stacked. But, as shown in Figure 3 above, all stacked SDRAM funnel through one facility in Texas. Stacking adds significant time and complexity to the supply chain. For example, Figure 3 shows that SDRAM from Supplier 4 can take four different paths toward being placed onto a DIMM. The following bullet points explain the complexities involved with Supplier 4's SDRAM supply chain flow:

- Supplier 4's top path flows SDRAM from Supplier 4 directly to HPSD's internal DIMM production facility. Compaq owns the SDRAM as soon as it arrives. HPSD places the SDRAM onto memory boards to produce 200-pin DIMMs.
- Supplier 4's second path from the top flows SDRAM from Supplier 4 to the stacking facility. This path is detailed as "Drop Ship" because Compaq has bought the SDRAM from Supplier 4, but has asked it to ship the SDRAM directly to the stacking facility. Compaq owns the material as soon as it arrives at the stacking facility. The stacking facility produces the stacked SDRAM and then ships them to HPSD's internal DIMM production facility where they are used to manufacture stacked 200-pin DIMMs.
- Supplier 4's third path flows SDRAM directly to the stacking facility, but it is still owned by Supplier 4. The stacking facility in Texas produces the stacked SDRAM and then ships it back to Supplier 4 in Asia. Supplier 4 places the stacked SDRAM onto memory boards to produce stacked 200-pin DIMMs. Then Supplier 4 ships the stacked DIMMs to the appropriate supplier hub.
- Supplier 4's fourth and bottom path flows SDRAM to its own DIMM production facility. It produces the 200-pin DIMMs and then ships them to the appropriate supplier hub.

HPSD had three internal module production facilities that decreased to two during this project, with only one of these facilities capable of producing the new 200-pin DIMM. DIMM production outsourcing was a major strategy, and by the end of this project, production of all 200-pin DIMMs was outsourced. These outsource manufacturers were a combination of actual SDRAM suppliers and contract manufacturers. In Figure 3 above, the SDRAM suppliers are labeled with numbers 1 through 5. If the DRAM supplier also produced DIMMs for Compaq, then the DIMM production site carries the same supplier number. Otherwise, the DIMM production site is labeled "Contract." The dash-lined triangles labeled "1 WH" represent Supplier 1's warehouse in California. Note in Figure 3 that if HPSD wants stacked DIMMs produced with Supplier 1 SDRAM, it always contracts the DIMM production to supplier 1. For a stacked DIMM using Supplier 1 SDRAM, the material flow is as follows:

- Supplier 1 ships SDRAM from Asia to its California warehouse. Then it ships the SDRAM from the warehouse to the stacking facility in Texas. The stacking facility produces the stacked SDRAM and then ships them back to the CA warehouse. Then Supplier 1 ships the stacked SDRAM to its contract DIMM manufacturer in CA who produces the stacked 200-pin DIMMs and returns them to the CA warehouse. Supplier 1 ships the stacked 200-pin DIMMs from the CA warehouse to the appropriate supplier hub.

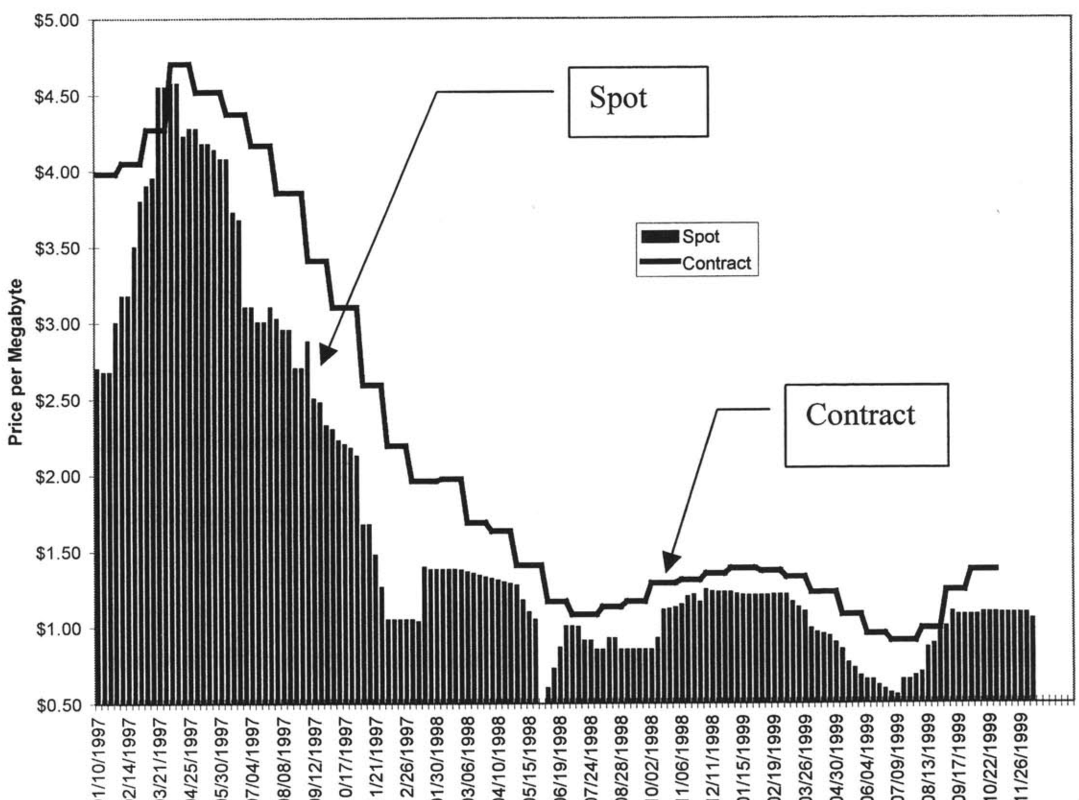
The triangles on the right in Figure 3 are the supplier hubs. They are located near HPSD's server manufacturing facilities worldwide. The final assembly plant and hub labeled "NIO" are shaded because operations there will cease in 2000. The hubs labeled "FRO" and MIO" are italicized because they are located near manufacturing sites that will start producing servers in 2000.

Compaq's corporate "memory" commodity manager determines the suppliers from whom the company, as a whole, will purchase SDRAM. HPSD's LCM group manages the supply planning for SDRAM and 200-pin DIMM manufacturing. LCM manages the 200-pin DIMM supply chain from SDRAM suppliers through delivery to the customer.

2.4 Computer Industry's Memory Market

As Professor Charles Fine puts it in his book, Clockspeed, every advantage is only temporary.[4] This mantra was played out in full force in the memory market during the term of this project, June –December 1999. The price of SDRAM had fallen at a rate of 40% per year for the last three years. The sharp decline in SDRAM prices in May 1999 made it very expensive for companies to have memory in inventory that month. Then, the summer months brought several problems to light in the market and the prices rose to earlier levels.[5] Figure 4 shows spot market and contract prices for SDRAM.

Figure 4. Industry DRAM Price Environment, 1997-1999



Dataquest, December 1999

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[4] Fine, Charles H. ClockSpeed: Winning Industry Control in the Age of Temporary Advantage, Reading, MA: Perseus Books, 1998.
[5] Network World, "Quake Pushes SDRAM Prices Up by 50 Percent," September 11, 1999.

Figure 4 shows the average SDRAM price volatility caused by supply and demand changes in the memory market for 1997-1999. The fourth calendar quarter usually sees very high seasonal demand for computers. This demand translates into high demand for memory in the same period causing the price of memory to stabilize and even rise in an allocated market (where SDRAM suppliers allocate certain percentages of production yield to each SDRAM buyer in high demand periods). In 1999 above, the mid-year increase in price was initiated by news of decreased supply in the SDRAM market and then fueled by an earthquake in Taiwan, affecting six percent of the world's SDRAM output (measured in megabytes).[6] The drive for cost reductions at Compaq's HPSD necessitated the hub strategy to keep the inventory of memory off its books because of its volatility in price. The hub strategy has developed industry wide and is not a unique Compaq supply strategy. This strategy pushes inventory costs back up the supply chain to the suppliers who in turn factor them into their cost structures and pass the costs back to the customers.

In the summer of 1999 many industry forces came together practically at the same time and caused chaos in the 64megabit SDRAM market. First, there was a tightening of supply for the 64megabit SDRAM as manufacturers shifted their product mix to the higher margin 128megabit SDRAM – resulting in lower 64megabit supply. Second, several producers were shifting production to the next-generation 0.18-micron manufacturing processes and such a shift always results in lower yields at the start and thereby resulting in lower 64megabit supply. Third, the sub-$1000 PCs suddenly moved from 32 megabytes to 64 megabytes of main memory –

[6] Dataquest's Tactical Memories Newletter, October 4, 1999, Vol. IV, No. 20.

resulting in higher 64megabit demand.[7] These dynamics sent the SDRAM spot market reeling and tripled the price for 64megabit SDRAM in eight weeks by the first week of September.

Compaq fared better since it negotiates contract prices, but they still increased substantially. With SDRAM prices on the rise, Compaq reversed its hub strategy in September by immediately pulling memory from the hubs as soon as the supplier shipped it there. Thus, Compaq did not allow the hub strategy, which was in place to help protect Compaq from falling memory prices, to reciprocate and benefit the SDRAM supplier in an opposite market environment. The world SDRAM market was further exacerbated by an earthquake in Taiwan on September 21. It shut down power to major manufacturing facilities for several days. Speculation of a supply shortage caused the SDRAM price to rise another 50 percent in late September.[8]

This memory price volatility significantly impacts HPSD's memory supply chain. When prices are increasing, Compaq wants to reverse its hub strategy by pulling memory and memory modules as soon as the material arrives at the hub. The specifics of Compaq's contract pricing with memory suppliers were not available for this study, but the hub contract stipulates that contract price changes are reflected immediately on material within the hub. SDRAM suppliers are required to keep a contracted amount of material in the hub at all times – for this study it was estimated to be two weeks supply. When memory prices increase and Compaq pulls everything from the hub as soon as it arrives, the supply chain is stressed to keep the minimum two weeks supply in the hub. The suppliers know what is happening. Compaq is taking ownership of the memory as fast as it can to minimize raw material costs. In this case where memory prices are

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[7] Electronic Buyers News, "Buying Spree Rolls DRAM Spot Market," September 15, 1999.
[8] "Quake Pushes SDRAM."

rising, Compaq is no longer having to write down its inventory valuation, but it is in danger of spending much more than it had planned to purchase memory. From the suppliers' point of view, Compaq's reversed hub strategy provides them no real "collaborative" incentive to expedite SDRAM to the hub because based on their experience they know the increased demand signals are overstated. Additionally, the suppliers do have an incentive to produce as much SDRAM as quickly as possible to take advantage of the increasing prices in the spot markets. With the memory prices fluctuating up and down, severe overstated demand signals are delivered through the supply chain as both suppliers and buyers try to take advantage of the situation. The end result is no collaboration in a very expensive supply chain.

During HPSD's outsourcing overtures for the 200-pin DIMM, the SDRAM prices hit rock bottom in the summer of 1999. The severe decrease in SDRAM price over the last three years has been driven by too much supply, too little demand, and technology improvements. Over the past two decades, the cyclical nature of DRAM prices has influenced companies to give up or change their approach toward DRAMs. NEC Corporation is the latest to give up as an independent supplier – they are merging with Hitachi Ltd., which is equally stressed by the falling market, to form the new NEC Hitachi Memory Inc.[9] Constant improvements in DRAM manufacturing techniques have enabled suppliers to keep driving down prices in a competitive environment. This is the ideal environment in which large computer manufacturers enjoy the SDRAM price revaluation (changing memory price) protection built into the hub strategy. As mentioned earlier, if the SDRAM or DIMMs are in the hub and the contracted price decreases, then the hub's supply immediately reflects that decrease. Since the supplier owns the material in the hub, the supplier has to write down its inventory valuation to the decreased market valuation.

This enables Compaq and other computer manufacturers to push those inventory revaluation expenses and inventory carrying costs up the supply chain to the SDRAM supplier.

Compaq consumes 10-15% of the world's memory output. HPSD's AlphaServer product line accounts for 5-10% of Compaq's DRAM business. There are several SDRAM suppliers in the world with the largest three being Samsung Electronics Co. Ltd., Micron Technology Inc., and Hyundai MicroElectronics Co. Ltd.[10] Compaq uses a multi-source strategy while procuring 85-90% of its memory demand from the five largest DRAM suppliers in the world. The large computer manufacturers have hubs (collection point for supplier-owned material) near their manufacturing sites where suppliers ship and hold inventory in consignment. The suppliers pay the freight (0.2% of unit cost for memory) to the hub from their fabrication facilities, or FABs, which have physical locations dictated by economies of scale in manufacturing since shipping cost is not a concern.[11]

2.5 Problems and Challenges in Memory Supply Chain

A major driver for Compaq's outsourcing of DIMM production is inventory cost. Figure 3 in Section 2.3 shows the point with a "$-----" at which Compaq acquires the DIMM onto its books. It is the point at which Compaq pulls the DIMM from the hub. That is only true if the DIMM production were outsourced because the suppliers ship to the hub and keep a pre-arranged stock of modules in that location. If HPSD produced the DIMM internally with stacked SDRAM, then Compaq owned the SDRAM at the point of shipment from the SDRAM supplier. In the case of

[9] "Only the Giants"
[10] Electronic Buyers News, "Only Giants Can Tame DRAM Monster," December 8, 1999.
[11] Conversation with Jackie Gross, Compaq DRAM Procurement Manager, June 28, 1999.

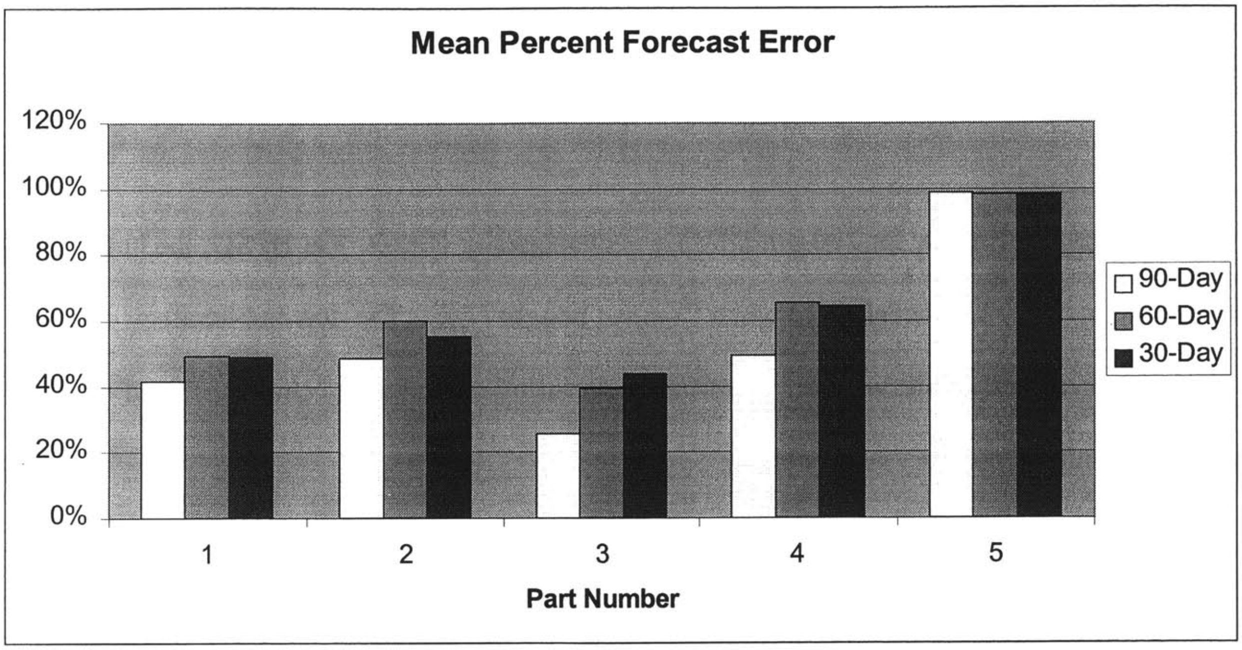
producing DIMMs with unstacked, or monolithic, SDRAM, Compaq draws the SDRAM from the hub. By utilizing the hub and keeping the SDRAM off of its inventory books, Compaq avoids the severe decreases in the price of DRAM, as shown earlier in Section 2.4, Figure 4.

Compaq's supply planning for 200-pin DIMMs is managed by HPSD. For HPSD, the hub strategy for memory was accelerated when Compaq bought DEC. The new hub strategy coupled with the requirement to outsource all DIMM manufacturing caused many challenges and questions about the memory supply chain.

- Where were the costs within the supply chain?
- What was the cost of the hub?
- How much time does memory spend in the supply chain for each supplier?
- Who owns the memory at what point in the supply chain?
- What is the effect of decreasing memory prices, or revaluation, on the costs in the supply chain?
- How can we capture the supply chain costs? How can we minimize them?

In addition to the complex supply chain, each month HPSD is tasked to adjust the sales forecast for 200-pin DIMMs. The sales forecast is consistently high. Without researching why the sales forecasts are always high, Figure 5 below shows mean forecast percent error data to justify the need for HPSD to adjust it.

Figure 5. Company Sales Forecast Error per DIMM – June to September 1999



The data in Figure 5 covers a four-month period from June to September 1999. The 90-Day forecast is a sales forecast received by HPSD at the beginning of a month for the third month. For example, in the first week of June, HPSD receives a 90-Day sales forecast for August, a 60-Day sales forecast for July, and a 30-Day sales forecast for June. HPSD's challenge is to adjust the sales forecast without causing a missed shipment due to a DIMM shortage. The cost of a missed shipment is the server system lost sale for the quarter, e.g. the sale may be lost forever or its shipment may be delayed until the next quarter. The cost of having too much inventory is much smaller due to the memory profit margin, but how can HPSD forecast and track their supply plans better to minimize costs whenever possible?

These challenges are significant since HPSD is trying to develop and stabilize a completely outsourced 200-pin DIMM supply chain. HPSD needs to know which suppliers have what costs at what point in the supply chain. It needs to know how much time memory spends in the supply chain, because, as stated earlier, Compaq pays for the costs in its supply chain even if those costs are pushed upstream to the supplier. HPSD needs to know the cost of its supply chain so it can make every attempt to minimize the costs while still maintaining enough flexibility to never risk missing a server shipment to a customer.

3 Cost Model

3.1 Customer Needs

HPSD's Life Cycle Management (LCM) group manages the supply plan for the 200-pin DIMM and other memory modules. HPSD takes inputs from sales forecasts and on-the-job experience and creates a supply plan each quarter for 200-pin DIMMs. They also update the supply plan, if necessary, during the quarter. The supply plan, which is actually HPSD's demand signal to suppliers, is divided among the suppliers based on their reported capacity and their history of meeting commitments. Through the lens with which this project was approached, HPSD understands that all costs in the supply chain are passed on to Compaq. Therefore, LCM's needs are to: (1) Identify the time and cost of the steps in the supply chain for each supplier; (2) Determine the revaluation cost associated with the time memory spends in the supply chain.

3.2 Description of the Cost Tool

The purpose of this Cost Tool is to identify the time and costs in HPSD's memory supply chain in order to provide decision support to help LCM determine which SDRAM suppliers minimize the overall memory supply chain cost.

The tool models the memory supply chain network shown in Figure 3, Section 2.3. The supply chain in Figure 3 consists of five SDRAM suppliers, one stacking plant, six DIMM manufacturing plants, and five final assembly plants. The DIMM manufacturing plants in the network are internal and external facilities. The stacking operation is performed at an independent external manufacturer. The tool looks at supply chain costs for a quarter.

The tool is divided into three areas: Input, Calculations, and Output. In the Input area, it allows the user to input data regarding time and cost. The time elements consist of the amount of time memory spends at each point in the supply chain network and the amount of time required to flow, or ship, from point to point in the network. The cost elements include the standard cost of the SDRAM, the cost of other raw materials used to produce a DIMM, the cost of the hub, the cost of transportation, the cost to stack SDRAM, and the cost to manufacture DIMMs.

The Calculations area uses the time and cost data from the Input area to calculate two major cost items. First, it calculates the memory price revaluation per quarter. Second, it calculates the supply chain costs for the quarter.

The calculation for memory price revaluation per quarter uses the time an SDRAM spends in the supply chain and the SDRAM raw material cost. First, using supply chain data for time from the Input area, the tool calculates the number of days SDRAM spends in the supply chain for each of the five suppliers. Figure 6 below shows an example of the time SDRAM spends in the supply chain for Supplier 1.

Figure 6. SDRAM Time in the Supply Chain – Supplier 1

	SDRAM Prod.	Trans.	WH	Trans.	Idle	Stack Process	Trans.	WH	Trans.	Receive	DIMM Process	Trans.	WH	Trans.	DIMM Receive	Total	
Time in SC	0.0	2.5	1.0	1.0	2.0	7.0	1.0	1.0	0.5	0.5	11.0	0.5	1.0	1.5	0.2	30.7	days
Normal Scenario	0.0	2.5	1.0	1.0	2.0	7.0	1.0	1.0	0.5	0.5	11.0	0.5	1.0	1.5	0.2	30.7	days
Best Case Scenario	0	2.5	0.5	1	1	7	1	0.5	0.5	0.5	7.5	0.5	0.5	1.5	0.2	24.7	days
Worst Case	0	2.5	2.5	1	7	7	1	2.5	0.5	0.5	15	0.5	2.5	1.5	0.2	44.2	days
Worst - No SDRAM	21	2.5	2.5	1	7	7	1	2.5	0.5	0.5	15	0.5	2.5	1.5	0.2	65.2	days

For each supplier, the tool draws time data into the shaded line called "Time in SC" at the top of Figure 6. The tool adds each number in the row and shows the results in the "Total" column. The tool repeats this process for each supplier using supplier specific data from the Input area.

By comparing the time SDRAM spends in each supplier's portion of the supply chain, LCM can determine which supplier will have the least exposure to revaluation costs (decreases in SDRAM prices). Any change to the Input data will be immediately reflected in these supplier calculations. Assumptions and estimates were made for supplier DIMM manufacturing throughput time since none of the suppliers would divulge this information. Estimates were also made for the amount of time memory spent in Supplier 1's warehouse and on some of the transportation routes between facilities. Also in Figure 6 above, there are four scenario time estimates – the four bottom rows. These scenarios estimate "Normal," "Best Case," "Worst Case," and "Worst Case-No SDRAM." This provides a sensitivity analysis of the time SDRAM could spend in the supply chain. The scenario "Worst Case-No SDRAM" estimates the extra time involved if a supplier does not have SDRAM in stock. The second piece of the memory price revaluation per quarter is the cost of the SDRAM. This cost is part of the Input data and is part number specific, meaning that DIMM part numbers could have different SDRAM and different SDRAM costs.

Revaluation calculations are performed for each of three cases: (1) The sales forecast acquired through the company sales forecasting system; (2) The LCM group's forecast that adjusts the sales forecast into a more accurate forecast; (3) The actual DIMM shipments for the quarter. Figure 7 shows the memory revaluation calculated for the three cases.

Figure 7. Memory Revaluation Calculation

Break down to calculate reval/day

	Sales Forecast Q399	LCM Forecast Q399	Actual Q399 Shipments	
Total # DIMMs	92030	78957	52137	A
WT AVG Cost per DIMM	$ 280.12	$ 264.43	$ 253.78	B
Q3 Memory Module COGS/Qtr	$ 25,779,670	$ 20,878,435	$ 13,231,472	A*B=C
DRAM Value of COGS	84%	84%	84%	D
DRAM COGS/Qtr	$21,691,811	$17,642,077	$11,162,418	C*D=E
Days/Qtr (365/4)	91.25	91.25	91.25	F
DRAM COGS/Day	$237,718	$193,338	$122,328	E/F=G
Days in SC	53.4	53.1	52.9	H
DRAM Value in SC	$12,703,269	$10,264,923	$6,467,890	G*H=J
% Reval per Qtr	10%	10%	10%	K
Reval/Qtr	$1,270,327	$1,026,492	$646,789	J*K=L
Reval/Day	$23,772	$19,334	$12,233	

The "WT AVG Cost per DIMM" is the weighted average cost per DIMM. This is based on volumes of DIMM part numbers multiplied by the appropriate DIMM costs then divided by the total number of DIMMs. The "WT AVG Cost per DIMM" changes with the forecast because the mix of DIMMs changes in each forecast or actual shipment. More specifically, the "Sales Forecast" above had a mix of DIMMs that included more of the higher cost DIMMs. With higher cost DIMMs, the average weighted cost is higher. The DRAM value percentage of DIMM costs, "DRAM Value of COGS," in the supply chain is calculated by the volumes of DIMM part numbers multiplied only by the cost of DRAM within that particular DIMM, then divided by the total number of DIMMs. The "Days in SC" is the weighted average number of days a DIMM would spend in the supply chain given the sales forecast mix and parameter set in the Input area. The days a DIMM could spend in the supply chain range from 19-65.2 days with its SDRAM spending 47-93.2 days in the supply chain. The "Reval/Qtr" is the revaluation cost incurred due to the price of memory decreasing over the quarter. These revaluation numbers answer a need for LCM. LCM can directly compare their forecast's revaluation cost per quarter to the sales forecast and calculate how much supply chain revaluation cost they saved by adjusting the sales forecast. LCM can also see how many revaluation cost dollars they left in the supply chain by comparing the LCM Forecast revaluation to the revaluation cost on the actual shipments for the quarter. LCM can use these side-by-side revaluation numbers to determine how effective their LCM Forecast is at trying to minimize the revaluation cost dollars left in the supply chain. A summary of the revaluation numbers in Figure 7 above shows that LCM saved approximately $245,000 for the quarter, but left approximately $380,000 in the supply chain. To increase the former amount and decrease the latter amount, LCM has to improve their forecasts – a task attempted in Chapter 4.

The final part of the Cost Tool calculates and details the supply chain costs for a specific segment of the 200-pin DIMM for the quarter. Figure 8 shows the supply chain costs for the third quarter of 1999.

Figure 8. Q399 Supply Chain Costs

Memory Supply Chain Costs for Q3 1999

Actual Total Cost	Q399	Annualized Total
Materials:		
SDRAM	$11,162,418	$44,649,673
Other	$615,321	$2,461,283
Sub-Total	**$11,777,739**	$47,110,955
Non-Materials:		
Handling	$3,937	$15,747
Transport	$20,915	$83,659
Process/Profit for SC Entities	$ 1,428,882	$5,715,528
Inventory Reval for the Qtr	$646,789	$2,587,156
Inv. Carrying Cost (5% per Qtr)	$661,574	$2,646,294
Forecast Error Reval		
Demand Forecast Reval	$623,538	$2,494,152
LCM Forecast Reval Savings	($243,835)	($975,338)
Net Forecast Error Reval	$379,703	$1,518,813
Sub-Total	**$3,141,799**	$12,567,198
Total	**$14,919,538**	$59,678,153

The supply chain cost total consists of "Material" costs and "Non-Material" costs for the "actual DIMM shipments" in Q3 1999. The "Material" costs are the costs of the SDRAM and other raw material that is used in producing the DIMMs for the quarter. The SDRAM cost for suppliers is assumed to be 84 percent of the cost Compaq actually pays for the SDRAM. This percentage was determined by assuming that DIMM suppliers paid the same amount for DIMM raw materials, other than SDRAM, as HPSD paid and that the suppliers made an arbitrary profit margin on the SDRAM. From an HPSD and LCM perspective, these costs can only be affected by the corporate memory commodity manager. The Non-Material costs include the topics listed in Figure 8 above. The "Handling" costs are calculated by determining the handling costs for each DIMM by supplier and multiplying that cost by the number of DIMMs acquired from each supplier. The "Transport" costs are calculated in the same manner as the "Handling" costs. The "Process/Profit for SC Entities" is the contracted standard cost per DIMM minus the DIMM's raw material costs multiplied by the number of DIMMs for the quarter. "Inventory Reval for the Qtr" is the revaluation per quarter calculated for the actual shipments (from Figure 7). The "Inv. Carrying Cost (5% per Qtr)" is the Material sub-total cost multiplied by five percent. The "Forecast Error Reval" is the memory price revaluation that was present in the supply chain even though LCM adjusted the sales forecast. The "Net Forecast Error Reval" is the sum of "Demand Forecast Reval" and "LCM Forecast Reval Savings." "Demand Forecast Reval" is the sales forecast revaluation (from Figure 7). "LCM Forecast Reval Savings" is the amount of revaluation saved by LCM's adjusting the sales forecast (from Figure 7, Sales minus LCM). This "Savings" is depicted as a negative number to show that LCM took this amount of revaluation out of the supply chain by adjusting the sales forecast. The "Net Forecast Error Reval" shows the amount of revaluation that is left in the supply chain that could be decreased with a better forecast. The Non-Material Sub-Total is the sum of all the Non-Material categories and uses the "Net Forecast Error Revaluation" number as the "Forecast Error Reval" number. The annualized numbers at the right in Figure 8 is the third quarter's numbers multiplied by four.

Table 3 in Appendix 1, section 1.4 details the equations used to produce the calculations in Figure 7 and Figure 8 above.

3.3 Tool Implications

The supply chain costs depicted in Figure 8 above provide HSPD and LCM with information that they can use to determine how to save money. HSPD can affect some of the Non-Material costs by working with the suppliers to improve supply chain throughput time. An improvement in this area will cause the SDRAM to spend less time in the supply chain and reduce revaluation costs. At the same time, LCM can improve its forecast adjusting efforts to increase the revaluation savings and decrease supply chain costs.

A learning from the analysis is that, on an annualized basis, LCM saved Compaq nearly $1million in revaluation costs and there is another $1.5million in the supply chain waiting to be claimed. On the other hand, the analysis shows that the corporate sales forecast causes nearly $2.5million in excess revaluation cost on an annualized basis. Another learning is that the actual inventory revaluation cost was over four percent of the total supply chain cost. This is a function of the SDRAM cost and the time it spends in the supply chain.

3.4 Using the Cost Tool for One Part Number

An additional model execution was performed for just one part number. Figure 9 shows the results of the single DIMM analysis.

Figure 9. Single DIMM Cost Model Analysis Results

512 MB (S) DIMM Revaluation Analysis

	Sales Forecast Q399	LCM Forecast Q399	Actual Q399 Shipments
Total # DIMMs Forecasted /Shipped	6564	3673	1808
AVG Cost per DIMM	$ 777.08	$ 777.08	$ 777.08
Q3 512MB DIMM COGS/Qtr	$ 5,100,720	$ 2,854,196	$ 1,404,952
DRAM Value of COGS	75%	75%	75%
DRAM COGS/Qtr	$3,837,577	$2,147,383	$1,057,029
Days per Qtr	91.25	91.25	91.25
DRAM COGS per Day	$42,056	$23,533	$11,584
Days in Supply Chain	59.2	59.2	59.2
DRAM Value in Supply Chain	$2,489,694	$1,393,151	$685,766
% Reval per Qtr	10%	10%	10%
Reval per Qtr	$248,969	$139,315	$68,577

512MB (S) DIMM Supply Chain Costs for Q3 1999

Actual Total Cost			Q399	Annualized Total
Materials:				
	SDRAM		$1,057,029	$4,228,116
	Other		$21,642	$86,567
		Sub-Total	**$1,078,671**	$4,314,684
Non-Materials:				
	Handling		$180	$719
	Transport		$870	$3,479
	Process/Profit for SC Entities		$ 325,231	$1,300,926
	Inventory Reval for the Qtr		$68,577	$274,306
	Inv. Carrying Cost (5% per Qtr)		$70,248	$280,990
	Forecast Error Reval			
	Demand Forecast Reval		$180,393	$721,571
	LCM Forecast Reval Savings		($109,654)	($438,617)
	Net Forecast Error Reval		$70,739	$282,954
		Sub-Total	**$535,843**	$2,143,374
Total			**$1,614,514**	$6,458,057

A comparison of LCM Forecast Reval Savings between Figure 8 (all DIMM volume) and Figure 9 (single DIMM part number) shows that nearly 45% of the revaluation saved by the LCM group's forecast is claimed by one part number. This single DIMM part number contributes only approximately 7% of the total DIMM volume. It is the highest cost DIMM, thus highly susceptible to revaluation costs. The significance of this single DIMM analysis is that LCM could track revaluation costs per DIMM part number in order to allocate resources toward the part numbers that have the most revaluation costs. For example, higher cost DIMMs should spend the least amount of time in the supply chain that is possible. As the suppliers prove their reliability in delivering quality 200-pin DIMMs on time, LCM could migrate higher cost DIMMs toward suppliers that are working to decrease their supply chain throughput time. This part number analysis can help with those decisions. Table 3 in Appendix 1 section 1.4 provides a walk-through of the cost model. Table 4 in Appendix 1, Section 1.5, details each step for the single DIMM analysis in the Cost Model.

4 Forecast Tool Solution Technique

4.1 Overview of Current Resident Forecast Technique

Compaq's sales force is separated into geographies, or GEOs. The GEOs submit forecasts by product family for their territories through a system called Explorer, a planning system that is part of the company's SAP system. Compaq generally operates on a weekly forecast change basis, but the AlphaServer product line operates on monthly changes. After the forecast is submitted into the Explorer system, each month the AlphaServer plants receive a DNUB, or a Desired Net Unit Billed report. The DNUB provides forecast data for all assemblies, including memory modules. The plants input the DNUB into Reflex, an I2 simulation tool, to determine if they have enough inventory or open purchase orders to meet the demand for assemblies and all components down to the lowest level for the forecast time horizon.[12] If the plants' open purchase orders have enough flexibility to handle an increase in forecast, then they communicate the increased forecast to their suppliers. If their open purchase orders can not cover the increased forecast, then the issue is raised to higher management and worked out with the suppliers at higher levels.[13] This process is used for all components and assemblies, including memory modules, but memory modules are given special attention. The plants look to the LCM Group for further guidance on memory module forecasts.

While the plants are receiving the DNUBs, the LCM Group is receiving them also. The memory and graphics demand/supply manager's team analyzes the DNUB for memory and compares the changes to what their internal forecast had indicated. The internal forecast is a combination of

[12] An open purchase order is a plant-specific purchase order with a supplier that has an agreed upon flexibility range for volume up and down due to unexpected changes, usually originated quarterly with each quarter's supply plan.
[13] Conversation with Joe Loura, the AlphaServer Demand/Supply Manager for the LCM Group, July 29, 1999.

two procedures. First, the group positions a trend line through the recent actual shipment data to acquire the expected minimum supply plan for the quarter. Second, the group uses on-the-job experience, internal information sources, and intuition to modify or adjust the supply plan to an acceptable level where the group will be sure "not" to underforecast. The cost of underforecasting memory is lost revenue or delayed revenue (lost revenue for the quarter). The LCM group adjusts the sales forecast DNUB because the sales forecast is habitually very high, as shown in Figure 5, Section 2.5. By adjusting the DNUB, the LCM memory group controls the global inventory for memory in an effort to minimize costs. LCM uses a moving average for demand data in the current quarter to forecast the supply plan for the rest of the quarter and the following quarter. A 30 % buffer is added to the moving average forecast to account for growth and desired end-of-quarter inventory.

The cost of a missed shipment is the amount of the server system sales price. The cost of having too much inventory is much smaller due to the memory profit margin, but how can HPSD forecast and track their supply plans better to minimize costs whenever possible?

4.2 Customer Needs

HPSD's Life Cycle Management (LCM) group manages the supply plan for the 200-pin DIMM and other memory modules. It takes inputs from sales forecast, or DNUB, and on-the-job experience and creates a supply plan each quarter for 200-pin DIMMs. It also updates the supply plan, if necessary, during the quarter. Therefore, LCM's needs are: (1) A mathematical method to determine the supply plan for a quarter given historical data from the previous quarter; (2) Once a supply plan is established, a way of tracking demand weekly and alerting LCM if the supply plan could be in danger; (3) A model that uses graphical chart report formats familiar to the LCM.

4.3 Concept of the Forecast Tool

The Forecast Tool performs three primary functions to meet LCM's needs. First, the tool applies a mathematical approach to the "load" (demand) data points in a current quarter to forecast the demand in the following quarter. Secondly, the tool tracks the "plan" (supply plan) versus the "load" versus the forecast to provide a weekly visual tracking mechanism to inform LCM if the supply plan is too high, on target, or in danger of being exceeded. Thirdly, the tool provides presentation quality graphical charts that replicate charts already in use at LCM.

Each week LCM gathers data about the 200-pin DIMM customer demand, factory shipments, and inventory levels through internal Compaq systems. The tool allows LCM to input this data into the tool each week by DIMM part number. Once the tool is updated for the week, it uses multiple techniques to forecast demand for the following week, for the remainder of the current quarter and for the following quarter. These techniques consist of a weighted moving average, detailed in Appendix 2, Section 2.2, and Holt's forecasting model for trended data, detailed in Appendix 2, Section 2.3. A quick summary of the underlying logic follows:

- The Weighted Moving Average used in the current quarter Forecast Chart is a 12-period weighted moving average to forecast the following week's demand. The current demand point has a weight of 3 (or is multiplied by 3). The most recent demand point has a weight of 2. The other 10 demand points have weights of 1. This allowed LCM to place a more importance on the two most recent demand points without minimizing the effect of the other 10 demand points. For example, if LCM is inputting data for week seven of the current quarter to forecast Week 8, the weighted moving average will use all seven demand points from the current quarter and reach back to the previous quarter's archived data to use the previous quarter's last five demand points. Week seven would be multiplied by 3, and week six would be multiplied by 2. This is explained in more detail in Appendix 2, Section 2.2.

- Holt's Forecast is a technique used in the current quarter to forecast the following week's demand.[14] For example, if LCM is inputting data for week seven of the current quarter, Holt's will forecast the expected demand for week eight. The smoothing parameters are set to react very quickly to any upward or downward trend in the demand. If the demand from week seven was significantly higher than the demand for week six, Holt's forecast will spike up dramatically. This effect was desired because LCM wanted an early warning if the quarter's supply plan was in danger of being exceeded by demand. More explanation can be found in Appendix 2, Section 2.3.

- A three-period weighted moving average is used to extend the 12-period weighted moving average forecast and Holt's forecast out to the end of the quarter. The weights are 3 for the current demand point, 2 for the most recent demand point, and 1 for the other demand point. This extension was desired by LCM to visually show where the forecast is expected at the end of the quarter so it can be compared to the supply plan on the same chart. For example, if LCM is inputting data for week seven of the current quarter, Holt's will forecast week eight demand and then this three-period weighted moving average will extend the forecast out for the rest of the quarter, e.g. for weeks nine through thirteen.

- The same three-period weighted moving average (as mentioned above) is used to forecast the demand in the chart "Next Quarter's Forecast Chart." An additional demand forecast on this chart is "Last Qtr Avg" which is the average of all demand data points available in the current quarter.

Several other forecasting techniques were compared to Holt's, to include exponential smoothing and other moving average formulations, but LCM preferred Holt's because it has a linear trend and smoothing parameters that can be set to be very responsive to demand stimuli. Historical demand data showed that demand for the new 200-pin DIMMs had growth and an upward trend. LCM wanted to capture any upward trend immediately in order to predict whether the quarter's supply plan would be at risk in the quarter. As mentioned earlier, several other techniques were tried, but only Holt's method provided the quick and visually evident reaction to an upward trend in demand. During this validation period, LCM noted that Holt's reacted just as severely to a

[14] Class notes from Logistics Systems 1.260J, Demand Forecasting II, p.2 .

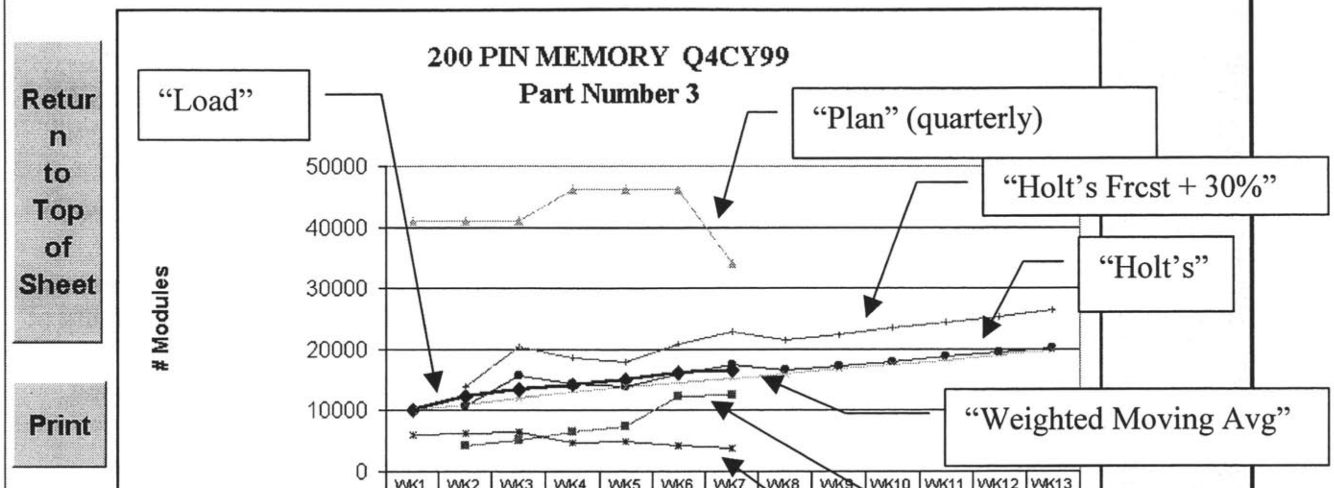
single week's downward trend. An assumption was made that a single week's downward trend was an anomaly that could be ignored given the goal to never underforecast. LCM settled on Holt's method graphed as a line on a chart that also showed a weighted moving average line as a comparison – moving averages were the accepted method to adjust the sales forecast and LCM wanted to see it on the chart also.

Using the macro-driven "What If Scenario" function, LCM has the flexibility of changing any of the inputs and quickly accessing the forecast graphs to see the effects. LCM can print graphs directly from the model. The tool has the capability built in to provide quarterly forecasts through the year 2001.

4.3.1 The Forecast Chart

The Forecast Chart graphs input data and calculated data in one chart to provide a visual representation of the current supply and demand environment in a format acceptable to LCM. Figure 10 shows an example chart of a Forecast Chart.

Figure 10. Forecast Chart Example



	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13
LOAD	10000	12298	13442	14014	14970	16126	16542						
SHIPS		4262	5154	6396	7292	12238	12516						
PLAN	41100	41100	41100	46094	46094	46094	34094						
INV	6094	6300	6613	4615	4897	4238	3816						
Holt's Forecast		10723	15712	14248	13855	15963	17546	16526	17278	18031	18784	19536	20289
Holt's Frcst +30%		13939	20426	18522	18011	20752	22810	21483	22462	23440	24419	25397	26376
Weighted Moving Avg.	10170	10998	12073	13076	13895	14589	15324	15952	16705	17457	18210	18963	19715

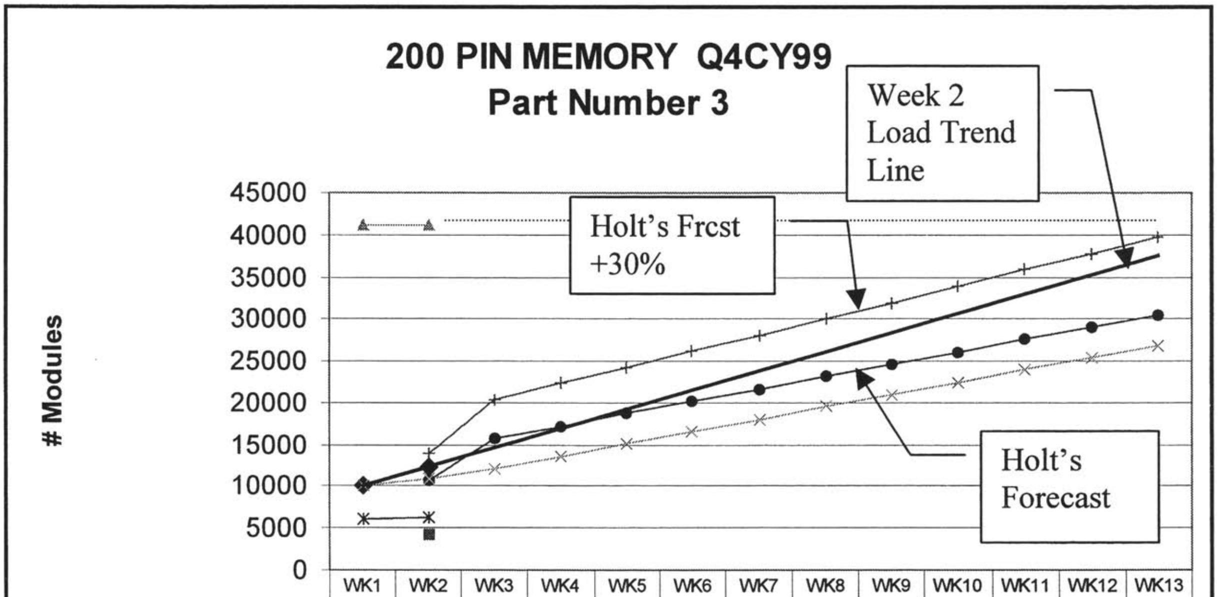
***All lines except "Plan" are cumulative for the quarter.

The "Plan" line at the top of the chart is the supply plan that represents the planned number of units for a quarter, as of the week on the X axis. The "Load" line is the cumulative customer demand and is the bold line that starts at 10,000 units at Week 1 (it starts at 10,000 units because of backlog from the previous quarter). The faint line just below the bold Load line is the "Weighted Moving Avg" line which uses the 12-period weighted moving average method described in the previous section. "Holt's Forecast" is the dark, thin line with circles that starts below Load at week two and then moves above it at week three. The "Ships" are the actual shipments sent out the factory doors. The Ships usually lag behind the demand until the end of the quarter where they catch up to the Load. "INV" is the inventory of this particular DIMM in the Compaq system for the week. The forecast methods represented in Figure 10 are applied against the weekly load, or demand, numbers (not the cumulative numbers), to forecast the next period's weekly demand. The chart shows the hyper-sensitivity of Holt's forecasting procedure with each of the smoothing parameters at 0.9. This makes Holt's forecast very sensitive to change as it captures any sign of trend and reacts greatly up or down (if the smoothing parameters were set at 0.1 or 0.2, Holt's method would not be nearly as responsive). In the example represented in Figure 10, the demand from Week 1 to Week 2 increased by just over 2000 units. The weighted moving average forecast line kept its very smooth approach, but Holt's procedure reacted greatly by moving higher as it predicted Week 3 demand. The "Holt's Frcst + 30%" line represents the user's desire to continuously have a 30% buffer to cover approximately 20% growth and a 10% buffer inventory at the end of the quarter. LCM used Holt's procedure as an early warning device because its hyper-sensitivity to upward trend produced a forecast that quickly approached the Supply Plan if the Load significantly increased for two to three consecutive periods. Although Holt's procedure performed in the same manner for a downward trend, the LCM memory group used it primarily for an increasing demand trend.

In the Figure 10 above, the Plan is established before the quarter begins and is communicated to the supplier base. The Plan is so much larger than the current forecasted quarterly Load represented because, during the previous quarter's planning, LCM had thought the quarterly demand would be greater than it was. The Plan remains constant at just more than 41,000 units for the quarter through Week 3. At the end of Week 3, LCM raised the Plan to just over 46,000 units for the quarter. This increase was caused by Week 2's unexpected small spike in Load (due to increased demand growth for that particular week) and LCM's use of a moving average trend line to predict demand.

Although LCM increased the quarter's supply plan after Week 3, Holt's Forecast represented on the Forecast Chart suggested leaving the supply plan alone. Figure 11 below shows the situation in the Forecast Chart at Week 2.

Figure 11. Forecast Chart With LCM Trend Line, Week 2

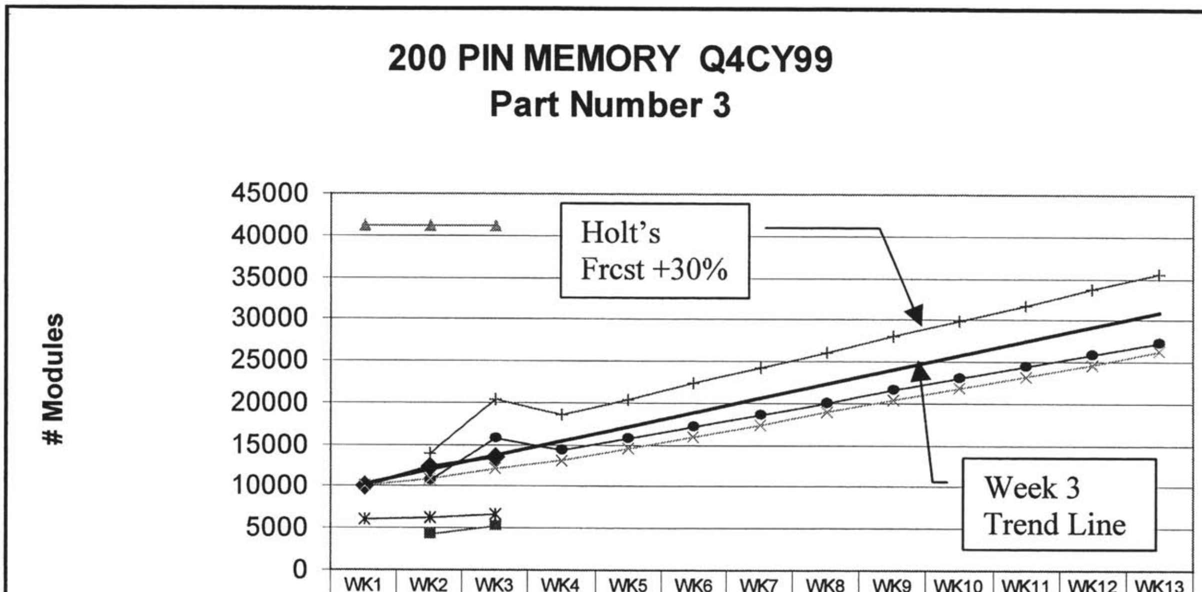


	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13
LOAD	10000	12298											
SHIPS		4262											
PLAN	41100	41100											
INV	6094	6300											
Holt's Forecast		10723	15712	17192	18673	20153	21633	23114	24594	26074	27555	29035	30515
Holt's Frcst +30%		13939	20426	22350	24275	26199	28123	30048	31972	33897	35821	37746	39670
Weighted Moving Avg.	10170	10998	12073	13554	15034	16514	17995	19475	20955	22436	23916	25396	26877

As shown above, the "Week 2 Trend Line" observed by LCM told them that if demand trend continued at the Week 2 pace then their supply plan will come close to being compromised by the end of the quarter. By adding a 30% buffer onto the Week 2 trend line, LCM observed that their supply plan would be exceeded. Instead of immediately raising the quarterly supply plan, LCM waited to observe Week 3's weekly demand to confirm the increased demand growth trend. In comparison, for Week 2, Holt's forecast was considerably lower than the Week 2 trend line, and Holt's Forecast +30% line was just below the supply plan for the quarter. This meant the new method using Holt's Forecast was telling LCM that, although it is very close, there is no need to increase the supply plan at the end of Week 2.

Week 3's demand did not keep pace with Week 2's growth. Figure 12 shows the situation at Week 3.

Figure 12. Forecast Chart With LCM Trend Line, Week 3



	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13
LOAD	10000	12298	13442										
SHIPS		4262	5154										
PLAN	41100	41100	41100										
INV	6094	6300	6613										
Holt's Forecast		10723	15712	14248	15703	17157	18612	20067	21521	22976	24431	25885	27340
Holt's Frcst +30%		13939	20426	18522	20413	22304	24195	26087	27978	29869	31760	33651	35542
Weighted Moving Avg.	10170	10998	12073	13076	14530	15985	17440	18894	20349	21804	23258	24713	26168

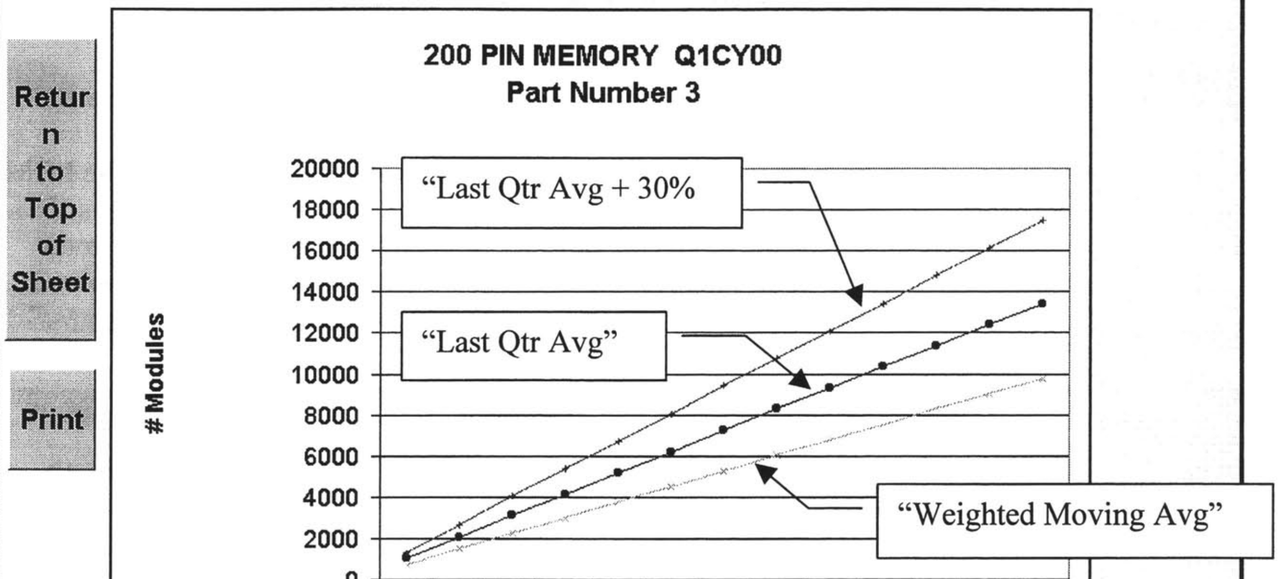
The "Week 3 Trend Line," although showing a considerably lower expected quarterly demand (as compared to Week 2's trend line in Figure 11), did not ease LCM's fears and they increased the supply plan beginning in Week 4 to 46,000 units for the quarter. Part of the decision's timing was to inform the suppliers as soon as possible, but the primary reason for the supply plan's increase was that the "Week 3 Trend Line," with an additional 30% buffer, came too close to the supply plan of 41,000 units for the quarter. In contrast, Holt's Forecast +30% line at the end of the quarter was over 5,000 units below the initial supply plan of 41,000 units for the quarter. The new method showed that there was no need to increase the supply plan. Indeed, the new method showed that the supply plan could be decreased by approximately 5,000 units. Relying upon Holt's forecasting method in this manner could help LCM more closely monitor their supply plan without raising the Plan prematurely. Note in Figure 10 that LCM decreased the Plan just three weeks after they had increased it. Demand growth was not as strong during the weeks following Week 2 and the trend line, weighted moving average line and Holt's line showed no danger since the Load was very smooth from Week 3 to Week 6.

More possible uses for the Forecast Tool are explored in Appendix 4, Section 2.4.

4.3.2 Next Quarter's Forecast Chart

The "Next Quarter's Forecast Chart" is a forecast for the following quarter's demand based on the demand from the current quarter. Figure 13 shows the chart.

Figure 13. Next Quarter's Forecast Chart Example



	1	2	3	4	5	6	7	8	9	10	11	12	13
Last Qtr Avg	1035	2069	3104	4138	5173	6207	7242	8277	9311	10346	11380	12415	13449
Last Qtr Avg +30%	1345	2690	4035	5380	6725	8070	9415	10760	12104	13449	14794	16139	17484
Weighted Moving Avg.	753	1505	2258	3011	3763	4516	5269	6021	6774	7527	8279	9032	9785

***The chart shows an "increasing" demand because it is cumulative by week.

This chart provides a rough mathematical look ahead at the next quarter. It helps LCM quickly grasp the likely demand in the following quarter based on the data in the current quarter. The "Last Qtr Avg" line is the average demand to date for the current quarter extrapolated cumulatively through each week in the next quarter. The "Last Qtr Avg + 30%" line adds 30 percent demand to the Last Qtr Avg forecast. The "Weighted Moving Avg" line is the same weighted moving average method used in the previous quarter's forecast. It is a three period time series equation using the latest three demand data points (weights are 3-2-1). At any time while using the tool, LCM can observe this chart to acquire a quick estimate of demand for the following quarter.

4.4 Tool Verification Tests

On several occasions, the graphical outputs from the Forecast Tool were checked against another Excel-based spreadsheet that was independently developed by the LCM memory manager. In each test, identical inputs were entered into the spreadsheets and the resulting outputs were compared. Any errors detected in the Forecast Tool during these tests were corrected. The LCM memory manager and his team used the model on various occasions to ensure they understood and felt comfortable with the tool. Any improvements mentioned by the users were incorporated into the tool in the manner suggested. The print quality of the output charts was checked against the needs of the users. The model's charts were modified until the format matched exactly, to include color coordination.

In order to explore the level of customer satisfaction for the tool, the user performed several "What If" scenarios similar to those detailed in Appendix 2, Section 2.4. Suggestions for improvements from LCM were incorporated into the tool. During the "What If" scenarios, the hyper-sensitive Holt's forecast provided satisfactory visual alarms to LCM as the forecast line approached the supply plan at the top of the forecast chart. LCM learned that although a small spike in demand caused an even larger spike in Holt's forecasted demand, it was usually followed by a reciprocating downward spike. Historically, actual demand could not continue to grow at the same high rate for more than one or two weeks. This knowledge caused LCM to watch closely when alerted by Holt's hyper-sensitive forecast and to avoid premature increases to the supply plan.

5 A Different Concept for DRAM Procurement

5.1 Introduction to Stacked vs. Monolithic DRAM Market

The most technologically advanced DRAM on the market in the computer memory industry is the 256megabit DRAM.[15] The next generation DRAM is expected to be a 1gigabit device.[16] DRAM is made in fabrication facilities, or Fabs. The memory suppliers in this study are major players in the market and are trying to estimate the memory requirement over the next few years in order to estimate returns on capital investments – Fabs are huge capital investments.

The stacking company in this study has a patented process where they take memory devices and stack them to double the density but retain the same device footprint on the memory module. For example, they take a 64megabit device and stack another 64megabit device directly on top of it. This process is a JEDEC standardized process.[17] The driver for this need for increased memory density is the development of faster and faster processors. With faster processors, the memory must be physically located as close to the processor as possible. In order to get the requested data back from the memory device on the same clock cycle, the memory must be physically very close to the processor or the system can't take advantage of the processor speed.

The DRAM suppliers are worried about companies that stack DRAM because the stacking companies are taking revenue from them. Compaq's DRAM stacking company stacks memory devices at a much lower cost than the newest monolithic (unstacked DRAM) devices with the

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[15] Conversation with Ron Cohen, Procurement, August 17, 1999.
[16] Ibid.
[17] Conversation with Bill Askins, [Stacking Operation Company's VP], August 18, 1999.

same density. For example, a certain given DRAM may cost $10 per device. The charge to stack two DRAM may cost $10, so a stacked DRAM of this sort may cost $30 total. In comparison, the equivalent density monolithic device could cost $100, depending on the timing within the life-cycle of the two sizes of DRAM.

Interviews with the stacking company yielded estimates that they saved Compaq several millions of dollars by stacking 64megabit devices as opposed to Compaq buying 128megabit monolithic devices.[18] For example, at the beginning of the 128megabit device's life-cycle, its price is high because it is the latest technology in the memory industry. During the 64megabit device's life-cycle, its price was high when it was first introduced, but it fell due to competition and increasing production yields. Demand for higher density memory devices caused the stacking company to start stacking 64megabit DRAM. At this point in time, Compaq satisfies its 128megabit purchase requirements from the stacked 64megabit DRAM. But, it purchases limited amounts of 128megabit monolithic DRAM for testing and small volume use purposes. Compaq monitors the prices of both stacked and monolithic DRAM and switches its volume purchasing over to the monolithic DRAM when the prices reach parity, the price-parity point.[19]

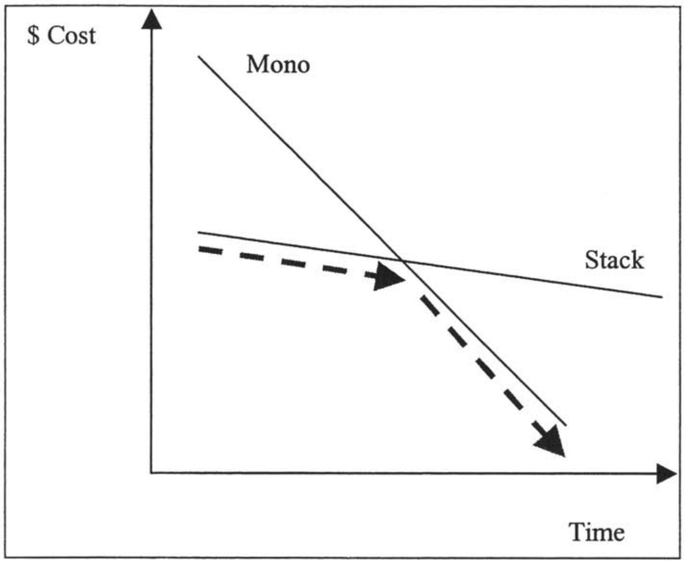
5.2 Price Tradeoff Concept Description

Delaying the purchase of large volumes of the latest DRAM saves costs since prices are high. The DRAM suppliers have learning curves similar to other industries where more volume lead to increased production yields which leads to increased productivity, lower scrap costs, and lower prices. Although prices also decrease because of market competition, the reductions are delayed

[18] Ibid.

because computer manufacturers buy the bulk of latest technology memory devices as stacked DRAM. Figure 14 illustrates the price-parity point at which Compaq currently switches procurement from stacked DRAM to monolithic DRAM.

Figure 14. Price-Parity Point for Stacked vs. Monolithic DRAM

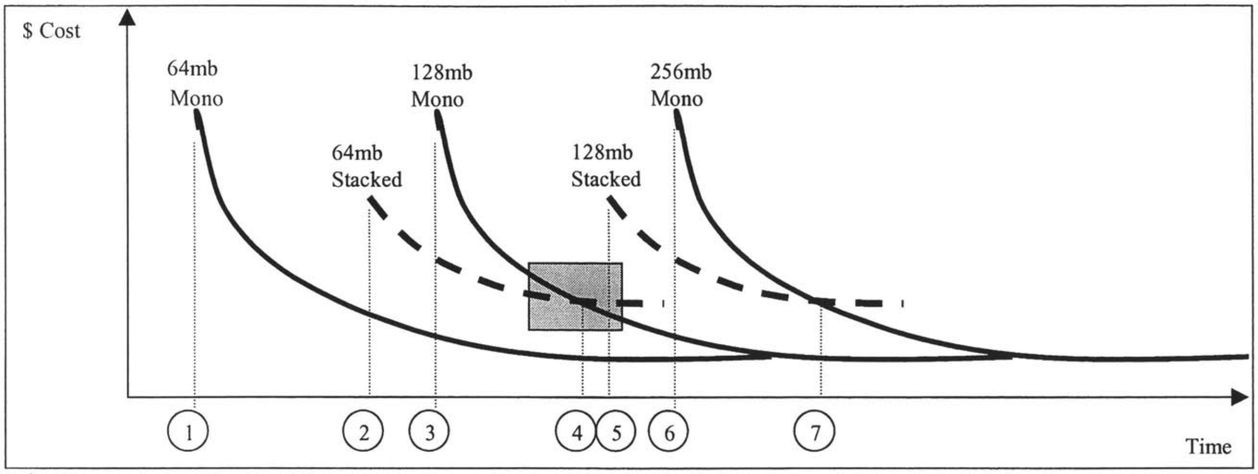


Following the arrows, at the beginning of the life-cycle for the latest monolithic DRAM, Compaq purchases the majority of its volume of a given density DRAM using stacked DRAM. As the monolithic DRAM price decreases with time, the two devices soon reach price parity. At that point Compaq switches to the monolithic DRAM.

In Figure 14 above, it is not immediately intuitive why the monolithic DRAM price, which is the higher density device, decreases at a faster rate than the stacked device. A macro perspective of this price comparison can be seen by graphing complete life cycles for the DRAMs. Figure 15 illustrates the life cycles of the 128megabit (the monolithic DRAM) and the 64 megabit DRAMs.

[19] Conversation with Cohen, August 17, 1999.

Figure 15. DRAM Life Cycles and Price Comparisons



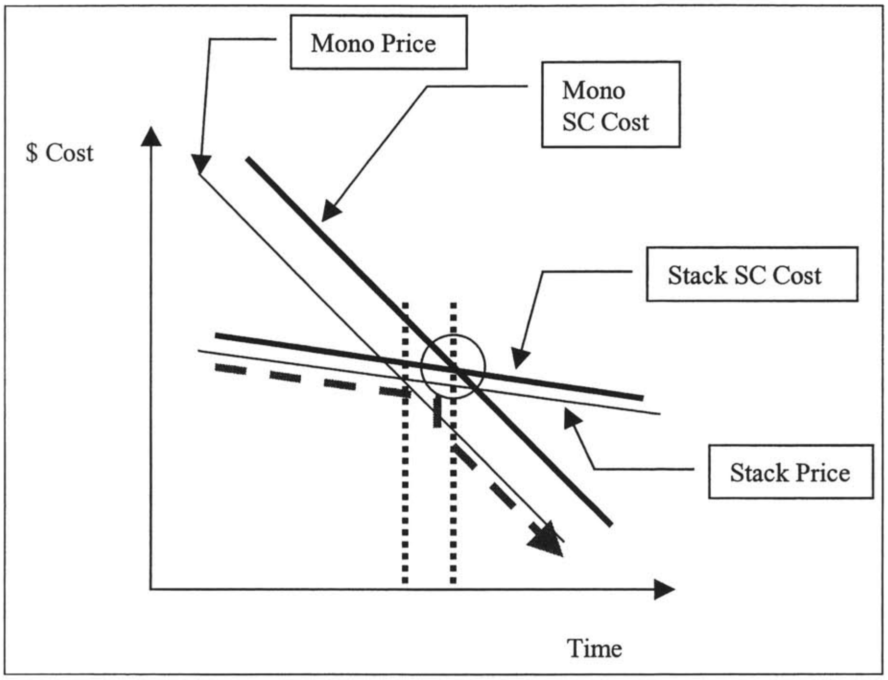
The shaded box in Figure 15 above is the graphical area shown in Figures 13 and 14. The figure above shows three different density DRAMs life cycles. An explanation of the numbered labels follows:

- (1) The point in time when the 64megabit DRAM starts production.
- (2) The point when the 64megabit DRAM is stacked to meet demand for higher density memory devices. The cost is higher because two DRAM are used in addition to the stacking production cost.
- (3) The 128megabit DRAM starts production.
- (4) The 128megabit monolithic DRAM reached price parity with stacked 64megabit DRAM. Compaq switches to 128megabit monolithic DRAM. Production of stacked 64megabit DRAM stops.
- (5) Stacked 128megabit DRAM starts production to meet demand for higher density memory devices.
- (6) The 256megabit DRAM starts production.
- (7) The 256megabit DRAM and stacked 128megabit DRAM reach price parity.

This study proposes an alternative point at which Compaq should switch procurement from stacked DRAM to monolithic DRAM. This alternative point is not the exact point at which the two prices reach parity – the current Compaq practice. The alternative price point takes into account the supply chain costs involved with procuring DRAM.

Figure 16 illustrates a concept that suggests a different point at which to switch the procurement of DRAM from stacked to monolithic devices.

Figure 16. Conceptual Price-Parity Point for Stacked vs. Monolithic DRAM



The alternative "switching" point circled in Figure 16 represents the proposed point at which Compaq should purchase the monolithic DRAM to satisfy its demand. The two thinner lines represent the DRAM purchase price curves for stacked and monolithic DRAMs (as in Figure 13). The two bold lines represent alternative supply chain cost curves for the two DRAMs. In addition to the price Compaq pays for the DRAM, these supply chain cost curves include all supply chain costs including revaluation, transportation, handling, and inventory holding costs. These additional costs cause the supply chain cost of a DRAM to be higher at any given point in time. The higher supply chain costs for the different DRAM options move both cost curves up, creating a new purchase switching point.

This alternative point takes place both later than the original price-parity point and at a lower monolithic DRAM price. This happens because the monolithic DRAM has significantly higher supply chain costs since its price is falling at a faster rate (its revaluation is greater). To illustrate an example of this concept, the study assumes the following information at the original price-parity point Compaq currently uses:

- S = the stacked DRAM (two DRAM devices)
  - S costs $27.70 ($10 per DRAM and $7.70 stacking cost)
  - S spends an average of 30 days in the supply chain
  - S decreases in value by 5% per year (revaluation – Figure 14)
  - S transportation and handling cost is an average $.01 per day

- M = the monolithic DRAM (one single DRAM device)
  - M costs $27.70
  - M spends an average of 20 days in the supply chain
  - M decreases in value by 40% per year (revaluation – Figure 14)
  - M transportation and handling cost is an average $.01 per day

Note that revaluation percentages are different because the prices of the two DRAMs are falling at different rates based on their individual life cycles. At the same point in time as Compaq's original price-parity point, the total supply chain cost of S is:

S(SC cost)= [DRAM cost] + [stack cost] + [revaluation] + [transportation & handling]

S(SC cost)= [$19.70] + [$8] + [$19.70*.05/12months] + [($.01)*30 days] =
= $28.08

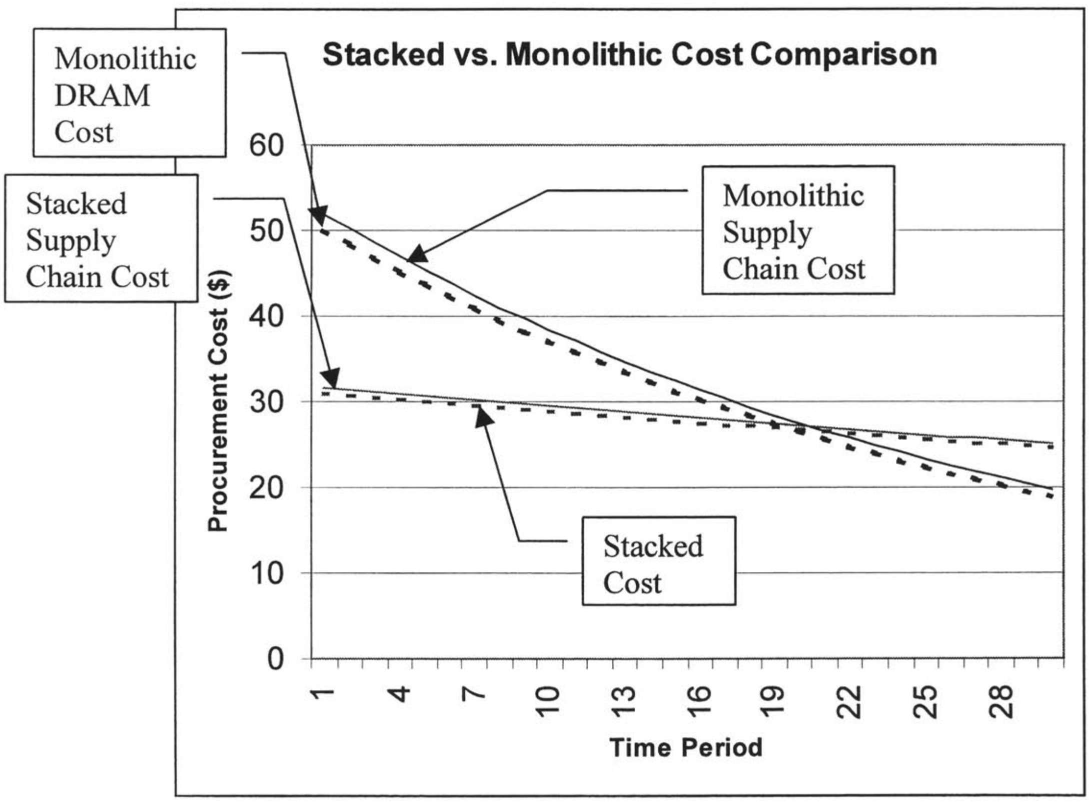
In comparison, at the same point in time the total supply chain cost of M is:

M(SC cost)= [DRAM cost] + [revaluation] + [transportation & handling]

M(SC cost)=[$27.70] + [$27.70*(.4)*(20 days)/(360days/yr)] + [($.01)*20 days] =
= $28.52

At Compaq's original price-parity point where the monolithic DRAM price equals the stacked DRAM price (in this case $27.70), the monolithic DRAM has a higher supply chain cost ($0.44 higher). Switching from stacked DRAM to monolithic DRAM at this point in time would cause more costs to be incurred in the supply chain. The monolithic DRAM has a higher supply chain cost for two reasons. One, its DRAM cost is higher at $27.70 compared to the $19.70 for the stacked DRAM. Two, the monolithic DRAM is at a point in its life cycle where its value is decreasing much more rapidly than the stacked DRAM (the monolithic DRAM's revaluation is higher). These two monolithic DRAM supply chain costs outweigh the costs incurred by the stacked DRAM's spending more time in the supply chain. The two cost equations detailed above are graphed using Excel in Figure 17 below.

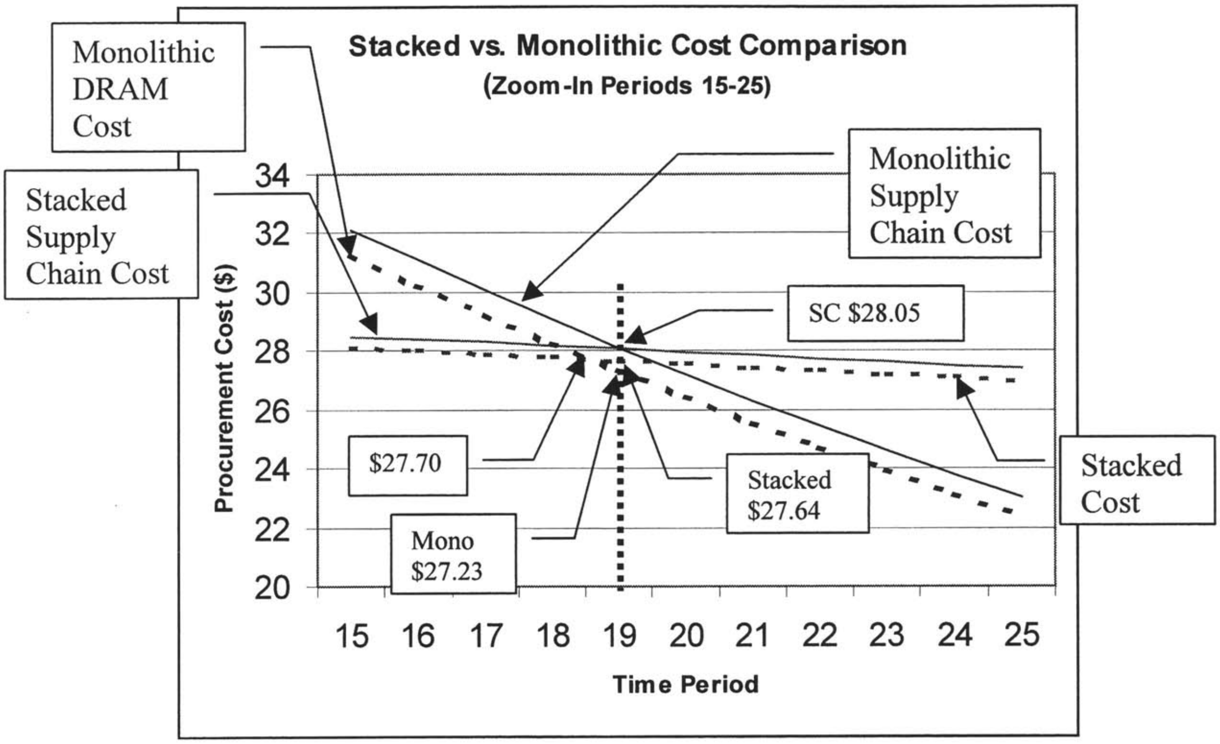
Figure 17. Stacked vs. Monolithic Cost Comparison Numerical Example



In the figure above, Compaq's original price-parity point is the intersection of the two dashed lines. The proposed "switching" point, where Compaq should switch from purchasing the stacked DRAM to purchasing the monolithic DRAM, is at the intersection of the solid lines.

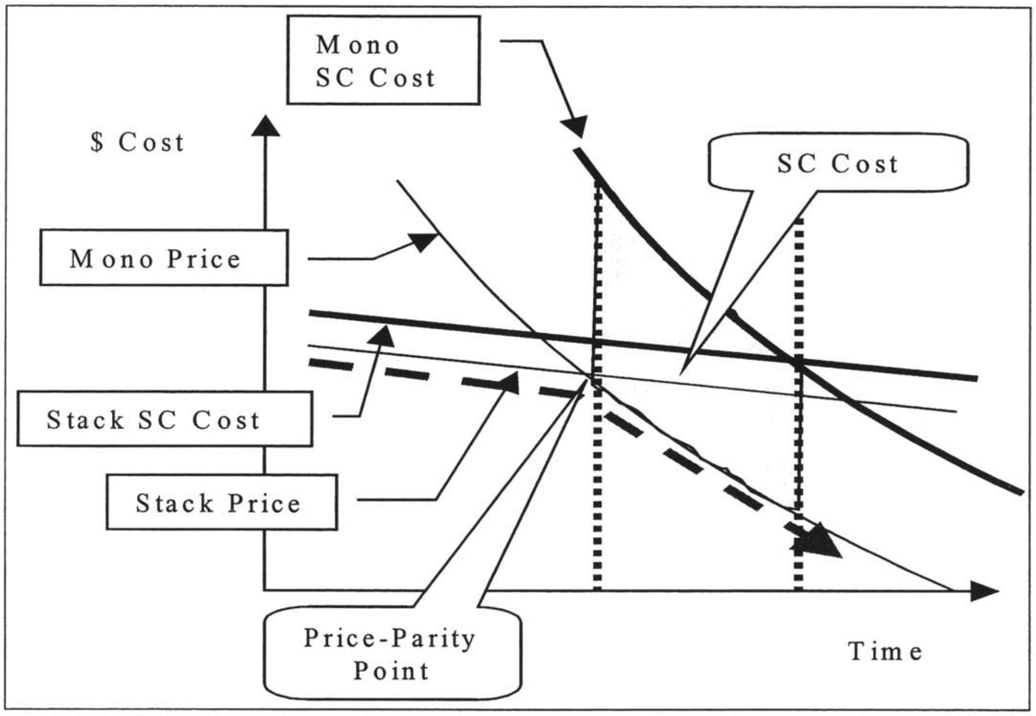
Note that this point is at a point in time later than the original price-parity point. To see the intersections more clearly, Figure 18 shows the time periods between 15 and 25.

Figure 18. Stacked vs. Monolithic, Time Periods 15 to 25



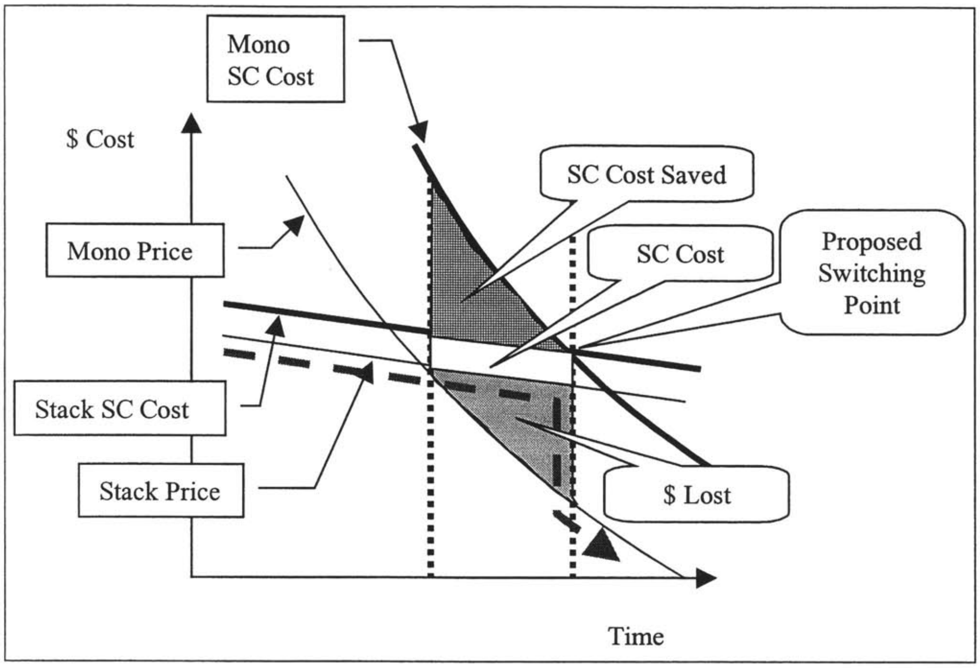
The dashed lines cross at the original Compaq price-parity point. The solid lines cross at the proposed point where Compaq should switch from stacked DRAM to monolithic DRAM. The original price-parity point shows that Compaq would switch purchasing stacked DRAM at approximately $27.70. In earlier calculations, it was shown that at this price-parity point the monolithic DRAM had higher supply chain costs. This study proposes that Compaq should switch from stacked DRAM to monolithic DRAM at the point where the supply chain costs are equal. This supply chain cost is $28.05 and is shown in Figure 18 as "SC $28.05." At this proposed switching point, the stacked DRAM price is $27.64. The monolithic DRAM price is $27.23 and has dropped below the stacked DRAM price by $0.41. On a pure DRAM price basis, Compaq would lose up to $0.41 per DRAM by using this proposed switching point, but the estimation for savings and losses is more complicated. Figure 19 shows a graph that illustrates the supply chain costs incurred by Compaq when it switches from purchasing stacked DRAM to monolithic DRAM.

Figure 19. Compaq's Price-Parity Point Supply Chain Costs



The shaded area in Figure 19 labeled "SC Cost" is the supply chain cost incurred by Compaq when it switches to monolithic DRAM at the price-parity point. Figure 20 below shows the costs and savings associated with Compaq's changing its purchase switching point to this study's proposed "switching" point (follow the dashed arrow).

Figure 20. Proposed "Switching" Point Costs and Savings



As discussed earlier, this study proposes that Compaq continue purchasing the stacked DRAM until the point in time where the monolithic supply chain cost curve equals the stacked DRAM supply chain cost curve. In Figure 20 above, if Compaq followed the method just mentioned, it would be paying more money for the stacked DRAM (an estimated average over time of $0.22 per stacked DRAM) and suffer the shaded loss that is labeled "$ Lost." Since Compaq would still be purchasing the stacked DRAM, the supply chain costs would be the shaded area labeled "SC Cost" (an estimated average of $0.11 per stacked DRAM). When the costs in Figure 20 are compared to the costs in Figure 19, the shaded area labeled "SC Cost Saved" is the benefit provided by using this study's proposed method. Keeping consistent with the numbers throughout this example, the estimated potential benefit from using the alternative switching point is $0.27 per DRAM. Even though this was an example for illustrative purposes only, the graphs in Figures 13-19 are practical representations for use in analyzing any commodity with similar cost characteristics.

6 Conclusions

6.1 The Cost Tool

6.1.1 Benefits of the Cost Tool

At this time, the Cost Tool is currently being used within HPSD. The tool captures revaluation costs and models them in a supply chain that is now well understood at HPSD. The revaluation costs associated with the varying forecasts and actual shipments are clearly presented and compared with other supply chain costs. HPSD management now has the capability to model a current supply chain environment with this tool and get information back with which they can make better supply planning decisions.

6.1.2 Limitations of the Cost Tool

This tool should not be used in isolation; rather, it should be thought of as being part of a total analysis that includes the consideration of strategic issues.

6.1.3 Extensions of the Cost Tool

Although the tool is initially focused on modeling supply chain costs for memory, with a few minor adjustments, it can be applied to any kind of product with a similar supply chain structure.

6.1.4 Improvements of the Cost Tool

Users are expected to modify the tool as the nature of their analysis changes, when more functionality is needed, and when more precise calculations are required. The tool was created with this notion in mind. There will always be an opportunity to apply macros to answer specific user needs such as navigational ease and "What If" scenario manipulation. As the users become more comfortable with the tool and increase their knowledge in Excel, macros and other improvements can be made to enhance the capability of the model.

6.2 The Forecast Tool

6.2.1 Benefits of the Forecast Tool

At this time, the Forecast Tool is currently being used within HPSD. The tool provides a multi-function graph that shows the quarter's supply plan to the user along with tracking each week's shipments and forecast. It allows the user to proactively detect if the supply plan is at risk or if it is extremely high. It also allows the user to perform "What If" scenarios to test intuition or worst case scenarios with mathematical tools. In its most basic use, it decreases the time involved in creating presentation style briefing charts that track the high-end memory commodity.

6.2.2 Limitations of the Forecast Tool

This tool should not be used in isolation; rather, it should be thought of as being part of a total analysis that includes the consideration of the sales forecast for memory and the supply chain costs as detailed in the Cost Tool. Holt's forecasting technique is adequate for the purposes of choosing large values for the smoothing parameters in order to make the forecast hyper-sensitive to upward trend, but it should not be relied upon to provide a definitive quarterly forecast. All forecasts are wrong.[20]

[20] Class notes on Forecasting, 15.762, Operations Management Models and Applications, Prof. Steve Graves, 1999.

6.2.3 Extensions of the Forecast Tool

Although the tool is initially focused on presenting and forecasting memory, with a few minor changes to the headings of the graphs and input area, it can be applied to any commodity. Additionally, the calculations area of each worksheet has Holt's model color coded so that the smoothing parameters can be changed.

6.2.4 Improvements of the Forecast Tool

For future refinement, seasonality could be added to the tool. There may be value in adjusting the weights on the tools weighted moving averages to take into account seasonality from Q4 to Q1 or from Q2 to Q3. In both cases, there is usually a faster quarter followed by a slower quarter. Users are expected to modify the tool as the nature of their analysis changes, when more detail is needed on the graphs, and when more precise or different forecast calculations are required. With basic Excel knowledge for graphs, a user can change the look of the graph to update it when presentation or tracking requirements change. As the users become more comfortable with the tool and increase their knowledge in Excel, macros and other improvements can be made to enhance the capability of the model.

6.3 DRAM Procurement Concept

HPSD and its LCM group are currently considering the proposed DRAM procurement concept. The current supply chain view is that the minimization of Compaq's costs is good, even if it means pushing costs up the supply chain to the suppliers. With this attitude, Compaq does not necessarily view revaluation incurred by suppliers as a bad thing. It has been established that revaluation costs incurred in the supply chain help neither Compaq nor its suppliers, so the

DRAM procurement concept presented in this study could be adopted at some point in time. There are supply chain costs savings caused by the proposed concept.

6.4 Overall Conclusion

The memory market is very competitive and hyper-sensitive about giving away any information about the actual costs and time involved in the production processes. Of the five memory suppliers contacted for interview, or attempted for interview, one gave general estimates of actual shipping times and costs. In this view, it would seem that overtures toward collaborative supply chain management would inevitably put one entity or another at risk. Until the memory market forces some more suppliers out of the business and the price settles down, there is too much competition to allow for effective collaborative supply chain initiatives. At the minimum, Compaq can measure the dollars on the table in the supply chain and work toward minimizing them with accurate forecasts and increased communication with suppliers. There is potential for collaboration in the memory supply chain. There is the potential for HPSD to link with their suppliers over the internet. By allowing suppliers to gain instant access to HPSD's current memory demand and forecasts, the suppliers would not have to wait for HPSD to decide whether or not it is going to decrease the current quarter's supply plan. The suppliers could perform the analysis themselves and adjust their production schedules accordingly. This could potentially prevent a supplier from having excess valuable DIMMs in inventory which would decrease in value and cause the supplier to take unnecessary losses. In exchange for this information made available to the suppliers and the trust HPSD would place in them to ensure that DIMMs are always available, the suppliers could provide instant access to production volumes and inventories to HPSD via the internet. Decreased memory inventories for both the supplier and for Compaq could amount to large savings, perhaps in the millions of dollars per year.

6.5 Learnings

The computer industry was new for me. It was quite an exciting change from the aerospace industry. I learned that things are happening so fast that without automated systems in place to perform the mundane tasks, you can be overwhelmed quickly. I gained knowledge about the server industry and memory industries. I learned that a picture speaks volumes – just placing the memory supply chain map on the overhead projector enticed everyone in a briefing room to discuss it openly, correct it, criticize it, and ask for a copy of it.

Compaq's HPSD has learned how to calculate revaluation for its memory commodity. It has also learned how poorly overforecasted the sales forecast is and how well the LCM group is doing to adjust the forecasts. By mapping and modeling the supply chain, HPSD can determine which suppliers are better than others based on revaluation and other supply chain costs.

Appendix 1

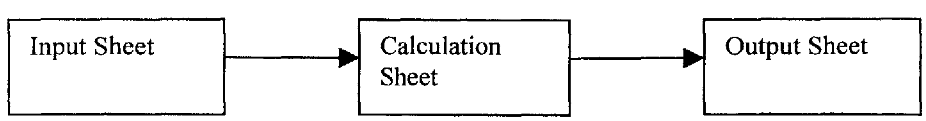
1.1 Detailed Explanation of Cost Model Functions

The tool is composed of three Excel worksheets. The names of these worksheets are: Input, Calculations, and Output. Each of these worksheets is organized to show the costs in the supply chain in column form along the vertical dimension. The exception to this rule is the Input worksheet which contains part of the supply chain model concerning the time element to the right of the input data.

Users have the flexibility of changing any of the inputs and toggling any of the buttons throughout the model to perform "What If" scenarios. The Input worksheet is color-coded, showing the user required input blocks in light green and calculation blocks in light orange.

Under ordinary circumstances, the Input worksheet is the only worksheet that requires users to enter data. All toggles that control the execution of the model are positioned within the Input worksheet. In addition, all of the model's macros are located within the Input worksheet.

Figure 21. Information Flow Between Worksheets

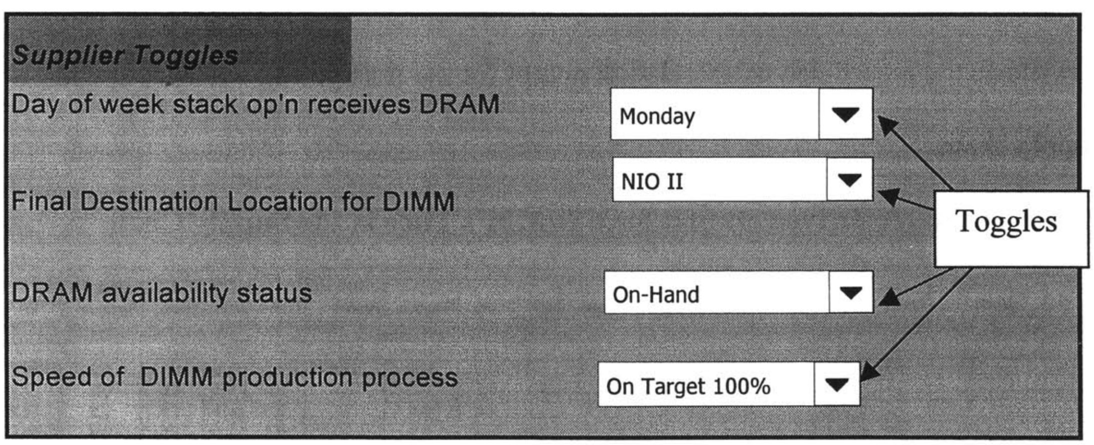


In general, the other two worksheets are passive; that is, the user's only interaction with these worksheets is to view their output. However, there are exceptions to this rule. These exceptions are as follows.

- Enhancements to the tool may require modifications to the equations contained in the worksheets.
- Changing the part number specific analysis located in the Output worksheet requires equation changes to ensure that data in the calculations is specific to that part number.

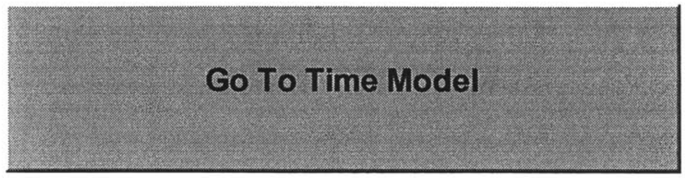
The Input worksheet also has 21 software toggle switches that enable the user to change input information instantaneously to impact specific calculations. Table 1 in Appendix 1, Section 1.1 provides a description of each toggle switch and identifies the type of supply chain costs that each switch influences. Figure 22 shows examples of four toggle switches in the model.

Figure 22. Toggle Switches in the Model.



The Input worksheet also has macros (procedures that run upon command) embedded into its programming. These macros perform specific and expeditious functions for the user. First, they provide ease of mobility to navigate the worksheet. For example, the input column has the macro button shown below in Figure 23.

Figure 23. Macro Button on Input Worksheet.



This macro button instantaneously takes the user to the time modeling section of the worksheet. There are other macro buttons at each of the five SDRAM supplier time model locations within the worksheet to assist in lengthy calculations of "What If" worst case, normal case, best case, and worst case/no SDRAM scenarios. This functionality gives the user a feel for impacts on the supply chain based on the toggle switches changed for each supplier. The model also contains a macro that executes all five supplier macros so the user can see immediate impacts in the scenarios of global input changes for the supply chain. To execute a macro, the user simply "clicks on it with his or her mouse."

Figure 24 shows the macro-driven calculation output for the time period a DIMM spends in the supply chain.

Figure 24. Macro-Driven Output for a DIMM's Time in the Supply Chain

	SDRAM Prod.	Trans.	WH	Trans.	Idle	Stack Process	Trans.	WH	Trans.	Receive	DIMM Process	Trans.	WH	Trans.	DIMM Receive	Total	
Time in SC	0.0	2.5	1.0	1.0	2.0	7.0	1.0	1.0	0.5	0.5	11.0	0.5	1.0	1.5	0.2	30.7	days
Normal Scenario	0.0	2.5	1.0	1.0	2.0	7.0	1.0	1.0	0.5	0.5	11.0	0.5	1.0	1.5	0.2	30.7	days
Best Case Scenario	0	2.5	0.5	1	1	7	1	0.5	0.5	0.5	7.5	0.5	0.5	1.5	0.2	24.7	days
Worst Case	0	2.5	2.5	1	7	7	1	2.5	0.5	0.5	15	0.5	2.5	1.5	0.2	44.2	days
Worst - No SDRAM	21	2.5	2.5	1	7	7	1	2.5	0.5	0.5	15	0.5	2.5	1.5	0.2	65.2	days

The amount of time is measured in days. The Input worksheet contains one output box as seen in Figure 24 for each of the five suppliers. Each output box has its own set of toggles to instantly adjust the supply chain to meet the current situation. The top line of numbers in pink cells, titled "Time in SC," changes instantaneously as the user manipulates the toggles. The macro-driven feature generates the lower four lines of numbers by automatically manipulating the toggles to the appropriate settings to match the scenario. The lower four scenario lines will not change unless the user pushes the "Run Scenario" macro button.

The Output worksheet summarizes the cost information for the user's ease. It also includes the output for an analysis of one part number for Q399.

1.2 Toggles in the Cost Model Input Worksheet

Table 1. Summary of Toggle Switches

Description of Toggle	Cost for which Toggle Applies
Allows the user to select the day of the week that the stacking operation receives the SDRAM.	The stacking manufacturing plant is a batch operation that starts a new batch once per week – on Wednesday. Similar to a plane taking off, the SDRAM on hand are prepared for stacking. If the SDRAM are not there on Tuesday, they can not get onto the plane (into the operation) on WED. The cost affected is the time-revaluation equation.
Final destination location for the DIMM.	Transportation costs affected by location of final destination for DIMM and location at which the DIMM was manufactured. Also affects time-revaluation cost equation.
SDRAM availability status.	No effect on cost in this model. This toggle allows user to analyze the supplier with varying availability of SDRAM.
Speed of DIMM production process.	The speed at which the DIMM manufacturer can produce the DIMM affects the time-revaluation cost equation.

1.3 Equations Used in the Cost Model Calculation Worksheet

Table 2. Cost Equations Associated with Calculations for Revaluation and Memory Costs in the Supply Chain

Cell Name	Equation and/or Description#	Units
WT AVG Cost per DIMM	(Σ Number of DIMMs Forecasted by type * Std Cost by type)/Total DIMM Volume	$/DIMM
Q3 Memory Module COGS/Qtr	Total # DIMMs * WT AVG Cost per DIMM	$
DRAM Value of COGS	(Σ Number of DIMMs by type * DRAM Material Cost by type)/Memory Module COGS	%
DRAM COGS/Qtr	*Memory Module COGS/Qtr * DRAM Value of COGS*	$
Days/Qtr	(365 days per year)/(4 Qtrs per year)	Days/qtr
DRAM COGS/Day	*(DRAM COGS/Qtr) / (Days/Qtr)*	$/day

Cell Name	Equation and/or Description#	Units
Days in SC	Sales WT AVG = sumproduct(median days in supply chain * # DIMMs forecasted) / total volume forecasted	Days
DRAM Value in SC	DRAM COGS per day * days in SC	$
% Reval per Qtr	Input Worksheet cell M222 / 4 quarters	%
Reval / Qtr	DRAM Value in SC * % Reval per Qtr	$
Reval/Day	(Reval/Qtr) / (Days/Qtr)	$
Cost of SDRAM Materials	*(DRAM COGS/Qtr for Actual Shipments)*	$
Cost of Other Materials	(Σ Number of Actual DIMMs Shipped by type * Cost of Other Materials by DIMM type)	$
Materials Cost Sub-Total	Cost of SDRAM Materials + Cost of Other Materials	$
Handling Cost	Σ (Number of DIMMs Actually Shipped) * (Average(Handling Costs per DIMM Supplier SC))	$
Transportation Cost	Σ (Number of DIMMs Actually Shipped) * Average(Transportation Costs per DIMM Supplier SC)	$
Process Costs & Profit for SC Entities	*(Actual Shipped Q3 Memory Module COGS/Qtr) – (Handling Cost) – (Transport Costs)*	$
Non-Materials Cost Inv. Reval for the Qtr	Actual Shipment Reval/Qtr	$
Non-Material Cost Inv. Carrying Cost	[(Materials Cost Sub-Total) + (Handling Cost) + (Transport Cost) + (Process/Profit for SC Entities)] * 0.05(carrying cost)	$
Demand Forecast Reval	*(Sales Forecast Reval/Qtr) – (Actual Shipment Reval/Qtr)*	$
LCM Forecast Reval Savings	[(Sales Forecast Reval/Qtr) – (LCM Forecast Reval/Qtr)] * (-1)	$
Net Forecast Error Reval	(Demand Forecast Reval) – (LCM Forecast Reval Savings)	$
Non-Materials Cost Sub-Total	*(Handling) + (Transport) + (Process/Profit for SC Entities) + (Inventory Reval for the Qtr) + (Inv. Carrying Cost) + (Net Forecast Error Reval)*	$
Total Memory Supply Chain Costs for Q3 1999	(Total Materials Cost) + (Total Non-Materials Cost)	$

1.4 A Walk-Through Explanation of the Cost Model

Table 3. A Walk-Through Explanation of the Cost Model

Worksheet	Description of Model Step or Calculation	Affects
Input	DRAM Stacking Input data provides parameters within which the model works. Compaq has an allocated capacity per production run (per week). The stacking operation will produce the allocated amount in the Production time Minimum, as entered. Then, if the stacking operation has promised more stacks than usually allocated, it will produce at least 10,000 more units each day while ensuring it produces all units it has promised for the week.	Time in SC
Input	DIMM Production Input. Depending on where the DIMM is produced, there are differing production times involved.	Time in SC
Input	Standard Cost. DRAM Suppliers are secretive about production costs and profit. User must estimate the percent of the standard DIMM DRAM cost that is actual cost to the supplier – in effect separating cost from profit for the supplier. Compaq also has standard costs for the DIMMs and the module materials listed on internal systems.	Material and Non-Material Costs
Input	Stacking Operation Prices. The prices are calculated from the information found in the Standard Cost table.	Material Cost
Input	Cost of Hub. These costs are contractual costs associated with the operation of the Hub. Calculations are shown on the Input worksheet to establish cost per DIMM.	Hub Cost per DIMM
Input	DIMM Shipping Cost. These costs were determined two separate ways for this analysis. First, several DIMMs were actually weighed along with the appropriate packaging materials. Second, an actual shipment was used to determine the cost per DIMM. Inputs are from contractual agreements with transportation coompanies.	Transportatio n Cost per DIMM per Shipping Location
Input	Transportation Time. Input transportation time from one location to another.	Trans Time per DIMM
Input	DIMM Forecasts and Actual Shipments. The Sales Forecast is derived from Compaq's internal forecast system. The LCM Forecast is derived from the the LCM Group in HPSD. The Actual Shipment information is derived from internal system reports.	Costs
Input	DIMM Data - SDRAMS/DIMM. Helps to understand cost structure behind DIMMs with stacked SDRAM.	Cost/SDRAM
Input	Number of Touches. Derived from the Input worksheet Time in Supply Chain calculations. For example, one supplier has more touches than another supplier for the same DIMM because in between every value-add operation, it sends the material to a warehouse in CA.	Time in SC and Cost

Worksheet	Description of Model Step or Calculation	Affects
Input	Days in Supply Chain (Target). The DRAM suppliers plan to have two weeks worth of DRAM in stock. Compaq has contractual requirements for suppliers to have two weeks worth of DRAM and DIMMs available at the Hubs. In final assembly factories (Stage 2) there is an average of four days WIP.	Time in SC
Input	Today's Date is used to reference the Day #, the Week #, the Week # for the quarter, and the Day name.	Information
Input	Other Times Required. User inputs these times as a general estimate of the amount of time required for these events: receiving DIMM at a hub, time spent at warehouse, time a manufacturing facility spends receiving DRAM.	Time in SC
Input	Macro = Run All After Change To Input Data. This Macro runs the scenarios for all five suppliers simultaneously – a global update for any Input changes.	Time in SC and Cost
Input	Toggles for each supplier are explained in Table 2.	Time in SC and Cost
Input	# of stacks to be produced for supplier. This individual supplier user input is referenced to the Stacking Operation input data to determine the number of days required to produce the specified number of stacks.	Time in SC
Input	Time in SC. These five sections (one for each DIMM supplier) are the calculation areas for the time memory spends in the Supply Chain. The cells draw upon all time elements from the input data and upon the user manipulated toggles to the right of each section.	Time in SC
Input	Time in SC. Right below each supplier is a section depicting the costs associated with each step in the supply chain per DIMM. It is for reference only.	Information
Calculations	Demand. The Demand section breaks the forecasts and actual shipments for DIMMs down to the SDRAM level by type. The breakdown calculations are for user knowledge. Only the DIMM forecasts and actual shipments are used in the model calculations.	Information and Costs
Calculations	Supply. The Days in Supply Chain section uses the "Normal" scenario data from the Input worksheet. Each DIMM time in the SC is arrayed with each supplier. The Min, Median, and Max time in the SC are calculated with Excel functions.	Time in SC
Calculations	*Supply. The weighted average Min, Median, and Max time in the SC are calculated for the Sales Forecast, the LCM Forecast and the Actual Shipments by the following formula example: =SUMPRODUCT(O102:O107,$F$23:$F$28)/$F$32, where the O column has the times and the F column has the numbers of DIMMs.*	Time in SC

Worksheet	Description of Model Step or Calculation	Affects
Calculations	*Cost. This section derives its data from the Input worksheet. The SDRAM, Other Material, and Process costs are from the Standard Cost section. The Handling and Transport costs are from the Time in SC Model section. The Inventory Reval/Day is calculated by: (40% Reval/Year) * (SDRAM Cost)/(365 days/year) * (Days in SC + Hub Inventory Tgt)*	Costs
Calculations	Cost. Subtotal for each DIMM is the sum of Materials, Handling, Transport, Process, and Inventory Reval/Day.	Costs
Calculations	Cost. Effective Standard Cost is from the Input worksheet's Standard Cost section.	Costs
Calculations	Break down to calculate reval/day. These equations are explained in Table 3.	Costs
Calculations	Memory Supply Chain Costs for Q3 1999. These equations are explained in Table 3.	Costs

1.5 Analysis for a Single 512MB (Stacked) DIMM

Table 4. Analysis for the 512MB DIMM(S)

Action	Description	Result
Enter Input Data	Enter all Input data into the Input worksheet. Each green cell calls for user input. For the 512MB(S) DIMM in particular, the Sales Forecast, LCM Forecast, Actual Shipments, and Standard Cost data must be updated. The other data are global and affect each DIMMs time and cost.	Data is set for the analysis
Final Data Input	On the Input worksheet in the Required Inputs area (orange border) below the input data section, update the date and other data to include the Percent Memory Revaluation per Year.	Final data input set
Go To Suppliers	In the Required Inputs section, push the Go To Time Model macro button.	Takes the user to the suppliers
Choose a Supplier	Scroll down to see all five sections for the suppliers and their Time in SC models. Choose a supplier to work with and scroll right to its toggle section.	Ready to change toggles
Adjust Toggles	In the supplier's toggle section, adjust the toggles to set the supply chain environment.	Environment set
Note the Time in SC	The Pink line to the left of the toggle area indicates the Time in SC for each step of the supply chain. The far right cell of the pink line has the total time the memory spends in the supply chain. The toggle changes instantly affect the times on the pink line and are reflected instantly into the Calculations worksheet. Global input data changes instantly affect the pink line and thus the Calculations worksheet.	Toggle changes instantly affect model

Action	Description	Result
Update the Scenarios to Get Worst, Normal and Best Case Situations	If the user chooses, he or she can update the scenarios in yellow below the pink line to update the scenarios for any global changes made in the input data. The toggles will be automatically manipulated by the macro button named Push to Run [supplier] Scenarios. Any toggles changes earlier by the user will be nullified by the macro as it updates the scenarios for global changes made in the input data. This area is for user reference only – the Calculation worksheet is driven from the pink Time in SC line. Once this macro button is pressed, the user will have to set the toggles again to change the Time in SC back to any specific desired environment.	User inculcates global changes into scenarios
Change Number of Stacks	Along with the toggles, the user may change the number of stacks that are being produced at the current point in time for the supplier.	Time in SC is affected by # of stacks
Run All Scenarios	The user can scroll to the top supplier and then scroll left a few cells to locate the "Run All After Change to Input Data" macro button. This action will update each of the five suppliers' scenarios to incorporate all global changes made in the input sections.	Updates all scenarios for global changes
Return to Main Menu	The user can scroll to any supplier and push the "Return to Main Menu" macro button to return to the orange area beneath the input sections.	Return to input sections
512MB(S)	The Q399 forecast for this DIMM was 6564 units.	Forecast
Forecast	LCM Groups forecasted 3673 units.	Reforecast
Actual Shipments	1808 units actually shipped.	Actual
Time in SC	Each 512MB DIMM spent anywhere from 20.7 to 30.7 days in the supply chain under normal scenarios, depending on which supplier provided SDRAM and where the DIMM was manufactured.	Time
Reval Time	Every day memory is in the supply chain, it runs the risk of revaluation. The table called Days in the Supply Chain under the Supply heading in the Calculations worksheet shows the minimum time a 512MB (S) DIMM spends in the SC is 52.7 days, while the median time is 59.2 and the max time is 62.7 days. The median time is used in the reval calculations.	Time
Begin Calculations	The 512MB(S) DIMM analysis begins by calculating the reval per quarter. All equations are explained in Table 3. As seen in Figure 8, there are three columns that are compared: Sales Forecast, LCM Forecast, and Actual Shipments. Using the same data from the same sources as described in Table 3 and Table 4, the revaluation per quarter is determined. The only stand-out difference is the Days in the Supply Chain line. This time is not a weighted average because the calculations are only concerned with the 512MB(S) DIMM.	

Figure 25. 512MB(S) DIMM Analysis showing equations

512 MB (S) DIMM Analysis

	Sales Forecast Q399	LCM Forecast Q399	Actual Q399 Shipments	
Total # DIMMs Forecasted /Shipped	6564	3673	1808	Input Data
AVG Cost per DIMM	$ 777.08	$ 777.08	$ 777.08	=AVG(784.15,770.00) = AVG(internal,external sourced)
Q3 512MB DIMM COGS/Qtr	$ 5,100,720	$ 2,854,196	$ 1,404,952	Multiply
DRAM Value of COGS	75%	75%	75%	= (6564 * 584.64) / (5,100,720), etc. for other columns
DRAM COGS/Qtr	$3,837,577	$2,147,383	$1,057,029	Multiply
Days per Qtr	91.25	91.25	91.25	=365/4
DRAM COGS per Day	$42,056	$23,533	$11,584	= (3,837,577) / 91.25, etc. for other columns
Days in Supply Chain	59.2	59.2	59.2	= median time in supply chain (table)
DRAM Value in Supply Chain	$2,489,694	$1,393,151	$685,766	Multiply
% Reval per Qtr	10%	10%	10%	= 40% / 4
Reval per Qtr	$248,969	$139,315	$68,577	Multiply

Appendix 2

2.1 Forecast Tool Detailed Explanation

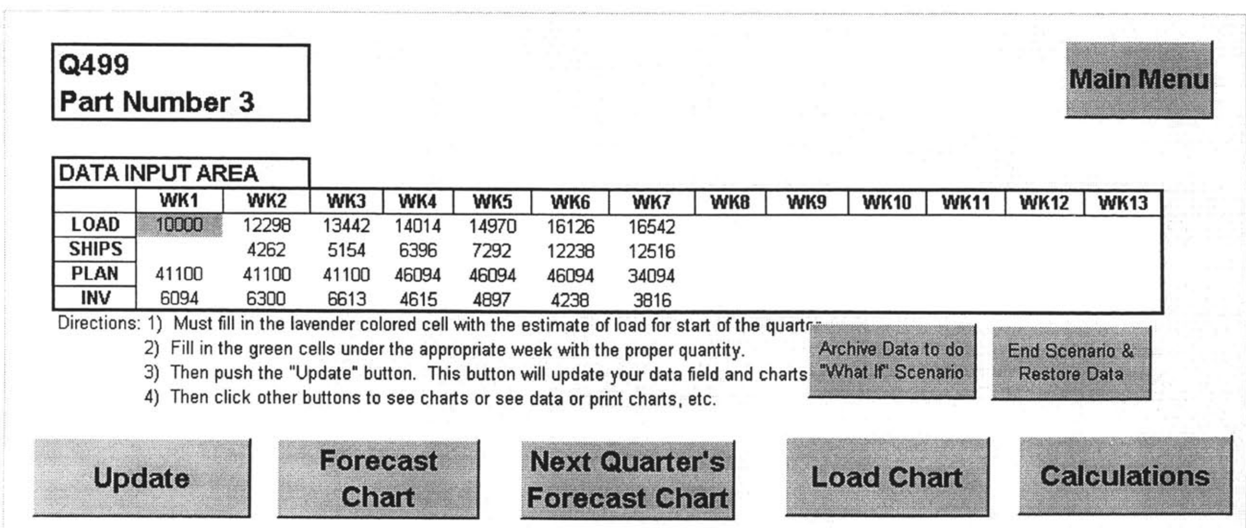
The tool is composed of a Main Menu worksheet and multiple worksheets, one per part number per quarter. The names of these worksheets are: Main Menu, Part Number 1(Q3), Part Number 2(Q3), etc. The Main Menu is organized to provide the user with easy access to any part number in any quarter contained within the model. The Part Number worksheets are organized vertically along the left side with the upper left hand corner as the input area and primary location from which the rest of the worksheet is accessed. Each of these Part Number worksheets has presentation quality forecast graphs located below the input area. The calculations are located to the right of the input area.

The Main Menu worksheet is organized for ease of use. It has 37 visual basic macros. One macro allows the user to save the changes to the model before exiting. The other 36 macros are buttons labeled with one of four part numbers for the quarters Q499 through Q401, or nine quarters per part number. By "clicking" the button, the macro instantly takes the user to the input area of the part number and quarter chosen. There are macros in the part number worksheets to bring the user back to the Main Menu worksheet.

The Part Number worksheets are organized into five sections: the Data Input Area, the Forecast Chart, Next Quarter's Forecast Chart, the Load Chart, and the Calculations area.

Data Input Area
The Data Input Area of the Quarterly Part Number worksheet is the first thing a user sees when accessing the sheet. Figure 26 shows the Data Input Area.

Figure 26. Data Input Area


Q499
Part Number 3

DATA INPUT AREA

	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13
LOAD	10000	12298	13442	14014	14970	16126	16542						
SHIPS		4262	5154	6396	7292	12238	12516						
PLAN	41100	41100	41100	46094	46094	46094	34094						
INV	6094	6300	6613	4615	4897	4238	3816						

Directions: 1) Must fill in the lavender colored cell with the estimate of load for start of the quart
2) Fill in the green cells under the appropriate week with the proper quantity.
3) Then push the "Update" button. This button will update your data field and charts
4) Then click other buttons to see charts or see data or print charts, etc.

The data input areas are color-coded, showing the user required input blocks in light green. The input area has eight visual basic macros that either update the data in the calculations area, "Update," or take the user to specific locations within the worksheet (or back to the Main Menu). The input area also provides a four-step instruction list detailing how to input the data and update the calculation area.

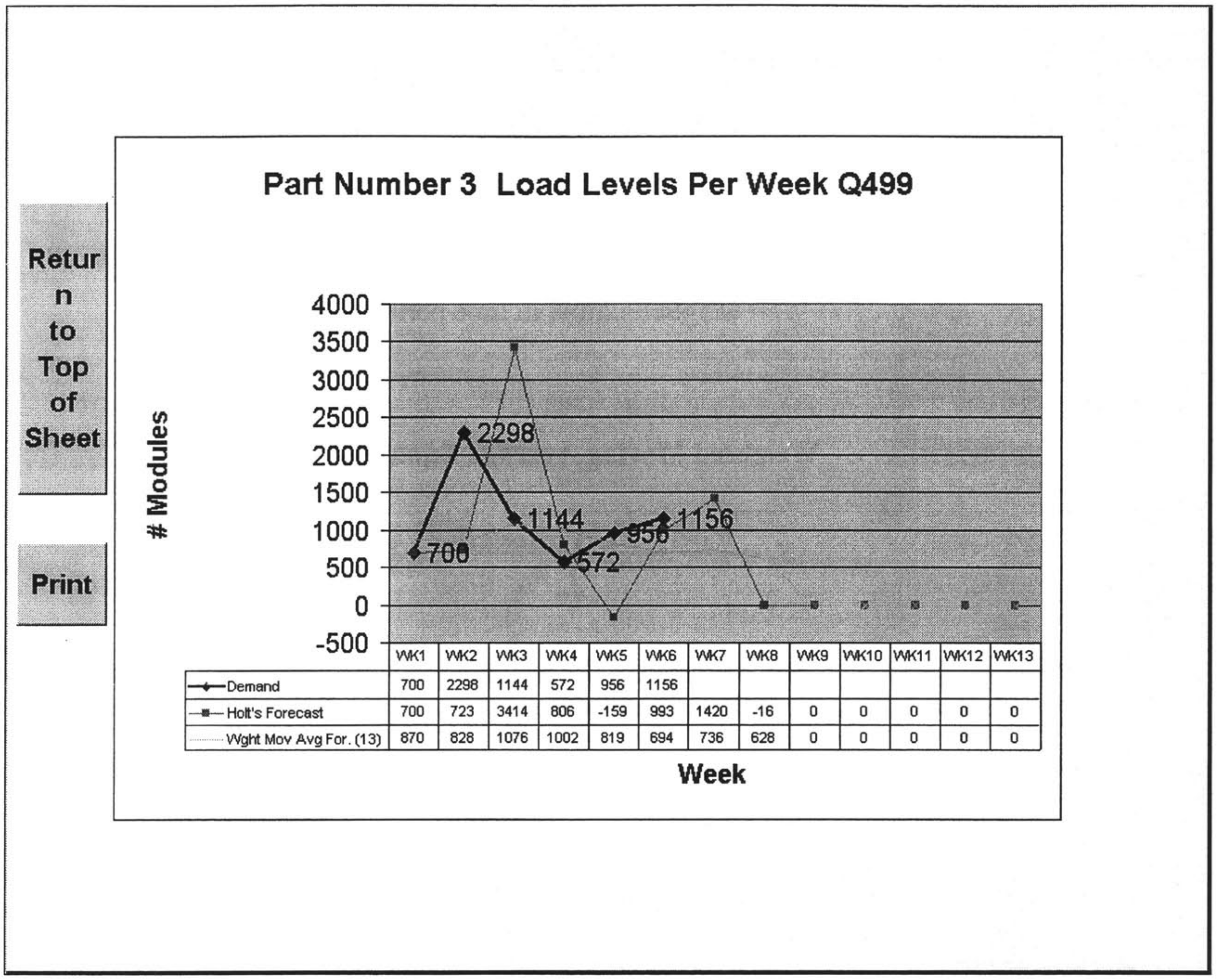
An important feature of the Input Data Area is the "What If" scenario macro buttons. This feature allows the user to conduct "What If" scenarios in any manner while not losing the original data. A "What If" scenario allows the user to change any information he or she chooses in order to see the impact on the forecast. The user first pushes the button that reads, "Archive Data to do What If scenarios." This button automatically copies the original data to a separate part of the worksheet which allows the user to change the original data in any manner. Once the data has been changed, the user must push the Update button just as before in order to send the input data to the Calculations area. Once the Update button has been pushed, the charts have been changed to reflect the data for the "What If" scenario. The user can repeat this sequence an infinite number of times. When finished with the "What If" scenario, the user simply pushes the "End Scenario & Restore Data" button to copy the original data back into the Input Data Area. The user is automatically prompted with words to push the update button to bring the charts back into original order.

Forecast Chart
The Forecast Chart is explained in Chapter 4, Section 4.3.1.

Next Quarter's Forecast Chart
The Next Quarter's Forecast Chart is explained in Chapter 4, Section 4.3.1.

The Load Chart
The Load Chart is another view of a graph detailing the comparison of actual demand against Holt's model and the weighted moving average forecasts. Figure 27 shows an example of the chart.

Figure 27. The Load Chart



This chart is not cumulative as the other charts are. This chart shows the hyper-sensitivity of Holt's procedure in more detail.

Calculations

The Calculations section of the worksheet is the area where the input data is copied when the user presses the Update macro button in the Data Input Area. Specific areas of the Calculations section are color coded to assist in locating detailed information. The input data is used by the weighted moving average equations and Holt's equations detailed in Appendix 2. Since the user inputs the raw data in cumulative format, the first calculation breaks out the actual demand. The actual demand and estimates for the first period Holt's variables gets Holt's forecast produced. This data is collected in the Current Quarter's Forecast area along with the weighted moving average calculations. The Next Quarter's Forecast section is assembled similarly. The forecast and load charts garner their source data from these sections of the Calculations area.

2.2 The Moving Average

In the forecasting model, time series three period and twelve period weighted moving average methods are used.

Variables

D_t = observed demand in time period t
S_t = estimate of future demand in current time period t
W_t = weight multiple in time period t

Weighted Moving Average Equation

$$S_t = \frac{W_1 D_t + W_2 D_{t-1} + \ldots + W_n D_{t-n+1}}{\sum_n W_n}$$

In the forecast tool's quarterly worksheets, the weighted moving average on the Forecast Chart is calculated using the following equation:

$$S_t = \frac{3 * D_t + 2 * D_{t-1} + D_{t-2} + \ldots + D_{t-11}}{15}$$

Where $D_{1\text{-}12}$ is the actual demand in the previous 12 weeks. The weighting and time period were chosen to satisfy the lead user's desire to capture 12 weeks of demand data and slightly weight the two most recent weeks' data, placing more relevance on recent data. It was thought that although the two most recent weeks of demand were most indicative of future demand, one could not ignore the growth and trends that could be in an entire quarter's worth of demand. The 12-week period is large enough to provide an "averaging out" effect which cancels out noise in the data.

The weighted moving average on a quarterly worksheet's Next Quarter's Forecast chart uses a three period weighted moving average equation as shown below:

$$S_t = \frac{3 * D_t + 2 * D_{t-1} + D_{t-2}}{6}$$

The smaller time period of three weeks captures the last three weeks of demand, with the most weight applied to the recent week. With this equation, recent increases or decreases in demand are captured and extrapolated out for the entire next quarter's forecast. This provided the user with a forecast based on the most recent demand data – three week's worth – which is what the user wants. For the user, this forecasting technique allows easy identification of changes as "What If" scenarios are performed.

The three period weighted moving average is also used to forecast the remainder of a quarter's forecast where Holt's forecast ends in the quarter. For example, if it is week 6, then Holt's equation forecasts week 7's expected demand. Then, the three period weighted moving average extrapolates to forecast weeks 8-12, e.g. the rest of the quarter as in Figure 10. This provides the user an understood mathematical approach to forecasting the entire quarter. Holt's forecast technique is explained in this appendix, Section 2.3.

2.3 Holt's Forecasting Technique

Variables

Z'_t = forecasted demand at time period t
L_t = exponential smoothing estimate of demand
T_t = current estimate of how much series is growing per time period
α = first smoothing parameter used to get L
β = second smoothing parameter to get T

Holt's Forecast Equations

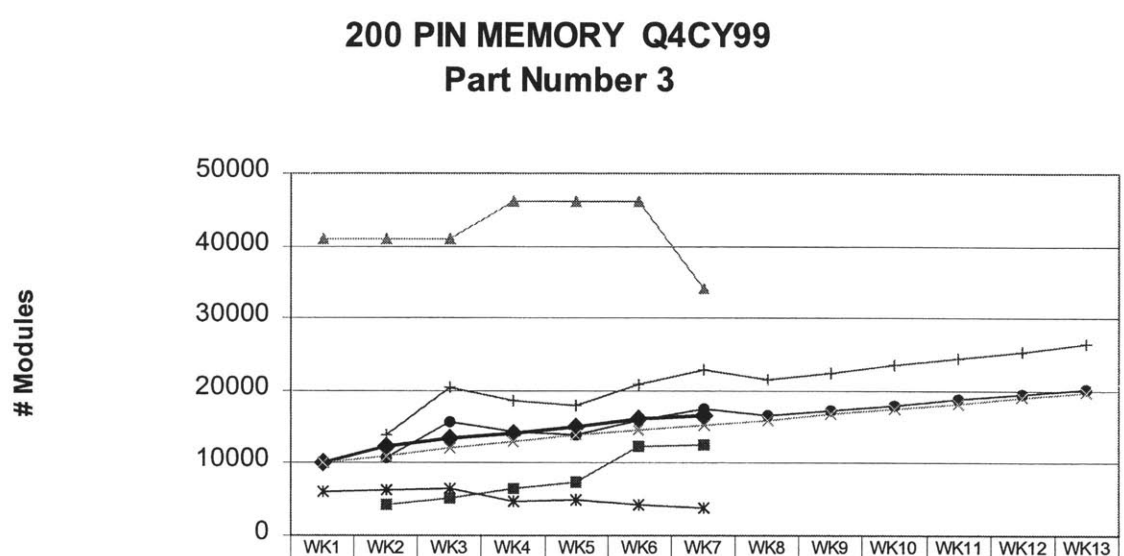
Forecasting Model: $$Z'_{t+1} = L_{t+1} + T_{t+1}$$
Where: $$L_{t+1} = \alpha Z_t + (1-\alpha)(L_t + T_t)$$
And: $$T_{t+1} = \beta(L_{t+1} - L_t) + (1-\beta)T_t$$

The effects of large versus small values for the smoothing parameters for calculating L and T are the same as in simple smoothing. For large α or β the forecast is responsive but nervous. For small α or β the forecast is stable and calm. This forecast procedure actually "looks" for trend.[21] First, Holt's procedure determines the next period's estimate of demand, L_{t+1}, by applying traditional exponential smoothing to the current period's actual demand, Z_t, exponential smoothing estimated demand, L_t, and its growth for the period, T_t. Then the procedure applies another exponential smoothing operation to get the next period's growth trend, T_{t+1}. In this project, the smoothing parameters were set at 0.9 to get as much responsiveness from Holt's forecast as possible.

2.4 Forecast Tool "What If" Scenarios

The primary concern is underforecasting. The cost of underforecasting is lost revenue – very high. This section walks through the forecast tool under "What If" conditions to simulate situations where the LCM group's memory supply plan may be in jeopardy. Figure 28 illustrates a typical forecast chart before a "What If" scenario performed by the user.

Figure 28. Forecast Chart Before Scenario

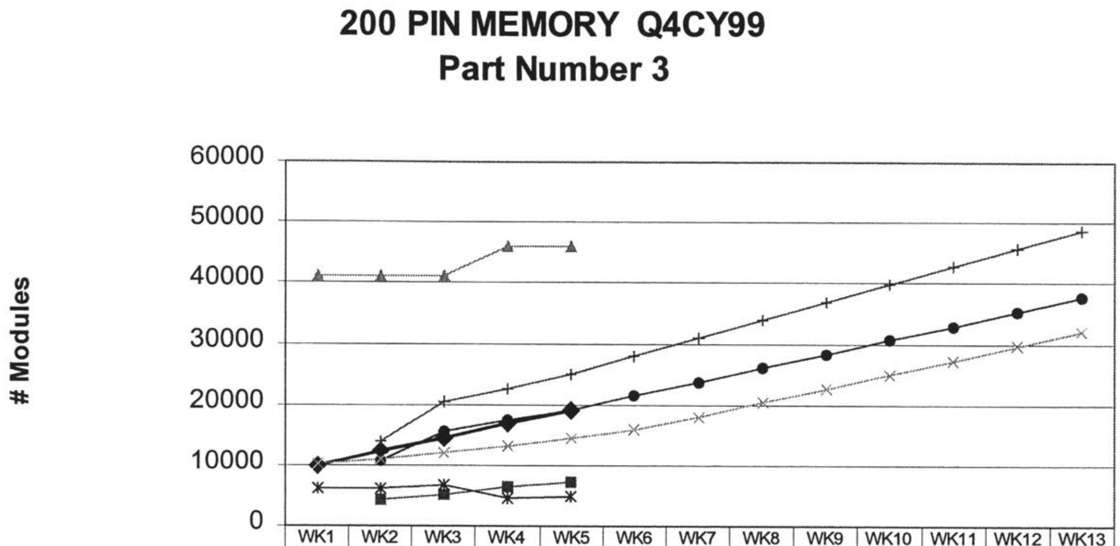


	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13
LOAD	10000	12298	13442	14014	14970	16126	16542						
SHIPS		4262	5154	6396	7292	12238	12516						
PLAN	41100	41100	41100	46094	46094	46094	34094						
INV	6094	6300	6613	4615	4897	4238	3816						
Holt's Forecast		10723	15712	14248	13855	15963	17546	16526	17278	18031	18784	19536	20289
Holt's Frcst +30%		13939	20426	18522	18011	20752	22810	21483	22462	23440	24419	25397	26376
Weighted Moving Avg.	10170	10998	12073	13076	13895	14589	15324	15952	16705	17457	18210	18963	19715

Now, the user chooses the appropriate macro button to archive the original data then starts changing values. For this scenario, the Plan (top line) is smoothed out by eliminating the decrease in week 7. Load values for weeks 3, 4, and 5 are increased the same amount as the difference between weeks 1 and 2. This represents a steady demand growth trend that is possible. Figure 29 shows the resulting forecast reactions to these data changes.

[21] Notes from Logistics Systems class 1.260J, Demand Forecasting II, p.3.

Figure 29. Forecast Chart After Scenario Changes

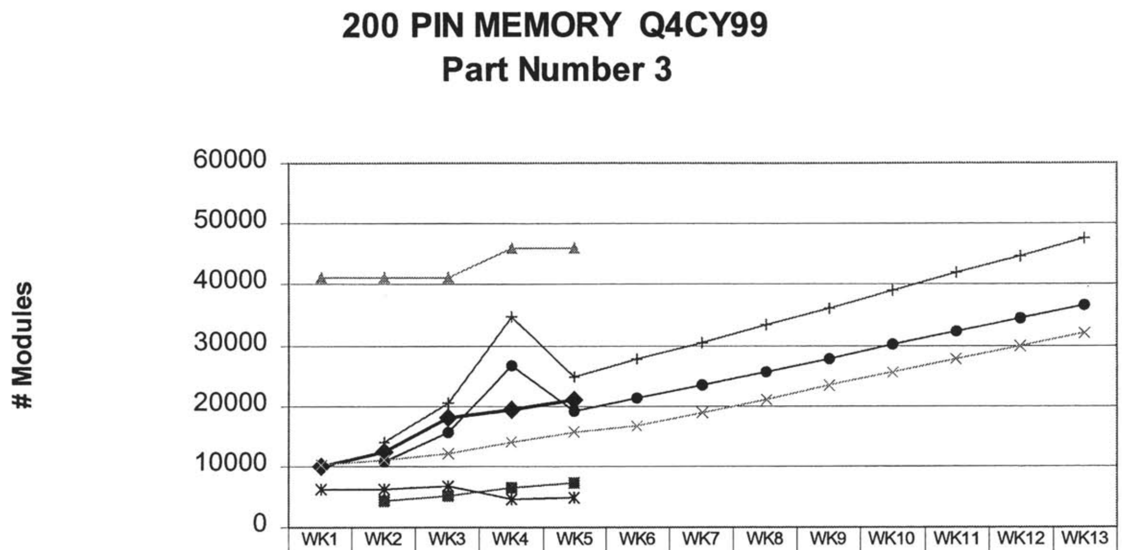


	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13
LOAD	10000	12298	14596	16894	19192								
SHIPS		4262	5154	6396	7292								
PLAN	41100	41100	41100	46094	46094								
INV	6094	6300	6613	4615	4897								
Holt's Forecast		10723	15712	17375	19220	21450	23748	26046	28344	30642	32940	35238	37536
Holt's Frcst +30%		13939	20426	22588	24986	27885	30872	33860	36847	39835	42822	45809	48797
Weighted Moving Avg.	10170	10998	12073	13292	14579	15812	18110	20408	22706	25004	27302	29600	31898

The user notes that Holt's forecast quickly reacts to the growth trend. Also, the user notes that the weighted moving average line is lagging behind since its equation incorporates 12 weeks of historical data. In week 5, the user is comfortable with the supply plan, but is wary of possibly exceeding it around weeks 11 and 12. With the minimum lead time of 30 days to flex up a preset contracted amount, the user plans to watch closely as weeks 6 and 7 pass. If the trend continues, the user will probably increase the supply plan a few thousand units to ensure desired supply levels are maintained. If growth begins to slow in weeks 6 and 7, and even 8, then the user will allow the supply plan to remain for the rest of the quarter. If demand slips to almost nothing for the rest of the quarter, the user has the ability to flex the supply plan down.

Another possible scenario is a spike in demand, or load, in a certain week. While this is likely and common on popular part numbers, it is rarely so large that it is unmanageable. But, nonetheless, during the project timeframe, there was an unexpected spike in demand in the last half of the quarter. The following two charts show demand spikes early in the quarter and later in the quarter.

Figure 30. A Spike in Demand (Load), Early in the Quarter

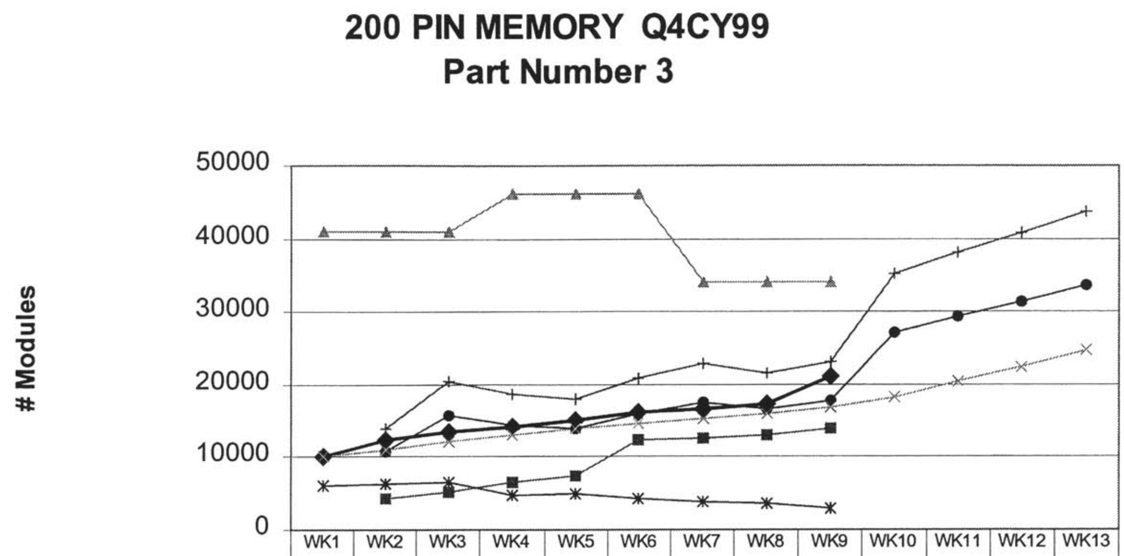


	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13
LOAD	10000	12298	18000	19500	21000								
SHIPS		4262	5154	6396	7292								
PLAN	41100	41100	41100	46094	46094								
INV	6094	6300	6613	4615	4897								
Holt's Forecast		10723	15712	26600	19086	21235	23435	25636	27836	30036	32237	34437	36637
Holt's Frcst +30%		13939	20426	34580	24812	27605	30466	33326	36187	39047	41908	44768	47628
Weighted Moving Avg.	10170	10998	12073	13930	15494	16690	18890	21091	23291	25491	27692	29892	32092

The spike in load is evident and a true cause for concern. The user will use experience and historical data to determine whether to raise the supply plan. With the 30-day lead time, the user still has time to raise the supply plan later in the quarter. If the spike had turned into a trend, then immediate action would be taken. Since it is a spike, caution is aroused and maintained with the spike's visual representation given by Holt's hyper-sensitive forecast equation.

Figure 31 shows a spike later in the quarter.

Figure 31. A Spike in Demand (Load), Late in the Quarter



	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13
LOAD	10000	12298	13442	14014	14970	16126	16542	17200	21000				
SHIPS		4262	5154	6396	7292	12238	12516	13100	13900				
PLAN	41100	41100	41100	46094	46094	46094	34094	34094	34094				
INV	6094	6300	6613	4615	4897	4238	3816	3500	3000				
Holt's Forecast		10723	15712	14248	13855	15963	17546	16526	17804	27083	29271	31460	33649
Holt's Frcst +30%		13939	20426	18522	18011	20752	22810	21483	23145	35207	38053	40898	43743
Weighted Moving Avg.	10170	10998	12073	13076	13895	14589	15324	15952	16747	18148	20336	22525	24714

The spike above is much more dramatic than the earlier spike illustrated in Figure 31. This spikes carries with it fear that demand has suddenly increased such that, if it continues to grow at this rate, shipments may be affected by the current supply plan. The user now has a dilemma. Action to increase the supply plan three weeks after the user dropped the plan will adversely affect relations in the supply chain. There are several options the user can choose, but the model brings the dramatic load increase to light much more effectively than does the weighted moving average or even a trend line if the user draws on for the load. Holt's forecast, on the hyper-sensitive mode, is saying "Hey! Watch out! If that recent spike turns into a new growth trend, you run the risk of missing shipments in week 13!" In this case, the tool serves as an early warning device for risks in the supply plan. Even though the end of the quarter is only 4 weeks out in this case, forecasts for the rest of the quarter still affect supply plans and supply chains.

References

Anderson, David L. *et al.* "The Seven Principles of Supply Chain Management," www.manufacturing.net/magazine/logistic/archives/1997/scmr/11princ.htm.

Electronic Buyers News, "Buying Spree Rolls DRAM Spot Market," September 15, 1999.

Electronic Buyers News, "Panic Sends DRAM Tags Up," September 29, 1999.

Electronic Buyer News, "Only Giants Can Tame DRAM Monster," December 8, 1999.

Fine, Charles H. ClockSpeed: Winning Industry Control in the Age of Temporary Advantage, Reading, MA: Perseus Books, 1998.

Graves, Stephen. Notes from class entitled, "Operations Management: Models and Applications," Massachusetts Institute of Technology, Spring 1999.

Handy, Jim et al. "Dataquest's Tactical Memories Newsletter," Vol. IV, No. 24, November 30, 1999.

Handy, Jim et al. "Dataquest's Tactical Memories Newletter," Vol. IV, No. 20, October 4, 1999.

Hoover's Online, "Compaq Computer Corporation: Company Capsule." www.hoovers.com, March 30, 1999.

Layden, John. "Thoughts on Supply Chain Management," Manufacturing Systems, 16(3): 80-88, March 1998.

Nahmias, Steven. Production and Operation Analysis. 3rd ed. Chicago: Richard D. Irwin, 1997.

Network World, "Quake Pushes SDRAM Prices Up by 50 Percent," October 11, 1999.

Rosenfield, Donald. Notes from class entitled, "Introduction to Operations Management," Massachusetts Institute of Technology, Summer 1998.

Sheffi, Yossi. Notes from class entitled, Logistics Systems," Massachusetts Institute of Technology, Fall 1999.