Factory-Installation of Software on Workstations and Servers

by
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Abstract

Built-to-Order computer systems provide consumers a high degree of computer system hardware customization. However, absent the installation and configuration of customer-selected operating system and application software, these systems fall short of being truly mass-customized. An opportunity exists for Compaq Computer Corporation to improve profitability and increase customer satisfaction by installing and configuring application software on Alpha Workstations and Servers in the factory at the time of assembly. This paper develops the requirements for such a factory service and assesses both the ability for Compaq to implement this factory service given the existing information and manufacturing systems as well as its potential profitability of this service. Constructing a profitability model for this factory service required developing a framework for factory-installation of software that includes the type of software being installed, the process by which the software is installed, and the level of configuration required. As with many new initiatives, the cost and revenue assumptions that comprise the profitability model variables possess considerable uncertainty. To create a financial model that incorporates these uncertainties, and which imparts greater intuition into the underlying economics of the project, the uncertain variables were modeled as probability distributions. Then, using the Monte Carlo simulation technique, numerous trials were simulated thereby developing a distribution of possible model results.

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1 Introduction and Overview

1.1 Factory-Installed Software Project Description

An opportunity exists for Compaq to use its manufacturing resources strategically to generate new revenue streams and to increase customer satisfaction, by implementing value-added services in the factory. One such factory service is the mass-customization of the software installed on Alpha-based workstations and servers. At the Salem Manufacturing Facility, where Compaq assembles Alpha Workstations and Severs, Compaq already mass-customizes the system hardware, providing customers tremendous flexibility with respect to system hardware configuration and supported system components. For software, however, Compaq only installs the most recent operating system software and select system utility software. Consequently, customers must install and configure application software themselves, or outsource this activity to a third party. By installing and configuring software applications in the factory, Compaq could provide its customers a completely customized computing solution.

Conceptually, a software installation and configuration service would allow customers to select software applications from a menu of pre-approved and tested applications, and have them installed and configured onto new Alpha workstations and servers in the factory during system assembly. Developing such a capability will require new software installation tools, manufacturing processes and management practices. The goal of this project is to assess feasibility of implementing this new factory service capability. The code name for this new factory service is **Custom-FIS**, and this term will be used throughout this paper.

1.2 Approach and Methodology

Developing and analyzing a process for loading and configuring software applications in the factory required comprehensive data collection. Numerous interviews were conducted with over 25 functional-area experts who either directly or indirectly influence the loading of software applications on computer systems at Compaq's Salem Manufacturing Facility, in Salem, New Hampshire. Through these interviews, I mapped the current ("as-is") FIS[1] process and developed the requirements and process map for the "to-be" Custom-FIS process. This data collection and process analysis was the primary input for assessing feasibility of implementing this project. The definitions of, and methodology for, determining project feasibility are as follows:

- ***Operational Feasibility (Can the Custom-FIS project be implemented?)***: Using the 'to-be' process map, determine if the new process can actually be implemented given the existing information and manufacturing systems. To do this, I mapped the entire manufacturing process from order-entry to product shipment. I then overlaid the process requirements for the Custom-FIS project to determine how the manufacturing process would need to be changed, if at all, to support the Custom-FIS service.

- ***Economic Feasibility (Will the Custom-FIS project be profitable?)***: The definition of economic feasibility is simply a non-negative project Net Present Value. Using the requirements and process map for the Custom-FIS project, I estimated the fixed and variable costs associated with developing and maintaining this project over a five year period, discounted at the company's cost of capital (Note: I assume the project risk to be comparable to the overall company risk.). I estimated the potential market for the project by analyzing historic Alpha-system sales data, and determined a range of potential prices for this new service based on comparable service offerings from other computer manufacturers. Key variables associated with the revenue and cost estimates possessed considerable uncertainty. To factor the uncertainties associated with these variables into the overall economic analysis, I built a stochastic economic model using estimated probability distributions for all of the sensitive revenue and cost assumptions. I then ran a Monte Carlo simulation to determine the distribution of possible net present values for this project.

[1] FIS- Factory Installed Software

2 Product and Market Background

2.1 Company Background and Recent Events

Compaq Computer Corporation is a global provider of computer systems and services. Compaq currently manufactures a full line of computer hardware ranging from sub-$1000 personal computers to high-end, multi-million dollar data centers. The company was founded in 1982, and now earns revenues of approximately $25-billion per year[1]. Compaq's original business model focused on selling industry-standard PCs, workstations and servers, which Compaq built to stock and sold through retail channels.

Compaq recently completed two major acquisitions that significantly altered the scope and nature of its business. First, in September 1997, Compaq acquired Tandem Computers. Tandem produced high-end (>$1-million) servers, which provide high-performance, non-stop computing solutions for enterprise critical applications and data centers. After the Tandem acquisition, Compaq acquired Digital Equipment Corporation. The acquisition of Digital provided Compaq with a more complete line of entry-level servers (those systems valued at <$100,000) as well as mid-range servers (those valued between $100,000 and $1-million.) The majority of Digital's workstations and servers use Digital's proprietary Alpha microprocessor. Alpha is a 64-bit, RISC-based microprocessor, which since its introduction in 1994, has been the most powerful general-purpose microprocessor available on the market. In addition to Digital's products, the Digital acquisition also gave Compaq a significantly larger field-services organization. The combined Compaq now possesses 750 service locations, with over 7000 software engineers and consultants, and 44,000 field service engineers. [2]

2.2 Overview of Compaq's Alpha-based Product Lines and Markets

In 1994, Digital Equipment Corporation introduced its proprietary, RISC-based microprocessor architecture called Alpha. The latest generation of this chip architecture, called the EV6 (21264), began shipping in 4Q98. Future generations of the architecture, the EV7 (21364) and EV8 (21464) are already in design, and will extend the power of the processor through larger on-chip (Level 2) cache, increased processor-to-processor bandwidth, and clock speeds in excess of 1-gigahertz. [3]

AlphaPowered is the trademarked branding that Compaq uses to describe workstations and servers that use Alpha microprocessors. The power and scalability of the Alpha help Compaq engineer some of the larger, higher-performing workstations and servers available. For example, Compaq's 8000 series servers support up to 14 processors per node[2] and 28-Gbytes of system memory, and can accommodate over a terabyte of storage. By comparison, Intel's latest server-centric microprocessor, called Xeon, supports only 4-way[3] nodes,[4] and is a 32-bit architecture, which inherently restricts system memory to 4-Gbytes. 8-way SMP[5] systems were announced at Comdex 98, and production releases of 8-way systems by various vendors, using Intel's Profusion 8-way chip set, will occur in the first half of 1999. [4] The table below compares the specifications of various top vendors using competing system architectures (note these are 1997 system specifications, and are intended to illustrate competitive architectures, and not to provide a current snapshot of system specifications.) [2]

Name	Max. Number of Processors	Processor Name	Processor Clock Rate	Maximum Memory Size per System	Communications BW per System
Compaq Proliant 5000	4	Pentium Pro	200 MHz	2,048 MB	540 MB/sec
DEC AlphaServer 8400	12	Alpha 21164	440 MHz	28,672 MB	2150 MB/sec
HP 9000 K460	4	PA-8000	180 MHz	4,096 MB	960 MB/sec
IBM RS/6000 R40	8	PowerPC 604	112 MHz	2,048 MB	1800 MB/sec
SGI Power Challenge	36	MIPS R10000	195 MHz	16,384 MB	1200 MB/sec
Sun Enterprise 6000	30	UltraSPARC 1	176 MHz	30,720 MB	2600 MB/sec

Table 1 Comparing Server Architectures

Workstations

Compaq's acquisition of Digital had a significant effect on Digital's existing workstation products. Many Digital workstations (specifically, the Intel-based workstations) competed directly with Compaq workstations, and were phased out during the post-acquisition integration. Alpha-based workstations, however, possess a performance advantage over Compaq's Intel-based workstations, leading Compaq to segment Alpha workstations exclusively into the high-end workstation market.

[2] In 1999, the Wildfire AlphaServer will increase SMP scaling up to 64 processors per node
[3] #-way refers to the number of processors supported in an SMP node
[4] Proprietary bus architectures exist that support larger SMP nodes
[5] SMP- Symmetric Multiprocessor

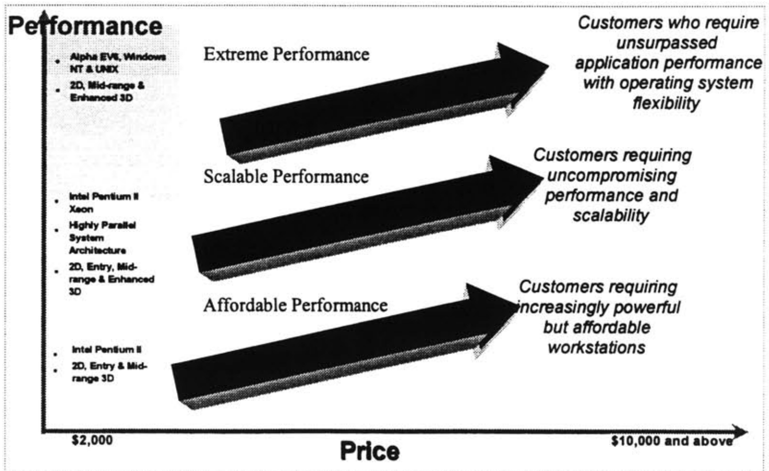

Figure 1 Compaq Workstation Positioning Chart

As shown in the graphic above, Compaq leveraged Alpha's 64-bit architecture, power and scalability to position Alpha workstations into a high performance niche, termed Extreme Performance, or EP. [6] Compaq's other workstation segments are Scalable Performance and Affordable Performance, both of which are based on Intel's IA-32 architecture, using the Xeon and Pentium II chips respectively. Although Compaq's Extreme Performance Line currently uses the Alpha chip exclusively, in the future, this line may also use Intel's IA-64 based microprocessor, called Merced.

Servers

Servers provide multiple users simultaneous computing services over a network. Understanding the server market is more complex than the workstation market in many respects, and deserves a more detailed discussion. Servers vary considerably in terms of scope, functionality and performance. For example, a $2000 machine may function adequately as a workgroup print-server, whereas an ERP application server may require $1-million or more worth of hardware to adequately meet the needs of a 1000-seat network. Many factors contribute to the performance of a server, including the following:

- Processor type (generation and architecture)
- Processor clock speed
- Number of symmetric processors
- Size of the Level 2 cache

- Level 2 cache clock speed
- Bus architecture (speed and throughput)
- Size of system memory
- Size and configuration of storage
- Use of clustering; number of cluster nodes
- Operating system and application

While a number of other factors also contribute to server performance, the large number of parameters above suggest that determining overall server performance can be quite complex. In fact, server manufacturers spend considerable resources trying to optimize the many server parameters above to yield either superior performance, or superior price/performance metrics for various server applications. In general, the ***price*** of a server tends to be a good proxy for overall system performance, and functions as a reasonable dimension for segmenting the server market. In fact, IDC, an IT industry market research firm, uses system price in this way to segment the server market. To begin, IDC defines three broad server price bands:

- ***Entry-Level***: Those servers priced below $100,000
- ***Midrange***: Those servers prices between $100,000 and $1,000,000
- ***High-end***: Those servers prices above $1,000,000

Within each of these broad price segments, IDC defines additional price bands to increase the segmentation granularity. These are: [7]

- Band 1 $0-2,999
- Band 2 $3,000-5,999
- Band 3 $6,000-9,999
- Band 4 $10,000-24,999
- Band 5 $25,000-49,999
- Band 6 $50,000-99,999
- Band 7 $100,000-249,999
- Band 8 $250,000-499,999
- Band 9 $500,000-999,999
- Band 10 $1,000,000-2,999,999
- Band 11 $3,000,000+

The table below shows Compaq's principal AlphaServer product lines through mid-1998, segmented into price band, with the number of server variants offered in each price band depicted in the table. From the table, we see that AlphaServers compete primarily in the pricier bands of the entry-level server segment, and in the mid-range. AlphaServers do not compete in the high-end server segment (prices >$1M), and therefore do not conflict with Compaq's high-end Tandem servers. With the acquisitions of Tandem and Digital, Compaq now possesses a server portfolio that covers the entire range of the server market- Compaq and Digital products competing in the low-end to midrange server segments, and Tandem servers compete in the high-end.

	Price Band					
	$6-9.9K	**$10-24.9K**	**$25-49.9K**	**$50-99.9K**	**$100-249.9K**	**$250-499.9K**
ALPHASERVER 800 5/333	1					
ALPHASERVER 800 5/500		1				
ALPHASERVER 1000		3				
ALPHASERVER 1000A 4/233			1			
ALPHASERVER 1000A 4/266			1			
ALPHASERVER 2000			2			
ALPHASERVER 2000 4/275			1			
ALPHASERVER 2000 5/250			1			
ALPHASERVER 2000 5/300			1			
ALPHASERVER 2100			2	1		
ALPHASERVER 2100A 4/275				1		
ALPHASERVER 2100A 5/250				1		
ALPHASERVER 2100A 5/300				1		
ALPHASERVER 4000			2			
ALPHASERVER 4100				2		
ALPHASERVER 8200					2	
ALPHASERVER 8200 5/300					1	
ALPHASERVER 8200 5/350					1	
ALPHASERVER 8400						2
ALPHASERVER 8400 5/300					1	
ALPHASERVER 8400 5/350					1	

Table 2 Compaq Server Lines

2.3 *Competition in the Server Market*

Competition in the server market is intense. The chart below shows two sets of data plotted against the server price bands. The bar chart highlights the total number of server series that are available in each price band (a server series includes the base server model and principle variants, such as different processor speeds or number of processors.) The line graph shows the number of vendors that offer products in each price band. This chart, compiled from IDC market share data [7], immediately conveys the competitiveness of the server market, showing literally hundreds of server variants and the dozens of vendors that compete in this market.

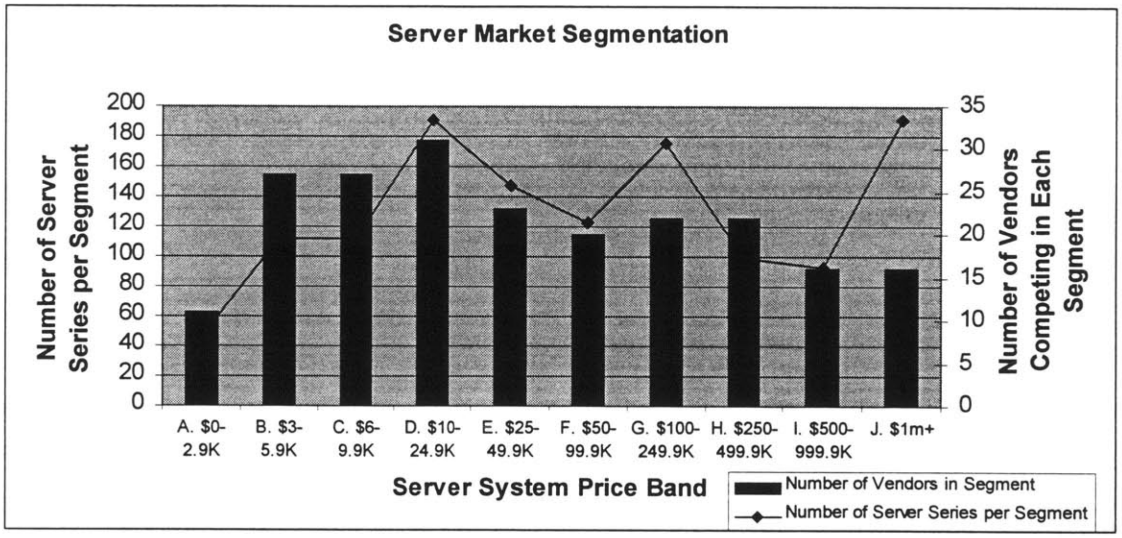

Figure 2 Profile of Server Industry

Examining the market share of various vendors in the three server price segments provides an even clearer picture of the rivalry of the server market. Shown below are three charts, one each for the low-end, midrange and high-end server segments. Each chart depicts the market share for various vendors from 1995 through 1997. The entry for Digital includes all Digital servers, including AlphaServers, Intel-based servers and VAX servers. IBM clearly holds a dominant position in each of the server segments. However, after IBM, there are numerous competitors possessing relatively comparable market shares, an important indicator of market competitiveness.

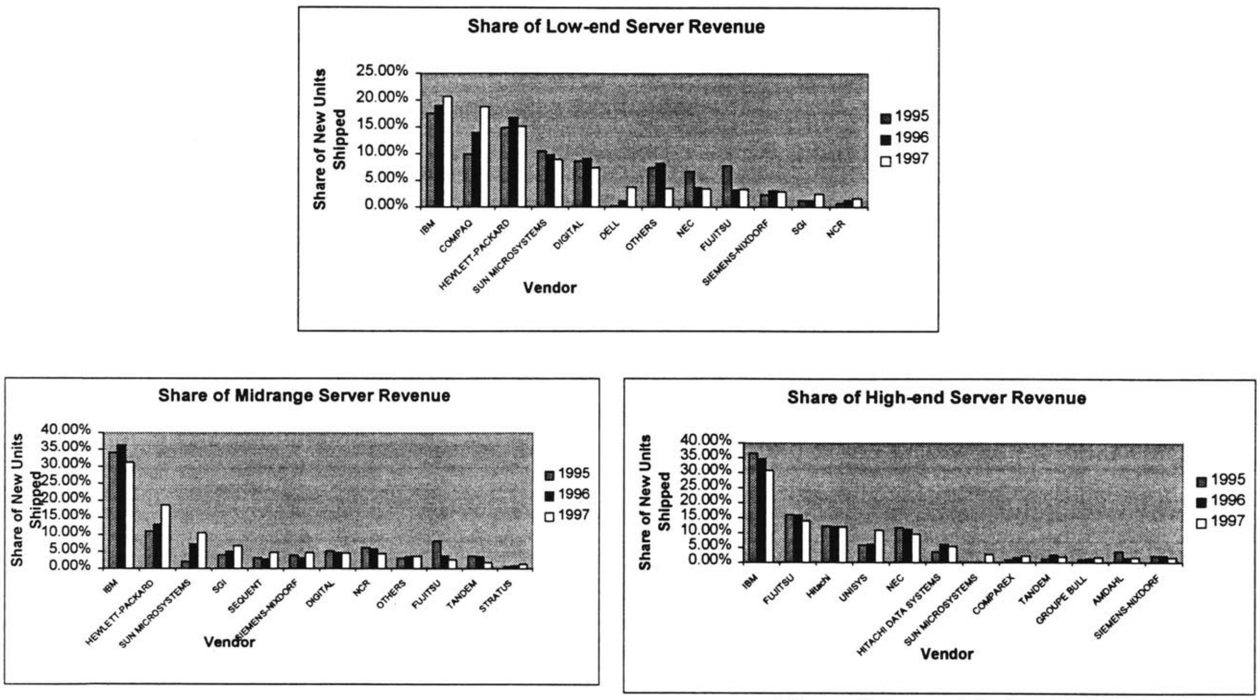

Figure 3 Server Market Share Profiles

3 Motivation for the Custom-FIS Project

3.1 Sources of Competitive Advantage in the Workstation and Server Markets

The sources of competitive advantage for vendors in the workstation and server markets are changing. Historically, vendors that could boast significant performance advantages possessed an arguably better competitive positioning in the marketplace.[6] To achieve a performance advantage, vendors developed integrated[7] and proprietary computer architectures. Large companies, such as Digital, HP, Sun Microsystems, Silicon Graphics and IBM all created these integrated architectures using proprietary microprocessors, system designs, I/O and operating system software. Proprietary architectures allowed vendors to develop high-performing systems and create distinctive product differentiation. In the long-run, however, consumers suffered as they became locked-in to proprietary, expensive, and inflexible computer architectures. Consider that:

- Proprietary architectures are more expensive given that vendors must develop and support all system componentry.
- Proprietary architectures are often compromises. A vendor may have particular strength in microprocessors, but lack a competency in system design, or operating systems.
- Proprietary architectures, by their nature, lock-in customers to a particular vendor's solution, preventing users from migrating to best-in-class componentry.
- Proprietary architectures create sizable switching costs, allowing vendors to sustain higher product margins.

Two trends are changing the nature of competitive advantage for workstation and server vendors. First, a vocal push by IT consumers to reduce the total cost of system ownership is moving the industry toward open system solutions. Customers are finding that the productive power of IT is tied inextricably to the compatibility of system hardware and software, and that the cost of creating compatibility bridges between proprietary hardware and software is huge. Consequently, vendors such as HP, Digital and IBM are redesigning their workstations, servers and operating system software to be more compatible with third-party hardware and software. For example:

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[6] Certainly this is an oversimplification, as many other factors contribute to competitive selling advantages. However, overall system performance even today remain an important, leveragable, advantage.

[7] Integrated architectures- meaning processors, bus-work, peripherals, and operating system software

- To promote hardware compatibility vendors are moving toward industry standard bus-work, and industry-standard networking protocols, such at TCP/IP. Recently, SGI, Sun and HP have all announced plans to move away from their proprietary microprocessors to Intel's IA-64 architecture.
- To promote software compatibility, there is a large industry movement to standardize the many variants of Unix.

The second trend affecting the nature of competition for server and workstation vendors is the increasing performance, and lowering cost, of industry standard hardware. Just as personal computers have become less differentiated, and more commodity-like, so too are lower-end workstations and servers. Prices for RAM and system storage, driven by supplier over-capacity, continue to fall, while the power of industry standard microprocessors continues to climb. Consequently, IT consumers are able to purchase tremendously more powerful computer systems at increasingly lower prices. The increase in performance of industry standard workstations and servers is particularly critical to vendors of proprietary system architectures (such as Digital, Sun, and SGI.) Performance has traditionally been a primary differentiator for proprietary systems, allowing vendors to compensate for higher production costs due to the lack of scale (i.e. sales volume) by charging higher prices. The closing performance gap between proprietary and industry standard systems means that IT consumers simply will not pay a premium for a proprietary architecture that does not provide substantially higher performance. Michael Dell commented on the impact of these trends at COMDEX 98, stating:

"The old industry approach was proprietary technology and vertical service solutions," Dell said. "Customers now universally reject these notions."

"Rather than a set of high-powered proprietary hardware and software supported by a particular vendor's group of service personnel, most customers now want interchangeable industry standards and flexibility in service"

"The idea of being all things to all people is a thing of the past," Dell said.[8]

Given the intense competition in the workstation and server markets, the increasing power of industry standard computing solutions and a growing movement among consumers to control IT costs, workstation and server profit margins are increasingly difficult to maintain. Consequently, low cost fulfillment has emerged as a significant competitive advantage for vendors in this marketplace. Vendors such as Compaq are striving aggressively to optimize their supply-chain in order to reduce inventory obsolescence, increase customer responsiveness, and lower the total cost of production. For

Compaq, this has meant a major revamping of its business model, including a re-designed supplied chain, build-to-order production, and direct-sale of computer systems.

3.2 Factory Services

Economic theory dictates that in competitive markets, sustaining profit margins requires increasingly lower marginal production costs. Compaq's redesigned supply chain, build-to-order production and direct sales initiatives are all attempts to improve the company's cost structure and in doing so, increase profitability. In addition to cost cutting, however, companies in competitive markets often seek improved profitability by changing the underlying economics of their business. This often means developing new revenue streams through value-added services.

In the computer industry, value-added services take-on a variety of forms. For example, vendor services may include on-site system integration or customized system configurations. Manufacturers such as Apple, Dell and Gateway offer consumer and business leases with guaranteed system upgrades every two years as a value-added service, and in doing so, are changing the way systems are purchased. Other services include adding asset tags, configuring RAID storage, or providing customer-specific system testing.

Introducing value-added services for Compaq is a tricky proposition. Compaq currently relies heavily on its channel partners to perform most services. The 'channel' refers to companies positioned in the demand-chain between the manufacturer and the customer. Channel partners take standard system-configurations held in their inventory and modify them to meet the specific needs of the end-user.[8] For example, a channel partner might install third-party hardware, install and configure a specific piece of software, or configure a storage system to a specified RAID configuration. For many channel partners, the revenue from these value-added services contributes significantly to their overall profitability. Compaq's channel for Alpha workstations and servers consists of the following:

- System Integrators- SIs sell hardware and software to large companies in conjunction with large, system integration projects. Example: Andersen Consulting
- Independent Software Vendors (ISV)- ISVs typically do not resell hardware; however, new hardware sales are often generated by ISV software sales. Examples: SAP, Oracle, Baan

[8] Under DECs Certified Integration Program (CIP), authorized channel partners are now stocking fewer completed systems, and are instead stocking base components, and assembling complete systems per the customer order.

- Value-added Resellers (VARs)- VARs enhance manufacturer products for the end user by installing and configuring specific solutions, such as vertical industry solutions, like health care specific software applications, or horizontal industry solutions like mail and messaging systems. Example: Pulsar Data System
- Distributors/Resellers- distribute or resell manufacturer products specifically to VARs. Example: Avnet/Hallmark, Pioneer, Wyle

Motivation for the Custom-FIS Project

With the continued trend toward open-system architectures, the increasing performance of industry standard computing solutions, and the intensity of competition for computer system hardware, Compaq faces unprecedented challenges in differentiating its Alpha Workstations and AlphaServers based solely on performance. Consequently, profit margins for these products are becoming increasingly difficult to maintain. An opportunity exists for Compaq to use its manufacturing resources strategically to improve profitability and increase overall customer satisfaction, by performing value-added services in the factory. One such value-added service is the installation and configuration of software applications.

4 Understanding Factory-installed Software

4.1 A Framework for Factory-installed Software

Factory-installed software (FIS) is a broad term describing any degree of software installation performed during the final assembly of a computer system. A discussion of factory-installed software first requires a framework for thinking about the scope and complexities associated with software installation. Three dimensions are important to consider:

1. The process by which the software is loaded
2. The product that is being loaded
3. The degree to which the software is configured

FIS Process: The process of installing software in the factory is broadly defined as *manual installation* or *image loading.*

Manual Installation - Manual installation of software in the factory mirrors the process that an end-user typically follows when installing software. In a factory setting, a technician will manually perform the software installation by inserting a storage medium (such as a CD-ROM, or a tape) containing the software into the computer and running the software's installation program. The advantage of manual installation is that it allows fine control and flexibility over the software installation process. Another advantage of manual installation is that it does not require investment in the equipment and technical resources needed to develop an automated installation process. For these reasons, the majority of software installations performed by Compaq's channel partners are manual installation.

In high-volume computer system manufacturing, manual installation of software has a number of disadvantages. The principal of which is time. The data transfer, the execution of the installation program and the multiple reboots required during installation combine to create a very protracted installation process. As an illustration, one Compaq engineer whom I interviewed described a recent custom installation of Windows 95 on a PC that required 6-hours and 38 reboots to complete. Two additional factors make manual installation ill suited for high-volume manufacturing. First, the complexity associated with manual software installation requires a skilled (hence more expensive) technician to perform the installation. Second, the high degree of operator interaction during the installation process makes manual installations susceptible to process induced variations, which ultimately influence quality and cycle time.

Image Loading- To avoid the limitations associated with the manual installation of software, computer manufacturers automate the installation process using software images. An image is an exact copy of a fully installed piece of software. The image is copied onto the hard drives of newly manufactured computer systems, thereby obviating the protracted manual installation process. The basic process is as follows: a FIS-engineer working in a laboratory manually installs software such as an operating system like Unix onto an AlphaServer. Once the manual installation iscompleted the engineer makes an exact copy of fully installed and configured hard drive. This copy is tested to ensure that it functions properly, then the copy, now called an image, is sent to manufacturing where it is loaded onto a network file server. As new computer systems are assembled, the image of the installed operating system is downloaded from the network to the new computer. When the transfer is completed, the new computer has a fully installed operating system residing on its hard drive.

The above example is clearly an oversimplification. The actual process is far more involved, as it must account a wide number of system configurations, such as number and type of processor, peripherals, and operating systems. However, this example does illustrate the advantages of using images to install software. First, a skilled engineer creates the image in a controlled laboratory environment. Manufacturing technicians need only to select the correct image to load on each new computer. Reducing human interaction greatly reduces the potential for process induced errors, thereby improving overall quality. Second, image loading is extremely fast. The installation of the software during production consists primarily of data transfer from a network server to the new computer. A typical installation of a Unix image on to an AlphaServer, for example, takes only 10-15 minutes, as opposed to the hours needed to install the operating system manually.

Product Being Installed

The second important dimension to consider when thinking about factory-installed software is the actual product being installed. For the purposes of this project, three product categories are defined, they are: operating systems, software applications and custom images.

Operating System (O/S)- Patterson and Hennessey define an operating system as the "Supervising program that manages the resources of a computer for the benefit of the programs that run on that machine." [5] Proper installation of the operating system is critical given the important role the O/S plays in managing hardware and software resources. All major computer companies, including Compaq, install operating systems on their newly manufactured computers as a matter of practice.

Software Application- A software application is installed on top of the operating systems, and uses the O/S to interface with the computer hardware to perform specific functions. Software applications vary tremendously. Some applications, such as an Internet Browser, are easy to install and configure, and other applications, such as a relational database, require a considerable expertise to properly configure. For the purposes of this project, I define three classes of software applications: Low complexity applications (LCA), mid-complexity applications (MCA) and high-complexity applications (HCA.) For these definitions, the term complexity refers to the complexity associated with installing a particular application onto a computer system and configuring that application to perform its designed function for a particular customer.

Low-complexity Applications (LCA): Low-complexity applications are easily layered on top of an operating system. LCAs have few configurable installation parameters. The configurable parameters they do have possess standard default values that end-users can readily change should the default setting be inappropriate for their needs. LCAs are generally horizontal applications that provide needed functionality to a variety of users, irrespective of their industry or job function. Examples of low-complexity applications include: Internet Browsers, Word Processors, Spreadsheets, Application Development Software and System Utilities.

Mid-complexity Applications (MCA): Mid-complexity applications have more involved installation processes than LCAs. These applications often interface with special hardware peripherals, or have very specific network requirements. MCA's are typically 'higher-end' applications that mandate optimal performance from the computer system. Consequently, they often require specific parameters within the operating system to be set appropriately in order to produce optimal application performance. *An additional characteristic of a MCA is that many configurable installation parameters do not possess standard default values.* This means that customer-specific configuration information, such as networking parameters, is required at the time of installation in order to configure the software properly. MCA markets tend to be much more fragmented than LCA markets, with more specific functionality, and smaller potential market size per application. Examples of mid-complexity applications include CAD/CAM Software such as Pro/Engineer and Mail and Messaging Servers such as Microsoft Exchange Server.

High-complexity Applications (HCA): High-complexity applications are those applications that mandate highly interactive installation by trained engineers in close coordination with the end-user. Examples of an HCAs is Enterprise Resource Planning Servers, such as SAP or BAAN, or Online Transaction Processing Servers used by ISPs.

The boundaries separating LCA, MCA and HCA are not precisely defined (nor is it likely that they could be.) Instead, these three categories provide a framework for thinking about a particular software application in context of factory installation.

Custom Image (CI)- The last product type important to the discussion of factory-installed software is a Custom Image. 'Custom Image' refers to an exact copy of the hard drive of a completely configured system (including all software applications) that is copied, bit for bit, onto the hard drive of newly manufactured systems. Copying a custom image from one hard drive to another may take between .25 and .5 hours, whereas installation of each application may take 8 hours or more. As an example, consider a customer planning a purchase of 100 workstations for a new engineering division. This customer intends to install the same suite of applications on each workstation.Rather than performing individual installations of each software application on all 100 workstations (where each installation could take many hours to complete) the customer may purchase one workstation, complete the software installations and configurations on that machine, then make an exact copy of the hard drive. That exact copy is called a custom image. The workstation manufacturer would take possession of this custom image and install it on the remaining 99 workstations as they are assembled. By doing this, the manufacturer saves the customer the time and expense of installing and configuring the suite of software applications on the new workstations. Furthermore, this process ensures that each machine possesses exactly the same software configuration.

Level of Configuration - The final dimension to consider when thinking about factory-installation of software is the level of configuration offered during the installation. Two configuration levels are defined: factory-installed and factory configured.

Factory-installed: *Factory-installed* describes an installation process where all variable installation parameters are set to default values. The installation process is not modified to include customer-specific configuration of the software.

Factory-configured: *Factory-configured* describes an installation process where software applications are configured in the factory so that they readily integrate into a customer's computing environment, and run optimally in accordance with the customers computing needs. Configurable installation parameters are set to appropriate values based on specific customer usage requirements. This implies that detailed information about the customer's computing environment (such as node name, or IP address) be accessible on the plant-floor at the time the application is installed.

Level of configuration relates to the type of application that is being installed. In general, low-complexity applications can be either factory-installed or factory-configured, as most have some configurable parameters that can be selected during installation. There is little value-added from factory-configuration of low-complexity applications, as there are typically no performance or connectivity issues of concern, and customers can easily perform select customizations when they receive their systems. While some mid-complexity applications can be factory-installed, most require customized configuration during the installation process (such as setting up networking parameters, adjusting the swap file size, or defining the number and type of users.) In fact, some applications do not allow certain parameters to be modified after initial installation. These parameter, therefore, have to be set correctly the first time, or else run the risk of an invalid installation.

The table below summarizes the proposed FIS framework

Installation Process	Product Installed	Level of Configuration
Manual	**Operating System**	**Factory-Installed**
Image Load	**Application** LCA- Low-Complexity Application MCA- Mid-Complexity Application HCA- High-Complexity Application	**Factory-Configured**
	Custom Image	

Table 3 FIS Framework

4.2 *Overview of the Manufacturing Process at the Salem Manufacturing Facility*

Compaq's Salem Manufacturing Facility, in Salem, New Hampshire, is one of three manufacturing facilities that produce workstations and servers based on the Alpha microprocessor architecture (the other two being located in Ayr, Scotland and in Singapore.)[9] The largest of the three sites, Salem comprises roughly 650,000 square feet of manufacturing and office space.

The diagram below shows a high-level view of the manufacturing process from the time the customer places an order until the time the product is shipped. The diagram is broken up into two sections. The left side of the diagram represents information flow, consisting of the administrative, credit and technical checks needed to approve an order for production. On the right is the material flow consisting of system assembly, testing and shipment.

- **Order-entry:** Customers place orders either by phone, fax or EDI (for large customers)
- **Administrative, Credit and Technical Check:** The customer order immediately hits three buffers, where the order administration and customer financing are both verified, and an initial technical screening of the order takes place (to ensure that the system ordered can actually be built)
- **Order Scheduling:** Once the order passes through the initial checks, the availability of parts needed to complete the order is checked, and the ship date of the order is scheduled.
- **Order Routing:** The order is then electronically routed to the manufacturing site that will assemble the system

[9] Correct as of the time of this thesis.

- **Verify Schedule and Technical Edit:** Once the order reaches manufacturing, the scheduling of the order is verified, as manufacturing typically possesses better information concerning parts availability than does the order-entry organization (due to disparate information systems.) The order then moves to Technical Edit, which is responsible for ensuring that the computer systems can actually be built as ordered. Simpler computer system orders can be automatically verified by a product configurator. The more complex systems, however, must be manually verified, as they are too complex for automated configuration checking.

- **Release Order to Production:** Once an order clears Tech Edit, it is released to production

- **Material Preparation and Delivery to Point of Use:** The parts and materials needed for productions are prepared and delivered to the point of use

- **Pre-assembly and High-Potential Testing:** The basic system is assembled, and then powered to ensure that there are no obvious system errors.

- **Assembly and First Turn-on:** Final system assembly is then completed

- **System Testing:** The system is then installed into a test rack where a series of installation and testing routines are performed.

- **Factory-Installed Software and Test:** The installation of the appropriate operating system occurs once system testing is completed.

- **Final Assembly and Test:** Once the system software is installed and tested, the rest of the system is assembled, a final test is then performed.

- **Pack and Ship:** after final test, the system is packed and shipped.

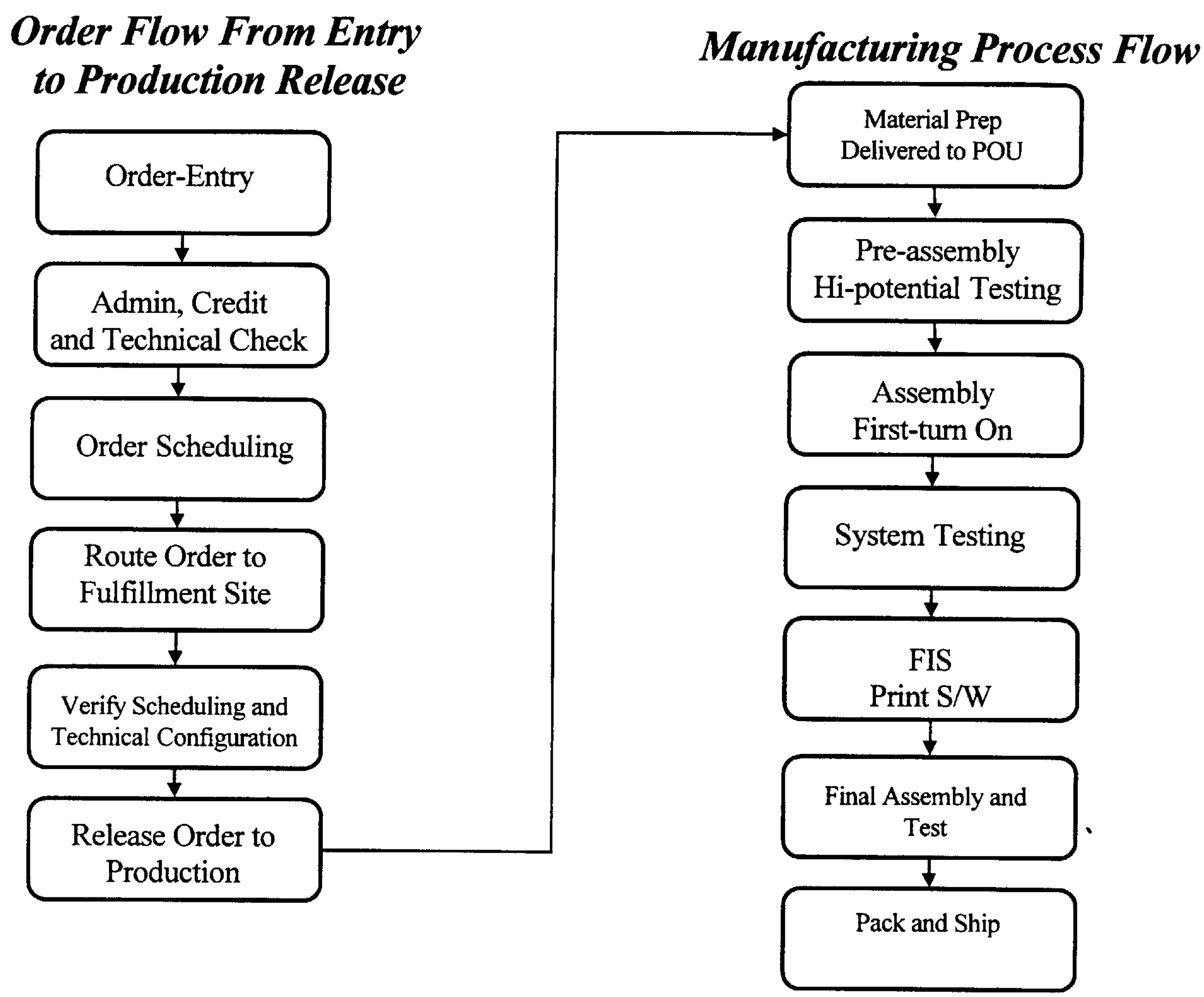


Figure 4 Information and Material Flow

4.3 Current FIS Process

Compaq currently uses software images to install and configure one of three operating systems on the Alpha Workstations and Servers manufactured at Salem- Unix, Open VMS and Windows NT. Of note, only the most recent revision of the operating system is installed on new systems. A customer running a corporate network using Windows NT version 3.51, for example, can only get the latest Windows NT version, Version 4.0, installed on a new computer system. In addition to the operating system, a suite of utilities and applications such as a web browser, are also installed.

Creating an image of an installed operating system, in theory, is a straightforward process. An experienced software engineer, colloquially called a FIS engineer, installs the operating system on a computer system in the engineering lab. The engineer then creates the image by making an exact copy of the hard drive of the fully installed system. The image is transferred to the network used by manufacturing, where it is installed on new computer systems during assembly. The process becomes significantly more complex due to the considerable hardware and software variations that the FIS engineers must accommodate. Consider the following:

Architecture Variation: the latest version of Digital Unix, for example, must have the necessary components to operate on a variety of computer systems, such as an Alpha Workstation, a single-processor AlphaServer 800, or a multi-processor AlphaServer 8100. These computer systems are considerably different architecturally, requiring substantively different operating system configurations. To accommodate variations in the computer system architectures and in the hardware (discussed below) the FIS engineers must develop adaptive installation scripts. These scripts query the computer system being assembled to determine the existing hardware configuration, and then modify the software installation accordingly.

Hardware Variation: Workstations and servers, by their nature, tend to be used for specific computing purposes, such as graphic design, engineering design, transaction services, or web hosting. Accompanying these specialized tasks is a host of specialized hardware, such as graphics cards, network cards and peripherals. The practice at Compaq has been to support numerous hardware options for Alpha Workstations and Servers. The decision to support a large number of hardware options has a direct economic consequence. Engineers must perform considerably more, and more extensive, testing to ensure that the computer system will run as designed with the supported hardware. For the FIS engineer, supporting numerous hardware options carries the burden of ensuring the correct hardware drivers for each of the supported hardware options are installed with the operating system.

Operating System Variation: While operating systems undergo major revision infrequently (every couple of years), minor revisions, or patches, occur quite frequently (multiple times per year.)

Software Application Variation: Software applications are problematic for FIS engineers for two reasons. First, software vendors issue both minor and major changes to their applications frequently. Second, software vendors do not always adhere to disciplined software development processes. This means that it is uncertain how the software application will interact with the operating system, or with other software applications, before actually installing and testing the application.

The real issue facing the FIS engineer is that all of the above variations- system design, system hardware, operating system and software- occur aperiodically, and in many cases, without advanced notice. Past efforts by Compaq to try to synchronize the release of new hardware or software variants- on a quarterly schedule for example- were unsuccessful. In general, when a new hardware or software upgrade is issued, customers demand the upgrade, and it becomes anti-competitive to wait until the end of the quarter to offer the revision. Consequently, the FIS engineers are constantly reacting to hardware and software changes.

Once the FIS image is created, an engineering test group performs a series of regression and performance tests on the image to ensure that the software performs as intended. Only after this testing is completed is the image approved for production.

5 Custom-FIS Service

5.1 Custom-FIS Requirements

Developing a set of requirements for the Custom-FIS service was the first step in the analysis process. The initial requirements for the Custom-FIS service are as follows:

1. At the time of order, customers will select specific software applications to be loaded and configured onto new computer systems. Customers will select these applications from a menu of applications, called the Custom-FIS application portfolio.

2. The Custom-FIS application portfolio will comprise only Digital Unix and Windows NT applications.

3. Custom-FIS applications will be loaded onto new computer systems directly from manufacturing's network, using a software image.

4. Configuring the Custom-FIS applications will be automated to the greatest extent possible using installation scripts. Any manual interaction required to configure a software application must follow a simple, defined process, and should consist of no more than keystrokes and simple data entry.

5. The Custom-FIS application portfolio will consist of only *low-complexity* or *mid-complexity* software applications.

6. Low-complexity applications (LCA) will be *installed* (as defined in section 3) with all configurable parameters set to default values.

7. Mid-complexity applications (MCA) will be *configured* (as defined in section 3) with key configurable parameters set to meet customer-specific usage and preference needs.

5.2 *Custom-FIS Service Process Flow*

With the broad requirements for the Custom-FIS Service offering defined, the detailed process needed to realize the Custom-FIS service had to be developed. After a series of team and one-on-one meetings, the following process was developed:

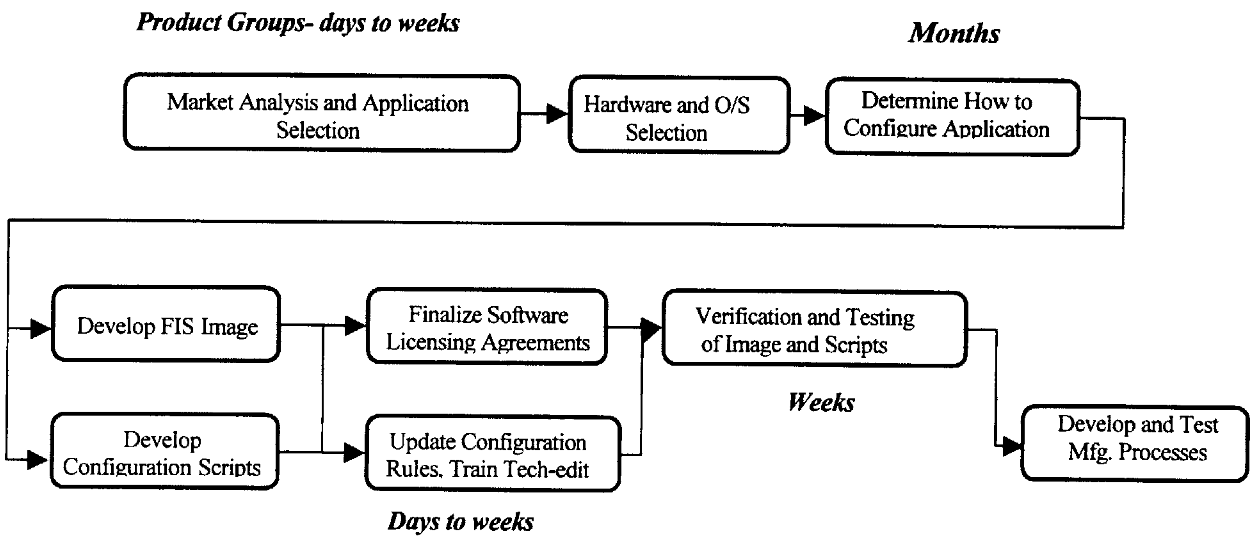


Figure 5 Custom-FIS Process Flow

Market Analysis: Market analysis is the first step in the Custom-FIS process. The purpose of this step is to develop a short list of software applications to offer as part of the Custom-FIS portfolio of applications. Given the time and complexity associated with preparing a software application for installation in the factory, identifying the highest potential applications to offer is critically important. The responsibility for completing the market analysis and selecting the applications to offer for the Custom-FIS Service resides outside of manufacturing, with the product marketing groups. The process of market analysis and application selection can take many weeks to complete, particularly if customer surveys are required.

Hardware and Operating System Selection: Once the software applications have been selected and prioritized, the hardware and operating systems must be selected. Should the software be installed on workstations, servers or both? Should the software be installed on Windows NT and/or Unix?

Determining Software Application Configuration: Once the software application and the target hardware and operating system have been selected, an engineer must determine how to correctly

Determining Software Application Configuration: Once the software application and the target hardware and operating system have been selected, an engineer must determine how to correctly configure the software application. A software installation requires considerable information to complete. This information could be something simple, like a time zone or a software license number, or something more complex, such as a network node name or IP-address. An engineer must learn how to configure the software- determining which information must be answered during installation, which information can be defaulted, and how various configuration parameters must be set. The goal here is to enable the FIS engineer to develop installation scripts that will allow the software configuration process to be automated. For low-complexity applications, very little work may be required to understand and properly configure a software application. For mid-complexity applications, however, the configuration process can be quite involved, requiring months to understand.

Develop FIS Image / Develop Installation Scripts: Once Compaq engineers learn how to properly configure a software application, the actual FIS image and installation scripts can be developed. Depending upon the application, this process can take anywhere from weeks to months to complete.

Finalize Software Licensing Agreements: Before reselling a software application, Compaq must finalize the appropriate business agreements with the respective the software vendors.

Update Configuration Rules, Train Tech-edit: An integral part of processing a new computer system order is verifying that the order, as written, can actually be built. It is common for orders to be incomplete, specify incompatible components, or incompatible combinations of components- this is particularly true for higher-end servers. In order to ensure that unbuildable, or 'dirty' orders do not make it to the plant floor (the most expensive place to catch a dirty order) Compaq utilizes a combination of automated and manual configuration verification processes. Compaq uses a rules-based expert system (an internally developed product configurator) to automatically check and validate system orders. Compaq's configurator is effective for checking the configuration of smaller systems, but is less suited for validating the configuration of larger, more complex systems. Consequently, all systems orders must pass through manual configuration validation, commonly referred to a Technical Edit, or simply tech-edit. In tech-edit, highly specialized engineers verify system orders prior to the order being released to the plant floor. Implementing a Custom-FIS service places an additional burden on the order verification process. For example, a particular software application may not support a certain graphics card, or peripheral. Therefore, in implementing the Custom-FIS service, the configuration rules in the automated configurator must be updated, and the tech-edit engineers must be trained appropriately, to ensure that only 'clean' orders get sent to the manufacturing floor.

Verification and Testing of FIS Image and Scripts: After the FIS engineers complete the development of the Custom-FIS images and installation scripts, they must be tested by engineers within the workstation and server groups.

Develop and Test Manufacturing Processes: The Custom-FIS image and associated installation scripts, in general, will not completely install and configure a software application. Some operator interaction will be required. If operator interaction is required from within a volume manufacturing process, a robust and repeatable procedure must be in place.

Training for Order-entry Personnel: The final step needed to implement a Custom-FIS service is training for order-entry personnel. The issue here is that many of the software applications, particularly the mid-complexity applications, will require a significant amount of customer-specific information in order to properly install and configure the software. The order-entry personnel will be responsible for either collecting the information from the customer directly, or directing the customer as to what information is needed, and how and when that information should be submitted.

6 Project Evaluation

6.1 *Operational Evaluation*

6.1.1 *Approach to Operational Evaluation*

An evaluation of the Custom-FIS service was necessary to determine if the Custom-FIS process as defined above could actually be implemented given the information and manufacturing systems in place at the Salem Manufacturing Facility. The Custom-FIS project is a factory service, and as such, it should not detract from Compaq's primary mission of assembling high-quality computer systems in a short cycle time, with predictable delivery dates.

In evaluating the operational feasibility of the Custom-FIS service, I traced the information and material flows needed to support the Custom-FIS service, looking for major bottlenecks or obstacles that might affect our ability to implement this service. My intentions were to model the new processes as they either interface to, or integrate with, the existing manufacturing process. However, such a detailed model proved to be unnecessary, as significant hurdles were identified that immediately called into question the feasibility of implementing this service.

It is important to understand that the issues I discuss pertaining to the implementation of the Custom-FIS project in no way reduce the strategic importance of embracing factory services as a core component of Compaq's manufacturing strategy. Moreover, these issues also do not mean that a Custom-FIS service *absolutely* cannot be implemented. Rather, these issues suggest that the manufacturing and information systems currently in place do not support the mass-customization of software in the factory.

6.1.2 *Issues Precluding Custom-FIS Implementation*

1. Collecting Customer-specific Configuration Information: A fundamental part of installing and configuring software applications in the factory is understanding the specific customer configuration needs and preferences required for proper software installation. Something as simple installing an application on a particular system hard drive is very important to some customers. For certain software applications, if select parameters are not correctly configured during the installation process, the entire installation is invalidated, and must be re-performed. Each software application possesses unique configuration parameters, and consequently, unique customer-specific information that must be collected.

For the Custom-FIS service to integrate into the manufacturing process, detailed customer-specific configuration information must be in-plant within 2-days of the customer order, and ideally, should accompany the order. Since the typical cycle-time for a computer system at the Salem Manufacturing Facility is 10 to 15 days, any delay in getting the appropriate configuration information in-plant could have a deleterious effect on cycle-time. Customer-specific information must be collected, validated for accuracy and completeness, and matched with the appropriate system order prior to the order being released to manufacturing for assembly.

Collecting the customer-specific information needed to support a Custom-FIS service is not currently possible for two reasons. First, the information systems at the Salem Manufacturing Facility will not support collecting amplifying order information in a structured fashion. The information systems in place are 15 to 20 years old, and are extremely inflexible. While, in theory, the needed information fields could be coded into the legacy order-entry system, such a modification does not make practical sense. Modifying the legacy order-entry system to support a Custom-FIS service would be challenging and of temporary value, as the legacy systems are slated to be replaced in 1999 by SAP's R/3. R/3 itself is somewhat inflexible, however the necessary modification could be made to support Custom-FIS. However, Custom-FIS requirements are not part of the current R/3 baseline, and adding this capability to R/3 must wait until after the R/3 cut-over.

Collecting customer-specific configuration information proved to be intractable for a second, more problematic reason. Collecting customer-specific configuration information presupposes that customers possess the needed information. This is far from the norm. At the time of order, many customers have no idea, for example, what node names, IP-addresses, or peripherals will be used with their new computer systems. Vendors that specialize in installing and configuring software for customers treat software installations as projects- assigning project managers that can entertain highly interactive information exchanges with the customer. Intermixing a project shop into volume manufacturing would introduce variations and uncertainties that would be difficult to absorb without increasing overall cycle-time.

2. FIS Development Time: The time needed to engineer the installation image and configuration scripts needed to automate the Custom-FIS manufacturing process could span 3 months or more per application. This long development time places practical limits on the number of software applications that can reasonably be prepared and supported for the Custom-FIS service given the current staffing level of 5 FIS-engineers.

3. Testing requirements: After a Custom-FIS image and associated configuration scripts are prepared, they must be properly tested before being approved for use by manufacturing. Engineering groups within the workstation and server divisions perform the testing of the software images. As initially conceived, the Custom-FIS service would offer customers an 'a la carte' menu of software applications that they could choose to have installed and configured on new computer systems. For example, if the Custom-FIS application portfolio consisted of five applications, Customer A could elect to install application 1 and 2, Customer B could elect to install application 2 and 5, and so on. For the test engineer, this is highly problematic, for if there are N applications in the Custom-FIS portfolio, the test engineers must test N-factorial combinations of applications. Testing combinations of applications is essential, for it is uncertain how two applications will interact with one another when installed and configured. Testing of this magnitude is unrealistic. Consequently, the requirements for Custom-FIS were modified so that customers could only choose a single application from the Custom-FIS portfolio.

4. Impact on Technical Edit: As discussed in Section 3.2, Tech-edit is the process where computer system orders are both automatically and manually checked to ensure that the system as ordered can actually be built. While the tech-edit process was not 'technically' considered a bottleneck, the tech-edit workers work extremely long hours trying to ensure that clean systems orders reached manufacturing in a timely fashion. Adding the burden of verifying Custom-FIS orders on top of an already burdened process would have negative effects on tech-edit, potentially increasing overall cycle-time.

6.1.3 *Operational Analysis Conclusion*

After mapping the processes needed to implement the Custom-FIS service, it is my assessment that it is not operationally feasible to implement the Custom-FIS service given the existing information and manufacturing systems at the Salem Manufacturing Facility. As outlined above, Compaq cannot collect the customer-specific information needed to properly configure application software in the factory; Custom-FIS development time is long, thereby limiting the number of applications that can be offered as part of the Custom-FIS portfolio; testing requirements are extensive; and there is an uncertain impact on the important tech-edit process. Absent an imperative to embrace value-added services such as Custom-FIS as a strategic component of manufacturing, and addressing these issues systemically, they will remain unresolved issues.

6.2 *Financial Evaluation*

6.2.1 *Approach to Financial Evaluation*

I developed a financial model for the two Custom-FIS service options under consideration, Low-complexity applications (LCA) and Mid-complexity Applications (MCA). For each of these service options, I attempted to answer two simple questions. 1. How much money can Compaq make from this service? and 2. How much will it cost to implement? I developed a five-year forecast, and determined the Net Present Value of the free cash flows associated with both the MCA and LCA Custom-FIS service optionS.

In gathering data to estimate the model's key revenue and cost variables, I discovered that nearly every key model variable, such as market size, price, and the labor cost to perform the majority of the Custom-FIS process steps, possessed considerable uncertainty. For example, the engineering time needed to develop a FIS image for a mid-complexity application varied from as little as 8-weeks to as much as 13-weeks. Without knowing exactly which software application we would be working with, and actually getting that application in-house and examining it, we could not narrow this large process variation a priori. Given that many essential model variables possessed large uncertainties, simply picking the mean value of the variation spread, and creating a deterministic spreadsheet model seemed inappropriate. At best, such a model would preclude understanding the error associated with the model results; at worst, the model could produce a totally erroneous answer.

In order to 'model-in' the uncertainty of each of the major variables, I created a stochastic financial model and used the Monte Carlo technique to simulate the model over a large number of possible states. In a stochastic model, each uncertain variable is represented as a probability distribution of possible values. The Monte Carlo technique uses a series of random numbers, generated from a fixed seed to select unique values for each uncertain variable from points along the probability distribution. This process of randomly selecting values along a probability distribution curve is then repeated over large sampling run, generating a distribution of values for the forecast variable being modeled- in this case, the Net Present Value. This distribution of possible net present values possesses key statistical information, like a mean, a standard deviation, and a mean standard error. So not only does the simulation produce 'the most likely value', but it also provides key statistics that give insight into the likelihood of that result.

6.2.2 *Financial Model Development*

Two financial models were developed, one for each of the two Custom-FIS service options being evaluated:

1. Low-complexity Application Custom-FIS Service
2. Mid-complexity Application Custom-FIS Service

Section 8 details the development of the financial model and Monte Carlo simulation. Specifically, Section 8 details the following:

1. **Derivation of the Custom-FIS Market Opportunity**- answering the question "On to how many computer systems could we possibly install application software?" proved to be difficult. The quick answer- "We could install applications on as many computer systems as we make in a year." is dead wrong. The derivation of the Custom-FIS market opportunity shows that only 10%-20% of the computer systems manufactured annually meet the criteria for the Custom-FIS service.

2. **Probability Distributions for Key Model Variables**- as mentioned above, many key model variables possessed irreconcilable uncertainties. To incorporate these uncertainties into the analysis, each variable was modeled by a probability distribution. The type of distribution chosen, as well as the range of values assigned to the distributions, were estimated from interviews conducted with Compaq managers and engineers experienced with factory installation of software.

3. **Model Assumptions**- the economic assumptions that underpin the financial model

4. **Low-Complexity Application Option: Financial Model and Simulation Results**- the financial model for the low-complexity application Custom-FIS service option

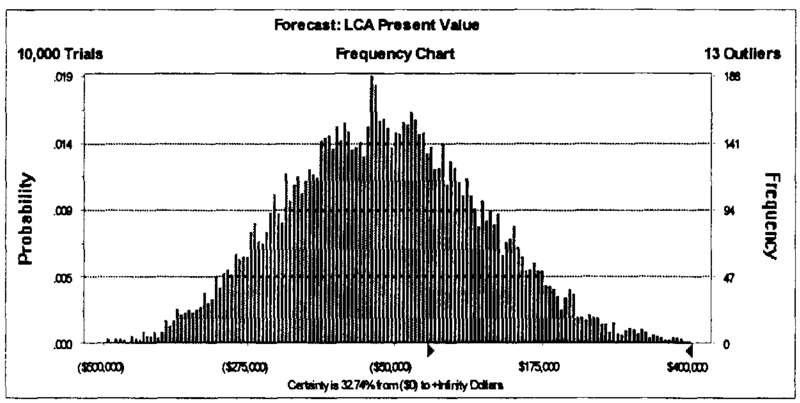
5. **Mid-Complexity Application Option: Financial Model and Simulation Results**- the financial model for the mid-complexity application Custom-FIS service option

6.2.3 *Low-complexity Application Option: Financial Model and Simulation Result*

The financial model and Monte Carlo simulation results for the LCA Custom-FIS service option suggests that this option can not be justified on the basis of profitability. Shown below is the distribution of net present values for this service option. From the distribution, we see that the expected value for this service option is -$127,000, and there is nearly a 70% certainty that this service option will be unprofitable.

The financial model also shows that the majority of the costs associated with the LCA Custom-FIS option are development costs. The marginal cost of production, once the application image and scripts are in place, is very small. This means that on a *per application* basis, there is an economy of scale- the more times you install a specific applications the more profitable the service. However, as the number of unique applications in the Custom-FIS portfolio increases, the service becomes *less* profitable. Consider that the second most popular application will be installed on fewer systems than the most popular application, and the third most popular application will be installed on fewer systems than the second, and so on. Each new application added to the Custom-FIS portfolio is therefore marginally less profitable.

Percentile	Dollars
0%	(512,110)
10%	(259,754)
20%	(196,371)
30%	(147,970)
40%	(106,597)
50%	(68,424)
60%	(28,288)
70%	12,069
80%	62,149
90%	131,730
100%	574,755

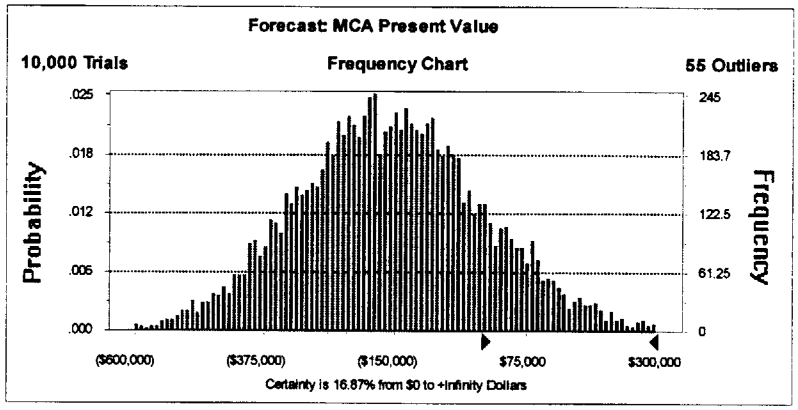


6.2.4 *Mid-complexity Application Option: Financial Model and Simulation Result*

The financial model and Monte Carlo simulation results for the MCA Custom-FIS service option suggests that this option can not be justified on the basis of profitability. Shown below is the distribution of net present values for this service option. From the distribution, we see that the expected value for this service option is -$153,000, and there is an

83% certainty that this service option will be unprofitable. As with the LCA Custom-FIS service option, each unique application offered as a part of the MCA Custom-FIS service option possesses scale economies, but each successive application added to the Custom-FIS portfolio of applications is marginally less profitable.

Percentile	Dollars
0%	($775,299)
10%	($359,445)
20%	($290,997)
30%	($240,351)
40%	($198,399)
50%	($156,914)
60%	($115,800)
70%	($73,291)
80%	($21,599)
90%	$57,318
100%	$536,267



6.2.5 *Potential for Incremental Sales*

A counter argument is often made when trying to justify value-added services. The argument states that even if the service is not profitable as a stand-alone offering, the additional value to the customer created by the service will generate additional product sales, thereby indirectly justifying the service. I do not believe this argument to be valid for value-added services associated with Alpha Workstations and Servers, and did not model a feedback effect on computer system demand for the following reasons. Value-added services, like Custom-FIS, are a second or third order buying criteria for Alpha systems. The Gartner Group, in a 1998 report discussing the outlook for the Alpha architecture, stated that the five-year horizon for Alpha systems represents a high-risk buying decision for corporations. According to Gartner, it is not clear whether Compaq will support the Alpha architecture past the 2003 or 2004 timeframe. A CIO making a multi-hundred thousand dollar buying decision places a primacy on the lifecycle potential of the architecture. Other factors, such as performance, cost, reliability, service and predictable delivery also are instrumental in the computer system buying decision. Only after these factors have been successfully navigated during the selling process will value-added services impact the buying decision. Ostensibly, the buying decision will have already been made by the time a customer considers a value-added services like Custom-FIS. Increased system sales resulting from offering a value-added service, in this case, are unlikely.

6.2.6 Custom Images

During the course of the Custom-FIS analysis, I also analyzed the possibility of offering customers a service whereby Custom Images would be installed in the factory on newly assembled workstation and servers. Operationally, custom images have little impact on manufacturing operations. With a custom image service, a customer buying multiple computer systems would take possession of a single system, and install and configure all of the software they wish to include on the system. Once this is completed, the customer would make an image of the fully configured system, and deliver that image to Compaq. Compaq would then test the image, load on a network server, and install the image on the remaining systems in the customer order. The benefits of this approach are:

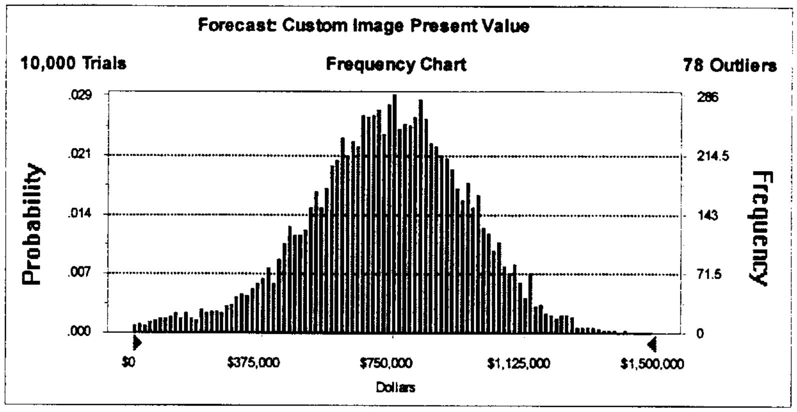
1. The customer is responsible for installing and configuring the software
2. Customers only need this service when they are buying multiple computer systems
3. Compaq delivers a valuable service, as the customer does not have to physically touch every new system in order to install their applications
4. This service has a visible impact on the customer's bottom-line, allowing Compaq to charge a premium service price
5. Compaq does not have to negotiate and pay for licensing and reselling agreements with independent software vendors.
6. The service has low implementation costs

Issues that must be addressed to implement a Custom Image Service include:

1. A process is required to ensure that the computer system on which the imagewas created exactly matches the newly manufactured systems on which the image will be installed.
2. Terms of service, such as the shelf life of a particular images, and the amount of testing, if any, that is required by Compaq, must be finalized.
3. Additional storage capacity on manufacturing's network will be required

I developed a financial model for the Custom Image service, using the same simulation methodology as with the Custom-FIS service options. The results of the model and simulation are shown below. We see that there is a greater than 90% certainty that the Custom Image service will be profitable, with a mean expected value of nearly $730,000. Section 8 provides further details of the Custom Image financial model and simulation.

Percentile	Dollars
0%	($580,171)
10%	$431,489
20%	$545,612
30%	$621,861
40%	$683,913
50%	$741,745
60%	$798,461
70%	$856,444
80%	$925,265
90%	$1,018,175



6.2.7 *Financial Analysis Conclusions*

The financial models and simulations used to analyze the two Custom-FIS service options suggest that both options will likely be unprofitable. Therefore, investment into a Custom-FIS service cannot be supported on a ROI basis. At issue are the relatively high development costs per application, and the relatively small market opportunity for these services.

7 Recommendations

Based on the analysis discussed above, it is my assessment that the Compaq should not pursue the Custom-FIS service at the Salem Manufacturing Facility at this time. Operationally, there are significant obstacles that call into question whether or not the service could even be implemented given the existing manufacturing and information systems. Even if could, it is unlikely that the service would be profitable. Fundamentally, the infrastructure needed to support a factory service like Custom-FIS is not currently in place at Salem, and the Custom-FIS, service in and of itself, does not possess the scale needed to support the required infrastructure changes. The analysis of the Custom Image capability looks promising, and suggests that this service should be analyzed in greater depth.

The real decision for Compaq is not the tactical decision whether to pursue the Custom-FIS service but the strategic decision whether to pursue factory services as a core component of its manufacturing strategy. Delivering value-added factory services requires the resources and commitment not just from manufacturing, but also from the organizations that support the marketing, supply, and information processing needed to fulfill such services. Moreover, the infrastructure changes needed to implement factory services cannot be justified by a single service like Custom-FIS. Implementing a portfolio of services, however, may collectively justify the needed infrastructure changes.

8 Financial Model

8.1 Derivation of the Custom-FIS Market Opportunity

Developing the revenue model began with a seemingly simple question- "What is the market opportunity?" The quick answer (which is quite wrong) is to assume the market opportunity equals the number of workstations and servers that are sold in a given year. In reality, the market opportunity is significantly smaller than this. The derivation of the market opportunity for the Custom-FIS project is as follows:

1. **What is the total number of workstations and servers sold in a year?** The numbers shown are approximate figures, the exact numbers being confidential. Also show here are the fraction of the workstations and servers that are sold with the NT operating system, and those that use Unix, or OpenVMS (this will play a part of the next step of the market opportunity derivation)

Workstations Sold (FY98)		40,000	units
	NT Fraction	30.0%	
	UNIX/OVMS Fraction	70.0%	
Servers Sold (FY97)		50,000	units
	NT Fraction	29.7%	
	UNIX/OVMS Fraction	70.3%	

2. **What fraction of customers that actually use the operating system that comes installed on the new systems?** This question is relevant to the Custom-FIS project. A 1998 Compaq customer survey revealed that a significant number of customers actually remove the factory-installed software from their new systems. Driving this is the fact that many customers integrate new system hardware in to legacy networks. To ensure compatibility with existing software applications and existing hardware, and to simplify network support, customers often install an older operating system version than the one that shipped with the new system.

Adjustment for Users who don't use O/S FIS				
	Workstations		Servers	
	NT	UNIX/OVMS	NT	UNIX
Number of Alpha Systems Sold Worldwide	12000	28000	14834	35166
Fraction of Customers that Use the O/S FIS	70%	40%	50%	40%
Potential FIS Market by Platform and OS	**8400**	**11200**	**7417**	**14067**

3. **What fraction of new systems is sold through indirect channels?** This question is relevant given that not all channel partners will want Compaq to install customer specified software in the factory, as this service would eat into a profitable part of the channel partners' business.

Adjustment for Direct v. Indirect Fulfillment		
Indirect	LCA	MCA
Percentage of Units Fulfilled Indirect	62%	62%
Fraction of Indirect Units Using Compaq FISed Applications	40%	40%
Indirect Multiple	25%	25%
Direct		
Percentage of Units Fulfilled Direct	38%	38%
Fraction of Units Using Compaq FIS	100%	100%
Direct Multiple	38%	38%
Adjustment Fraction for Direct v. Indirect Fulfillment	**63%**	**63%**

4. **What fraction of systems shipped use English language versions of the operating system and software?** Due to the complexity of testing non-English variants of operating system and application software, we concluded that trying to offer the Custom-FIS service for non-English software variants would require an inordinate amount of engineering testing. Consequently, we decided to offer Custom-FIS only for English-version software applications (values shown in the next table.)

5. **Finally, what fraction of the remaining market opportunity could we realistically capture given that we would only be offering a small number of applications through the Custom-FIS project?** If the reality were that we could offer any software application as part of the Custom-FIS suite of software applications, then we could realistically target all of the remaining market opportunity. However, if we sell a workstation to a graphics design firm, and the only software application we offer is a CAD/CAM application, then we could not view that system sale as a potential Custom-FIS sale. For Low-complexity Applications (LCA), such as a word processor or spreadsheet, the broad applicability of these applications suggests that a small

handful of applications could ultimately reside on any system. Mid-complexity applications, however, tend to be more focused on a specific function, are more costly, and are also more fragmented (there are many engineering tools, graphics tools, data base tools etc.) As a result, a handful of Custom-FIS applications would only serve a fraction of the potential market.

The final market potential for the Custom-FIS factory service is shown below.

Potential Market	LCA	MCA
Systems Where FIS is Used	41083	41083
Adjustment Fraction for Direct v. Indirect Fulfillment	63%	63%
Adjustment for English Language Applications	75%	75%
Fraction of the Market that we can Capture with a Limited Set of Applications being offered	100%	40%
Potential Number of Systems for Custom-FIS	**19350**	**7740**
Percentage of Beginning Systems	**21.5%**	**8.6%**

8.2 *Custom-FIS Financial Model Key Variable Probability Distributions*

Developing the financial model for the Custom-FIS project required making a significant number of assumptions for both the revenue generation and project cost. The revenue side of the model consisted of estimating the market potential and service fee. The derivation of the market potential is shown above. Market prices for comparable services were used to estimate Custom-FIS service fees.

The cost side of the model was driven exclusively by the labor costs needed to develop and maintain a portfolio of Custom-FIS applications. While a percentage of certain infrastructure costs could have been allocated to the Custom-FIS project, these costs were not modeled. The facilities and networking costs associated with the delivering the Custom-FIS service were deemed to be small in comparison to the associated labor costs. Using the Custom-FIS process map, I interviewed numerous engineers and managers to determine the labor hours required to complete each step in the process.

What became clear rather quickly is that many of the key variables in the financial model varied considerably. For example, FIS image development for a low-complexity application might take as little as two weeks, or as much as 5 weeks or more. Reducing the variation in these variables a priori proved to be intractable. Picking a specific number within the range of variation (3.5 weeks for example) and creating a deterministic financial model created a dubious answer, and preclude understanding the error and variation associated with the model. To address these uncertainties, each variable for which a significant uncertainty existed was modeled with a probability distribution. Additionally, some variables are interrelated- such as sales price and sales volume- where a lower price might drive a higher sales volume, and vice versa. Where such interrelationships were reasoned, a correlation factor was estimated, and included.

The probability distributions and correlation between key variables were then included in a financial model, and 10,000 iterations of the model were run. The probability distributions, and the correlation between key variables were derived from the interviews conducted with the engineering experts associated with this process. While these are qualitative assessments, they do provide greater modeling accuracy than would be possible by selecting mean variable values with no variable correlation.

Model Definitions

LCA- Low-complexity application. Low-complexity applications define a class of software application that are easily installed on to a computer system, requiring relatively little configurations

MCA- Mid-complexity applications. Mid-complexity applications define a class of software application that requires sizable configuration of the software at the time of installation.

Custom Image- an exact copy of a fully installed and configured computer system that includes the operating system, software applications and utilities.

Sale Price- the fee charged to a customer for factory installation of a software application on a new computer system via the Custom-FIS service.

Sales Potential- the upper bound for the number of potential systems that could be sold annually via the Custom-FIS service.

FIS Image Development- the process by which Compaq software engineers create an image of a software application so that it can be installed on new computer systems directly from a network during final assembly in the manufacturing plant.

Contract Development- the process of negotiating the licensing and reselling arrangements with Independent Software Vendors that will allow a particular software application to be including in the Custom-FIS application portfolio, and sold along with new computer systems.

FIS Image Qualification and Test- the process of testing an image on a variety of operating systems and platforms to ensure that the image installs correctly on a new computer system, and functions as intended.

System Engineering Development- correct installation and configuration of mid-complexity applications is not a turn-key process. Correctly installing and configuring such applications requires a understanding the application, its intended use, and its interactions with system hardware. This all must be accomplished before the FIS engineer can begin creating the FIS image for use by manufacturing.

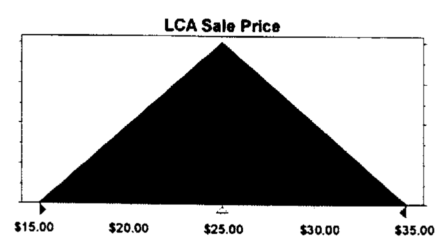
Average Quantity per Custom Image Order- the unit cost of a installing custom images on new computer systems depends on the number of computer systems sold per customer order. Using historical data, a profile of customer orders where greater than 25 systems per order was modeled.

Low-complexity Application Model Probability Distributions of Key Variables

Assumption: LCA Sale Price

Triangular distribution with parameters:

Minimum	$15.00
Likeliest	$25.00
Maximum	$35.00



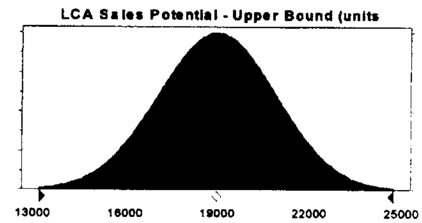
Selected range is from $15.00 to $35.00
Mean value in simulation was $25.02

Correlated with:
LCA Sales Potential - Upper Bound (units (B11) -0.40

Assumption: LCA Sales Potential - Upper Bound (units)

Normal distribution with parameters:

Mean	19000
Standard Dev.	2000



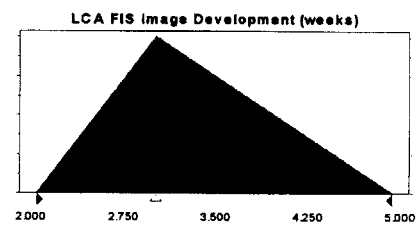
Selected range is from 0 to +Infinity
Mean value in simulation was 18993

Correlated with:
LCA Sale Price (B8) -0.40

Assumption: LCA FIS Image Development (weeks)

Triangular distribution with parameters:

Minimum	2.000
Likeliest	3.000
Maximum	5.000

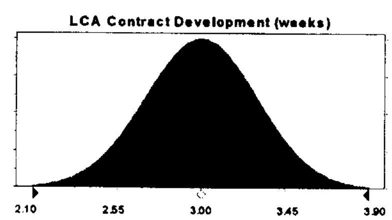


Selected range is from 2.000 to 5.000
Mean value in simulation was 3.334

Assumption: LCA Contract Development (weeks)

Normal distribution with parameters:

Mean	3.00
Standard Dev.	0.30

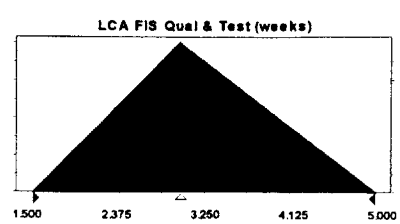


Selected range is from 0.00 to +Infinity
Mean value in simulation was 3.00

Assumption: LCA FIS Image Qual & Test (weeks)

Triangular distribution with parameters:

Minimum	1.500

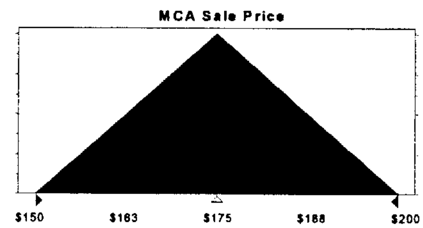


Likeliest	3.000
Maximum	5.000

Selected range is from 1.500 to 5.000
Mean value in simulation was 3.168

Mid-complexity Application Model Probability Distributions of Key Variables

Assumption: MCA Sale Price



Triangular distribution with parameters:

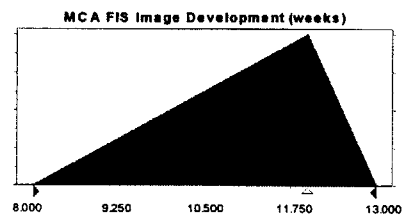
Minimum	$150
Likeliest	$175
Maximum	$200

Selected range is from $150 to $200
Mean value in simulation was $175

Correlated with:

MCA Sales Potential - Upper Bound	-0.10

Assumption: MCA FIS Image Development (weeks)

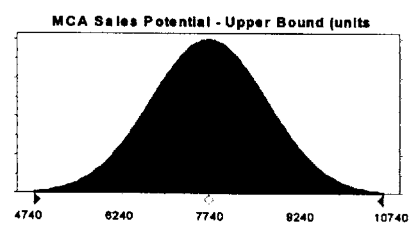


Triangular distribution with parameters:

Minimum	8.000
Likeliest	12.000
Maximum	13.000

Selected range is from 8.000 to 13.000
Mean value in simulation was 11.000

Assumption: MCA Sales Potential - Upper Bound



Normal distribution with parameters:

Mean	7740
Standard Dev.	1000

Selected range is from 0 to +Infinity
Mean value in simulation was 7759

Correlated with:

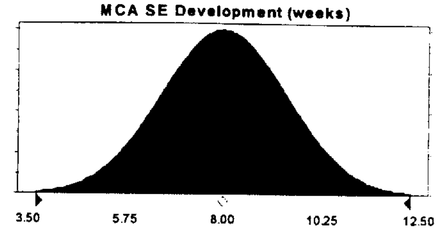
MCA Sale Price (C8)	-0.10

Assumption: MCA System Engineering Development (weeks)

Normal distribution with parameters:

Mean	8.00
Standard Dev.	1.50

Selected range is from -Infinity to +Infinity
Mean value in simulation was 7.99

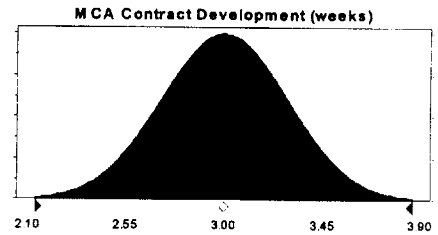


Assumption: MCA Contract Development (weeks)

Normal distribution with parameters:

Mean	3.00
Standard Dev.	0.30

Selected range is from 0.00 to +Infinity
Mean value in simulation was 3.00

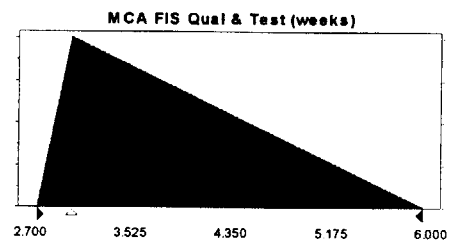


Assumption: MCA FIS Image Qual & Test (weeks)

Triangular distribution with parameters:

Minimum	2.700
Likeliest	3.000
Maximum	6.000

Selected range is from 2.700 to 6.000
Mean value in simulation was 3.895



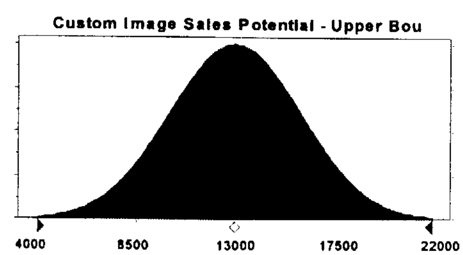
Custom Image Model Probability Distributions of Key Variables

Assumption: Custom Image Sales Potential

Normal distribution with parameters:

Mean	13000
Standard Dev.	3000

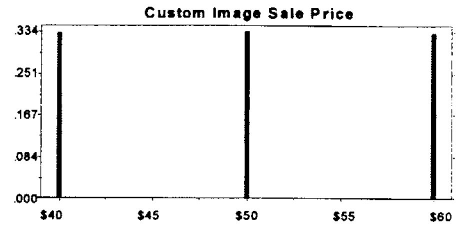
Selected range is from -Infinity to +Infinity
Mean value in simulation was 12960



Assumption: Custom Image Sale Price

Custom distribution with parameters:

Single point	$40
Single point	$50
Single point	$60
Total Relative Probability	



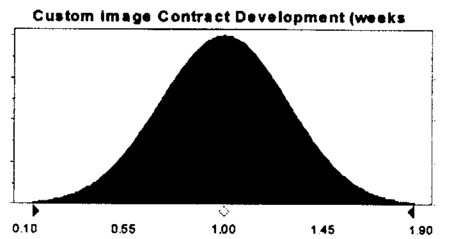
Mean value in simulation was $50

Assumption: Custom Image Contract Development (weeks

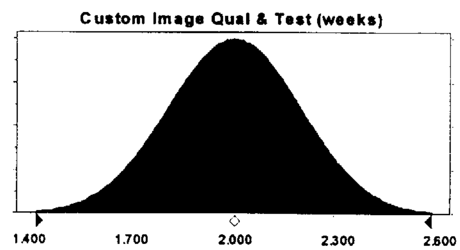
Normal distribution with parameters:

Mean	1.00
Standard Dev.	0.30

Selected range is from -2.00 to +Infinity
Mean value in simulation was 1.00



Assumption: Custom Image Qual & Test (weeks)



Normal distribution with parameters:

Mean	2.000
Standard Dev.	0.200

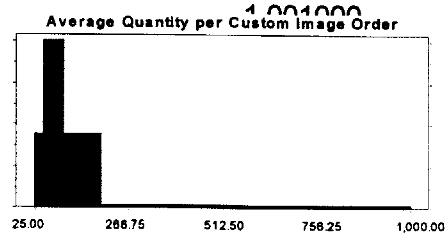
Selected range is from 0.000 to +Infinity
Mean value in simulation was 1.995

Assumption: Average Quantity per Custom Image Order

Custom distribution with parameters:

				Relative Prob.
Continuous range	25.00	to	50	0.100000
Continuous range	50.00	to	100	0.450000
Continuous range	100.00	to	200	0.400000
Continuous range	200.00	to	500	0.050000
Continuous range	500.00	to	1,000	0.001000
Total Relative Probability				1.001000

Mean value in simulation was 114.51



8.3 Custom-FIS Financial Model Assumptions

The table below shows the integration of key assumptions into the Custom-FIS financial model. Shaded areas refer to variables for which probability distributions have been estimated.

Custom-FIS Cost Model Assumptions

Corporate Tax Rate	35%
Project Discount Rate	16%

	LCA	MCA	Custom Image	
Revenue per Application ($)	**$24**	**$180**	**$60**	
Sale Price	$24.39	$180	$60	
Sensitivity Multiple	1	1	1	
Sales Potential - Upper Bound (units)	20696	6513	12910	
Sales Potential - Assumption	19350	7740	13000	
FIS Engineering Costs				
FIS Engineer Salary	$130,000	$130,000	$130,000	per year
FIS Image Development (weeks)	4.737	9.353	0	
FIS Image Development (yrs)	0.09474	0.18707	0	yr/application
FIS Image Sustaining Engineering	0.18947186	0.093532639	0	yr/application
System Engineering Costs				
System Engineer Salary	$130,000	$130,000	$130,000	per year
FIS Image Development (weeks)	0	7.00982913	0	
FIS Image Development (yrs)	0	0.140196583	0	yr/application
FIS Image Sustaining Engineering	0	0.070098291	0	yr/application
Sales and Marketing				
Initial Sales Force Training	$50,000	$50,000	$50,000	
Annual Sales and Marketing	$75,000	$75,000	$75,000	
Software Vendor Contract Management				
Project Manager Salary	$100,000	$100,000	$100,000	per year
Contract Development (weeks)	2.74	3.22	0.65	
Contract Development (yrs)	0.054721112	0.064329739	0.013	
Project Management				
Project Manager Salary	$100,000	$100,000	$100,000	per year
Custom-FIS Projects per Year	0	360	0	systems/yr

Average # of Systems per Project	0	10	0	
PM Cost per System	$0.00	$27.78	$0.00	
Manufacturing Engineering Costs	$100,000	$100,000	$8,000	
Manufacturing Costs				
Hourly Salary	$20	$20	$20	$/hr
Incremental Touch Time	8.16	18.13	6.10	min
Manufacturing Costs per System	$2.72	$6.04	$2.03	$/hr
Engineering Qualification and Test				
Engineer Salary	$130,000	$130,000	$130,000	per year
FIS Development Qual & Test (weeks)	4.024	4.581	1.978	
FIS Image Development (yrs)	0.080	0.092	0.040	yr/application
Sustainment Qual and Test	0.080	0.092	0.000	yr/application
Web-site Development and Hosting				
Basic Capability Development	$0	$75,000	$0	$
Extended Capability Development	$0	$150,000	$0	$
Trigger for Upgrade	1.00E+99	15000	1.00E+99	Apps/year
Site Hosting and Maintenance	$0	$24,000	$0	$/yr
FIS Network Upgrade	$150,000	$150,000	$150,000	$
Trigger for Upgrade	15000	15000	15000	Apps/year
Average Number of Systems per Customer Order	N/A	N/A	122.3184567	

8.4 *Low-Complexity Application Option: Financial Model and Simulation Results*

Financial Model for Low-complexity Application Custom-FIS Service

	Year 1	Year 2	Year 3	Year 4	Year 5
Total Number of Saleable FIS Applications	2	4	8	12	16
Average Number of FIS Sales per Application	2,070	2,587	2,328	2,113	2,070
Number of Applications per Order	1.00	1.25	1.50	1.75	2.00
Total Number of Applications FIS'd	4139	10348	18626	25352	33113
Revenue per Application	$24	$25.61	$26.89	$28.24	$29.65
Net Sales	$100,964	$265,031	$500,909	$715,883	$981,782
Cost of Goods Sold (Labor Cost)	$7,686	$19,215	$34,586	$47,076	$61,486
Development and SG&A	$351,690	$333,560	$642,120	$555,860	$619,600
EBIT	($258,411)	($87,743)	($175,797)	$112,947	$300,695
Tax Due	($90,444)	($30,710)	($61,529)	$39,531	$105,243
Net Income	**($167,967)**	**($57,033)**	**($114,268)**	**$73,416**	**$195,452**
LCA Present Value	**($127,428)**				

	Year 1	Year 2	Year 3	Year 4	Year 5
Annual Development Cost					
FIS Engineering- Initial Development	$24,631	$24,631	$49,263	$49,263	$49,263
FIS Engineering- Revisions and Updates	$49,263	$49,263	$98,525	$98,525	$98,525
System Engineering- Initial Development	$0	$0	$0	$0	$0
System Engineering- Revisions and Updates	$0	$0	$0	$0	$0
Engineering Qual & Test- initial Dev.	$20,926	$20,926	$41,852	$41,852	$41,852
Engineering Qual & Test- Revs and Updates	$20,926	$41,852	$83,703	$125,555	$167,407
Manufacturing Engineer	$100,000	$100,000	$100,000	$100,000	$100,000
Software Vendor Contract Management	$10,944	$21,888	$43,777	$65,665	$87,554
Sales and Marketing Cost	$125,000	$75,000	$75,000	$75,000	$75,000

Web Site Development					
Basic Capability	$0				
Extended Capability	$0	$0	$0	$0	$0
Network Upgrade	$0	$0	$150,000	$0	$0
Total Annual Fixed Cost	**$351,690**	**$333,560**	**$642,120**	**$555,860**	**$619,600**
Percent of Total Cost	98%	95%	95%	92%	91%
Variable (Transaction) Cost					
Project Management	$0	$0	$0	$0	$0
Manufacturing (Transformation)	$7,686	$19,215	$34,586	$47,076	$61,486
Web-site Hosting & Maintenance	$0	$0	$0	$0	$0
Variable (Transaction) Cost	**$7,686**	**$19,215**	**$34,586**	**$47,076**	**$61,486**
Percent of Total Cost	2%	5%	5%	8%	9%
Cost Total	**$359,376**	**$352,775**	**$676,706**	**$602,936**	**$681,087**
Marginal Cost	**$1.86**	**$1.86**	**$1.86**	**$1.86**	**$1.86**
Personnel Requirements (man-years)					
FIS Engineering	0.57	0.57	1.14	1.14	1.14
System Engineering	0.00	0.00	0.00	0.00	0.00
Test Engineering	0.32	0.48	0.97	1.29	1.61
Project Mangers	0.00	0.00	0.00	0.00	0.00
Software Manager	0.11	0.22	0.44	0.66	0.88
Manufacturing Engineer	1.00	1.00	1.00	1.00	1.00
Total New Technical Resource	**2.00**	**2.27**	**3.54**	**4.08**	**4.62**
Average Annual Salary	$115,000	$115,001	$115,002	$115,003	$115,004
New Labor Costs	$229,976	$261,076	$407,154	$469,354	$531,554

Simulation Statistics for Low-complexity Application Custom-FIS Service

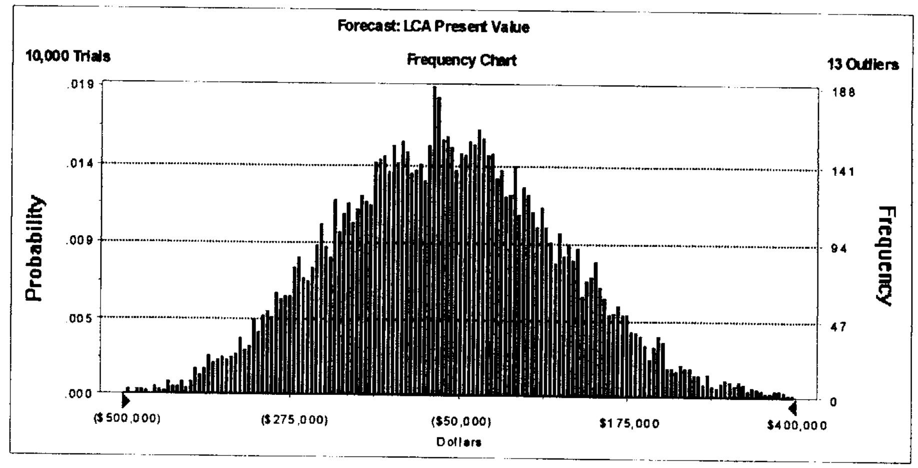
Forecast: LCA Present Value

Summary:

Display Range is from ($500,000) to $400,000 Dollars

Entire Range is from ($512,110) to $574,755 Dollars

After 10,000 Trials, the Std. Error of the Mean is $1,502



Statistics:	Value
Trials	10000
Mean	($65,151)
Median	($68,424)
Mode	---
Standard Deviation	$150,172
Variance	$22,551,741,881
Skewness	0.15
Kurtosis	2.86
Coeff. of Variability	-2.30
Range Minimum	($512,110)
Range Maximum	$574,755
Range Width	$1,086,865
Mean Std. Error	$1,501.72

8.5 *Mid-Complexity Application Option: Financial Model and Simulation Results*

Financial Model for Mid-complexity Application Custom-FIS Service

	Year 1	Year 2	Year 3	Year 4	Year 5
Total Number of Saleable FIS Applications	2	4	6	8	10
Average Number of FIS Sales per Application	326	407	434	529	521
Total Number of Applications FIS'd	651	1628	2605	4233	5210
Revenue per Application	$180	$188.90	$198.35	$208.26	$218.68
Net Sales	$117,172	$307,578	$516,731	$881,672	$1,139,391
Cost of Goods Sold (Labor Cost)	$45,785	$78,463	$111,140	$165,603	$198,281
Development and SG&A	$486,220	$438,530	$515,840	$593,150	$670,460
EBIT	($414,832)	($209,415)	($110,249)	$122,919	$270,651
Tax Due	($145,191)	($73,295)	($38,587)	$43,022	$94,728
Net Income	**($269,641)**	**($136,120)**	**($71,662)**	**$79,897**	**$175,923**
MCA Present Value	**($251,705)**				

	Year 1	Year 2	Year 3	Year 4	Year 5
Annual Development Cost					
FIS Engineering- Initial Development	$48,637	$48,637	$48,637	$48,637	$48,637
FIS Engineering- Revisions and Updates	$24,318	$48,637	$72,955	$97,274	$121,592
System Engineering- Initial Development	$36,451	$36,451	$36,451	$36,451	$36,451
System Engineering- Revisions and Updates	$18,226	$36,451	$54,677	$72,902	$91,128
Engineering Qual & Test- initial Dev.	$23,822	$23,822	$23,822	$23,822	$23,822
Engineering Qual & Test- Revs and Updates	$23,822	$47,643	$71,465	$95,287	$119,109
Manufacturing Engineer	$100,000	$100,000	$100,000	$100,000	$100,000
Software Vendor Contract Management	$10,944	$21,888	$32,833	$43,777	$54,721
Sales and Marketing Cost	$125,000	$75,000	$75,000	$75,000	$75,000
Web Site Development					

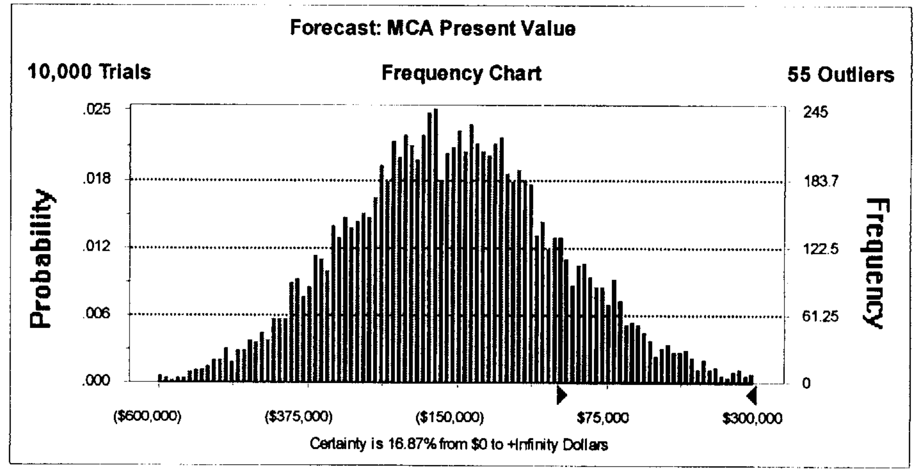
Basic Capability	$75,000				
Extended Capability	$0	$0	$0	$0	$0
Network Upgrade	$0	$0	$0	$0	$0
Total Annual Fixed Cost	**$486,220**	**$438,530**	**$515,840**	**$593,150**	**$670,460**
Percent of Total Cost	91%	85%	82%	78%	77%
Variable (Transaction) Cost					
Project Management	$18,092	$45,229	$72,367	$117,596	$144,733
Manufacturing (Transformation)	$3,693	$9,234	$14,774	$24,007	$29,547
Web-site Hosting & Maintenance	$24,000	$24,000	$24,000	$24,000	$24,000
Variable (Transaction) Cost	**$45,785**	**$78,463**	**$111,140**	**$165,603**	**$198,281**
Percent of Total Cost	9%	15%	18%	22%	23%
Cost Total	**$532,005**	**$516,992**	**$626,980**	**$758,753**	**$868,740**
Marginal Cost	**$70.30**	**$48.19**	**$42.66**	**$39.12**	**$38.05**
Personnel Requirements (man-years)					
FIS Engineering	0.56	0.75	0.94	1.12	1.31
System Engineering	0.42	0.56	0.70	0.84	0.98
Test Engineering	0.37	0.55	0.73	0.92	1.10
Project Mangers	0.18	0.45	0.72	1.18	1.45
Software Manager	0.11	0.22	0.33	0.44	0.55
Manufacturing Engineer	1.00	1.00	1.00	1.00	1.00
Total New Technical Resource	**2.64**	**3.53**	**4.42**	**5.49**	**6.38**
Average Annual Salary	$115,000	$115,001	$115,002	$115,003	$115,004
New Labor Costs	$303,443	$405,948	$508,456	$631,771	$734,282

Simulation Statistics for Mid-complexity Application Custom-FIS Service

Forecast: MCA Present Value

Summary:

Certainty Level is 16.87%
Certainty Range is from $0 to +Infinity Dollars
Display Range is from ($600,000) to $300,000 Dollars
Entire Range is from ($775,299) to $536,267 Dollars
After 10,000 Trials, the Std. Error of the Mean is $1,616



Statistics:	Value
Trials	10000
Mean	($153,780)
Median	($156,914)
Mode	---
Standard Deviation	$161,591
Variance	$26,111,726,374
Skewness	0.15
Kurtosis	3.02
Coeff. of Variability	-1.05
Range Minimum	($775,299)
Range Maximum	$536,267
Range Width	$1,311,566
Mean Std. Error	$1,615.91

8.6 Custom Image Option: Financial Model and Simulation Results

Custom Image Revenue Projection

	Year 1	Year 2	Year 3	Year 4	Year 5
Number of Custom Image Transactions	5	13	21	37	43
Average Number of FIS Sales per Application	122	122	122	122	122
Total Number of Applications FIS'd	651	1628	2605	4559	5210
Revenue per Application	$180	$188.90	$198.35	$208.26	$218.68
Net Sales	$117,172	$307,578	$516,731	$949,493	$1,139,391
Cost of Goods Sold (Labor Cost)	$1,162	$2,904	$4,647	$8,132	$9,294
Development and SG&A	$242,330	$141,434	$151,843	$213,746	$165,905
EBIT	($126,319)	$163,240	$360,241	$727,614	$964,192
Tax Due	($44,212)	$57,134	$126,084	$254,665	$337,467
Net Income	**($82,107)**	**$106,106**	**$234,157**	**$472,949**	**$626,725**

Custom Image NPV $706,487

	Year 1	Year 2	Year 3	Year 4	Year 5
Annual Development Cost					
FIS Engineering- Initial Development	$0	$0	$0	$0	$0
FIS Engineering- Revisions and Updates	$0	$0	$0	$0	$0
System Engineering- Initial Development	$0	$0	$0	$0	$0
System Engineering- Revisions and Updates	$0	$0	$0	$0	$0
Engineering Qual & Test- initial Dev.	$27,390	$41,085	$41,085	$82,171	$27,390
Engineering Qual & Test- Revs and Updates	$0	$0	$0	$0	$0
Manufacturing Engineer	$8,000	$8,000	$8,000	$8,000	$8,000

Software Vendor Contract Management	$6,939	$17,348	$27,757	$48,575	$55,515
Sales and Marketing Cost	$125,000	$75,000	$75,000	$75,000	$75,000
Web Site Development					
Basic Capability	$75,000				
Extended Capability	$0	$0	$0	$0	$0
Network Upgrade	$0	$0	$0	$0	$0
Total Annual Fixed Cost	**$242,330**	**$141,434**	**$151,843**	**$213,746**	**$165,905**
Percent of Total Cost	99.5%	98%	97%	96%	95%
Variable (Transaction) Cost					
Project Management	$0	$0	$0	$0	$0
Manufacturing (Transformation)	$1,162	$2,904	$4,647	$8,132	$9,294
Web-site Hosting & Maintenance	$0	$0	$0	$0	$0
Variable (Transaction) Cost	**$1,162**	**$2,904**	**$4,647**	**$8,132**	**$9,294**
Percent of Total Cost	0.48%	2%	3%	4%	5%
Cost Total	**$243,491**	**$144,338**	**$156,490**	**$221,879**	**$175,199**
Marginal Cost	**$1.78**	**$1.78**	**$1.78**	**$1.78**	**$1.784**
Personnel Requirements (man-years)					
FIS Engineering	0.00	0.00	0.00	0.00	0.00
System Engineering	0.00	0.00	0.00	0.00	0.00
Test Engineering	0.21	0.32	0.32	0.63	0.21
Project Mangers	0.00	0.00	0.00	0.00	0.00
Software Manager	0.07	0.17	0.28	0.49	0.56
Manufacturing Engineer	0.08	0.08	0.08	0.08	0.08
Total New Technical Resource	**0.36**	**0.57**	**0.67**	**1.20**	**0.85**
Average Annual Salary	$115,000	$115,001	$115,002	$115,003	$115,004
New Labor Costs	$41,410	$65,496	$77,467	$137,755	$97,275

Simulation Statistics for Custom Image Service

Forecast: Custom Image Present Value

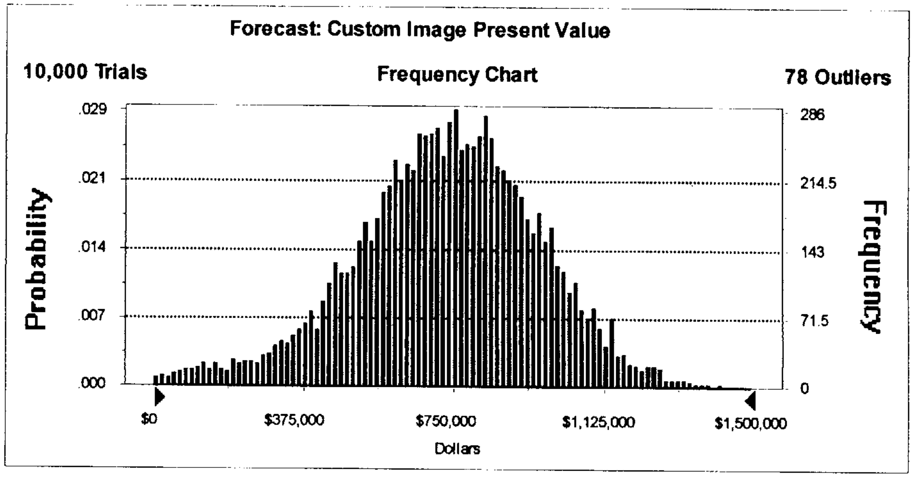
Summary:

Display Range is from $0 to $1,500,000 Dollars

Entire Range is from ($580,171) to $1,573,114 Dollars

After 10,000 Trials, the Std. Error of the Mean is $2,428

Statistics:	Value
Trials	10000
Mean	$727,706
Median	$741,745
Mode	---
Standard Deviation	$242,780
Variance	$58,942,065,624
Skewness	-0.52
Kurtosis	3.90
Coeff. of Variability	0.33
Range Minimum	($580,171)
Range Maximum	$1,573,114
Range Width	$2,153,285
Mean Std. Error	$2,427.80



9 Bibliography

1. 1997 Compaq Annual Report

2. Gartner Group, 98, *TCO: A Critical Tool for Managing IT*, 12 October

3. InfoWorld Electric, *Alpha, PowerPC Manufacturers Sketch Future Plans*, October 19, 1998

4. InfoWorld Publishing Company, *Eight-way Server Field Steps to the Foreground,* November 10, 1998

5. Patterson and Hennesey, Computer Organization and Design, The Hardware/Software Interface, Second Edition, c. 1998

6. Compaq Computer Corporation, White Paper, *Compaq Professional Workstation Affordable Performance Line Positioning Paper*, October 1998

7. David Floyer, Steve Josselyn, *High-End Server Market Share: 1997 Results Show Growth in Unix and the United States*, IDC Report #16958, October 1998

8. InfoWorld Electric, *Michael Dell Keynote Highlights User Concern*, 17 November, 1998