

Software Content Delivery in an Outsourced Electronics Manufacturing
Environment

by

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Bachelor of Science in Electrical Engineering, Rice University (1998)

Submitted to the Department of Electrical Engineering and Computer Science and the Sloan
School of Management in Partial Fulfillment of the Requirements for the Degrees of

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Master of Business Administration

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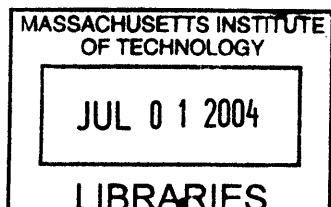
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Abstract

The trend towards integrated hardware and software solutions has become prevalent in the corporate server market. At the same time, companies struggle with the apparently conflicting goals of providing customers more customized and relevant products while handing over control of manufacturing to third party vendors. Competition is fierce, as customers who once chose on technology have begun to discriminate on price, compatibility and integration services as well.

This thesis describes an effort at Sun Microsystems, Inc. to prototype the factory installation of software. Several of its competitors have already initiated factory software installation, and Sun would like to determine whether software preload is viable on systems manufactured at Sun's external manufacturers (EMs). The capability was already available on systems built internally, but these constitute the high end, low volume systems sold by Sun. The systems produced by EMs are much higher in volume, but they tend to be lower in cost and complexity.

It is a challenge to convert a fully documented, highly controlled internal process into a flexible, easily deployable external process. This thesis discusses the obstacles that must be overcome to transfer software installation processes and also sets some criteria on when and where to make such changes. These findings are useful not only to Sun, but to other companies contemplating outsourcing of specific processes.

As the prototype progressed, several organizational issues had to be addressed to make deployment beyond the pilot site possible. Therefore, we discuss some of the organizational concerns and channel conflicts that affect the project, both on a short-term and long-term basis. We also cover the strategic choice of transitioning from mass production to mass customization. The software download capability opens a wide array of customization options, but the organization and its processes must be ready to support the change. Affecting change remotely with both internal and external stakeholders is critical in today's business environment.

The project confirmed the feasibility and cost-effectiveness of having external manufacturers load software for a family of hardware/software configurations, and Sun Microsystems plans to deploy the software installation capability at the EM in the future.

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Chapter 1 Introduction and Overview

1.1 Project Description

Sun Microsystems, Inc. (Sun) has traditionally kept software and hardware programs functionally separate in design, marketing, manufacturing and sales. In previous years, integration was considered unnecessary since customers were skilled enough to create their own solutions to custom fit their needs. Recently, competitive pressures and customer expectations have begun to challenge these long held beliefs, as many companies in the server industry move towards solutions selling, and customers are less tolerant of perceived product complexity. Sun would like to advance its own solutions strategy with software installation on its low-end volume systems, but it needs to do so in a cost effective manner. The volume servers are all made by Sun's external manufacturing (EM) partners. These products tend to be lower in cost and complexity and more sensitive to changes during manufacturing.

The work presented in this thesis was hosted over a seven-month period at Sun Microsystems' Worldwide Operations (WWOPS) group in Hillsboro, Oregon. The bulk of the work, however, will impact the manufacturing and operations of Sun's Volume Systems Products Group and select external manufacturing sites.

The WWOPS group was originally created to support software installation for internal manufacturing. Using a caching server mechanism, the most current content could be downloaded and installed to the production units automatically. All internal manufacturing sites utilize this capability to pre-install the Solaris operating system before shipment to the customer.

This thesis explores the possibility of enabling factory-based software installation on volume systems at Sun's EM's. To do so requires the completion of three main goals:

- 1) Understand the existing software download process used at Sun manufacturing facilities.
- 2) Evaluate the Return-on-Investment (ROI) of enabling software download at EM's, including an analysis of tradeoffs and minimum requirements, through a pilot at the EM.
- 3) Identify and address significant technical and business barriers unique to working with an EM, such as firewalls, custom processes, network security, vendor management policies, cultural differences and customer privacy.

Though the WWOPS group was a strong advocate of the network cache methodology, multiple delivery mechanisms were considered in this analysis, and no method was recommended without sound rationale behind the decision.

1.2 Project History and Motivation

In the Enterprise products space (high-end systems), the value of factory-installed software has been understood for some time. High-end systems, which can sell retail at prices ranging from \$500,000 to \$1.3 million, tend to be purchased in small quantities by highly competent customers. These large systems are not customer-installable, so each new system includes Sun installation services.¹

¹ From Sun Store website – server installation service included:

http://store.sun.com/CMTemplate/CEServlet?process=SunStore&cmdStartWebConfig_CP&familyCode=SER-CAT&baseSelected=1

Prior to the introduction of factory-installed software, a Sun service engineer would visit the customer site and physically install the operating system and customer applications via compact disc (CD). The CD installation could take between 1-2 days depending on hardware and software complexity. There were three operational problems in this model:

- Poor customer experience – When purchasing such complex systems, customers expected a server that would be ready to use. The additional time waiting for a CD installation was perceived as aggravating and unnecessary.
- Inefficient use of field time – At a charge rate of over \$100/hour, Sun field personnel were not being utilized to their full potential. Since software installation was bundled into the system purchase price, all installation costs reduced profit margin. Furthermore, this non-revenue service time represented an opportunity cost to Sun Professional Services (PS), preventing service engineers from pursuing more consulting revenue.
- Inconsistent implementation – After the operating system installation, each service engineer may choose to add a different set of patches and updates. This inconsistency meant that installations may differ from one another, leading to unpredictable field quality issues.

In response to field installation differences, Sun's PS organization devised a standard installation procedure. Though installations became more alike, it also became apparent that many of the steps could be completed earlier in the delivery process in a more efficient manner. From this insight came the foundation for factory-installed software.

Sun's Worldwide Operations (WWOPS) organization developed the factory installed software capability that helped reduce the amount of non-value added work performed by PS engineers at the customer site. Through operational efficiencies in the factory, a CD installation in the field taking over 1 day could be dramatically reduced by a software download and installation in the factory. All stakeholders gained from this change in strategy: customers received a system that was closer to completion; Sun's field personnel could concentrate on higher margin services; and Sun was able to reduce the bottom-line cost of delivering a viable customer solution.

Having implemented factory-installed software in all internal manufacturing and in Sun's system integration groups, the next logical step was to consider whether this function would benefit volume products, all of which were produced by external manufacturing partners. This is the basis of this thesis project.

According to Sun's terminology, volume systems are servers that include between 1 to 8 processors, which is significantly fewer processors than in the high-end systems. Volume systems also differ from high-end systems because they are customer-installable (no Sun Professional Services required), are generally built-to-order, are offered in limited configurations and are often sold through an indirect channel. These characteristics contribute to the uncertainty of whether factory installation of software will be appropriate for all of Sun's servers.

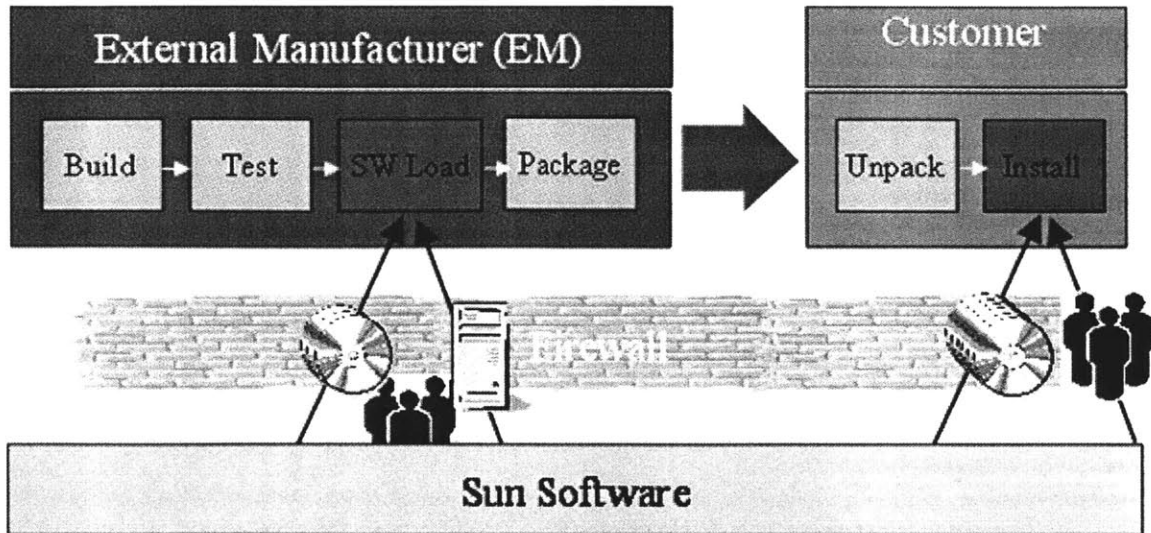


Figure 1: Current software delivery process

The current process to transfer files to the EM's requires significant manual intervention by engineers at both Sun and the EM (Figure 1). First of all, the new software must be packaged in a format that is deliverable to the vendor. In some instances, an engineer records a compact disk (CD) with the software content. However, most volume manufacturing environments have taken an additional step, placing a disk image onto the hard disk. This process is known internally as Hard Disk Duplication (HDD), and it is the most common methodology to install software in manufacturing. For both cases, the physical media (either CD or hard disk) is then shipped to the customer.

When a product is released to manufacturing, a specific Operating System (OS) revision is qualified for that product. From that point onwards, the same version of OS is installed onto all systems. Not only is there no consistent qualification process for new software, the software update process within manufacturing is very tedious, so updates are rarely implemented.

1.3 Overview of the Remaining Chapters

The other chapters in this document attempt to provide some background to the project, to describe the structure of the prototype and to analyze the results of the work.

Chapter 2 is discusses the business and industrial background from which this project originates. We describe Sun's history, building its reputation around open standards and network connectivity. In Chapter 3, we review the structural and cultural qualities that define Sun as an organization. These characteristics that make Sun unique also have an indelible effect on the project. Chapter 4 goes into more detail around the project motivation, both external drivers (such as competition) and internal pressures (such as Sun's corporate strategy).

Chapter 5 discusses the results of project deployment at one of Sun's EM's. There are several sections in this chapter, covering both the technical challenges and the organizational and business obstacles. For both topics, there is a discussion of the results and perceived impact on manufacturing.

Finally, Chapter 6 summarizes the results of the project and then suggests some ways for Sun to move forward with mass customization of software in the future. At the end of the project, Sun still needs to choose when it wants to deploy this capability and to what extent it wants to use the manufacturing infrastructure developed in the pilot.

1.4 Disclaimers

All statements, unless explicitly stated, are the opinion of the author. Furthermore, due to confidentiality constraints, facts and figures in the thesis have been altered or omitted to protect Sun proprietary content. Unless otherwise noted, organization and product names have been modified.

Chapter 2 Industry and Corporate Background

Sun Microsystems, Incorporated (Sun) is a global company that designs, manufactures and services network computing products. The products range from million-dollar data center servers to thin-client desktop appliances and workstations.

Sun had \$12 billion in revenue in the fiscal year ending in 2002, down from the 2001 revenue of \$18 billion. Revenue declined again in 2003, with only \$11.4 billion in revenue. Net losses also increased in 2003 to 3.4 billion (\$1.07 per share).²

Sun began as a small startup out of Stanford University (SUN once stood for “Stanford University Network”³) in 1982. From the very beginning, Sun was a strong proponent of ‘open system’, the concept of using non-proprietary parts and materials.

From those humble beginnings, Sun now offers a wide range of hardware and software business products. Sun’s hardware product lines including everything from desktop workstations to large enterprise servers and to network storage. On the software side, Sun supports its own version of UNIX® and Solaris™ software. Sun also is the originator of Java™ programming language, one of the most popular programming languages for platform-independent application development.

Sun’s strategy has been to focus on the network and the connection between machines and individuals. As part of that strategy, Sun has become one of the more vertically integrated organizations in the computer industry from an R&D point of view, designing everything from the processors and motherboards to operating systems and server applications. Companies can single source from Sun most of their enterprise computing needs.

2.1 Industry Description

Sun offers products in the highly competitive network computing market. For the purposes of this thesis, the focus is on servers and associated software and services. In generic terms, a server is a piece of equipment that ‘serves’ content via a network connection. Typical uses for servers are for databases, mail, Enterprise Resource Planning (ERP) systems, web pages and e-commerce.

Servers range in size from very small (1 processor) to extremely large and complex (> 100 processors)⁴. In aggregate, Gartner reports that the 2003 market size for servers is between \$40.8 - \$44.0 billion, though growth was negligible that year.⁵ Server sales growth in general has been flat since the collapse of the internet “bubble” in 2001, though conditions appear to be improving year-over-year in 2003.

Low-end servers are used for a wide variety of e-commerce, application hosting, network perimeter security and customer relationship management (CRM) purposes, generally by small

² Sun’s 2003 annual report: http://www.sun.com/aboutsun/investor/annual_reports/sun_ar03.pdf

³ Wikipedia entry: http://en.wikipedia.org/wiki/Sun_Microsystems

⁴ Gartner partitions the server market into low-end (1-2 processors), “midrange” (4-16 processors) and “high-end” (greater than 16 processors). Linux can currently support up to 4 CPUs (Red Hat, Inc. has an enterprise edition that supports up to 8).

⁵ Gartner Group. “Hardware Platforms Weekly, Issue 37.” Note Number HWPW-WW-NT-0337. 22 September 2003.

and medium sized businesses. These customers tend to be the most cost sensitive, but the sales volume for low-end servers is very high.

Mid-range servers are used in larger offices for functions such as ERP hosting, database management and computer aided design and visualization applications. Finally, powerful high-end servers are utilized by large corporations for large-scale application hosting, software development, financial analysis and high-end technical computing.

The sales and service channel for servers varies widely between the vendors. Many vendors rely on an indirect sales channel, where Value-Added Resellers (VARs) are the direct and main interface with the end users. This is especially true when dealing with niche markets (e.g., government) or small businesses with low volume requirements. However, some new entrants, such as Dell, adhere to a direct model, using its own sales force for all customer interactions.

Sun Microsystems has a large indirect sales channel, which has been a consideration in the company's previous product decisions⁶. A more detailed description is provided in the Section 2.4: Company Position and Strategy.

2.2 Industry Trends and Environment

The industry has become increasingly more competitive. On the processor side, chips made by Intel Corporation have closed the performance gap with proprietary designs such as SPARC® processor (Sun) and PA-RISC® (HP), thus opening the door for Intel-based servers to effectively compete for mid-range server businesses. As of July 2002, Intel-based servers owned 89 percent of worldwide units shipped.⁷ This has also led to fierce industry competition from low cost suppliers like Dell, Inc. and the development of Sun's own Intel-architecture based servers.

Changes in operating systems have also had a profound effect on the server market. Windows NT and Linux-based servers have achieved broader acceptance within the lower end of the server market. As the enterprise capabilities of these operating systems improve, there is a possibility that Linux products will continue to capture market share from UNIX operating systems (e.g. Sun's Solaris software, Hewlett-Packard's HP-UX®, IBM's AIX®) and become more viable for mid- and high-end servers. A key reason for this change is the open-source nature of the Linux product and its lower cost structure compared to Windows Server Enterprise/Datacenter Edition and to proprietary UNIX standards. On the other hand, current plans by The SCO Group, the title holder to UNIX code, to sue Linux users over copyright infringement and business concerns about indemnification may place a damper on the current enthusiasm for this OS.⁸

Much of the server market is changing to de-emphasize high-end, high cost computing and beginning to focus on less complex, yet scalable solutions. Some of the perceived reasons are listed below:

Fewer technical customers – Demand for more standard solutions has increased as the level of customer expertise has decreased. In the past, data centers were the realm of very capable

⁶ See Sun's iForce[sm] initiative - <http://solutions.sun.com/>

⁷ Gartner Group. "Servers Worldwide Quarterly Statistics, 1Q02 (Executive Summary)." Note Number: HARD-WW-EX-0276. 30 July 2002.

⁸ Hicks, Matt and Galli, Peter. "SCO's Linux Case: Is Winning Everything?" eWeek (<http://www.eWeek.com/article2/0,4149,1394405,00.asp>). 21 November 2003.

technologists, but that skill level has deteriorated as organizations try to reduce costs while still growing capabilities.

Recommended systems – As a response to the reduction in technical proficiency, many server vendors, including Sun⁹, now provide ‘reference architectures’, which suggest specific server configurations for hardware, operating system and even recommended software applications.

Systems integration – Customers have also become more demanding about purchasing ‘plug-and-play’ systems. Anecdotally, customers complained about receiving ‘hundreds’ of boxes whenever they purchased a data center solution. In the case of Sun, a customer could receive a server from Oregon, spare parts from California and networking equipment from a distributor. This piecemeal approach often led to delays, lost components and general customer frustration. In response to this, vendors now offer system integration capabilities, configuring systems in the factory and shipping the integrated product to the customer as a single entity.

2.3 Server Hardware Competition

In its wide range of businesses, Sun competes with a variety of different companies in operating systems (e.g., Microsoft, Linux), software (e.g., Veritas), storage (e.g., EMC, HP), services (e.g., Accenture, IBM) and servers. The focus of this thesis is on Sun’s competitive position within the volume product space, which Sun has defined as servers with 1-8 processors.¹⁰

Some key competitors and strategies are shown below. Particular attention is given to the competitor’s system integration and software installation capabilities:

2.3.1 IBM

IBM has been a long-time competitor in the enterprise server hardware market and currently has the highest revenue of the 4 largest hardware vendors¹¹. IBM’s strengths lay in its ubiquitous presence, its wide variety of products and its comprehensive services offerings.

IBM has an extremely strong professional services organization (IBM Global Services) that it leverages to do most custom software installations. Global Services is very profitable, and as a result, IBM has been willing to discount both hardware and software in the effort to obtain large service contracts. This capability has been seen as a key differentiator, especially for customers interested in a ‘hands-off’ approach to enterprise computing. IBM also has the capability to support competitor’s products, and Global Services is one of several resellers for Sun equipment.

Software Installation:

IBM Manufacturing can pre-install the operating system and a list of supported software applications (mostly IBM products). For its mid-range AIX servers, the default OS is AIX, and any other operating systems such as Linux must be installed by the user. For Intel-based servers, versions of Windows and Red Hat® Linux are the available preloaded. Other operating systems must be installed manually.

⁹ <http://www.sun.com/products/architectures-platforms/refarch/>

¹⁰ Sun’s Volume Systems Products group (VSP) is responsible for the design and marketing of volume servers. The Enterprise System Product Group (ESP) handles all larger servers (> 8 processors).

¹¹ According to InfoTech trends, IBM obtains the most server revenue, though HP has the highest market share by volume. Sun is 3rd in revenue and 4th in volume, respectively. (<http://www.infotechrends.com>)

IBM will install and test a number of different software applications (e.g., C compilers or WebSphere®) along with the preloaded operating system. Therefore, when a new system is received and cabled, there are assurances that the loaded content is operational.

Next, customers can install software applications manually through an IBM-supported interface. Once a mid-range server (iSeries) arrives at a customer site, the customer can connect a PC to the server and insert a CD-ROM into the PC, which initiates the EZ-Setup program. EZ-Setup is a GUI-driven application that provides a step-by-step form to configure the server for NetServer, Directory services, security settings, TCP/IP, Domino® and support, among others.¹²

Finally, customers can hire IBM services (or third party service providers) to execute a full install for an additional charge. IBM's professional services organization is extremely well organized and respected, and it also has the capability to install and support the competition's hardware. Hardware is first sent to one of IBM's software integration centers for custom installation, testing and integration. Further work can be done on site if necessary.

Sales Channel:

IBM utilizes both direct and indirect sales channels for all of its regions, though most of its volume comes from direct sales bundled with services. VARs are used mostly for niche markets and smaller customers.

2.3.2 Dell

Dell, Inc. has become the fastest growing player in the server market, capturing market share every year. Dell focuses exclusively on the low-end of the server market, and it is perceived as the low-cost manufacturer.

The company builds all of its servers to order, thereby nearly eliminating inventory. It is also the expert in mass customization hardware choices and in software configurability.

Manufacturing:

Dell assembles all of its servers in Dell-owned manufacturing sites. Components and subassemblies are usually contracted out to vendors, but the final assembly is done by Dell. The company considers its build-to-order capabilities as a core competency, so Dell has the internal capability to mass customize systems for hardware configurations and software loads.

Software Installation:

Dell offers a range of software options for pre-installation. Generally, all Dell servers come with a choice of pre-loaded operating systems and for other popular third-party applications. Standard software is loaded in 2 locations: directly onto the hard disk prior to final assembly or after assembly in the "burn-in" section of Dell's Austin assembly plant. Dell utilizes a series of test servers to store the available software content to be pulled during burn-in.

Dell also offers a "Custom Factory Integration" service for situations where customers would like their hardware pre-racked and custom software installed. Unlike HP or IBM, Dell's factory integration occurs at the actual manufacturing facility as opposed to a remote integration center.

Sales Channel:

¹² "IBM eserver iSeries System Handbook, Version 5 Release 2", May 2003, Page 622

Dell adheres almost exclusively to the direct model of sales. Rather than use indirect channel VARs, there is a cultural belief that a direct model gets Dell closer to its customers. Dell claims that this relationship makes it more responsive and furthermore increases the velocity at which new products and features can be deployed.

2.3.3 Hewlett-Packard

Hewlett-Packard Corporation is the second largest provider of server hardware. HP has relatively unstructured system integration offerings. However, HP does have some very strong software applications (HP OpenView®) and third party software support.

Software Installation:

Factory installation of the operating system is available on all of HP's servers. Furthermore, HP offers the widest flexibility in OS choices, allowing customers to receive several different flavors of Linux, along with Windows, Novell NetWare®, HP-UX and even Solaris.

For more complex installations, HP has several factory integration centers that will rack the hardware and then install and configure customers' software requirements.

Sales Channel:

HP has the most balanced use of both direct and indirect sales channel. As with IBM, HP uses VARs to sell to niche markets and to smaller customers. However, VARs hold significantly more sway, since legacy volume systems (from Compaq) were sold extensively through indirect means.

2.4 Company Position and Strategy

Economic factors, industry trends and competitive forces have softened demand for Sun's hardware considerably. Sun has put in place strategies which attempt to address the new marketplace. Some of the key software and operating system strategies are listed below:

Linux – Sun has begun marketing Linux-based servers (Sun Fire™ V60x and Sun Fire™ V65x) using third-party OS vendors (Red Hat, Inc. and Novell). Previously, Sun's strategy had been unclear; it first discounted the value of Linux and then later offered its own 'flavor' of the OS that was not successful.¹³

Solaris™ x86 – Sun has created a version of its Solaris Operating System that runs on the Intel x86 architecture. Along with the Linux offerings, this is Sun's attempt to provide scalability and flexibility to existing customers.¹⁴

Sun Java™ Desktop System – This is a suite of desktop office applications which represents Sun's product to compete against Microsoft's desktop supremacy¹⁵. Running on Linux, Java Desktop System provides everything a user needs for office productivity - a desktop environment, word processing, spreadsheets, presentation application – for a low per user cost.

¹³ Shankland, Stephen. "Sun to drop its customized Linux" CNET News (<http://news.com.com/2100-1016-994602.html>), 28 March 2003.

¹⁴ Solaris Operating System for x86 Platforms website - <http://www.sun.com/software/solaris/x86/index.html>

¹⁵ Java Desktop System Analyst Reports - <http://www.sun.com/software/javadesktopsystem/analyst.html>

Sun Java™ Enterprise System™ – Similar to the Java Desktop System in pricing structure, the Java Enterprise System (JES) bundles all server applications into a single integrated unit that has been fully tested and validated for interoperability¹⁶. In addition, updates of the individual components, such as Sun’s application/web services, network identity services and portal server, will be coordinated and bundled for quarterly release.

Manufacturing:

Sun uses a mix of internal manufacturing for high-end systems and external manufacturing for volume servers. Currently, high-end systems are built at Sun factories in Hillsboro, OR, Newark, CA or Linlithgow, Scotland.¹⁷ Volume products, such as low end servers and all workstations, are built at a variety of external manufacturers in locations such as Europe and Asia.

Software Installation:

Sun’s strategy around software installation to this point has been determined by the individual business units and product lines. There has been considerable flexibility on what software content is placed onto each server and the method of content delivery. Furthermore, each product line has been responsible for its own policy on software installation maintenance and updates.

The following table shows the wide variety of software installation possibilities based on server product. High-end systems tend to allow for software customization while volume systems provide less flexibility. ‘OS Ready’ systems are shipped with a boot stub, a small boot-up program which prompts the user to install operating system CD’s once the system is first powered on.

Table 1: Software installed on selected Sun Servers¹⁸

Server Name	Number of Processors	Manufacturing Location	Software Pre-installed
Sun Fire™ 15K	16-106	Internal	Multiple instances of Solaris 8 or Solaris 9 – choice of revisions
Sun Fire™ 6800	2-24	Internal	Solaris 8 or Solaris 9 – choice of revisions
Sun Fire™ V880	2,4,6,8	External	<i>OS Ready</i>
Sun Fire™ V480	2,4	External	<i>OS Ready</i>
Sun Fire™ V240	1-2	External	Solaris 8 12/02 pre-loaded
Sun Fire™ B100s	1	External	<i>OS Ready</i>
Sun Fire™ V60x	2 (Intel® Xeon™)	External	<i>OS Ready</i> or Solarisx86 9 08/03

In the past, the belief was that each product line was closest to the customer and thus could make the best decision about software installation. However, several factors, such as those associated with JES, have initiated a shift in the strategy. These factors will be described in detail in Chapter 4.

¹⁶ More information about JES is at: <http://www.sun.com/software/javaenterprisesystem/index.html>

¹⁷ On January 15th, 2003 Sun announced the closure of its Newark manufacturing facility. Production will be moved to Oregon and Scotland.

¹⁸ Product information from Sun’s website: <http://www.sun.com/servers/index.html> and internal documents

Sun also offers a system integration service called Sun™ Customer Ready Systems (CRS), described more fully in Section 3.1.5. As part of the cost of the service, CRS has the capability of installing customer-specified operating systems and software.

Sales Channel:

Sun has a very large indirect sales channel, particularly for its volume servers. A majority of server volume flows through the indirect channel.

Figure 2 depicts the sales channels. For the indirect channel, once an EM has manufactured finished goods, they are shipped to a Channel Distribution Partner (CDP), such as GE Access, MOCA or Techdata.¹⁹ The CDP holds the servers in inventory until they are sold to an end customer. Before that can happen, a Value-Added Reseller (VAR) must first solicit and receive an order from the customer. VARs serve the purpose of customizing Sun’s products for small customers and specific markets. As part of their value, VARs may solicit new orders, configure systems, integrate third-party components, install customer-specific software and provide installation services.

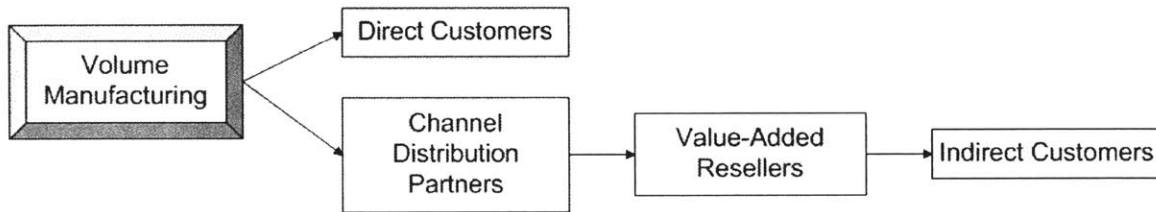


Figure 2: Sun’s sales channels

The widespread use of the indirect channel offers some advantages and poses some unique challenges for Sun. In my opinion, the indirect channel stabilizes demand and helps reach customers Sun could not handle itself. VARs are also seen as more impartial because they often work with multiple hardware vendors. On the other hand, the VARs own the relationship with the customers, so Sun has less visibility into the needs of end users. Furthermore, Sun must make product decisions based on keeping the channel satisfied. Configurations of volume servers out of the EM have been kept at a minimum so as to reduce the number of part numbers that the CDP’s need to hold. Finally, any product changes require the excess inventory within the channel to be flushed before new products can reach customers.

Specifically for software installation, channel partners generally do not add content to Sun’s servers, though they have the ability for basic CD-based installation. VARs are often very involved in software installation, using a mix of methods as needed based on volume and complexity. They handle software issue ranging from complicated storage network or cluster setup to simple generic operating system loads.

External view of Sun’s strategy:

Though Sun has been very enthusiastic about its strategies to address the server marketplace, external analysts have not been as kind to the company’s direction. One major concern is that Sun cannot execute on its multiple strategies²⁰. In attempting to provide a solution for all

¹⁹ Currently, Sun actually ships finished goods to a Sun-owned distribution center. At the time of writing, this is in the process of changing to a direct-ship model from manufacturing to the CDP’s.

²⁰ Chu, Richard. “SUN MICROSYSTEMS, INC”, SG Cowen Securities Corporation, 22 July 2003.

processor architectures, most operating systems and a large range of server sizes, Sun may be spreading its resources too thinly and not focusing enough on any one customer segment.

From Michael Porter's competitive forces analysis, Sun's wide scope also brings it to head on competition on a large number of fronts.²¹ On the low end, Sun is pressured by Microsoft on software and Dell's direct model on the hardware. On the high end, Sun struggles against the behemoths HP and IBM. IBM is particularly formidable because of its strong services arm and its ability to sell solutions. Sun also must contend with potential substitutes such as Linux and grid computing, which may reduce demand for mid-range servers. Customers, now more than ever, have a wide array of choices for their servers, and barriers to switching are falling.²²

On the other hand, advocates point out that Sun is one of the only vendors that can provide an end-to-end solution that does not require difficult integration of many third-party components.

²¹ Michael Porter, "How Competitive Forces Shape Strategy", Harvard Business Review (July-August 1997).

²² Competitors such as HP are currently offering conversion services, including giving \$50,000 of migration services and providing trade-in rebates for Sun hardware.
<http://www.hp.com/large/promo/64595/index.html>

Chapter 3 Organizational Structure and Culture

Sun is organized into several different product lines called 'Business Units'. Some of these teams represent horizontal markets, such as enterprise (high-end) servers, volume servers and workstations. These groups research, design and market the products to meet target customer needs. However, there are also functional groups that represent shared corporate capabilities, such as Human Resources, Information Technology (IT) and Worldwide Operations (WWOPS). Individuals in these shared groups operate in a matrix organization.

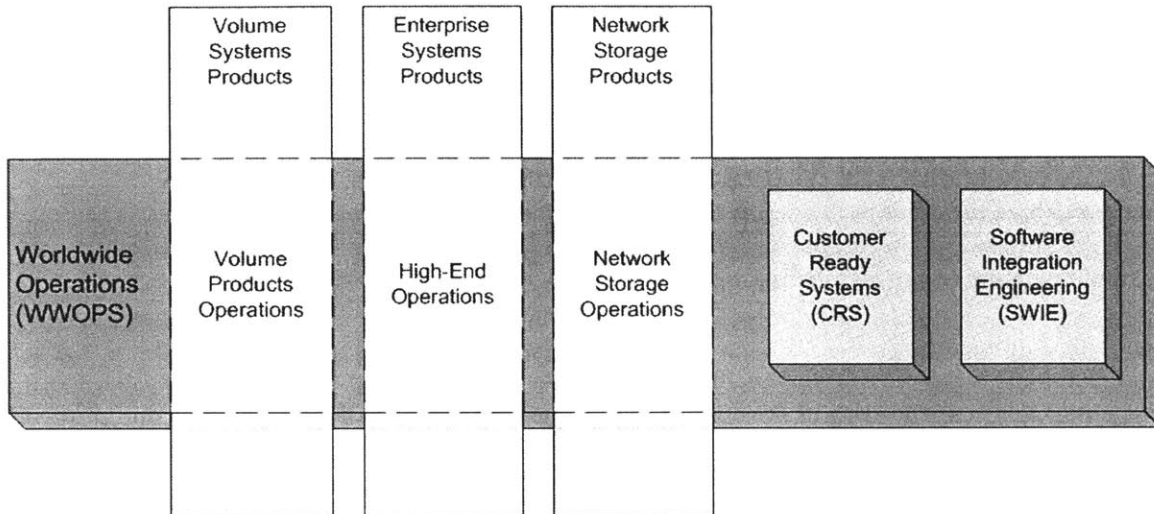


Figure 3: WWOPS matrix organization

Work done for this thesis was completed within the WWOPS organization, which itself is divided based along the product lines that it supports, as shown in Figure 3. A product group within WWOPS would include manufacturing, materials management and operations engineering.²³ For example, there is a High-End Operations group in WWOPS that works closely with the Enterprise Systems Products (ESP) Group to supply, manufacture and deliver products. ESP first researches and designs the products and then passes the designs over to Operations.

In addition to product specific operations, there are groups specific to WWOPS. One example of this is the Customer Ready Systems (CRS) group, which builds to order customer-specified systems using building blocks from Manufacturing and third party vendors. There are also WWOPS support groups, which are the infrastructure technology teams that enable manufacturing; this includes test infrastructure, datalogging and software installation.

Software integration engineering (referred to as SWIE in this thesis) is an infrastructure team, and SWIE's purpose is to support the installation of software for the various product line operations groups. Up until recently, SWIE only supported internal manufacturing activities, but now its mandate has expanded to consider volume products and external manufacturing partners.

The thesis project was very cross-functional in nature, requiring cooperation from business teams (Product Marketing, Engineering), Information Technology, Operations (Technology, Sustaining

²³ WWOPS website - http://www.sun.com/corp_emp/operations/

Engineering, Engineering Management, Supply Chain) and one of Sun's external manufacturing partners. Some of these groups are discussed in more detail in ensuing sections of this chapter.

To facilitate communication between different functional groups, Sun utilizes Operations Managers to coordinate the flow of information. These individuals sit on various teams in engineering, marketing, supply chain and manufacturing and attempt to be the linkage between all groups. Invariably, the Operations Managers are extremely busy.

Unfortunately, many projects do not fall neatly into the bounds of an Operations Management role due to their global nature. Individuals often define their roles based on the impact to a specific product line versus broader corporate goals. Therefore, it became evident during the course of the project that a silo mentality had to be overcome in order to gain cross-functional support for the project.

3.1 More about the Manufacturing Organizations

Sun uses three different processes to build its broad line of workstations, servers and storage devices. Depending on complexity and competencies, Sun utilizes internal manufacturing, external manufacturing and distribution partnerships.

Internal Manufacturing

Sun maintains some internal manufacturing for high-end enterprise systems. These systems still contain a significant amount of vendor supplied content in the form of chassis, chips and printed circuit assemblies. However, the final assembly, test and distribution of these systems are handled internally.

External Manufacturing

Sun has been a leader in promoting open systems and using standard components in manufacturing. Through the years, Klosterman writes that Sun has increased the percentage of components it designs, but it has consistently used vendors as opposed to building internal production capabilities.²⁴ Thus, it comes as no surprise that Sun outsources much of its manufacturing to External Manufacturers (EM's). Not only are components contracted out, whole systems are built by EM's and then delivered into Sun's product distribution process.²⁵

Volume products are built by a variety of external manufacturers. Each product line is responsible for choosing the best EM based on cost, quality, delivery and previous working relationships. Some EM's are more technically advanced than others and are thus able to manufacture more complex systems. Operations groups manage the relationship with the EM's, providing engineering support and rating the capabilities of the vendors.²⁶

Distribution Partnerships

²⁴ Steven Klosterman, page 16.

²⁵ An example is Benchmark Electronic International's relationship with Sun. Schlegel, Darrin. "COMPANY OF THE YEAR: Benchmark Electronics", Houston Chronicle (<http://www.chron.com/cs/CDA/story.hts/special/chron10003/1926571>), 28 May 2003.

²⁶ Sun operates a 'Supplier Awards' program that uses scorecard results on such metrics as quality, on-time performance and responsiveness. (<http://www.sun.com/smi/Press/sunflash/2003-10/sunflash.20031001.1.html>)

Finally, Sun does have some products that are manufactured and sold by a partner company, and just Sun acts as a distribution partner. An example of this is the Hitachi Data Systems partnership, where Sun sells Hitachi high-end storage systems as the re-branded Sun StorEdge 9900 Series.²⁷

For the purposes of this thesis, both internal and external manufacturing resources were engaged. Internal manufacturing already utilized customized installation of software on all of its products, so its processes and metrics were used as a benchmark for the project. Except for limited, static applications, external manufacturing did not have software installation in place.

3.1.1 Software Integration Engineering

Software Integration Engineering (SWIE – the project host team), provides technology and processes that can be used across Operations. Other infrastructure groups are involved with test infrastructure and diagnostics solutions. As a result, Sun has developed a test scheduling program. The program has been deployed internally and in some external locations, and it will be described in more detail in Chapter 5.

SWIE is a relatively new addition to WWOPS. Started in 2001, SWIE now provides software installation capabilities to internal manufacturing and to CRS.

SWIE has been tasked with the expanded role of supporting external manufacturing. As a result, it finds itself in the unfamiliar position of working outside of its traditional functional partnerships. The process of this project exposed the group to stakeholders within volume products and at the EM's that previously had not been involved.

3.1.2 Hillsboro Operations

Hillsboro Operations supports the manufacturing of high end servers for Enterprise System Products (ESP) organization. Subassemblies are brought in from internal and external vendors, and then the components are subject to incoming inspection. Afterwards, the final product is built-to-order based upon customer purchase.

Operations is considered low volume, with a maximum capacity below 500 units per quarter. Due to the high margin, low volume nature of the business, Hillsboro Operations values quality and delivery over cost. Previous work in software installation and download focused on this type of manufacturing as opposed to higher volume external manufacturing.

3.1.3 Volume Systems Products and Operations

Volume Product Operations manufactures Sun's volume servers, which range from the 8-processor Sun Fire V880 to the single processor blades and desktop systems. Though this group is underneath WWOPS, each team is associated with supporting operations for a particular product within Volume Systems Products (VSP) marketing/engineering organization.

Each product team within operations works with VSP to choose an external vendor for manufacturing that best fits the product cost and quality objectives.

The Volume Systems Products organization attempts to maximize performance and reliability at aggressive prices. This has led to a drive towards lower complexity in manufacturing, including a

²⁷<http://www.sun.com/storage/feature/2001/08-stg.html>

reduction in product options and configurations.²⁸ Even though many of its EM's have the capability to build-to-order and customize the products, VSP has chosen not to utilize this functionality.

While Hillsboro Operations works directly with end users, VSP organization recognizes that a majority of its products go through the indirect sales channel. Thus, all products are currently build-to-stock and are thus subject to forecasting errors and a potential for excess finished goods inventory held by Sun and/or its channel.

3.1.4 Software Operations (SWOPS)

Software Operations (SWOPS) is a group within operations that distributes released software content to both manufacturing and to external customers. For the purposes of manufacturing, SWOPS is notified by the software development teams when new content is ready for distribution. SWOPS then validates the content and places the content in an accessible location.

For external manufacturing, SWOPS has generally been involved in creating CD's with software content for physical delivery to the vendors. These CD's are then copied at the manufacturer and the copies are physically placed within the same box as the server.

3.1.5 Customer Ready Systems (CRS)

Customer Ready Systems group, or CRS for short, is a relatively new group within WWOPS that offers a factory-integration service. The CRS group orders components from internal and external manufacturing, ships them to the central factory and builds a complete solution for the customer. This is especially helpful for customers who are purchasing complex configurations or multiple copies of systems, reducing logistical and setup delays.

Concerning software installation, CRS works with customers to specify an installation package containing custom applications and configurations. SWIE is involved in delivering this software content to CRS integration centers. Thus, CRS has been a strong advocate for the continued expansion of SWIE's ability to provide custom software.

3.2 Organizational Culture

As a company that helped define the economic roller coaster ride of the 1990's, Sun is well known for its headstrong culture, starting from the top with its outspoken CEO, Scott McNealy. Through its 21 year history, Sun has grown from a startup of 4 individuals to a multinational corporation with approximately 36,000 employees.

Steven Klosterman suggests that Sun has undergone several cultural transformations throughout its history.²⁹ After the initial foundation as a fast-growing startup, Sun began to mature but remained a very flat organization. During the late 80's to early 90's, the flat organization led to problems; there was little product or revenue accountability and customers felt Sun was unresponsive and brash. Very few documented processes were put in place. Management tried a re-organization

²⁸ Knox, Neil and Masters, Clark. "Sun's Systems Strategy", (http://www.sun.com/events/analyst2003/presentations/Knox_Masters_WWAC_022503.pdf).

²⁹ Steven Klosterman, pages 70-134.

into “Planets”, independent product groups for software, processors and hardware that had separate profit-and-loss responsibility.

This blunt separation led to a different set of problems, where one planet became the monopoly supplier of key components to the other planets. This in turn led to severe hold-up situations, where the supplier planet had no incentive to communicate effectively or to improve support. The bureaucracy governing the relations between planets became a major frustration. Decisions made by the planets were locally optimized but damaged the overall mission and focus of Sun as a corporation.

The current structure of Sun was designed to bring Sun back together as a single company with a consistent message and objective. Though this has been successful in eliminating many of the structural barriers between groups, the organizational remnants of the independent entities still exist. Three such vestiges are the diversity of goals, distributed authority and the availability of actionable information.

3.2.1 Diversity of Goals

Having grown from very independent roots and with the informal motto of “kick butt and have fun”, it comes naturally that Sun employees have a wide range of interests and objectives. Though this has fostered significant innovations such as NFS and Java technologies to come to market³⁰, I also believe that some cross-functional innovations are ignored in this environment. Consider the Sun 2004 top down strategy, which is designed to be the guiding document for all corporate activity. The strategy contains 1 vision, 1 mission, 3 strategies, 10 priorities and 11 goals.³¹ Furthermore, most functional groups, such as Human Resources, Operations, Network Storage and Legal, have their own strategies. All of these statements are noble and are individually valuable, and they help every employee at Sun understand their role in the success of the company. Nevertheless, the sheer number of different drivers can be confusing. Projects such as software download fall outside the bounds of traditional employee roles and responsibilities. Therefore, it can be difficult to convince some individuals of the importance and priority of the initiative.

For example, the software distribution and installation capability may fall under two of the priorities and one of the goals. Though this fact proves alignment with corporate goals, employees within Sun may be tasked to execute on a very different set of goals. Comparing the software download project versus other initiatives and responsibilities requires a prioritization decision that can be difficult to make and hard to predict.

3.2.2 Distributed Authority

Another part of Sun’s cultural legacy is the distributed authority to each structural group, including middle management. Unless formal structures have been put in place, there is relatively little cooperation between different teams. Though individual contributors at Sun tend to be polite and respectful, not all feel empowered to make decisions or to offer their expertise without the direct blessing of their supervisors.

³⁰ From Sun’s website: <http://www.sun.com/aboutsun/coinfo/history.html>

³¹ These strategies are Sun Proprietary/Confidential and thus cannot be directly referenced.

Individuals must work up through their own management chain to a point where middle management can influence another group to support a project. The problem is exacerbated when working between functions, such as reaching out beyond WWOPS and into the Business Units. Figure 4 illustrates how it was sometimes necessary to first obtain upper management support before individual contributors feel empowered to participate in a cross-functional project.

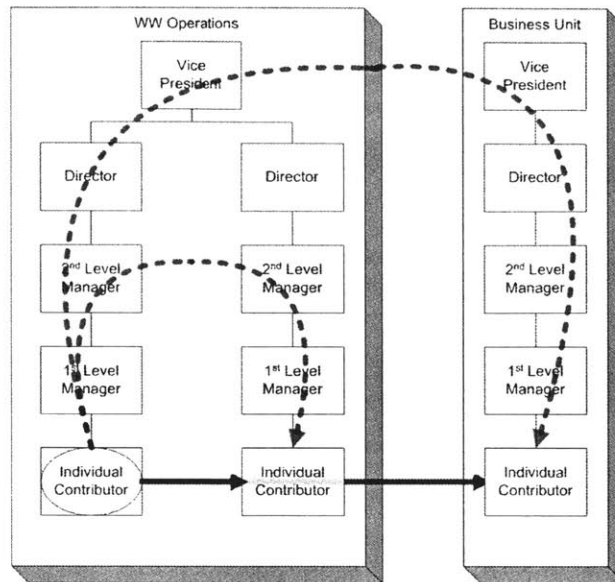


Figure 4: Coordination requires high level support

Even when upper management has agreed upon a certain direction or goal, change management remains a challenge. As with every large organization, there is significant inertia within levels of management and employees towards any deviation from the status quo.

The problem of executing change has been deemed large enough that Human Resources has created a 'Change Acceptance Process' to help Sun's organizations improve the effectiveness of their initiatives. All employees are required to participate in on-line training, and management continues to find ways to improve the agility of the organization.

3.2.3 Dissemination of Information

Another result of the organizational heritage of Sun is that knowledge is highly distributed among the different teams and individuals. A large number of people own small pieces of responsibility, but few people actually have a 'big picture' of Sun's processes.

Pockets of data exist solely on local spreadsheets or in employees' minds. Information is best gathered through referrals and personal contacts as opposed to a central repository.³²

As a consequence, a considerable amount of individual effort is required to coordinate initiatives that span across functional groups. Collaboration is relatively uncommon where a formal bond does not already exist. Marketing, Engineering and Operations will communicate well if they all

³² Sun does have an internal web repository which is widely used. However, the sheer number of documents, acronyms and tools make its usage difficult when one does not know what he or she is looking for.

work on the same product line. However, those same groups may display stubbornness or even animosity towards outside initiatives or projects. Sun suffers from a 'not invented through the proper channels' bias, which is a derivative of the 'not invented here' mentality seen in many engineering organizations. Time and effort are wasted as groups wait for a specific trigger (often coming from a direct manager) to act.

Many times, individual contributors do not even know whom to contact when requiring cross-functional support. One of the benefits of the project has been to introduce his team to groups and individuals that he had no contact with before. Expanding interpersonal networks is particularly valuable in a more global environment where informal contact is less common.

These communication issues have been compounded by the realities of modern global business. Sun has been on the forefront of fostering remote teams and flexible work locations. As a result, many teams within WWOPS include individuals at different locations, time zones and countries. SWIE, for instance, has members in 3 different time zones. Participants in this project from other teams physically sit in other parts of the world as well. Furthermore, given recent cost controls, very little travel is authorized. Therefore, employees must become adept at executing in teams that may never meet face to face.

Despite all of Sun's organizational challenges, it should be highly lauded for its strengths. First, hierarchical barriers at Sun remain very low, and it is not uncommon for an engineer to discuss proposals with managers at several managerial levels. Second, there is a great amount of independence within projects involving a single functional group. Management encourages initiative, and execution can be swift when done under one manager's span of control. Finally, employees at Sun have a fierce conviction that their contrarian vision of network computing has a real opportunity to succeed.

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Chapter 4 Project Motivation

Several reasons exist for developing software download capability for Sun's products. Some of the key reasons, both internal and external, are described in this chapter.

4.1 Sun's Software Distribution / Download Capability

One major factor to explore in software installation at external manufacturers is that the feature is already available for Sun-internal manufacturing. Over the last few years, WWOPS has driven the development of a software distribution, download and installation process that utilizes the existing network connecting internal manufacturing.

As described in Chapter 1, Sun was looking for a way to install current software content on internally manufactured systems automatically. It was also important to have the content revision controlled and tied to the bill-of-materials (BOM).

The Software Download and Installation (SWDL) infrastructure meets those needs in a cost-effective manner. The installation is done through the use of a Solaris feature called Solaris JumpStart™ software that enables the automated installation of multiple systems with identical operating systems.³³ Internally, WWOPS developed special scripts around JumpStart software that link installations to specific software content based on a manufacturing BOM.

As a first step, the operating system is bundled and compressed into a file called a flash archive. JumpStart software accepts this type of file as input, and it will automatically download, unpackage and install the contents once prompted.

Another key feature of JumpStart is its ability to accept content from an http location. This has enabled WWOPS to serve content in a caching architecture identical to the caching of web pages.³⁴ For example, when a target system requires the installation of Solaris software, the test server requests that the appropriate flash archive be executed onto the target unit. Though the test code will point back to a URL, the test server will first scour the web caches for a local copy of the file.

Figure 5 below displays how the infrastructure consists of a series of cascading network caches. Each manufacturing facility has two top-level caches and a multitude of leaf caches. The leaf caches are closest to the target systems and are the first cache to be accessed during a download event. If the immediate cache does not have content, it will first look horizontally to the other leaf caches before pointing upwards to the top-level cache (TLC). Two TLC's per site provide failover redundancy, a requirement for many manufacturing environments. If neither TLC has the correct content, the golden content is taken from the web server. The local caching mechanism shelters the manufacturing floor from Internet connectivity problems and expedites bit delivery.

³³ Documentation explaining JumpStart can be found at:

<http://www.sun.com/solutions/blueprints/1100/jssec-updt1.pdf>

³⁴ Though any caching mechanism can be used, WWOPS has chosen to use the Squid caching software, which is freely available for Unix platforms: <http://www.squid-cache.org/>

The process starts with the original content providers, such as the Solaris OS business team. When a new version of Solaris is available, this team pushes out a 'golden' copy to the web server. Manufacturing is notified of the new version, and an engineer attempts to pull the file from the server in a secure fashion.

If the content is correctly pulled and is deemed ready for manufacturing, the file is pre-populated to the top-level caches. As new orders begin to specify the latest software build in the bill-of-materials (BOM), the leaf caches search for the correct content. The simplified search order is:

1. Check contents of memory and hard drive. If not available...
2. Ping other leaf caches for content and then download to hard drive. If not available...
3. Ping top level cache (TLC) for content and then download to hard drive. If not available...
4. Request TLC to check web server for content.

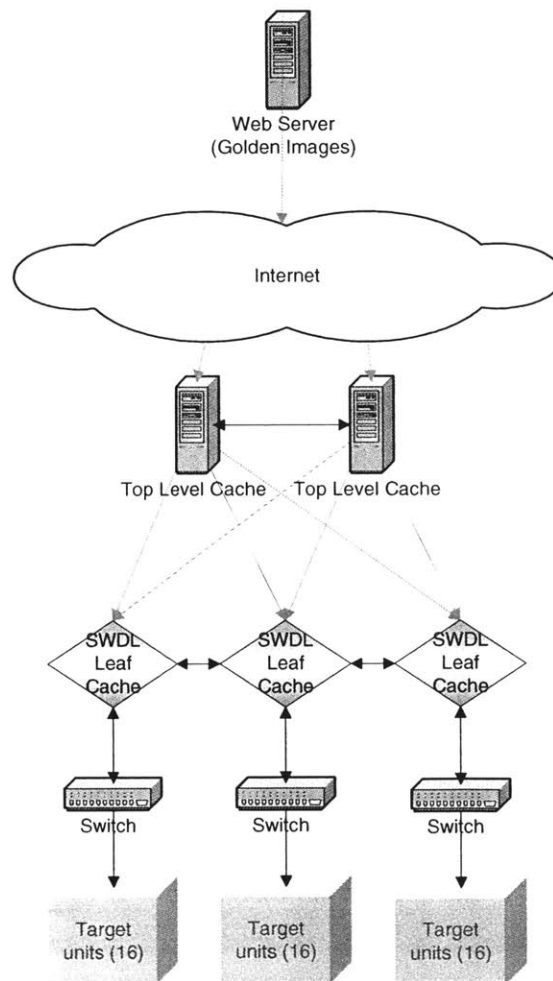


Figure 5: Network cache mechanism

Sun's download method using caches is very valuable in rolling out new software content quickly. Other methods often require manual intervention to transmit and to receive content and then to place the software in the correct location for manufacturing use.

Change control is performed by a combination of the software product teams, SWOPS and SWIE. The product teams create golden content and place it in a specific location on their servers. SWOPS then grabs the content and stores it on the web server. SWIE is then alerted and prepares the content for manufacturing (creation of flash archive, testing, notification of the manufacturing facilities).

Building on these internal capabilities, the project sought to expand software installation capabilities to the external manufacturing environment. As discussed earlier, there were three main goals of the project:

- 1) Understand the existing software download process used at Sun manufacturing facilities.
- 2) Evaluate the ROI of enabling software download at EM's, including an analysis of tradeoffs and minimum requirements, through a pilot at the EM.
- 3) Identify and address significant technical and business barriers unique to working with an EM, such as firewalls, custom processes, network security, vendor management policies and cultural differences.

There were serious questions as to whether transferring an internal manufacturing process to an EM could be done successfully. Chesbrough and Teece argue that innovation within an outsourced environment works best when incentives are aligned and required knowledge can be easily duplicated. These types of autonomous innovations can happen with little direct intervention. On the other hand, if the process uses significant tacit knowledge, it might be a systemic innovation that requires a higher level of information sharing and flexibility for local conditions.³⁵ This thesis contends that manufacturing process technology such as software download capabilities are mostly autonomous innovations that can be shifted to multiple EM's relatively easily. This project should help test this hypothesis.

4.2 Previous Customer Requests

Sun's customers have been demanding a more solutions-centric approach from Sun. The overall customer experience is affected by the amount of time required to place a server into service on site. Compared against other server vendors who offer 'plug and play' capabilities, Sun customers require the extra step of installing the operating system and custom application stack. See Appendix II for more information.

Depending on the number of systems purchased and the technical capabilities of the customer, installation may come in two forms:

- **Image installation** – Large customers prefer this quick method to install an operating system and applications onto new servers.³⁶ In about an hour per system, a technician can install an exact replica of a 'golden image' onto each server, overwriting any content already on the system. This work can also be done in parallel for multiple systems.

Creating the 'golden image' is time consuming and requires a level of technical competency at the customer (or VAR) that is not always available.

³⁵ Henry Chesbrough and David Teece, "Organizing for Innovation: When is Virtual Virtuous?", Harvard Business Review, August 2002, pages 127-135.

³⁶ Image installation is performed via an application called JumpStart that is described in more detail in Section 5.1.7: Software Installation Options.

- **CD installation** – This process requires insertion of CD’s and then navigation through interactive menus. After the base operating system installation, the operator must install patches to update the OS for critical defects. Overall, the process may take around half a day for a mid-sized server. Unlike image installation, multiple systems cannot be completed as easily in parallel. In addition, this does not include the additional time required to load other applications, which is always the case.

Small and medium sized customers are more likely to use the CD installation method, since image installation is only worthwhile when multiple systems are ordered. These customers may also lack the technical resources or revision controls needed for ‘golden image’ creation.

Due in part to Sun’s detachment from the majority of end customers, particularly small/medium sized businesses serviced by the indirect channel, there is no clear view as to what method is used more. However, interview results indicate that most VARs and small customers may use the CD-based installation method.

Sun does have direct contact with large corporate customers with considerable investments in technology personnel and infrastructure, but this may give a skewed view of the general level of competency of customers. Many smaller customers can not afford the in-house expertise required to install and maintain Sun equipment. Therefore, many end customers using Sun servers feel the pain of software installation, either through the expenditure of direct labor time or by contracting a VAR for services. Software installation becomes a hidden cost that affects the total cost of ownership of the server.

Thus, factory software installation becomes a customer satisfaction issue. Sun’s past behavior on software installation may create an environment where smaller customers are more inclined to transition from Sun for more user-friendly vendors. Sun’s customer base becomes even more technical, reinforcing the perception that ease-of-use is not necessary. In the long term, Sun may struggle to attract new customers that are unwilling to invest the effort required to make Sun systems successful.

In response to these customer concerns, Sun would like to move to a supply chain that considers deployment as part of the customer value. Figure 6 describes how Sun plans to move towards solutions thinking to solve customer needs.

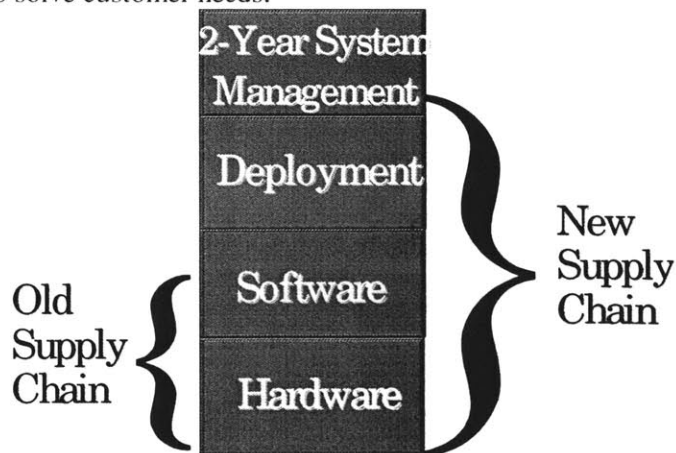


Figure 6: What customer’s buy from Sun

Sun traditionally has had strong product offerings in hardware and software. However, the company has not held a competency in integrating hardware and software together and deploying solutions to the customer. This project, among others, helps Sun create a new supply chain that places emphasis on the customer experience with all of Sun's products.

4.3 Competitive Offerings

Another key driver for the push towards software installation capabilities has been the strategy of Sun's competitors to offer more integrated hardware and software solutions. Sun is currently at a competitive disadvantage in regards to software installation capabilities.

For example, consider the products that compete directly against Sun's Sun Fire™ V480 volume server in Table 2.

All of Sun's major competitors already provide the option for a full factory installation of an operating system. Sun stands out in its inability to do so. Currently on the V480 server, Sun provides a 'boot stub', which prompts the end user at startup to install a full operating system (either through CD's provided with the server or through a customer created image).

Table 2: Comparison of competitive products

Company	HP	HP	Dell	IBM	IBM	Sun
Model	ProLiant™ DL580	Integrity rx5670	PowerEdge® 6650	xSeries® 360	pSeries® 640	V480
# of processors	1-4	1-4	1,2,4	1-4	1,2,4	1-4
Factory SW Installation Available?	YES – for some available operating systems	NO	YES – on ALL operating systems	YES – for very limited OS selection	YES – AIX installed in configuration	NO
Notes	Non-installation actually costs \$90 more for Windows Server 2003 Standard Edition + 5 licenses ³⁷	Itanium processor, only offers Windows and Linux enabled packages	Can either choose no OS or pre-installed OS only.	Most OS options are "customer provided and installed". Only 2-3 options can be pre-loaded	Linux available installed through IBM's channel	'boot stub' OS installed allowing customers to turn on system and then install real OS from CD or image.

The value of factory installed software is difficult to quantify directly, as the service is usually provide free of additional charge by the equipment manufacturers. However, there is a licensing

³⁷ Cost for Windows Server 2003 Standard Edition with 5 Client Licenses:
 HP (installed) = \$699; HP (not installed) = \$789; Dell (installed) = \$799

fee for the installed operating systems, the cost of which may include some margin for the installation capability. Generally, industry professionals view factory software installation as a step towards mass customization.

Sun will improve its positioning if it can follow the lead of its competitors and provide software pre-installed on its servers. A further step would be to offer choices in operating systems and pre-loaded applications.

4.3.1 Sales and Distribution Channel Relationships

Competition also comes from Sun's own partners in the indirect channel. The VARs offer a variety of installation services, including the installation of software operating systems and custom applications.

Some manufacturers, such as Dell, consider factory software installation of both standard and custom components a competitive advantage. Dell believes customization enables it to streamline its distribution channel by taking away profits from resellers. Furthermore, Dell believes that the reduction of 'touches' also reduces costs; the company can perform customization more efficiently than third parties.

Sun is in a very different situation due to its heavy reliance on the distribution channel. Therefore, many people at Sun are concerned that expansion into mass customization, including software installation, will damage the close relationship with the channel.

In interviews with Sun employees responsible for VAR satisfaction, the fear turned out to be unfounded. In the view of VARs, they often include basic software installation as a free service with the purchase of hardware. Thus, a reduction in this non-value effort would actually be appreciated, especially for VARs whose own technical resources are stretched thin.

Nevertheless, VARs do have some valid concerns around software pre-installation. First, many customers, particularly government agencies, qualify a specific software revision and use that version for a long time. Will Sun be able to provide pre-load options for these outdated OS versions? Second, since the indirect channel requires time to expend inventory, how will VARs know what software has been loaded on any given system?

4.4 Internal Initiatives

4.4.1 Existing WWOPS Strategies

Customer Ready Systems (CRS) and Enterprise Installation Standards are indications that WWOPS is already moving towards a solutions-centric strategy. Systems Integration through CRS has enabled customers for the first time to get a complete system – servers, storage, software, cabling – from Sun. Software installation from SWIE provides CRS with the framework to deliver software solutions. Enterprise Installation Standards, on the other hand, define best practices for the field and for the customer. Sun can now offer a software OS and patch bundle that meets most needs, reducing complexity for the end user.

Therefore, factory software installation can be seen as another way in which Sun can provide more complete products to the market.

4.4.2 Sun Java™ Enterprise System Rollout

The Java Enterprise System (JES) has become a major impetus for the development of factory software installation. In order for JES to be an effective marketing tool, it must achieve a maximum amount of exposure.

Initially, JES will be available for trial download from Sun's website. However, the barrier for adoption remains relatively high, since users must be made aware of the application stack and must have enough interest to obtain the software. In response to this barrier, Sun has chosen to include JES on hardware systems where appropriate. As a side consequence, many product lines will need to install a full operating system first so that JES can be installed on top. Though a hard date has not been set for full compliance, product lines have begun considering the potential repercussions.

Some product teams have been resistant to this change, arguing that their customers do not want or need JES. Opponents also claim that most of their customers will ignore any content pre-loaded onto the systems. Interestingly, many of the same arguments have been made against software installation, and this subject will be explored further in Section 5.4 Organizational Analysis.

As a credible means by which to load JES onto servers, software installation becomes an important part of Sun's strategy.

4.4.3 Quality

Quality in servers has been notoriously difficult to achieve for all technology vendors, and Sun has been subject to the same quality concerns. One key driver of this project is the potential to enhance quality in four ways:

HW validation on current Operating System – Since volume servers are currently installed with an older version OS (if at all), there is some possibility that customers will be exposed to a problem that was fixed in a later software release. Thus, the perceived out-of-box quality is improved. In addition, combining the hardware with the latest software will allow Sun to be the first to test compatibility instead of the customer.

Reduce potential of human error – The current process forces customers to install the latest software version themselves. Though this is generally a painless procedure, some human factor mistakes can happen, especially with novice customers. Software pre-load ensures that the customer starts off on the right track with a workable operating system.

Customer perceived quality – End users often complain about problems with the operating system that have been fixed by more recent patches. With Volume Systems Products group's previous strategy, either old operating systems or no OS were installed. As a result, customers unaware of new patches may think software quality is poor. Installing up-to-date patches will improve the perception around quality.

New fault management technologies – In addition to defect fixes found in newer OS versions, Sun has also incorporated a suite of fault management tools into more recent patches. These tools help improve service uptime and enhance system manageability.³⁸

³⁸ More information about Fault Management Technology can be found at the website:
<http://www.sun.com/servers/dependability/>

Volume Systems Products group currently does not track software as part of its quality metrics due to the static or non-existent nature of the software content placed on its systems.

4.4.4 Time-to-deployment and Engineering Costs

Time-to-deployment describes the period it takes to propagate a software change into manufacturing. With Volume Systems Product group's current methods of software installation, any change to software content can be a long process taking almost a month to complete. Content is first developed and packaged by a Sun software engineer and then sent to WWOPS, where the content is validated. Finally, copies of the content are mailed to manufacturing sites on CD's or hard disks. The time delay is exacerbated by the use of multiple EM's in widely dispersed geographies. Content must be shipped to each location individually.

As a corollary to the time-to-deployment issue, significant engineering resources are required to create updated content within the current methodology. Each software update requires a build by a software engineer with the proper content and partitions. Operations engineers then need to customize the master copy so that it works correctly on the supplier hardware options. Different hard disk vendors and disk sizes may affect functionality.

A third concern is the lack of process around software updates. For most volume product lines, a specific software revision is qualified when the product is first released to manufacturing. From that point, minimal effort is made to qualify newer patches and changes. Consequently, the same software revision could be installed for several years, leading to an operating system that may have critical defects and lack important new features Sun would like to circulate.

Any new software installation capability must be designed for easy updates and include a revision control mechanism.

4.4.5 Mass Customization

Mass customization has become a major influence to electronics manufacturers. The ability to mass produce and still customize inexpensively has become the mantra of companies such as Dell. However, Sun has a long held belief in optimizing around mass production techniques.

Many organizations find the transition to mass customization difficult due to the counter-intuitiveness of some of the supply chain changes required for success. Mass customization assists with a concept called market mediation, which matches the selection of products with the customers' preferences. Fisher suggests that there are two classic functions of a supply chain: that of the physical function – the movement of raw materials and goods, and that of market mediation – managing product supply to meet demand and minimize lost sales.³⁹ For innovative products with short life cycles and high margins, failing to deliver a product customers want results in significant losses in revenue.

Thus, Fisher states that the ideal supply-chain strategy for a given product can be found by matching the product type (innovate vs. functional) and supply chain (responsive versus efficient) in a 2x2 matrix (Figure 7):

³⁹ Fisher, Marshall L. "What is the Right Supply Chain for Your Product?" Harvard Business Review (March-April 1997): 105-116.

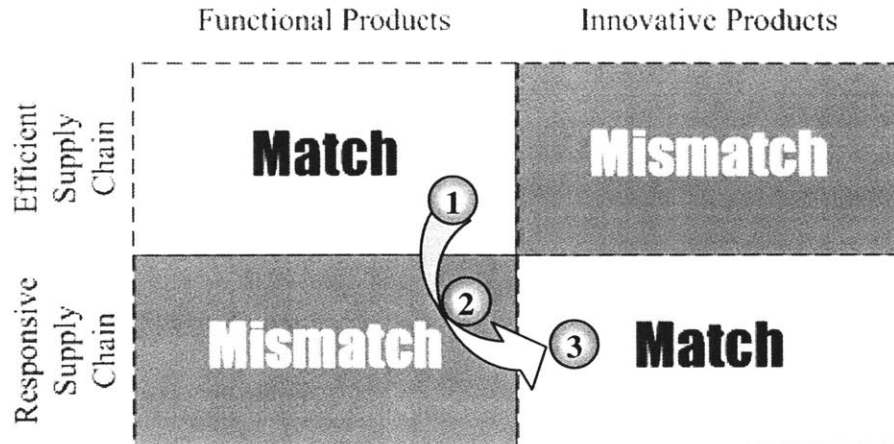


Figure 7: Matching supply chains with products (Fisher:109)

In my opinion, Sun's Volume Systems Products group builds servers that straddle between functional and innovative. Though there are competitive offerings that offer similar functionality and performance, profit margins remain healthy, life cycles are short and demand is unpredictable. Nevertheless, Sun has designed its supply chain to be efficient (low inventory, flat BOM structure, part number minimization, infrequent changes) rather than responsive.

Immediately, this model demonstrates one of the difficulties of this project. The addition of software content, especially customized content, is an attempt to migrate volume servers into the innovative product realm (2 → 3). However, the supply chain is not yet ready for this transition.

This project steps the supply chain towards a more responsive and flexible supply chain (1 → 2). Unfortunately, this change is occurring *before* the innovative product strategy has been clearly enunciated to the organization. Thus, there is a perception that a mismatch between the product type and supply chain will emerge from this project, which invariably leads to resistance to change. Organizational experience and initiatives to create functional products with a more efficient supply chain have to be acknowledged and dealt with.

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Chapter 5 Project Implementation/Methodology

As part of the project implementation, planning was required to gain enough organizational support, to choose the appropriate external vendor(s) and to design a technical and business implementation that could be used in the pilot.

The negotiations surrounding each of the four tasks involved very different stakeholders and tasks. Each will be discussed in the sections below.

5.1 Technical Implementation

This section covers all the technical aspects of the project, from deciding minimum requirements to treating all networking, file sizing and security problems.

5.1.1 Summary of Technical Challenges

In preparation for this project, a variety of stakeholders were polled about the potential technical challenges involved with enabling factory installation of software at the EM's. Since software installation had been limited to high-end servers in the past, there was significant uncertainty about the risks of adding this factory feature into volume manufacturing. Individuals at Sun involved with outsourcing were also skeptical about the applicability of the internal manufacturing processes to the external manufacturing environment.

First, there were the standard challenges that are associated with any change to a manufacturing process. These factors include manufacturing cycle time, labor touch rates, capacity constraints, inventory levels and manufacturing flexibility (e.g., changeover times). Additional considerations when dealing with external manufacturing environments are scalability of the manufacturing feature and transferability to other locations and even other vendors.

Secondly, the network architecture of the internal solution requires additional performance measures:

Transfer rate: When connecting to vendors over the Internet, the transfer rate is constrained by the section of the connection that has the smallest bandwidth. What transfer rate to the EM could Sun tolerate?

Reliability: of the Internet connection. Can we trust that the EM's own network infrastructure and service providers would be stable enough for use in a manufacturing environment?

Security: With the proprietary nature of the software content to be sent to the EM's, how does Sun ensure that only the appropriate parties gain access?

Next, working in a higher volume environment requires the consideration of several factors that were not critical for high-end manufacturing. Manufacturing metrics such as qualifying updates, deploying ECO's (engineering change orders) for software and vendor expertise become important. The experience level of the engineers and technicians can vary widely between different vendors and even different manufacturing sites, especially around the integration of software content.

Finally, besides network architecture, it was useful to work with an EM that had already implemented Sun's test scheduling program. This program is run from the test servers and exercises the target units with a variety of executables designed to uncover hardware or software failures (in a manufacturing step called System Functional Test, described in Section 5.1.3). SWDL, as it is implemented in internal manufacturing, runs as a software module within the test scheduler. To reduce the work overhead, preference for the prototype project was given to EM's that had this in place. Otherwise, additional engineering would be required to install SWDL into a foreign test scheduler.

When choosing the EM, we considered all these attributes, finally settling on an EM and location where we felt we had the best opportunity for success. The EM chosen is a top-ten contract electronics manufacturer with an established relationship with Sun⁴⁰. The prototype was to be run at one of the EM's large European manufacturing sites, with some support from an American location.

5.1.2 Engineering Commitment and Costs

When working with external vendors, additional work outside of standard manufacturing often costs money due to Non-Recurring Engineering (NRE) costs. This project was an exception to this guideline because the EM decided that the work required for the pilot was covered under current product engineering. Furthermore, the EM perceived an opportunity to lock in additional business from Sun, so this was an investment to build stronger vendor bonds.

5.1.3 External Manufacturing Characteristics

The external manufacturer assembled two server models for Sun, each of which had 3 distinct configurations. The combined quarterly volume was over 10,000 units.

The first step of understanding manufacturing impact was to map out the current production process at the EM (Figure 8 below). This represents a simplified material flow from order to finished goods. Some of the key steps:

Order In – For volume products, Sun has its EM's build to forecast. On a periodic basis, the EM will manufacture the forecasted model in batches.

Kitting/Build – The EM pulls the appropriate parts based on the bill-of-materials (BOM) and then assembles the product.

System Functional Test (SFT) – The fully assembled unit-under-test (UUT) is connected into the test server and diagnostic functional tests are executed on the UUT. For a majority of the units, this is the final pass/fail test before shipment to customer. The length of SFT is dependent on model and configuration, but for the purposes of the thesis, we will assume that this stage takes over one day.

At the end of SFT, the small 'boot stub' OS is installed on the target system that will give the end user just enough functionality to install a proper OS onto the system. This boot stub generally does not change once a model is sent into production.

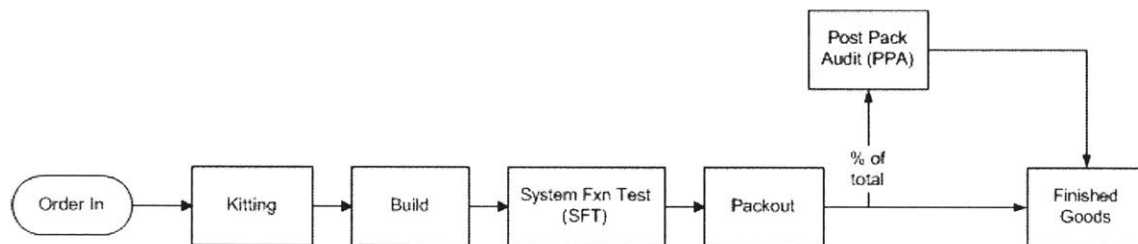
⁴⁰ Based on total revenue in 2002. Source: "EMS Industry Bottoms Out" – September 18, 2003. <http://www.manufacturing.net/pur/article/CA323194>

The SFT stage is completed in a test bay area with dedicated test servers. Each test server can be connected to up to 16 units simultaneously through a switch.⁴¹

Packout – Tested units are packed and boxed in preparation for shipment to Sun’s distribution center or directly to the customer.

Post Pack Audit (PPA) – As part of Sun’s commitment to improving quality, a fraction of all finished units undergo the Post Pack Audit procedures, which is a final check to ensure outgoing product quality. The percentage going to PPA is dependent on product, but it is a required step mandated by Sun’s quality group. Units are unboxed, cabled in and booted up. The operator checks to see that the server displays the correct startup messaging and other boot parameters. If all checks look correct, the hard disk is flushed (the boot up process writes to the disk) and the unit is boxed and shipped.

PPA is performed in a test area separate from SFT. Test servers are still required to log results of PPA. The PPA process takes approximately one hour.



EM Manufacturing Process

Figure 8: External Manufacturer manufacturing flow

5.1.4 Project Scope and Length

Once the EM was chosen using the criteria in the previous sections, a project plan was needed to define the scope and length of the engagement. Consequently, a requirements document was created that listed objectives and expectations.

The project was scheduled for 2 months (October – November) at the beginning of a low volume quarter.⁴² It was believed that this time period would ensure more attention from the EM technical staff and would reduce interference to mainline manufacturing.

The project goal was to demonstrate the technical and economic feasibility of Sun’s software distribution and installation capability at the EM. Those objectives were achieved through the following specific deliverables:

1. Measures of success (Section 5.1.5)

⁴¹ The actual capacity of the test bays is dependent on the product model and configuration. 16 units is the maximum for one specific configuration.

⁴² The prototype project actually took from October through January due to some delays and vacations. However, the expected deliverables were achieved without affecting production.

2. Development of file transfer infrastructure between Sun and the EM (Section 5.1.6)
3. Delivery and installation of fixed OS configurations via software download (Section 5.1.7)
4. Determination of change control and SW validation requirements (Section 5.1.8)
5. Infrastructure options analysis (Section 5.1.9)

Each of these deliverables had minimum requirements and stretch goals, described in their respective sections.

5.1.5 Metrics

The following table shows the metrics that were measured during the course of the pilot:

Table 3: EM pilot metrics

Metric	Purpose	Collection Responsibility
Bandwidth usage	Does Software Download inhibit other data transfers? Does it need to be a scheduled event?	EM's IT department
Transfer success rate	How often do we succeed in pulling files from the web server?	EM's IT department
Cycle Time	SWDL impact to manufacturing	EM's Manufacturing
Labor time	Do we need more operators?	EM's Manufacturing
Process Changes	What behaviors and flows must be modified?	EM / Sun
Infrastructure Requirements	SWDL hardware cost to manufacturing?	EM
Infrastructure Failure Analysis	What are the potential failure modes of SWDL, the impact and mitigation plans?	EM / Sun
Cost	What is the overall cost for both startup and sustaining engineering?	EM / Sun

The metrics are fairly self explanatory. The items in bold are important as part of the final decision and deployment process.

There were several other factors considered during the pilot. One such point of interest is the effect on overall quality. Quality in the installation of software has not been an area of much research. It is usually assumed that the installation works without a glitch as long as the process is completed.

In this situation, there was a concern about software quality, particularly around the following questions:

- How do we track software's effect on overall quality in a direct ship to customer environment?
- Will software quality affect the ability to identify hardware problems through trend analysis?

Internal manufacturing, particularly Hillsboro Operations, had been grappling with such concerns for several years, and this team was able to respond to the concerns:

Tracking software quality – Generally, the problems are minor and result in relatively painless software reload. This has occurred less than 1% of the time.

Software effect on hardware quality tracking – In all of the failure analyses done on DOA parts, none have been attributed to a software problem. Software has neither caused nor masked a hardware defect; therefore it has not had a material effect on the correlation of hardware trends over time.

5.1.6 Content Distribution Options

Section 4.1 described Sun's current software distribution process for internal manufacturing. Unfortunately, the internal methodology is not feasible for EM's given the security and firewall restrictions placed by Sun's IT security group. External parties cannot have access to any web servers or network drives within Sun's intranet. As a result, a new solution for content distribution had to be found.

For the purposes of the project, a file transfer was required that met the following requirements:

- Large file content capability - can handle files up to 2 GB
- File aging - automatic removal of old files
- Good outbound transfer speeds (1 Mbit/sec)
- Strong security - digital certificates or equivalent
- Checksum capability - to acknowledge a good file transfer
- Relatively low cost
- High automation content

Several alternatives were considered. Briefly:

Virtual Private Network (VPN) – A VPN is a dedicated connection between Sun and an external location or company. This connection is secure and can be high bandwidth, depending on configuration. Furthermore, VPN allows direct access into Sun's intranet. However, there are very high fixed costs associated with installing a dedicated line, since the connection must be maintained by Sun. In addition, a VPN allows unfettered access into Sun's intranet, which is more access than is warranted.

Internet Service Providers – Another choice is to host the software content through a third party vendor. Many such vendors exist within local markets, and they can provide reliable connectivity to specific content. Costs are based on several factors, including data stored, bandwidth used, transfer speed, cabinet rental and overage penalties. Since a third party is used, flexibility comes at additional cost. From outside quotes, recurring costs amounted to approximately \$300/month for most vendors.

Internal hosting – One option is to find an internal group to host an externally viewable server. Though this option is not available in all situations or corporations, Sun has a hosting facility. Costs are hidden, as the cost of hosting is absorbed into the internal infrastructure.

FTP – A traditional way to transfer files between Sun and its vendors is the secure File Transfer Protocol (ftp). Though reliable and safe, ftp has the drawback that it cannot be automated using the caching mechanism. Each file must be discretely updated and cannot take advantage of the automated content verification of caches.

'SunExchange' – This is another internal tool that offers secure, browser based data transfer to exchange data between Sun and its business partners. Though a very good tool for transferring files via the Internet and automating some of the process, it was also incompatible with the caching mechanism.

A table summarizing the options and their advantages/disadvantages is shown below:

Table 4: File transfer comparisons

Content Distribution Option	Advantages	Disadvantages
Virtual Private Network (VPN)	<ul style="list-style-type: none"> • Secure • High bandwidth • Compatible with current caching system 	<ul style="list-style-type: none"> • Highest fixed costs for operation • Security concerns – allows unfettered access into Sun
Internet Service Providers (ISPs)	<ul style="list-style-type: none"> • Secure (through IP authentication) • High bandwidth available • Maintenance managed externally • Flexibility of services provided • Compatible with current caching system 	<ul style="list-style-type: none"> • High fixed and variable cost for operation • Physical location of content remote from Sun
Internal Hosting	<ul style="list-style-type: none"> • Secure (through IP authentication) • High bandwidth • Compatible with current caching system • Cost of connection 'sunk' (paid for by other Sun groups) 	<ul style="list-style-type: none"> • Support on 'as available' basis only
FTP	<ul style="list-style-type: none"> • Secure • Inexpensive 	<ul style="list-style-type: none"> • NOT compatible with current caching system • Manual transfer of files only
'SunExchange'	<ul style="list-style-type: none"> • Secure 	<ul style="list-style-type: none"> • NOT compatible with current caching system

A decision was made to use the internal hosting option because the cost for the existing infrastructure was already sunk; thus the incremental cost to SWIE was minimal. Negotiations between SWIE and an IT group involved with web hosting were successful.

5.1.7 Software Installation Options

Besides the numerous file transfer possibilities, there are also multiple methods by which software content can be installed onto the target machine. Each of these options offers certain benefits while posing specific challenges in implementation. Generally, the choices hinge on four

key characteristics: flexibility, scalability, the need for a network infrastructure in manufacturing and cost.

Flexibility – How easy is it to update content being installed? Does mass customization remain an option?

Scalability – Two questions: First, how is the current manufacturing process impacted by this new step, particularly in volume environments? Second, can the methodology scale for larger sized images (e.g., Java Enterprise System + Solaris)?

Need for network infrastructure – How connected is the EM's manufacturing floor with test schedulers and metrics collection? In particular, the JumpStart and Quark options described below are only possible when the EM's manufacturing floor can be reached via the network.

Cost – What are the costs associated with deploying the installation across an entire manufacturing floor or to other EM's?

The software content to be installed consisted of three discrete packages:

1. Solaris Operating System – approximately 1.2 GB
2. Solaris OS patches – approximately 200-300 MB, depending on the age of the installed OS.⁴³
3. Java Enterprise System (JES) – approximately 1 GB. This content was not available until the end of the project.

Due to JES unavailability, the cumulative file size for the prototype was only about 1.5 GB. When JES is on hand, the total file size will reach 2.5 GB.

Several options were available for consideration at the EM's Sun has worked with:

Pre-built image (PBI) – For the prototype EM, the current software load procedure is to install a boot stub immediately after SFT.⁴⁴ A copy operation using the UNIX 'dd' command installs the image onto the target unit's hard drive. The copied image checksum is verified after install to ensure it copied correctly.

PBI has the advantage of being very lightweight and easy to update. Unfortunately, the process cannot handle a full operating system installation due to speed and size limitations of the capability. With a potential future state for Sun of a combined Solaris OS and Java Enterprise System installation on hardware, clearly PBI would be unable to handle the task.

Hard Disk Duplication (HDD) – This describes the process of loading a hard drive with a static image before the hard drive is incorporated into the final assembly. Usually, two separate 'slices' of data are loaded onto the disks. One slice is for manufacturing test purposes while the other is for customer installation. The customer installation, once booted, will delete the manufacturing slice.

The slices represent an exact bit-by-bit replication of the contents of the exact same model of disk drive. Any changes in disk drive vendor or configuration requires a new HDD image to be produced.

⁴³ As the installed Operating System becomes older, it also becomes more out-of-date with patches. As a result, the size of the patch load increases until they are incorporated in a newer update of the OS.

⁴⁴ As mentioned in Section 4.3, a 'boot stub' OS is installed, allowing customers to turn on the system and then install a full OS from a CD or image.

The disk duplication process can occur before the final assembly stage. In some cases, the hard drive vendor may offer to image the disks prior to delivery. The actual process is completed using a machine colloquially known as a 'disk blaster'. Disk blasters start with a master hard drive pre-installed with the target content. They duplicate the content onto any number of target drives. These products can make between 4-16 duplicates simultaneously with speeds up to 2 GB/minute. Disk blasters cost around \$4000 - \$6000 per machine.⁴⁵

A significant disadvantage of HDD is the update delay. This one-month process is described in Section 4.4.4 and applies specifically to the HDD process. With HDD, each vendor must be sent a copy of the disk, which can become a logistical nightmare.

Another disadvantage is the buildup of disk drive inventory with an old image load. Since the content can be placed months beforehand, Sun must decide whether to exhaust existing inventory or to re-image the disks whenever a software update is available.

HDD is used primarily in the low end of the volume space. It has been considered for mid-level servers, but it has not been implemented.

PB – PB is a homegrown application. Disk partitioning and image content reside in different files that both must be available for the process to work. A UNIX command is first run to partition the disk appropriately. Next, another command is run that actually overlays the operating system bits into the proper partition. Thus, this utility is considered more rudimentary than HDD, because an extra step needs to be taken in order for the partitioning to be set.

PB suffers all of the same problems as HDD, with the addition of being a proprietary process with minimal supportability.

JumpStart and Q – Q is a term used in this thesis for a proprietary suite of scripts wrapped around the JumpStart application that allows the SWIE group to automate the software download and installation process for manufacturing. It is the current methodology used internally to install content onto target systems.

For captive manufacturing, JumpStart installation is performed immediately after test and before packout. Each target unit, if uniquely identified, can actually receive a different installation based on the BOM. The Q scripts parse the software part number from the BOM, correlate the part number with a particular image and then instruct JumpStart to install the correct software content. Thus, disk drive inventory is held in an unaltered state before final assembly; image changes do not require a massive inventory adjustment. Furthermore, JumpStart/Q can fully utilize the cached infrastructure described in Section 4.1 to quickly update the available images.

In terms of software deployment times, the Q method, coupled with the caching infrastructure, can be updated within hours to all manufacturing sites (internal and external) simultaneously. Of course, each site will need to undergo a qualification process with the new content, but distribution becomes dramatically simpler and the accuracy of the content can be easily verified.

Finally, the combination of Q and the cache infrastructure leads to the real possibility of customizing the content placed onto systems to match customer needs.

⁴⁵ Information retrieved from several web searches. Sample systems include the ICS Image MASter 4008i and the Logicube OmniClone® 15U Hard Drive Duplicator.

On the other hand, the JumpStart/Q combination is significantly more complicated than either PB or HDD, requiring the EM to have a solid network infrastructure and appropriate business processes. Some of the minimum requirements identified were:

- 1) Reliable internal network connection to manufacturing floor (minimum 100 MB)
- 2) Reliable broadband Internet connection (minimum T1)
- 3) Test scheduler (to initiate software download and record results)
- 4) Familiarity with caching mechanisms
- 5) Good engineering relationship with Sun

All available options were then considered head-to-head:

Table 5: Relative comparisons of software installation options

	PBI	HDD	PB	JumpStart	JumpStart/ Q
Flexibility (to change SW content)	0	-	-	+	++
Scalability for Volume	0	+	-	+	+
Need for Network Infrastructure	0	0	0	0	-
Cost	0	0	+	-	-

From the table, there is no clear choice; each method has its own advantages and drawbacks to contend with. Thus, it is important to rank the 4 criteria.

With Sun's emphasis on JES availability, the relative weight of the scalability and flexibility attributes becomes much higher. As a result, the team chose to employ the JumpStart/Q mechanism for the pilot project.

5.1.8 Change Control

The level of software change control in manufacturing varies drastically among product groups. For high-end servers, the manufacturing test engineers receive content from SWIE and perform validation testing. Once the new software package is approved, the new content is phased in on new manufacturing starts.

In contrast, many volume product lines have not defined a procedure for updating software content in manufacturing. There is no good method to modify the software content installed onto new systems.

Part of the complexity derives from the disposition of the system type. High-end systems are Assemble-to-Order (ATO), which means that their configurations are definable by the customer. Volume systems, on the other hand, are Pick-to-Order (PTO), meaning they are built to fixed configurations to a quarterly forecast. Sun's policy for PTO systems is that any change to a subcomponent compels a change to the marketing product number.

Since customers sometimes qualify a specific marketing product number, Sun is generally reticent about performing such a change. Such stringent qualifications are particularly the norm

in government, military and telecommunications markets, where any hardware modifications must be documented and approved. Software changes, however, may not require the same type of control and product number changes, since there is no *physical* alteration to the product. Nevertheless, Sun's volume products groups have so far argued that the PTO configuration prevents them from making any software changes to those products once a configuration is set. Software updates may only occur, if at all, when a major hardware subcomponent is modified. Furthermore, as mentioned in Chapter 3, Volume Systems Products group has a long-standing position that the number of products and configurations offered should be reduced. Configurable or frequently updated software is contrary to this objective.

5.1.9 Infrastructure Options

Several different infrastructures were considered for deployment. The main solutions are shown in Appendix III. Each option had its own advantages and disadvantages associated with either price or performance.

Internal equipment transfer costs were used in the analysis, since Sun would move equipment to the EM to support manufacturing. Alternatively, some capital equipment was idle due to shifts in manufacturing strategy, so those servers could be deployed as well.

Due to the proprietary nature of internal transfer costs and capital equipment quantity, a full cost analysis has been omitted from this thesis. However, the appendix does provide a comparison of the viable options and some of the advantages/disadvantages of each.

5.2 Results of Technical Implementation

5.2.1 Content Distribution Decision

After discussing the distribution options shown in Section 5.1.6, the team decided to use internal hosting allowed us to set up a 'De-Militarized Zone' (DMZ) server that was outside of Sun's firewall but still accessible from inside Sun so that appropriate content can be 'pushed' out (See Figure 9).

The boxed area on the left is what currently exists to support software installation for internal manufacturing. On the bottom right hand side are the EM's, who have previously been disconnected from Sun's caching infrastructure.

Apart from the normal process used internally to support high-end operations, a Sun employee would manually push content packages to the DMZ server. From there, EM's could pull the content using the existing caching capabilities. Security is handled through identifying the EM's IP addresses; only pre-approved EM's will have visibility into the server.

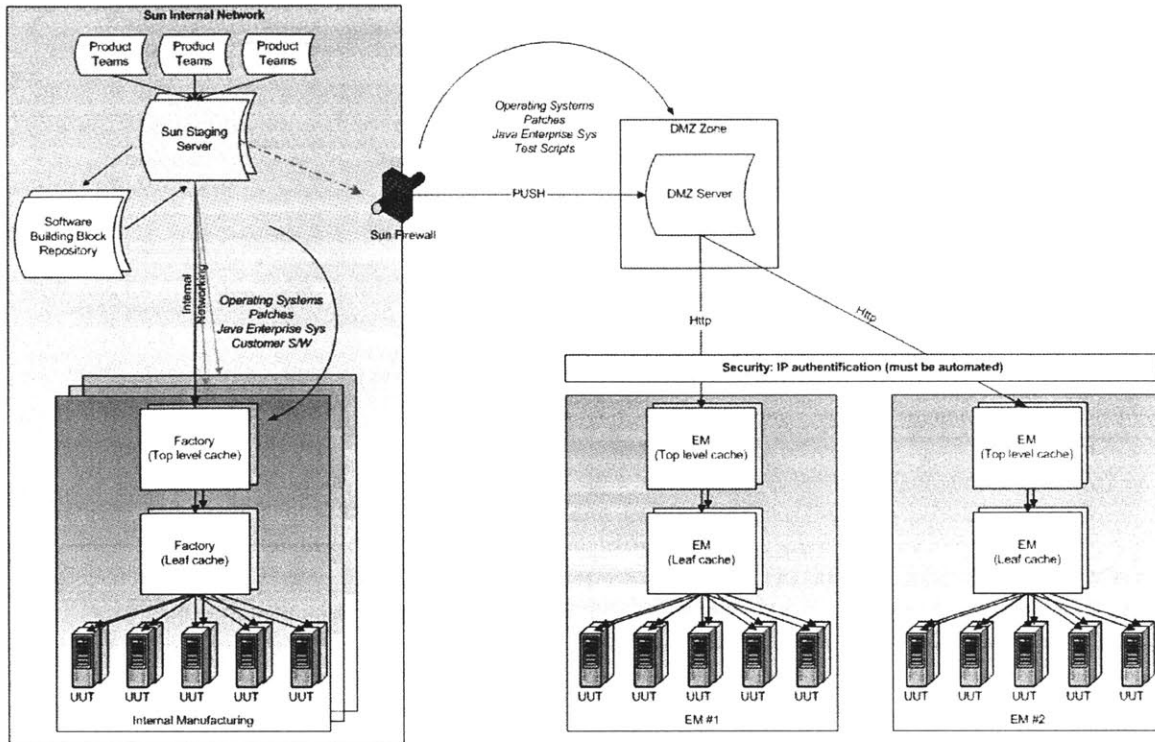


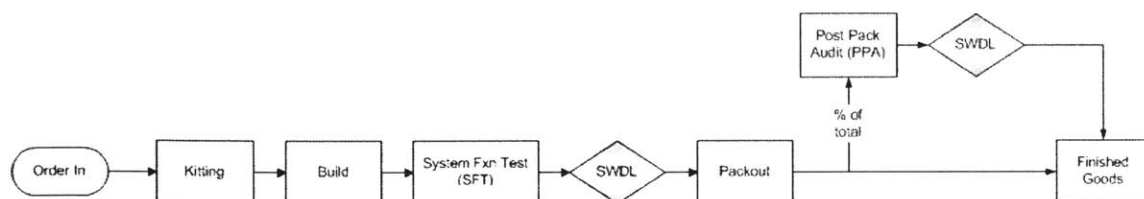
Figure 9: Content distribution solution

Once content is sent from the DMZ onto the EM's top level cache, the content will be pulled by the leaf caches (via the Squid cache) for installation purposes. The Jumpstart/Q mechanism is then used for the actual software installation onto the target units.

Initial trials show a download speed of up to 3 MB/sec. This is much faster than the EM's capabilities (30 KB/sec). Therefore, the DMZ server will have no problem accommodating multiple downloads from EM's in the future.

5.2.2 Impact on Manufacturing

Having agreed upon a network infrastructure, there was still the question of how the software download process could actually be implemented on the factory floor. What was the best way to utilize existing infrastructure, capital equipment and floor space without drastically increasing labor or material flow complexity?



Future Process with Software Installation

Figure 10: Proposed changes to the manufacturing process

In Figure 10, the planned manufacturing change of adding a software installation step into production is described. This process, labeled “SWDL” in the diagram, occurs after System Functional Test (SFT) and Post Pack Audit (SWDL stands for Software Download, the internal name for the entire software install process). The placement of SWDL after SFT makes the most sense, since there is a reasonable assurance that the target unit hardware is not defective by this point in the manufacturing process. Placing SWDL anywhere earlier in the process would lead to difficulties in diagnosing the root cause of any downstream defects.

At the end of PPA, the hard disk is flushed to return the system to an untouched state. Therefore, SWDL must be re-run to load the appropriate content for such systems.

5.2.2.1 Manufacturing Capacity

A critical question was whether the software installation would have a significant impact on capacity. Sun and the EM have devised a process to determine the amount and type of capital equipment required for each of the current test stages (SFT and PPA). This model takes the quarterly forecasts for volume and then determines a daily production rate. Comparing this rate with the capacity of each test server (up to a 16-unit capacity), the EM is able to determine the total number of test servers required.

The times measured for successful software installation are shown below (using a baseline of X minutes for total download time and Y units for shift capacity). Note that the installation package was a full instance of the Solaris operating system. Tests were done using one separate leaf cache⁴⁶:

Table 6: Manufacturing Capacity for SWDL (pilot infrastructure)⁴⁷

Units in Parallel	Total Download time	Average hourly capacity	Unit capacity for 8-hour shift
1	X minutes	-	Y units
2	X minutes	-	2.0*Y units
6	X minutes	-	6.0*Y units
8	1.4X minutes	-	5.9*Y units
10	2.3X minutes	-	4.5*Y units
12	2.3X minutes	-	5.3*Y units
15	3.7X minutes	-	4.0*Y units

⁴⁶Details of this configuration can be found in Appendix III: External Manufacturing Infrastructure Options.

⁴⁷ Capacities are theoretical. Table 6 and Table 7 do not account for SFT or time to cable target systems in and out of the tester.

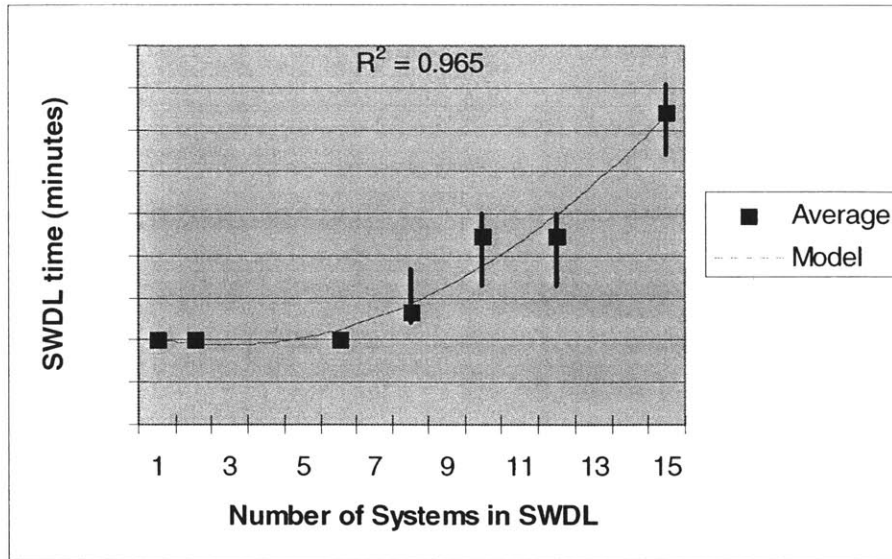


Figure 11: SWDL performance with pilot infrastructure

Times were also measured using the combined SFT/SWDL server on disk 0⁴⁸:

Table 7: Manufacturing Capacity for SWDL (combined SFT/SWDL infrastructure)

Units in Parallel	Total Download time	Average hourly capacity	Unit capacity for 8-hour shift
1	X minutes	-	Y units
6	1.2X minutes	-	5.0*Y units
8	1.6X minutes	-	5.2*Y units
8	1.9X minutes	-	4.2*Y units
9	2.1X minutes	-	4.4*Y units
10	2.6X minutes	-	3.8*Y units
16	9.5X minutes	-	1.7*Y units

⁴⁸ Test server systems at the EM held 2 hard disks. Disk 0 also contains the operating system and the test application.

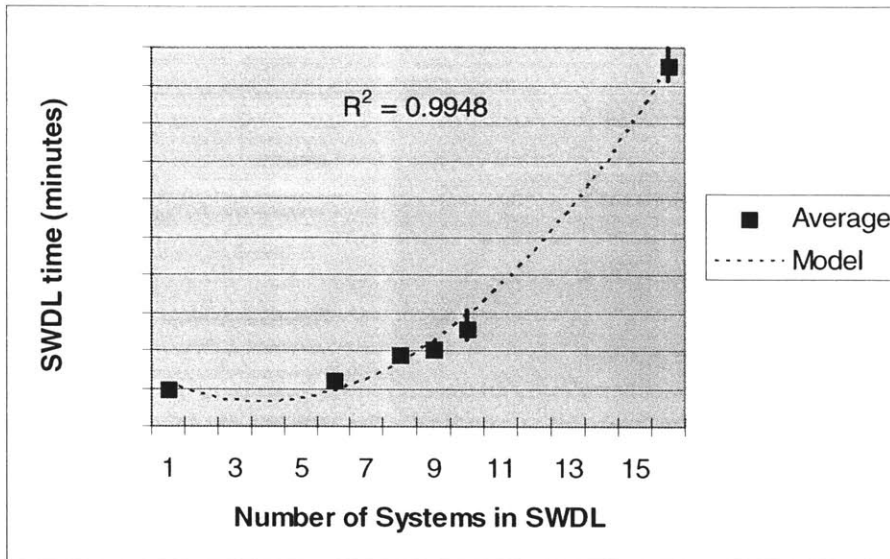


Figure 12: SWDL performance with combined SFT/SWDL server

For either case, it is clear that software installation times hold steady up to a certain number of units running in parallel (probably around 7). After that point, installation times trend upwards quickly. This result was a concern, since it was previously unknown whether large-scale simultaneous installation situations would occur in real life manufacturing.

On the other hand, more units completed in parallel can improve the throughput statistic. By running software download on multiple units simultaneously, the average hourly capacity of a test server can increase. Though the results were not conclusive, running between 6-8 units in parallel appears to offer the best manufacturing capacity for an 8-hour shift.

To resolve this unknown, log data collected to determine the frequency of unit arrivals into the software installation phase of manufacturing. The results are detailed fully in Appendix IV. The conclusion of the analysis indicates that the likelihood of receiving a large number of target units in parallel is relatively unlikely. Therefore, the large increase in installation times in large parallel situations is not a major implementation impediment.

5.2.2.2 Post-pack Audit Capacity

With handling time, estimates from the pilot project indicated that the software installation of an operating system would only add less than 1 hour of total processing time. At first glance, this additional time would seem fairly trivial. For the case of SFT, this additional time only accounts for less than 2% of the total time.

For the PPA stage, however, the additional SWDL time becomes 33% of the total time:⁴⁹

⁴⁹ Sun is planning to install additional content on servers as part of its Java Enterprise System initiative (<http://www.sun.com/software/javaenterprisesystem/index.html>). This represents additional content and additional disk space requirements that will increase the total software installation time.

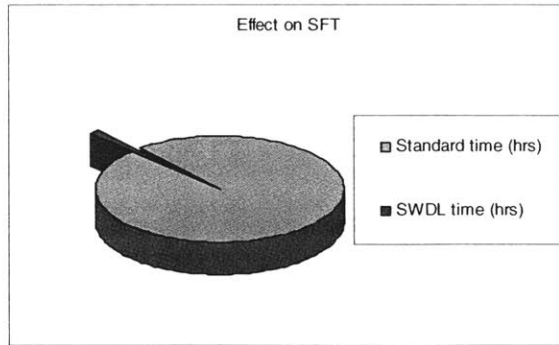


Figure 13: SWDL as a percentage of SFT and SWDL

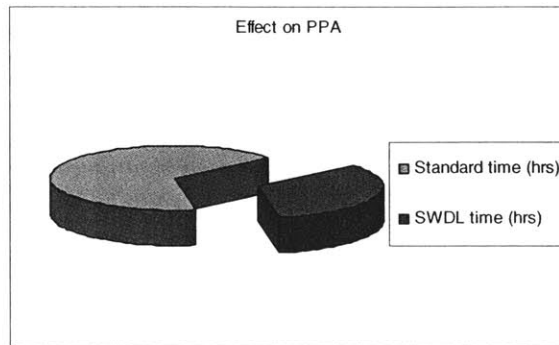


Figure 14: SWDL as a percentage of SFT and PPA

With the significant change in PPA time, Sun might have to make a choice as to whether reduce the percentage of units going into PPA or increase the number of test domains and incur the capital expense.

Calculations for the actual effect of the additional software installation time on capacity are shown in Appendix V. Adding additional capacity can be quite expensive; an additional test domain hardware package would cost over \$25,000.⁵⁰ Fortunately, it appears that current capacity capabilities at the EM can handle a fairly large increase in overall test times. However, slack will be reduced, limiting the EM’s ability to accommodate extraordinary demand spikes. Therefore, additional investment in test capacity may need to be considered in the future.

5.2.3 Remaining Technical Issues

At the end of the pilot project, there were still some technical unknowns. These issues were deemed non-critical, and they would be dealt with in a future deployment phase of software distribution and download:

SFT/SWDL Interaction Testing – For the Combined SFT/SWDL server configuration noted in Appendix III, there has not been thorough testing on executing SFT and SWDL simultaneously on the same server. So far, the EM has successfully run 7 units SFT and 6 units SWDL. An upper bound stress test would utilize 8 units SFT and 8 units SWDL running together.

⁵⁰ A test domain roughly consists of a controller, a special test harness (capacity 8-16 units), an Ethernet switch, I/O cards, cabling and operator interface equipment.

Java Enterprise System inclusion – An installable version of JES was unavailable until the last few weeks of the prototype. Described in Section 4.4.2, JES is a bundle of server applications that Sun is marketing to its customer base. During the project, only the operating system was installed using SWDL, meaning that the installation times only represented the installation of approximately 1.5 GB of content. The additional 1 GB has significant implications on manufacturing.

First, the manufacturing times will definitely increase. Preliminary tests on a combined SWDL/SFT server show that installing 1 unit with the 2.5 GB of content takes around 1.2X minutes.⁵¹ 8 units running in parallel took approximately 5.4X minutes. Clearly, the larger file size affects the download and installation times for a large number of parallel systems. Thus, capacity analyses done previously should be iterated once complete performance data is available. The arrival rates of units to SWDL may become more of a problem if installation times cross over 1.5X minutes for a smaller number of simultaneous installations.

Secondly, the hardware infrastructure may necessitate some adjustments to handle the additional processor and bandwidth load. Possible mitigating enhancements include adding additional memory (to improve server caching), connecting a second Ethernet cable from the SWDL server to the test switch (effectively doubling the effective bandwidth⁵²) or reducing the number of test domains covered by each SWDL server.

Finally, the manufacturing capacity may be affected. As SWDL times increase, there is a possibility that the EM will require additional manufacturing infrastructure hardware to support peak demand times. Appendix V provides some guidance on how this assessment will be made.

5.3 Organizational Implementation

Achieving results at the EM was not merely a technical endeavor. Arranging the project and then understanding the organizational impact were also critical to the success of the pilot. The following sections will discuss what factors were observed and the resulting actions of the team.

5.3.1 Internal Organization Challenges

5.3.1.1 Structure and Organization

Understanding the potential for organizational holdup was an important success factor. Structurally, the author was located under Software Integration Engineering, while the project had its greatest impact Volume Systems Products (VSP) and Operations. VSP Operations eventually reported into WWOPS, while VSP Marketing is governed separately from Operations.

While SWIE is rewarded for increasing its influence and reach on the factory floor, VSP has a different incentive structure. Interviewees noted that there was ‘no money for manufacturing enhancements’ and were thus surprised by the existence of this project (and its potential repercussions). Furthermore, the interview was often the first time people had heard of the

⁵¹ X again equals the amount of time to download and install software on one target unit by itself, from Table 6.

⁵² This is Sun’s IP Network Multipathing feature:

<http://docs.sun.com/db/doc/816-5249/6mbdgpip?q=IP+multipathing&a=view>

initiative. Though employees were always courteous, there was skepticism about the stated goals and its potential cost.

5.3.1.2 Political/Cultural Considerations

Besides the alignment issues, there were additional political and cultural considerations during the project. Many of the organizational tendencies discussed in Chapter 3 were observed, in particular the distributed authority and the dispersion of information.

Being an individual outside of the standard organizational structure, the author did not have a clearly defined role to many people within Sun. Consequently, some observations may be explained through a political lens analysis. Due to the cross functional and unconventional nature of this project, some individuals could perceive the project as a loss of influence or control over part of their product lines. The prototype project could be interpreted as imposing a solution on a group that had no internal impetus to change.

Furthermore, there was skepticism around the need for a project that was not driven down from the proper management channels. Many groups were looking for additional endorsement for the project before cooperating fully. To them, this could have been just another pet project without true merit.

Many directives at the executive level take a long time to gain widespread adoption because of a communication lag through management layers to the individual contributors. Thus, despite the executive support, very few knew of the project's purpose.

Described earlier in Section 3.2.2, there is a 'Change Acceptance Process' that is supposed to encourage adoption of initiatives. Unfortunately, this project did not fall under the auspices of the acceptance process, meaning the publicized executive support, the project 'champion'⁵³ and the formal documentation procedure did not exist. Therefore, the author was responsible to define, to advocate and to execute the project deliverables.

Culturally, Sun appeared very focused on the metrics assigned by managers to the group. Generally, this is a positive. However, in the case of an unconventional initiative such as software download, the focus on specific metrics can impede progress, especially when the metrics *preclude* the recognition of the potential benefits of a change. The discussion in Section 5.4 will provide more details of the mental models.

5.3.1.3 Logistical Challenges

One of the chief concerns that groups had was with the processing of engineering change orders, or ECO's. Traditionally, an ECO is required when a hardware component of the product is modified. This component may be altered for several reasons, including improved functionality, end of life of the old part and quality benefits. When a decision for a part change is made, an ECO is created, which in turn triggers a series of approvals from individuals within Marketing, Operations, Manufacturing and Engineering.

Changes in software are different from changes in hardware. Though tangible benefits can be had from a software change, there is no need for the additional overhead of exhausting old part inventory, of performing mechanical reliability testing and of examining supply chain readiness.

⁵³ Project champions are Sun's name of Six Sigma black belts.

Therefore, it might be possible for the ECO process for software to be streamlined substantially, circumventing many of the required checks for hardware ECO's.

On the downside is the requirement for a new software ECO process that is inconsistent with existing hardware ECO processes. As a result, support from operations groups is critical in ensuring that software ECO's are not adversely delayed.

5.3.2 Coordination with the External Manufacturer

External vendor relations can vary from being very collegial to very adversarial. At Sun, the relationship with the contract manufacturer is often dependent on the relative power and holdup potential.

When selecting an external manufacturer for this project, some key factors were considered:

- Complexity of business with Sun – Higher complexity manufacturing would provide an easier transition for our high-end manufacturing process.
- Location – Where is the EM located? How will this location affect interaction between the parties?
- Connectivity – For a process so dependent on data transfer, it is important to have a stable and fast connection into the EM.
- Previous experience – Has the EM been involved with software installation in the past? How was this done for other customers?
- Working relationship – How successful has the EM been when working with internal engineers for sustaining engineering?
- Cost – Check with the contract negotiator on whether the project will be viewed as a sustaining engineering effort or as NRE.

The EM participating in this project was chosen because it best met the above criteria. In particular, the team considered the working relationship and network connectivity of the vendor. Other factors, such as location, were less important. In fact, the chosen supplier was located in Europe.

After building internal recognition and support for the prototype, a presentation was made to the EM. This triggered additional activity, eventually leading to a formation of a core team of technical and business experts from both Sun and the EM.

Communicating with the EM was a challenge due to the time differences and the distance. Furthermore, travel restrictions prevented any face-to-face interactions. As a result, additional effort was required to coordinate actions and drive progress.

Other, more subtle differences also had to be taken into account when working with a remote contract manufacturer. Some of the key challenges included:

- Large time zone differences – The EM was located several hours ahead of my internship location. Therefore, phone conferences and communications had to occur in the morning to catch the end of shift at the EM. The time zone difference caused delays in responsiveness. For example, the EM encountered an unforeseen error in their morning. They sent us an e-mail asking for advice. By the time the engineers in the U.S. could respond with a solution, it was the end of the day in Europe; the implementation would need to wait for the following morning.

- Less visibility into manufacturing – It was not feasible to visit the manufacturing floor whenever a minor issue arose. Therefore, the status of the project was occasionally unclear, and proactive plans were difficult to develop.
- Inability for quick troubleshooting – The time zone difference also meant that iterative troubleshooting was nearly impossible. Without an engineer with expertise in caching systems located on premises, fixing even minor issues was laborious. We discovered that the SWIE engineers owned some tribal knowledge about caching and manufacturing implementation that was difficult to convey quickly.
- Heavy reliance on EM resources and existing infrastructure – Another result of the remote location was the need to utilize EM engineers and infrastructure for the project. The engineers, though knowledgeable of standard manufacturing, did not own expertise in software implementation. Furthermore, the project had to contend with being one of the many priorities and tasks assigned to the EM engineers. Sun had multiple projects running simultaneously.
- Increased importance for careful documentation and formal communication – A fundamental learning was that capturing discussions and documenting action items was critical to achieve progress. To maintain coordination, the author worked closely with a single point of contact at the EM, and together we planned meeting agendas, deliverables and deadlines. This information was shared regularly with the rest of the team.

5.3.3 Channel Concerns

Interviews detailed Section 4.3.1 indicated that the indirect sales channel (VARs) was comfortable with Sun pre-installing operating systems and basic software in the factory, since this service is often thrown in for free by the VARs. Pre-loading the operating system would rid the VARs of a tedious task.

However, the concept of enabling custom software installation is considered more of a threat, since this feature would encourage a direct distribution model. End customers cannot take advantage of image installation if they purchase stock inventory from a distribution partner or VAR.

5.4 Organizational Analysis

Figure 15 below is a stakeholder map that offers a glimpse of the relevant network used in the execution of this project. Each of the circles represents individuals within different groups, starting from the home group, SWIE.

The direct chain upwards of SWIE was very supportive of the project, and generally other groups within operations (Hillsboro Operations, Volume Products Engineering) were also willing to provide backing. Furthermore, once the EM engineers were contacted, they were willing to put resources and time onto the project, which was a good indication of their support.

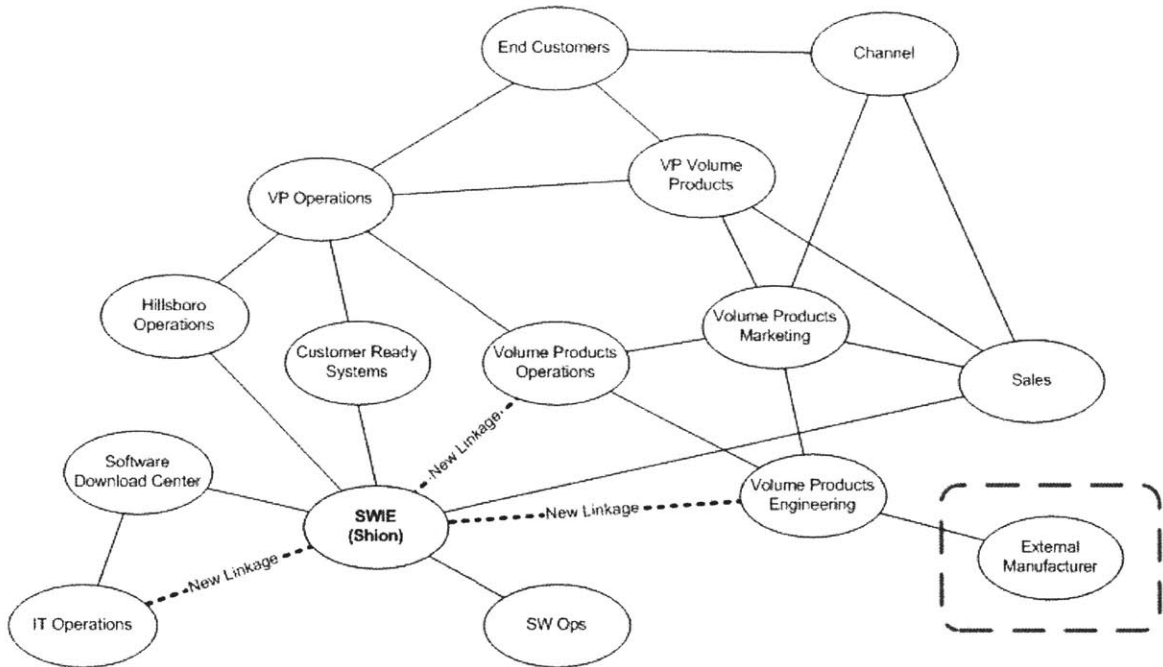


Figure 15: Stakeholder Map

On the other hand, there were groups, particularly in the Volume Systems Products business unit, that had valid concerns about the project and its ultimate implications. Without the eventual support of the Volume Products business unit, it will be difficult to actually deploy the capability into manufacturing. The project could be viewed as taking power away from Volume Products business teams, since Operations would now be dictating manufacturing strategy in a way that directly affects customers.

For the time being, the pilot project to install the basic OS has been approved. However, the next step of software mass customization certainly cannot be implemented in this present environment. Thus, the current process needs to be validated and then management within Operations and the Business Units must decide whether to embrace or to ignore the potential of mass customization.

5.4.1 Mental models

Some of the most difficult battles fought during the implementation of the prototype were strictly internal. In particular, some groups had divergent ideas about customer needs, company focus and individual direction.

Peter Senge describes the effect of mental models on organizational behavior. Mental models are 'deeply held internal images of how the world works, images that limit us to familiar ways of thinking and acting.'⁵⁴ In companies that arose from small beginnings, such as Sun, the mental models that were the basis for meteoric success can now become a hindrance to innovation and progress once the environment changes.

⁵⁴ Senge, Peter. *The Fifth Discipline*, 1990, Currency Doubleday, New York, NY.

Certain perceptions are reinforced by habits that lead to re-affirmation of the original perception. Though a reinforcing loop is generally beneficial, it can also hide systemic problems and lull organizations into a false sense of security. The following is my assessment of Sun's perceptions.

Consider the mental model held by some individuals Volume Systems (Figure 16 below): a belief that software is not an integral part of a hardware product. Starting from some feedback received in the past that customers did not want Sun to install software, the hardware teams do not place high value on software integration. Due to this initial belief, software is not prioritized on new hardware, leading to outdated software being installed or even the omission of software altogether. This in turn has led Sun's customers to generally ignore the software content loaded on the systems, deleting this content and replacing it with their own operating system, patches and applications.

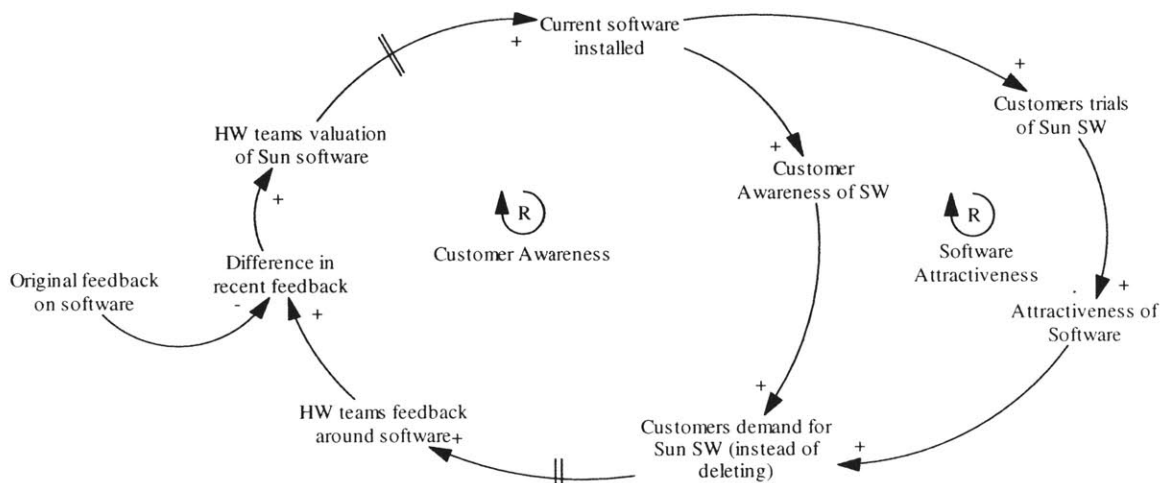


Figure 16: Reinforcing loop on software integration

Over time, customers become used to this arrangement, and Sun ends up not receiving any contrary responses around its software installation policy. Thus, the hardware groups receive no feedback contradicting their original view of software, thus propagating this behavior. Similarly, since customers are not trying the new OS or Sun's software, the attractiveness of Sun's software products lags the hardware, and customer demand further erodes.

Ostensibly, this arrangement is not particularly detrimental, since both Sun and its customers have come to a tacit understanding over the years. However, the reinforcing loop can insulate Sun from changes in customer and industry norms. As the industry has matured, customers have become more accustomed to factory software installation. These new customers may view Sun's stance on software as antiquated and consider the time required to install software manually as a barrier to usability.

One argument for Sun's current position is that many of its customers are return customers, many of which prefer to remain on an older, unsupported version of Solaris. On the other hand, Sun's software groups have a goal to encourage customers to try the latest operating systems and applications, since they include many enhancements and defect fixes. At the least, the dynamics model demonstrates that the hardware groups' behavior does not align with Sun's software goals.

5.5 Financial Analysis

Any proposed change in manufacturing will incur costs that will help determine the feasibility of the change. This project is no exception – adding the infrastructure (both hardware and software) would require an investment by Sun at the EM site.

During the course of the project, financial metrics were gathered and an analysis of the implementation cost was taken. First, the team determined areas where outlays may be required:

1. Internal support – time required from Sun employees to support EM software installation
2. Content distribution – moving content to the EM
3. EM services – the EM's operator and engineering costs billed back to Sun
4. EM infrastructure – hardware investment at the EM
5. EM capacity – if the additional manufacturing step reduces capacity, additional infrastructure may be needed

Also considered briefly were the potential customer benefits of implementing software installation and the financial impact of these benefits to total cost of ownership.

5.5.1 Financial Metrics

The financial metrics of the project focused on the cost of implementation of the various hardware configurations listed in Appendix III. Due to the confidential nature of internal pricing and equipment availability, the discussion will be kept at a general level.

Internal Support – Sun currently uses three full time engineers to support three internal manufacturing sites. These engineers maintain the software download infrastructure, initiate improvements and facilitate the availability of new content. We expect that a similar site support ratio might be necessary, though economies of scale suggest that efficiencies can be gained with each additional site.

Content Distribution – This topic was discussed extensively in Section 5.1.6. Since the chosen method (Internal hosting) had a sunk cost that is not carried by WWOPS, there was no incremental cost to the organization. If this financial situation changes, Sun may need to consider an external hosting option, whose monthly cost averaged around \$300/month.

EM infrastructure – This line item encompasses all the capital equipment investment Sun will need to make to deploy SWDL at the EM. This amount depends heavily on the configuration chosen and the relative size of the EM site. Considering the options very briefly:

Table 8: Hardware requirements for infrastructure options

	Separate SWDL Stage	Shared SWDL Leaf Cache	Combined SFT/SWDL Server
# of Top level servers	2	2	2
Approximate # of Leaf cache servers ⁵⁵	2	7	0
Upgrade required to existing servers?	NO	NO	YES – more memory and disk space
Other equipment required?	2 network switches	None	none
Additional costs?	Floorspace + Labor	None	None

The recommended server configuration for the leaf caches was:

- 1 UltraSPARC processor
- 1GB Memory
- Large Hard Drive
- Quad FastEthernet PCI Card

Each configuration had different costs associated with the deployment. However, another factor to consider is the availability of used equipment. At the time of the project, some of the hardware requirements could be met through capital transfers from other plants.

EM services – Services includes cost of deployment and recurring engineering and operating costs. For deployment, Sun and each EM will decide whether the work required to deploy software installation is within the purview of the sustaining engineering contract, or if NRE must be charged. For the prototype project, the EM decided that NRE would not be charged. Regarding continued operating support, there are no additional costs as long as additional manufacturing resources are needed. However, if additional engineers or operators are necessary (e.g., if a separate SWDL stage is used), a labor charge will be added.

EM Capacity – Appendix V describes the methodology used to determine whether additional test domains are required. If software download and installation times become too long, an additional investment in test infrastructure will be needed to meet peak demand. For the cost calculations, it was assumed that no additional domains were needed (e.g., SWDL times were below the cut-offs).

Total Cost of Ownership – The availability of software installation and download will be an immediate benefit for some customers, particularly those who currently install the operating system and patches via CD. Other customers will not derive benefit unless Sun takes the next step to allow for custom image installation.

Rather than try to calculate the benefit on an aggregate basis, the team chose to look at the different customer segments and determine the value to them individually. Besides the indirect channel / direct channel assessment mentioned earlier, there was no available information about the installation method and requirements of customers.

⁵⁵ The external manufacturing location used in the pilot had approximately 20 test domains supporting Sun products.

Table 9: Software download benefits by customer type

Customer Type	Benefit from OS + patch Load	Benefit from custom image
CD Load / Indirect channel	≤1/2 day installation time saved	None – not available through channel
Image Load / Indirect Channel	Limited – may install own	None – not available through channel
CD Load / Direct Channel	≤1/2 day installation time saved	≥1 day installation time saved
Image Load / Direct Channel	Limited – may install own	≥1 day installation time saved

Installation time can cost money to the customer in terms of IT personnel resources or the wages of an external service technician. Furthermore, providing a pre-installed OS encourages the use of newer, more powerful OS versions that may improve customer satisfaction.

Customers were divided by their delivery channel and by their installation method. Customers that use CD installation will be most likely to benefit from Sun pre-installing a valid operating system and recent patches. On the other hand, companies using a direct channel will find more value in a future case where Sun provides custom image installation.

In addition to the OS and custom applications, Sun’s strategy is to expose all customers to the Java Enterprise System. Though not a quantifiable benefit, this will hopefully lure Sun’s installed base to try and eventually purchase Sun’s applications.

5.5.2 Financial Results

Having considered all of the costs for the three configurations, the cost to deploy software distribution and installation at the EM site was less than \$3.00 per unit in hardware alone. Using used equipment could reduce the cost by half. The calculations took the full deployment cost and divided that by the total volume production over one year. If an additional Sun engineer is required to support manufacturing, the cost may increase up to greater than \$10 per unit. All values in this section have been altered, since actual costs and unit volumes are confidential.

Caveats to this analysis are that the benefits to the total cost of ownership are not included. A customer who currently uses CD installation would save hundreds of dollars in time or service costs. Furthermore, sustaining costs of SWDL would only be the cost of Sun labor and incremental maintenance.

Finally, the cost per unit above assumes a certain level of existing infrastructure at the EM. If a manufacturing location does not have a broadband connection or test scheduling capabilities, those will need to be implemented first before SWDL can be added.

Chapter 6 Recommendations and Conclusions

This chapter summarizes the results of the project and then suggests some ways for Sun to move forward with mass customization of software in the future. At the end of the project, Sun still has to decide when it wants to deploy this capability and to what extent it wants to use the manufacturing infrastructure developed in the pilot.

There are other options and configurations for software installation, and those options may need to be explored when dealing with a wider variety of EM's and varying levels of competency. Attributes such as EM experience with software, current connectivity and software installation time versus total manufacturing time must be pondered.

This chapter is split into process, organizational and financial recommendations. All recommendations are the opinion of the author.

6.1 Process Recommendations

The pilot project established that several capabilities are available for use at an EM site:

- Secure content distribution from Sun to an EM can be done cheaply and easily.
- A caching mechanism can be used by the EM to pull content automatically from Sun and then propagate the content through manufacturing.
- The caching mechanism and download process can accommodate the higher product volumes found at the EM's.
- The EM has the expertise to implement and maintain software distribution and installation.

And most importantly:

- Software download can be cost effective, particularly when utilizing excess equipment.

However, at the time of writing, there were still some technical loose ends that should be considered and dealt with. First and foremost was resolving communication glitches between the software download system and the existing test infrastructure. Next, Sun could optimize the new hardware infrastructure given desired specifications. The configurations shown in Appendix III are just a sample of the possible choices. For example, if Sun were to choose the Shared SWDL Leaf Cache configuration, the number of domains being served by the test server will depend on performance needs.

Finally, these types of hardware decisions must be seen in conjunction with the possibility of applying new operator rules. If, for instance, operators are directed to distribute systems between domains evenly (instead of batching several target units onto one domain), the variance of load on the test servers can be reduced. By doing so, the SWDL infrastructure could be made less robust and still deliver similar performance. However, the tradeoff is a higher potential for human error and less flexibility to accommodate high demand situations.

There is a suite of issues that will be best handled once a full deployment plan is put in place. These are mostly procedural in nature. On the front end, SWIE and SWOPS need to coordinate to make available and deliver current software content at the prescribed schedule. On the manufacturing floor, a documented process is needed to handle and accept ECO's in software content or the new versions of the SWDL software. Also, if operator behavior changes are needed, those must be clearly enunciated. With the potential of target unit limitations on a per

domain basis, additional software that prevents too many simultaneous downloads may be valuable.

As discussions progressed, we discovered other manufacturing questions to consider in the implementation process:

- Should there be a certification program at the deployment of any new OS revision? Currently, Sun's internal manufacturing sites individually accept new software through a validation process. Should a similar process be repeated at the EM, or should they just 'trust' the content?
- Should an exact description of what was loaded onto each system be kept? Some customers, particularly government customers, require a strict accounting of what their systems contain. There needs to be a way to give the customer a list of the exact hardware/software configuration and to retain this information at Sun.
- How does Sun notify customers of the new content? With the long history of not including updated software on systems, Sun's customers will not be accustomed to look for the new OS and JES features. One idea is to place a sticker on the system that indicates a pre-load has been done. This raises the visibility of the software download, and it may increase the acceptance of the practice.

6.1.1 Pick-to-Order versus Assemble-to-Order

Perhaps the most pressing long-term process question is whether Volume Products servers should remain PTO or change to ATO to adapt for software installation. Software download poses a challenge to the existing product structure.

VSP continues to have a metric to reduce manufacturing complexity and part numbers. The indirect sales channel also prefers to keep marketing part numbers to a minimum so that it can be in a better position to fulfill demand. Furthermore, some government and military contracts require Sun to offer a qualified configuration consisting of precise levels of hardware and software. From these requirements, the Volume Products Group has chosen to provide very limited configurations based on hardware performance only.

Having a frequently updated software operating system could force some changes in product configurability. Consider first the base case where fixed, but frequently updated, OS and JES revisions are installed on each volume server. Part numbers for a product or subassembly must be rolled when a change is made to the 'form, fit or function' of that part. The ECO process for part numbers is fairly laborious, taking almost 1 month from start to finish for the appropriate approvals to be completed at Sun and the EM's. Since Sun has limited capacity to perform ECO's, there is pressure to reduce the frequency of updates.

Next is the problem of part number obsolescence. Sun currently has a marketing rule that requires all part numbers to be available for purchase for at least 6 months after discontinuation. If the OS and JES stack were to be updated on a quarterly basis, Sun would be doubling the number of orderable part numbers at any given time. Moreover, to abide by government contracts, Sun may have to retain some older part numbers for significantly longer. Besides the process difficulties of maintaining more part numbers, Sun also announces all changes to marketing part numbers to the sales channel. Frequent part number revisions may add to channel confusion.

A solution to these issues is not clear. Guidelines such as 6-month availability and sales announcements were put in place to protect the customer. One option for Sun would be to declare that minor patches in software do not affect 'form, fit or function' so that no part number changes are needed. Another choice would be to rationalize the ECO process for software, acknowledging that software changes require fewer approvals and less control than hardware changes. Perhaps the ECO overhead could be reduced significantly by eliminating several nonessential approval steps. However, Sun risks increasing the number of 'exception' policies that can add to organizational confusion. Therefore, if Sun chooses to retain PTO for products with software, part number proliferation may be unavoidable.

An additional option is to separate hardware and software part numbers. When software changes, there would then be no change to the hardware part number. The difficulty is finding a way to link the two part numbers together, which is not possible at this time. How would the EM know that the software part number implies a specific software load onto the target hardware?

A final possibility would be to fully convert volume products from PTO to ATO, allowing software to be modified without changing the base hardware configuration. In the most basic case, customers would still not be allowed to make customization decisions; the ATO flexibility would only enable Sun to modify the software content offering without need for the ECO and marketing overhead. In this case, Sun would have to reconcile ATO with the potential 'Pandora's box' of temptation to offer special configurations – a situation that VSP has driven hard to avoid so far.

In the longer term, Sun should consider the long-term goal of enabling customized pre-installed software on volume products systems. In this scenario, Sun would offer customers the opportunity to pick and choose what software to load onto their systems. This offering could extend to allow customers the option to load their own images if desired. Since Sun's wants to improve the customer experience through integration, this is the logical realization of this goal.

It is useful to compare SWDL with the software capabilities of Sun's CRS program, which already offers software installation capabilities for customers. As described in Section 3.1.5, CRS provides an integration and customization service. The team orders the appropriate hardware from Sun's manufacturing facilities and EM's, consolidates it in a CRS staging area and assembles the order to specification.

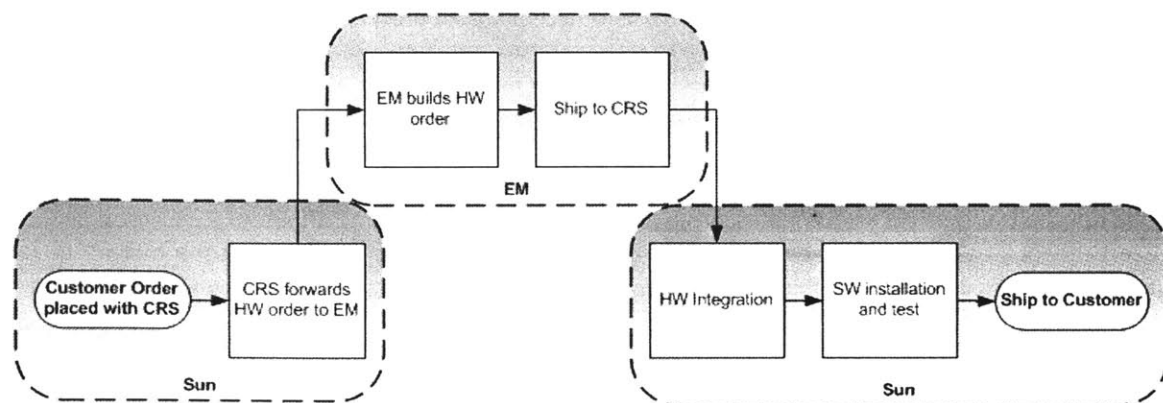


Figure 17: Simplified CRS build process with software customization

SWDL, on the other hand, cannot replace the full systems integration capability of CRS, but it would be able to handle simple software customization faster and more cheaply than CRS. All software customization work is done at the EM, instead of at Sun, which translates to less cost per unit and faster delivery schedules.

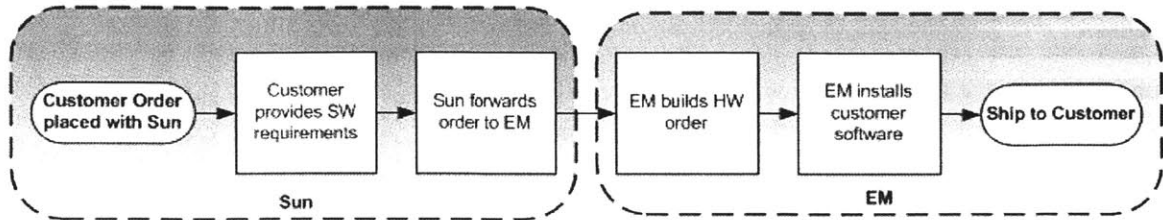


Figure 18: SWDL process with software customization

Deploying true software customization for volume products requires investments in a new order entry process to permit the execution of customer preferences. This investment would entail some way to capture customers' software content, whether that be a web menu form used by PC manufacturers such as Dell or an internal portal into Sun's ERP system to allow salespeople to enter this information. Once in the system, another mechanism must be in place to transfer customer requirements to the EM. The order must also trigger the automated retrieval and factory floor availability of the custom software content, which is installed onto the correct systems during the manufacturing process.

Customers of this service will be at a delivery disadvantage to others who choose the PTO configurations. PTO customers are accustomed to immediate availability of systems held as finished goods inventory. Conversely, products with software customization must be built to order, so a longer delivery period would be expected.

6.1.2 Alternative Software Download Models

In the future, if Sun chooses to pursue a strategy of software customization, a threshold might be met where the network installation takes too much time, which begins to affect manufacturing effectiveness. At this point, a combination solution with HDD and network installation may need to be considered. Dell, Inc. has already pioneered this methodology using a statistically determined image that is pre-loaded onto hard drives. During final assembly, a network installation is performed on the disk to add customer-specified components.⁵⁶

Due to limitations to the bandwidth available between the test server and the target units, an increase in the total size of content has a non-linear effect on performance. Therefore, a time may come in the future where the software download infrastructure will be inadequate to supply the OS and application at the speed and cost expected for manufacturing. However, it is important to consider the tradeoff between manufacturing efficiency and the cost of an alternative, such as reverting back to customer CD installation. Even a 2 hour software download in the factory is still less expensive to the total cost of ownership than a half day of field installation time.

David Valys from Dell suggests a schema where commonly used or slow changing content is pre-loaded onto the disk using something similar to hard disk duplication (HDD). In this case, the software download stage during SFT would only include software content that changes frequently

⁵⁶ Valys, David. United States Patent US 6,549,914 B1, 15 April 2003 - <http://www.dell.com/downloads/global/corporate/patents/6549914.pdf>.

or has been personalized for a customer. This content is placed next to the pre-loaded image, and then any unnecessary files from the pre-load are removed.

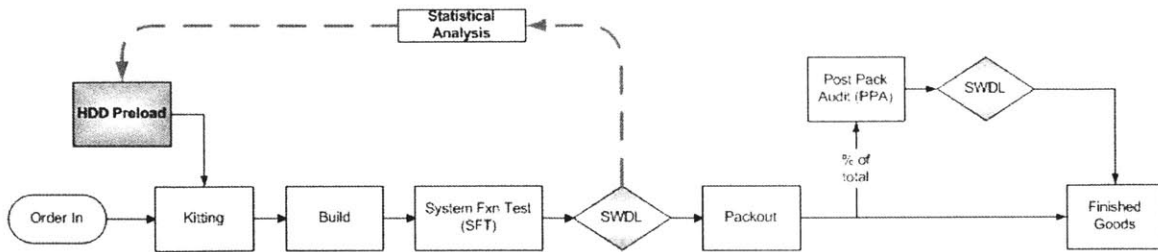


Figure 19: Proposed statistical download process with HDD and SWDL

Valys uses a measure of software installation efficiency as shown by the following equation:

$$Efficiency = 1 - \left(\frac{Downloaded_Bits}{Total_Bits} \right)$$

In this two-stage method, 'Downloaded_Bits' is the total size of the files downloaded during SFT while 'Total_Bits' are the total size of all files loaded onto a hard drive (pre-load plus SWDL). Higher efficiencies mean less time is spent executing SWDL.⁵⁷

If Sun were to implement a similar manufacturing strategy, it would first choose how to partition its existing software download content. Slow moving content, such as an old application or the base operating system may go onto the HDD image. Content specific to a customer or frequent patches from the software developer would remain in the SWDL stage. Over time, additional analysis can be made to determine what files customers most commonly request, and appropriate changes can be made to the HDD image (shown as a dashed line in Figure 19).

Additional thought can be placed in preferentially choosing files for pre-load based on file size, since smaller files take less time to download but have increased access times, especially if a file has to be pulled from the test server's disk drive instead of from memory. Comparing 1 large file versus 10 smaller files 1/10th the size, the aggregate time to load the 10 small files will be larger, since total access time will be greater.

In terms of timing, perhaps the current content size of 2.5 GB can be handled effectively, but as new applications are added, the total file size will only go up. A tradeoff between download times, quality and hardware investment will result, and at some stage, the cost of performing all software download during SFT may become cost prohibitive. Adding more capacity using HDD may be significantly cheaper than the options. Therefore, the combination HDD and SWDL solution should be considered by this time, if not sooner.

The above suggestion is predicated on the ability for Sun to create software building blocks that can be installed independently of each other. If this is not currently possible, additional work in software architecture design of applications might be necessary before this type of solution is possible.

⁵⁷ Valys, David, 2003.

6.2 Organizational Proposals

An area of improvement potential is on the organizational axis. This section will investigate possible ways to initiate a perceptual shift in the importance of solutions and ideas on working in remote teams.

6.2.1 Shifting the Mental Model

To address the current perception that software is not part of the core hardware offering, start by expanding on the model in Figure 16 on page 61. In Figure 20 below, I first proposes that the indifference to software has long-standing roots from the proud, independent culture of early Sun customers. This original feedback has depressed any push towards integrated hardware/software solutions for the installed base. Thus a reinforcing loop where customers don't ask for software and Sun's product teams don't provide it has been created.

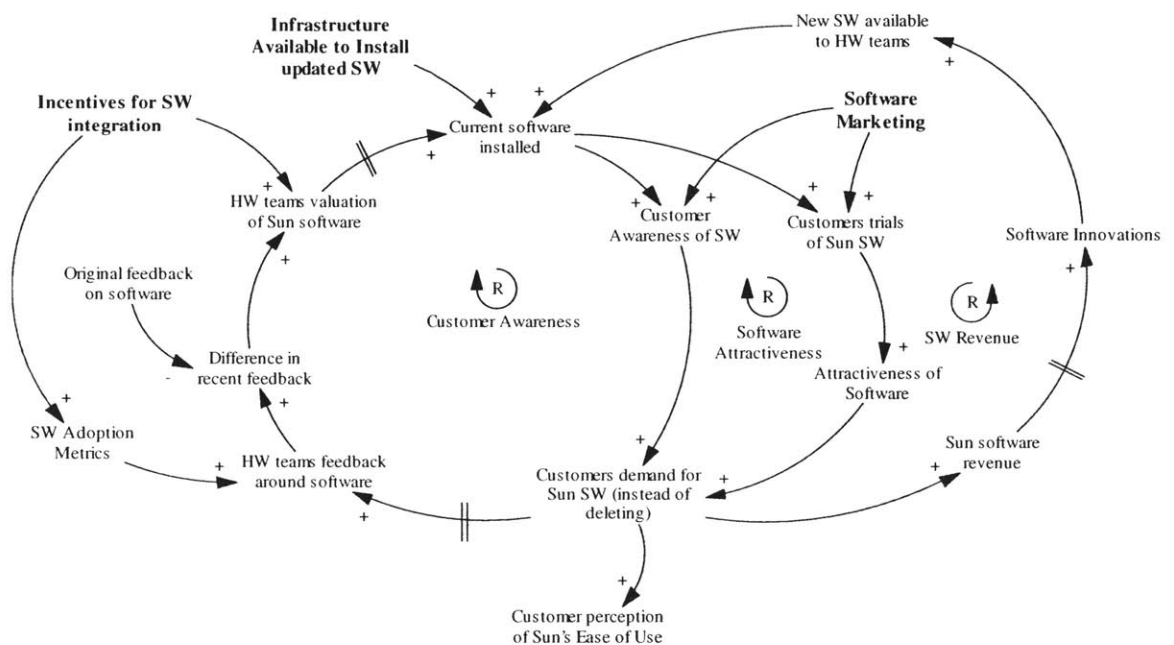


Figure 20: Creating a solutions-centric culture

The reinforcing loop itself is not detrimental; it can positively reinforce solutions demand by modifying some critical inputs. The three new factors are:

- **Incentives for SW integration** – Sun's management must put in place the proper incentives for the hardware teams to become enthusiastic about software. Though corporate playbooks and executive direction describe the importance of integration, groups within product teams are not measured on customer software adoption rates.

Incentives will also promote the creation of metrics to measure adoption success. Metrics will naturally make it easier for the hardware teams to determine their success.

- **Infrastructure available to install updated software** – This project was the first step in creating a global framework to enable just-in-time download and installation of cutting-edge software content. If the investment is made for this facility, it will be much easier to install new

content in manufacturing.

- Software Marketing – Coupled with a strong marketing effort to push the Java Enterprise System and Solaris' most recent improvements, Sun can make customers aware of the available applications and induce some of those customers to try it. If the software lives up to the messaging, Sun should observe increased demand.

These three influences in conjunction can affect customer demand for software. Over time, these encouraging results will trickle back to the product teams, which will slowly break down firmly held beliefs.

Another reinforcing loop also exists in that JES is a key initiative for the company. If Sun can generate customer excitement about the applications, Sun's software revenue will increase, which not only helps Sun improve its financial standing. Sun will also be able to pump more money into software R&D, which can create new innovations and even more demand.

The intended end result is that Operations meets its goal of providing integrated solutions to its customers, offering hardware, software and deployment efficiencies that make Sun a strong player in the volume server market.

6.2.2 Remote Teams

Parts of Chapters 3 and 5 discussed some of the difficulties encountered when working in a global team. Janice Klein et al. suggests that though tension always exists between local and global priorities, it is greatest when a group tackles problems where resolutions require changes or cooperation on a local level that run counter to immediate local interests.⁵⁸ These types of decisions are seen as a corporate directive that ignores local experience. The SWDL project fell into this description, as there was local resistance.

The solution to this dilemma is two-fold: the project manager must first show that the project has high level strategic repercussions and then demonstrate how the remote sites can benefit from this global initiative. Klein notes that distributed teams can perform as well as co-located teams when these criteria have been met. For both cases, the author admits that more effort could have been made at building local management support and explaining in tangible terms the benefits of the project. Furthermore, people desire intrinsic recognition, and more could have been done to informally acknowledge help received.

As a longer-term resolution, the structure of remote teams could be changed to evaluate and provide incentives based on global team and corporate performance. For example, if Volume Products management were rewarded on fostering innovation and materially assisting global initiatives, this project would have obtained much stronger support.

6.2.3 Customers and Competitors

Throughout this discussion, it is imperative that Sun provide a clear vision and strategy for its employees to follow. There can be more awareness about critical initiatives within Worldwide Operations and more direct knowledge about two external groups: customers and competitors.

⁵⁸ Klein, Janice and Barrett, Betty, 2001.

Besides the sales and marketing personnel assigned directly to customer needs, there was limited employee interaction with the indirect sales channel and the end customer. For example, spending a day in a customer data center might generate more awareness of the inconvenience of receiving a new Sun server and not being able to use it immediately (due to lack of software preload).

Similarly, widespread knowledge of the strategies of Sun's competition is thin in parts of the organization. While installing the operating system and applications software is new to Sun, few employees interviewed knew that all of Sun's major competitors already offered this capability.⁵⁹ As a result, an initiative that should have been seen as a 'parity' strategy to catch up with competition was instead perceived as a very new and untested capability.

Sun has been seen as an industry and technology leader for most of its lifetime, so the organization is unaccustomed to being behind its industry counterparts. However, failure to keep up on features important to the customer experience can be dangerous. Richard Nardo suggests that parity is required to "ensure that your product offers everything that customers expect of the market. A failure to have a product attribute the niche expects would cause a flight to someone else's products."⁶⁰ One of Dell's great achievements was achieving parity on all critical technical features while exceeding expectations on price and delivery.

Everyone at Sun can benefit from increased awareness of these industry trends. To continue to foster innovation in Operations, Sun can begin by encouraging employees to invest time to learn about customers and competitors in an objective fashion. Developing a healthy respect for one's competition and environment will encourage faster acknowledgement of trends and quick innovation that builds upon industry achievements.

6.3 Financial Recommendations

The cost analysis from the project indicated that software distribution and download would cost less than \$3.00 per unit for hardware costs, and additional costs might be required if an additional sustaining engineer at Sun is required. These are first year costs, and after the capital investment, it would be expected that future years would only require maintenance and replacement costs – a fraction of the startup expenses.

Though the general perception within Sun is that the cost is reasonable, it is important to stress that the EM chosen for the pilot was already a high-end supplier that had capabilities that may far exceed Sun's other manufacturing partners.

When deciding on the breadth of deployment, Sun should consider whether it is willing to invest in the foundational capabilities at an EM (Figure 21 below). These competencies may not come cheaply and thus may limit the extent to which software download can be implemented.

⁵⁹ See Table 2 on page 35.

⁶⁰ Richard Nardo, page 65.

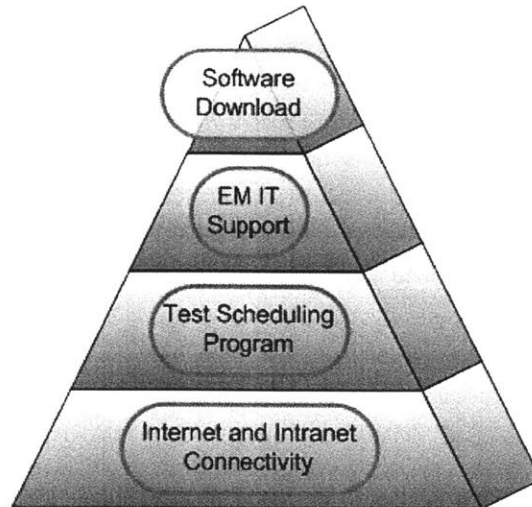


Figure 21: Requirements for Software Download

EM's must first have Internet and intranet connectivity at broadband speeds. This connection must make its way to the manufacturing floor so that machines used in the test process can access Sun's software content. This connection is in fact no small feat, since some of Sun's EM's currently operate manufacturing lines that run unconnected.

Next, SWDL requires a test scheduling program to call SWDL and to execute it. A variety of the test scheduling programs run at EM sites. Since test schedulers differ, additional implementations may require supplementary NRE.

Finally, Sun must have the EM provide support for the IT infrastructure and the software download installation. At low cost EM's, sustaining engineering resources may be spread extremely thin managing more pressing needs. Furthermore, Sun may encounter language and cultural difficulties when initiating high complexity procedures at factories in developing nations.

Therefore, Sun needs to ask itself whether the capability to add software download capabilities to an EM warrant the large investment costs. As a result of these discussions, SWIE has begun making contingency plans that utilize the content distribution system (DMZ server) along with a more manual process installation process. For example, an EM engineer could download the secure content onto her office PC, copy the contents onto a hard drive and use the HDD process to install content onto server disk drives. This process, though slower than SWDL, will save considerable deployment time over the physical shipment of reference hard drives overseas.⁶¹

6.3.1 The Challenge of Incremental Outsourcing

Once production has been outsourced, how does a company continue to innovate its manufacturing processes? The software distribution and download project is a good example of how a company and its EM can cooperate to successfully validate a new capability.

This particular project benefited from a tremendous amount of support from the EM during the project. Despite the difficulties of working in a remote environment, communication was consistent and progress was made at a good pace. Therefore, disseminating such incremental

⁶¹ The topic of time-to-deployment and engineering costs was discussed in Section 4.4.4 on page 38.

improvements to EM's is an autonomous innovation that can be duplicated externally, albeit through a fairly lengthy training process.⁶²

Somewhat astonishingly, the EM did not request any reimbursement for time and labor, as the entire project fell underneath sustaining engineering. For future deployment at other EM's, the relationship between parties may not be as cordial. Even if an EM is contractually obliged to provide engineering support for new manufacturing initiatives, the intensity of effort can vary considerably between companies and even manufacturing facilities. There is risk that a project can flounder when the direct supervision of the initiative is not possible.

To allay some of these concerns, some lessons from this thesis experience might prove useful:

1. Get contracts help – Find the individuals responsible for the contractual relationship with the EM. Ask for advice on the financial implications of a project.
2. Set up a coordinating meeting with the account manager – The EM generally has an account manager assigned to your company. Utilize this person's connections to find the right individuals within the EM's organization.
3. Recognize your bargaining position – As a fairly large outsourcer, Sun enjoys the benefit of having considerable negotiating leverage with its suppliers. Since contract electronics manufacturing has been commoditized, Sun can always threaten to pull business away from one vendor if manufacturing problems arise. In practice, EM's are not changed during the middle of a product life cycle, and rarely will an EM lose the business for any follow-on products. Nevertheless, it is to both parties' interests to maintain a resilient partnership and to make sacrifices that enable mutual gains.
4. Agree to a set of deliverables and metrics – As early as possible, work with the EM to agree on a clear set of goals for any project. In its final form, the requirements document covered the following project attributes:
 - Scope
 - Schedule
 - Hardware configurations tested
 - Quantities used
 - Metrics (with responsibilities)
 - Success criteria (with minimum and stretch goals)
 - List of best known options
 - Expected outcomes
5. Overcommunicate – Without the benefit of a face-to-face relationship, it becomes even more critical to use multiple communications vehicles to assess progress. Though large phone conferences were only scheduled once a week, significant one-on-one correspondence took place during the rest of the week. Furthermore, the lead member of each team kept a living document detailing the latest results and action items.

These suggestions will not guarantee success, but they can serve as a useful guideline for other projects of this nature.

⁶² Autonomous and systemic innovations are terms used by Chesbrough and Teece, 2002.

6.4 Final Recommendations

This section offers some thoughts about what other changes are required at Sun in order for the company to realize the true benefit of providing solutions (hardware and software) to its customers. There are some longer term opportunities to improve the time throughput of the value chain for volume products. Joseph Pine suggests that every part of the organization must challenge itself to reduce cycle times and increase flexibility to become true advocates of Mass Customization.⁶³ Whether Sun takes action on this idea depends very much on what strategy Sun wants to take, as different visions for the future continue to exist.

At the end of this project, we have found that software distribution and download to External Manufacturers is feasible and cost-economical. However, the current scope only unlocks a small fraction of the potential value available through SWDL capabilities. The primary strategic question Sun must answer is the choice between mass customization and mass production.

Envision a future state where Sun's customers can order exactly the software content they want. Either the customer gets a series of software building blocks built on top of each other, or they receive a server with a custom image pre-loaded and tested. Picture the potential time savings of the end customer, who can now just cable in new systems, input any additional information or proprietary applications and then begin taking advantage of their purchase. On Sun's side, imagine manufacturing lines that can build a customized order within days.

Before this vision can become a reality, Sun needs to clarify its manufacturing strategy to all groups in Operations and the product groups. There are still many teams who foresee a drastically different future – one of limited configurations and build-to-forecast products.

The author believes that in order to compete in the volume space against fierce competitors such as Dell, Microsoft and Linux, Sun must offer value added services that bind installed base customers and reduce barriers to entry for new customers. Yet Sun must provide these services in a cost effective and resource minimal way, as it cannot compete person-for-person with service behemoths such as IBM and HP.

For the time being, Sun can continue to argue that it has the best technology and vertical integration potential. However, with competitors such as Dell driving commoditization of the server market, specific performance metrics will become less relevant to customers. If Sun is to cultivate new customers, it must be on par on such basic services as the OS load and then *exceed* expectations with value-added applications and low-cost customization potential. Otherwise, it must fight tooth and nail to be the low cost commodity provider, a very difficult proposition against Dell and low-cost Asian manufacturers.

6.4.1 Project Impact on Sun

Changing from mass production to mass customization is not easy. One first step is the propagation of SWDL capabilities to Sun's EM base. Returning to Figure 7 on page 39, this project has provided the flexibility to offer more innovative software products in manufacturing, but the inertia of the organization has not yet shifted to offer this flexibility to customers. After a strategy and the appropriate metrics are set, Sun can continue address the responsiveness of the rest of the supply chain.

⁶³ B. Joseph Pine III, *Mass Customization*, pg 189.

Though this project has only confirmed that a small portion of the supply chain can become more responsive to customer needs, it is an important proof-of-concept. If Sun's strategy continues towards customization, this project can serve as a baseline template for future cooperative ventures on software customization, order communication, quality control and channel realignment.

Perhaps even more important to SWIE is the creation of new linkages and relationships throughout Operations and Volume Products. If SWDL continues to grow, these linkages become extremely useful in deploying the capability quickly and efficiently.

Ultimately, the impact of this project depends on the direction that Sun takes for manufacturing in the future. Installing static software is already possible using a myriad of methods that Sun already is using at EM's. For a quarterly updated OS load, SWDL is overkill. Only when a commitment to software customization is made will software distribution and download reach its full potential.

6.5 Conclusions

Sun is one of many organizations that have grown from very small aggressive foundations in nascent markets into large installed-base corporations in mature industries. Where once technological advantage was critical, customers now consider many other factors in choosing vendors. Issues such as cost, convenience and solutions availability are now as important as the technology. An organization facing such shifting industry trends must learn how to be flexible and agile in new ways. First-to-market may not be enough anymore – first-to-volume and first-to-integration are additional imperatives. We review some of the key lessons and conclusions of this thesis below:

Project Management / Execution Lessons

This thesis has taken an integrated look into the issues involved in preloading software both inside and outside of a manufacturing organization. Through the course of the project, we have uncovered and described not only the technical architecture but also some of the organizational and business issues surrounding such decisions. Many of the points we learned in this process are applicable not only to the transfer of this specific process at Sun, but to other companies as well. Further, there are implications for any organization engaged in shifting to a strategy entailing more customization. Here are the critical lessons learned in the process:

- Create a well-defined problem statement.
- Identify and engage stakeholders early.
- Examine the practices of competitors.
- Thoroughly understand the internal processes, and how they might be affected if transferred to external partners.
- Understand the basic nature of the organization and its culture, and how it could affect implementation and deployment.
- Run an experiment or pilot to unearth unexpected issues, and gather data for impact assessment.⁶⁴ In this case, running multiple experimental configurations helped the team gain new insights and make modifications quickly.

⁶⁴ Stefan Thomke, in "Enlightened Experimentation", makes a strong case for the use of experimentation as a means of rapid learning. Key steps include organizing for rapid experimentation, fail often (while avoiding easy mistakes), exploit early information and combine new and traditional technologies.

- Position the project as a small experiment when facing uncertain support. In this way, the project team can collect information quickly that helps justify further investment.

Technical Lessons

For this project, there were a handful of critical issues that arose during experimentation:

- Secure software content delivery
- Software installation options
- Test infrastructure configurations
- Success criteria
- Effective virtual internal/external teams

Within each of these topics, the team strived to understand the impact the options had on manufacturing, on performance and on organizational acceptance. Although there were other possible solutions, the team completed a design for the feasible realization of preloading software. The EM was fully engaged and has been very supportive of the project.

Organizational Lessons

The choice surrounding the deployment of mass customization is just as much an organizational discussion as it is a technical decision. Even with proper managerial motivation, creating a responsive supply chain cannot be achieved overnight. Thus, some of the key achievements of this thesis are cultural and organizational in nature. Some universal lessons include:

- Engage stakeholders early – This gives the key people time to absorb and to accept the potential changes.
- Manage misaligned incentives – Know how a project fits into stakeholders' incentive and mission structures.
- Working with global teams – Global teams are a reality now for nearly all major manufacturers. Effective teams require high-level management support and strong consideration for alignment of incentives.
- Set expectations with external partners – By agreeing to a requirements document and holding regular update meetings, we were able to maintain velocity and progress throughout the pilot.
- Understand the organization's network – Culture and organizational structure have a greater impact on project outcomes than most technical concerns. Understanding the influencers and allies within the company can allow a project to overcome its obstacles.

As a useful technique, systems dynamics can be used to illuminate the existing mental models held by stakeholders and provide insights on how to encourage solutions thinking in the future.

By bringing together diverse groups together, motives could be understood and beneficial relationships could be built. This thesis is a good example of working through many functional organizations and of achieving success in execution. Conversely, valuable lessons can be learned from the inability to create broader support and excitement for the project throughout Sun.

Strategic Considerations

We have proven the technical capability to execute a key component of customization, but significantly more work is needed on preparing the rest of the value chain for this future. Issues

to consider include order capture, sales channel strategy, change control and customer privacy concerns.

We took a forward look at manufacturing decisions that an organization must make when considering whether to deploy software preload, and more generally, mass customization. Before embarking on projects such as software preload, companies must consider how these capabilities fit into their overall manufacturing strategies. Fundamentally, creating supply chain flexibility only provides value when combined with a larger strategy of mass customization. Offering customers dynamic content installation has the potential to offset a competitive deficiency and reduce the customers' total cost of ownership. As with many prospective technical improvements, however, supplemental changes to the value delivery chain must be made before customers can really benefit from faster deployment, tailored content and lowered costs.

Sun has decided to deploy a version of the software download and installation methodology, starting with the EM used in the project. Officially, this capability will allow for the load of static content, such as the operating system and Java Enterprise System, onto new systems. However, software download holds the promise and potential for much more. If mass customization continues to be one of Sun's key goals, software preload will be just the first step in a larger transformation of Sun's supply chain and customer experience.

Chapter 7 Bibliography

2002 Sun Annual Report and Chairman's Letter -

http://www.sun.com/aboutsun/investor/annual_reports/sun_ar02.pdf .

2003 Sun annual report: http://www.sun.com/aboutsun/investor/annual_reports/sun_ar03.pdf

Carbone, Jim. "EMS Industry Bottoms Out", Purchasing.com

(<http://www.manufacturing.net/pur/article/CA323194>), September 18, 2003.

Chesbrough, Henry and Teece, David, "Organizing for Innovation: When is Virtual Virtuous?"

Harvard Business Review (August 2002), 127-135.

Chu, Richard. "SUN MICROSYSTEMS, INC", SG Cowen Securities Corporation, 22 July 2003.

Dell, Inc. website – <http://www.dell.com>

Fisher, Marshall L. "What is the Right Supply Chain for Your Product?" Harvard Business

Review (March-April 1997), 105-116.

Gartner Group. "Hardware Platforms Weekly, Issue 37." Note Number HWPW-WW-NT-0337.

22 September 2003.

Gartner Group. "Servers Worldwide Quarterly Statistics, 1Q02 (Executive Summary)." Note

Number: HARD-WW-EX-0276. 30 July 2002.

Greaver, Maurice F., *Strategic Outsourcing: A Structured Approach to Outsourcing Decisions and Initiatives*, 1999.

Hewlett-Packard website – <http://www.hp.com>.

Hicks, Matt and Galli, Peter. "SCO's Linux Case: Is Winning Everything?", eWeek

(<http://www.eweek.com/article2/0,4149,1394405,00.asp>), 21 November 2003.

IBM website – <http://www.ibm.com>.

InfoTech trends website - <http://www.infotechrends.com>

Jones III, H. Earl. LFM Thesis - "Factory Installation of Software on Workstations and Servers"

(Cambridge: Massachusetts Institute of Technology, 1999).

Klein, Janice and Barrett, Betty. "One Foot in a Global Team, One Foot at the Local Site".

Virtual Teams (Volume 8, 2001), 107-125.

Klosterman, Steven. SDM Thesis - "An Analysis of the Strategic Management of Technology in the Context of the Organizational Life-Cycle" (Cambridge: Massachusetts Institute of Technology, 2000).

Knox, Neil and Masters, Clark. "Sun's Systems Strategy", Sun Website (http://www.sun.com/events/analyst2003/presentations/Knox_Masters_WWAC_022503.pdf), 25 February 2003.

Nardo, Richard. LFM Thesis – "Strategic Outsourcing Model: Decision Support For Determining Supply Chain Structure" (Cambridge: Massachusetts Institute of Technology, 2003).

Pine III, B. Joseph. *Mass Customization* (Boston: Harvard Business School Press, 1993).

Porter, Michael. "How Competitive Forces Shape Strategy", Harvard Business Review (March-April 19).

Schlegel, Darrin. "COMPANY OF THE YEAR: Benchmark Electronics", Houston Chronicle (<http://www.chron.com/cs/CDA/story.hts/special/chron10003/1926571>), 28 May 2003.

Shankland, Stephen. "Sun to drop its customized Linux" CNET News (<http://news.com.com/2100-1016-994602.html>), 28 March 2003.

Sun Microsystems websites – <http://www.sun.com> .

- Fault Management Technology - <http://www.sun.com/servers/dependability/>
- iForce[sm] initiative - <http://solutions.sun.com/>
- IP Multipathing - <http://docs.sun.com/db/doc/816-5249/6mbdgpoip?q=IP+multipathing&a=view>
- Java Desktop System Analyst Reports - <http://www.sun.com/software/javadesktopsystem/analyst.html>
- Java Enterprise System - <http://www.sun.com/software/javaenterprisesystem/index.html>
- JumpStart - <http://www.sun.com/solutions/blueprints/1100/jssec-updt1.pdf>
- Reference Architectures - <http://www.sun.com/products/architectures-platforms/refarch/>
- Solaris Operating System for x86 Platforms website - <http://www.sun.com/software/solaris/x86/index.html>
- Supplier Awards - <http://www.sun.com/smi/Press/sunflash/2003-10/sunflash.20031001.1.html>
- Sun Fire 15K: http://store.sun.com/CMTemplate/CEServlet?process=SunStore&cmdStartWebConfig_CP&familyCode=SER-CAT&baseSelected=1
- WWOPS website - http://www.sun.com/corp_emp/operations/

Squid Caching website - <http://www.squid-cache.org/>

Senge, Peter. *The Fifth Discipline* (New York: Currency Doubleday, 1990).

Sterman, John. *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Boston: Irwin McGraw-Hill, 2000).

Thomke, Stefan. "Enlightened Experimentation: The New Imperative for Innovation", Harvard Business Review (February 2001), 67-75.

Valys, David. United States Patent US 6,549,914 B1. "System and Method for Statistical File Preload for Factory Installed Software in a Computer", 15 April 2003 - <http://www.dell.com/downloads/global/corporate/patents/6549914.pdf>.

Wang, Bing. LFM Thesis - "Developing Factory-based System Integration Services for a Computer Manufacturer" (Cambridge: Massachusetts Institute of Technology, 1999).

Wikipedia website - http://en.wikipedia.org/wiki/Sun_Microsystems

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Chapter 8 Appendixes

Appendix I: Acronym List

ATO – Assemble-to-Order

BOM – Bill of Materials

CD – Compact Disc

CDP – Channel Distribution Partner

CRS – Customer Ready Systems

ECO – Engineering Change Order

EM – External Manufacturer

ERP – Enterprise Resource Planning

ESP – Enterprise System Products

HDD – Hard Disk Duplication

HW – Hardware

JES – Java Enterprise System

NRE – Non-Recurring Engineering costs

OEM – Original Equipment Manufacturer (in this thesis, this is Sun).

OS – Operating System

PTO – Pick-to-Order

SW – Software

SWDL – Software Download (and Installation)

SWIE – Software integration engineering

SWOPS – Software operations group

TLC – Top-level cache

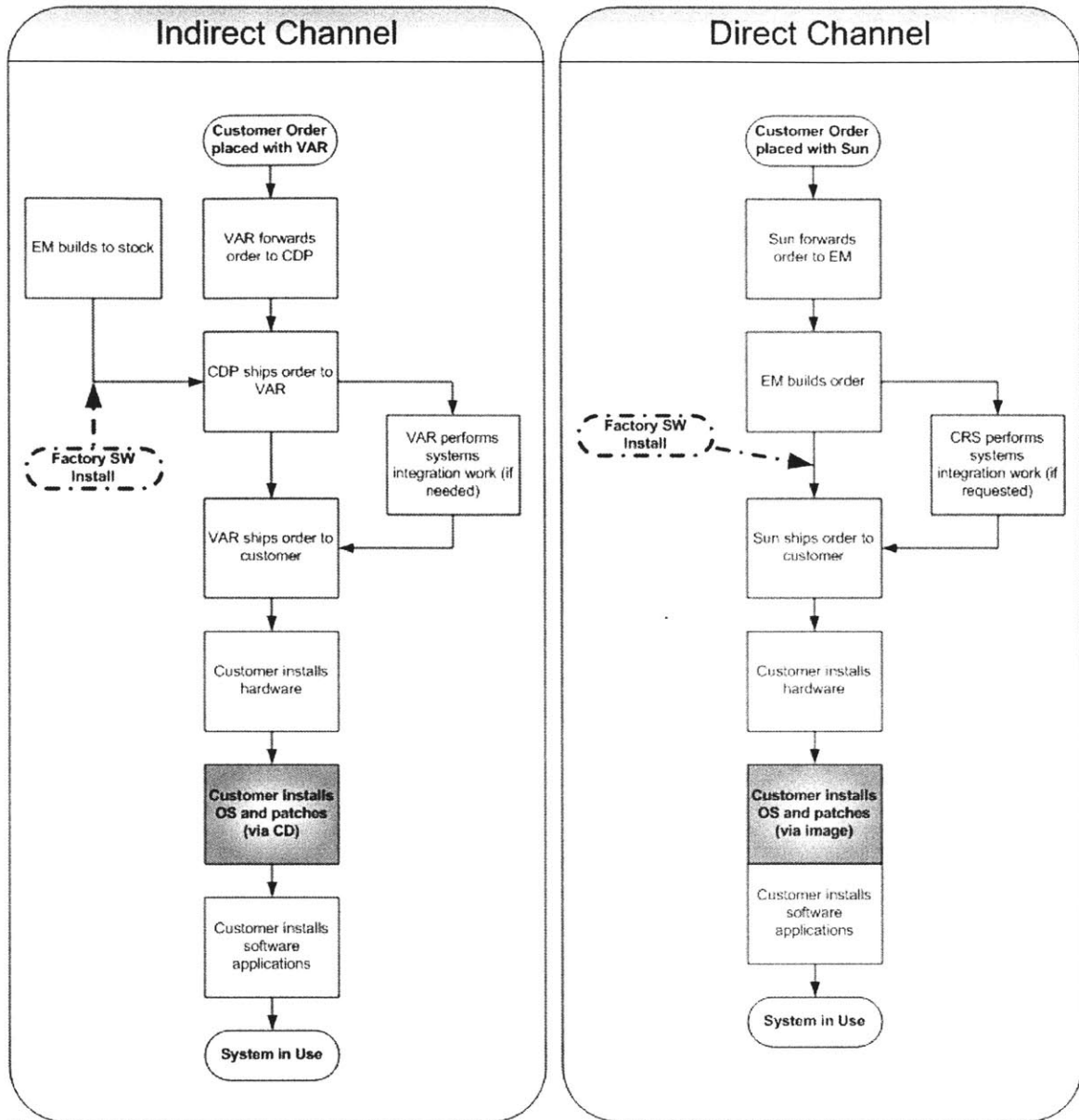
UUT – unit-under-test (target unit)

VAR – Value-Added Reseller

VSP – Volume Systems Products

WWOPS – Worldwide Operations

Appendix II: Customer Order Process



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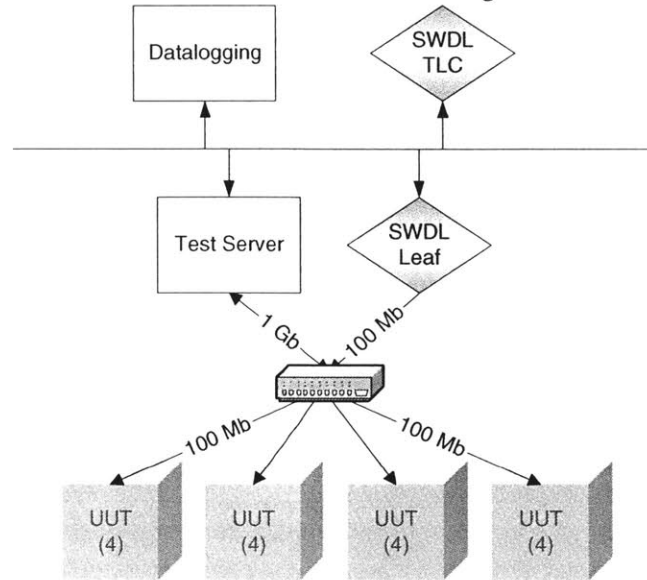
By performing factory software installation, Sun will be able to eliminate one step in the customer installation process for some customers. This is particularly true for customers who use CD's for installs. A factory software load can be done faster and with fewer mistakes than a manual CD installation.

For customers with image installation capabilities, Sun will need to provide the ability to install custom images. Otherwise, the customer will still need to install software applications on top of the OS.

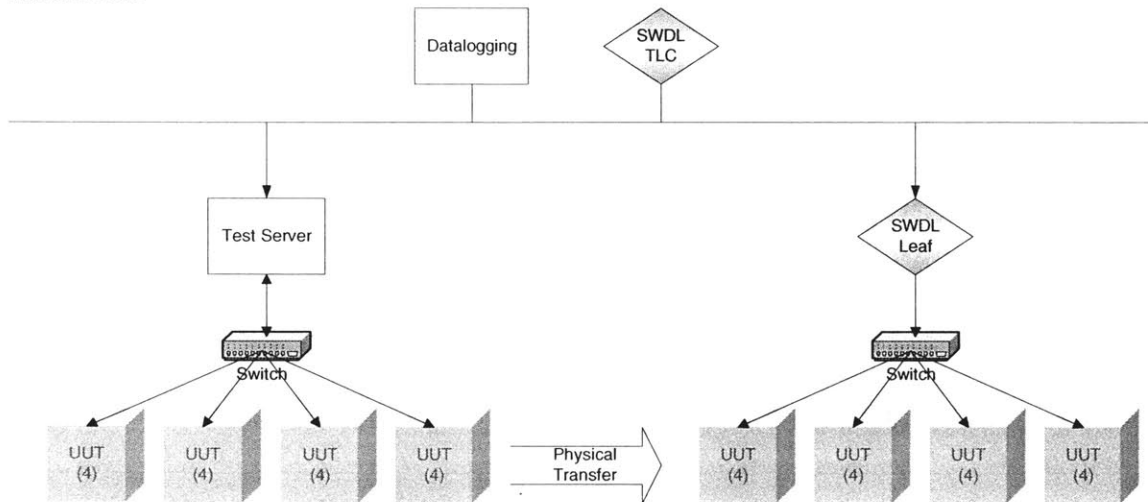
⁶⁵ Adapted from Earl Jones, MIT LFM Knowledge Review, January 1999, Cambridge MA

Appendix III: External Manufacturing Infrastructure Options

Pilot Infrastructure: For the purposes of the pilot at the EM, we chose to use the following configuration that connected a SWDL leaf cache to an existing test server.



Separate SWDL Stage: In this configuration, target units are physically transferred from the SFT stage to a separate SWDL area, where dedicated SWDL servers perform the software installation.



Advantages

- Does not interrupt current processes
- Fully known to work
- Less complex integration

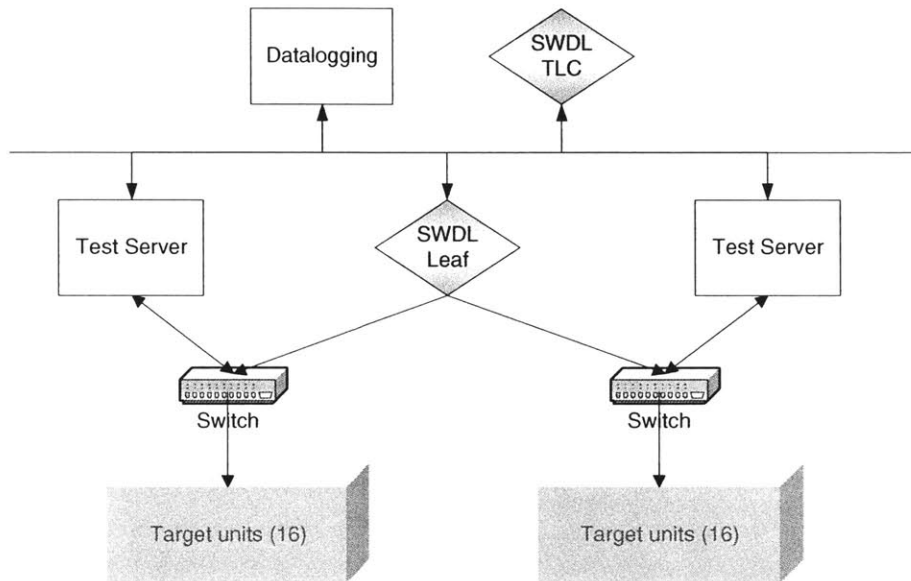
Possible Disadvantages

- Floorspace
- Labor required to move and re-cable the target units

- NRE for test scheduler modifications
- Uneven demand due to batching
- Quality impact (additional touches = potential damage)?

Shared SWDL Leaf Cache: For this proposed configuration, we recognize that a SWDL leaf cache for each test server may be underutilized. As a result, it may be possible to share a single leaf cache among multiple test domains.

Optional I/O cards can be purchased for the leaf cache server so that it can connect to multiple switches. Since tests have shown that bandwidth is generally the limiting factor in installation performance, a leaf cache may be able to support multiple test domains while not inhibiting installation times.



Advantages

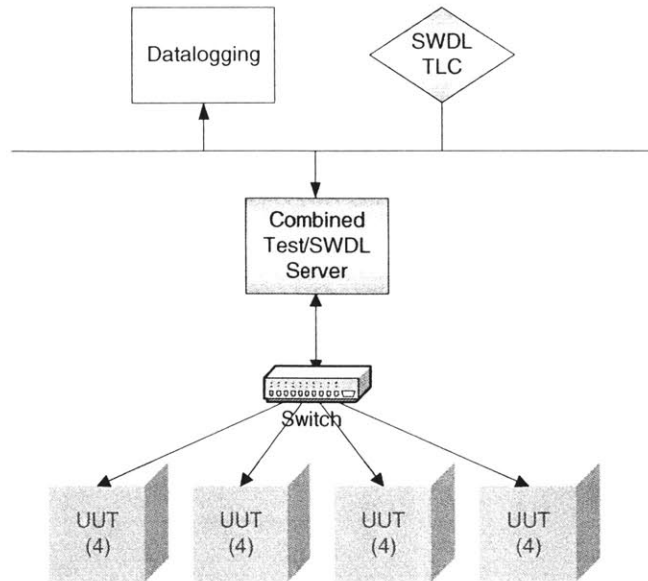
- Fastest choice (no interactions)
- May serve 3-4 domains

Possible Disadvantages

- Single failure disables multiple domains
- Additional servers to be purchased
- Higher potential of performance slowdown (more target units)
- Modification of the test network required

Combined SFT/SWDL Server: Instead of using a separate leaf cache for software installation, another possibility is to add the caching and installation software onto the existing SFT test server. This of course would limit new hardware purchases, but there are concerns about the overall performance of the test cell. Not only will bandwidth need to be shared with existing SFT processes, the hard drive, the processor and the server memory will be stressed.

To pursue this option further, consideration should be made for the upgrade of hard disk and memory on the test server to handle the additional burden.



Advantages

- No additional servers or floor space

Possible Disadvantages

- Interactions between SFT and SWDL (slower than using a unique SWDL server)?
- Bandwidth conflicts with SFT and SWDL?
- Memory and disk upgrades required

Appendix IV: Projected Arrival Rates into Software Download

Data for system functional test (SFT) exit times were compiled for the month of October for a representative volume server. From those times, an analysis was done to determine how many systems would potentially enter the software download (SWDL) at any point in time. As discussed earlier, SWDL will run immediately after SFT.

First, an analysis was made on a per domain basis. Each domain can hold up to 16 target units running SFT simultaneously. Recall that we would like to keep the number of simultaneous software downloads below 7 per domain to prevent performance degradation. Therefore, the data was sorted by domain to see if this situation occurred. Out of the 18 domains, the results were promising:

Quantity of units overlapped within a 1.5X minute period	Number of occasions during month
3	51
4	19
5	6
6	3
7	0

Though there were two times during the month that 6 systems would have entered SWDL on a single domain within a 1.5X minute timeframe⁶⁶, there were no situations where 7 or more units enter SWDL. Thus, we expect no degradation in SWDL leaf cache performance for similar monthly volumes and stable operations behavior.

Another question is whether a leaf cache might be shared over multiple domains. In this case, we are most worried about total number of target units in SWDL for a number of domains. The worst case scenario is one leaf cache per four domains. Therefore, we looked for the situations for the highest number of systems exiting SFT in a 1.5X minute period and examined the domain distribution.

⁶⁶ 1.5X minutes is 50% longer than the time required to install a single target unit with software content.

Domain	# systems exiting SFT per domain
1-1	2
1-3	2
1-4	1
1-8	1
2-4	2
2-7	6
TOTAL	14

Domain	# systems exiting SFT per domain
1-7	1
1-8	4
2-2	2
2-3	2
2-8	2
TOTAL	11

Even at the highest volume periods (11, 14 units entering SWDL within 1.5X minutes), the domain distribution is fairly wide. Taking the 4 highest demand domains, the leaf cache must be able to serve 12 target units simultaneously.

A final analysis was to aggregate the SFT exit times to determine a theoretical probability for situations where > 6 systems exit SFT within a 1.5X minute period.

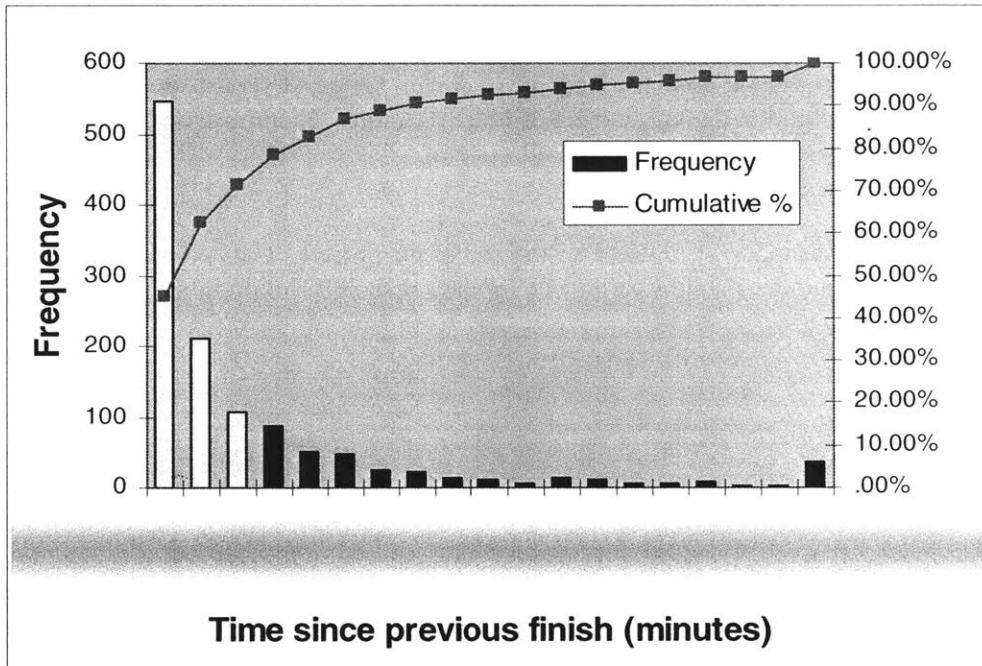


Figure 22: SFT start times in a low demand month

*There were several data points where the previous finish was over 12 hour earlier. This was assumed to be because the EM has no night shift, so finished systems will remain idle. Over 12 hour delays may also be due to weekends.

71.35% of systems finish within 1.5X minutes of the previous unit. 45.17% of systems finish within 0.5X minutes of the previous unit.

We would also like to know how often a cache server will be overburdened during any 1.5X minute period. Empirical evidence suggests that the cache servers will slow down whenever 7 or more systems are running software download simultaneously.

Therefore, as a conservative approximation, we can determine the probability that 6 or more units will finish within 0.5X minutes of the last unit in a row.

$$\begin{aligned}
 P(>7) &\approx P(6 \text{ in a row}) + P(7 \text{ in a row}) + P(8 \text{ in a row}) + P(9 \text{ in a row}) + P(10 \text{ in a row}) \\
 &\approx 0.008493 + 0.003836 + 0.001733 + 0.000783 + 0.000354 \\
 &\approx 0.015198 \\
 E[>7] &= \# \text{ of opportunities} * P(>7) \\
 &= 1211 \text{ units/month} * 0.015198 \\
 &= 18 \text{ instances/month}
 \end{aligned}$$

In reality, there were 93 instances in the month where 7 or more target units exited SFT within 1.5X minutes. This is another clear indication that finish times are not uniformly distributed and some ‘batching’ is occurring.

According to the EM, there are several reasons why batching of target system exit times may occur:

- Weekends – Operators tend to start a large batch of systems through SFT on Friday afternoon at the end of the day. These systems then all finish at approximately the same time.
- Test harness capacity – Within each domain are several test harnesses which hold the cabling for the target units. Operators have been instructed in the past to not disturb a unit running SFT for fear of vibration damage during disk drive testing. Therefore, operators often fill a whole test card before initiating SFT on all systems. These systems will finish at approximately the same time.

Another set of data was made available near the end of the project. The analysis was done on a larger data set from another manufacturing site (greater than 3000 total units):

Quantity of units overlapped within a 1.5X minute period	Number of occasions during month
4	101
5	28
6	9
7	6
8	5
9	0

The above data indicates that there are some situations where cache usage is heavy. Nevertheless, there were only 11 instances during the time period where this occurred, meaning that only $[7*6 + 8*5] / (> 3000) =$ less than 3% of total output was affected.

This level of risk was deemed to be acceptable.

Appendix V: Manufacturing Sensitivity to Software Download times

This appendix provides details on the method used to calculate the manufacturing impact for one of the models manufactured at the EM. The following assumptions were made, though volume and manufacturing times have been masked:

- SFT takes on average of Z hours per unit, which equates to 60Z minutes.
- One target system can be placed into one test bay. There are 16 testbays in a domain.
- Consider a maximum monthly volume for this model at 22A units. With an average of 22 working days each month, there is a daily output of A units.
- The EM uses an ‘effective minutes per day’ quantity that accounts for the ability of a SFT test bay to process the target units. This includes factors for yield loss during SFT and idle time. The value is B minutes.

To determine the current number of domains required:

$$\text{Domains} = A \frac{\text{units}}{\text{day}} * 60Z \frac{\text{min}}{\text{unit}} * \frac{1 \text{ testbay}}{B \text{ min}} * \frac{1 \text{ domain}}{16 \text{ testbay}} = 11.25, \text{ rounding up to 12 domains}$$

Adding X minutes to the SFT test time to account for software download, we get:

$$\text{Domains} = A \frac{\text{units}}{\text{day}} * (60Z + X) \frac{\text{min}}{\text{unit}} * \frac{1 \text{ testbay}}{B \text{ min}} * \frac{1 \text{ domain}}{16 \text{ testbay}} = 11.41, \text{ which would still be 12 domains.}$$

At worse, software download plus Java Enterprise System might add 4.5X minutes to SFT test times. The result would be:

$$\text{Domains} = A \frac{\text{units}}{\text{day}} * (60Z + 5X) \frac{\text{min}}{\text{unit}} * \frac{1 \text{ testbay}}{B \text{ min}} * \frac{1 \text{ domain}}{16 \text{ testbay}} = 11.72, \text{ still 12 domains.}$$

Continuing this same analysis for all of the models, there did not appear to be any situations in the forecasted future where additional domains would have to be purchased for SFT. If SWDL times reach approximately ~7.5X minutes, another domain would definitely be needed.

PPA has a separate calculation. Though the real PPA rate is variable and proprietary, assume that 20% of units go into PPA for this calculation.

- 0.20A units enter PPA each day at maximum forecasted demand.
- PPA is generally C hours, but software download will need to be re-run, adding at least X minutes to the time.

$$\text{Domains} = 0.20A \frac{\text{units}}{\text{day}} * C \frac{\text{min}}{\text{unit}} * \frac{1 \text{ testbay}}{B \text{ min}} * \frac{1 \text{ domain}}{16 \text{ testbay}} = 0.625, \text{ which is just one domain.}$$

The table below shows the relationship between SWDL times and domains required:

SWDL time	Domains	Domains Rounded Up
0	0.625	1
X minutes	0.729	1
4.5X minutes	1.094	2

A 4.5X minute software download is highly probable once Java Enterprise System is installed. Therefore, it is anticipated that an additional domain will be required in the future.

Consideration should also be made for the impact of increasing the load on existing domains. Figure 11 on page 53 shows how software download slows with added load. Particularly for PPA, where a high percentage of time will be spent in software download, the transition to additional domains may be necessary earlier than anticipated above.