A NEW FRAMEWORK FOR MAKING SOURCING DECISIONS REGARDING LOW-VOLUME, HIGH-COMPLEXITY PRODUCTS

by

Dan Moshe Grotsky

B.Sc., Industrial Engineering, Tel-Aviv University, 1997

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

Master of Business Administration

and

Master of Science in Electrical Engineering and Computer Science

in conjunction with the

Leaders For Manufacturing Program

at the

Massachusetts Institute of Technology

December 2001

Signature of Author____
Sloan School of Management
Department of Electrical Engineering and Computer Science

Certified by____
Professor Stephen C. Graves, Thesis Advisor
Sloan School of Management

Certified by____
Professor Joel Moses, Thesis Advisor
Department of Electrical Engineering and Computer Science

Accepted by____
Margaret Andrews, Executive Director of the Master's Program
MIT Sloan School of Management

Accepted by____
Arthur C. Smith, Chairman, Department Committee on Graduate Students
Department of Electrical Engineering and Computer Science

A NEW FRAMEWORK FOR MAKING SOURCING DECISIONS REGARDING LOW-VOLUME, HIGH-COMPLEXITY PRODUCTS

by
Dan Moshe Grotsky

Submitted to the Sloan School of Management and the
Department of Electrical Engineering and Computer Science
on December 21, 2001
in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration

and

Master of Science in Electrical Engineering and Computer Science

ABSTRACT

Compaq Computer Corporation's High Performance Systems Business Unit (HPSBU) manufactures a series of high-end computer servers called Alpha Servers. These servers are manufactured in relatively low volumes, typically for large institutions that require complex computer systems – either rapid number processing, as in scientific applications, or massive data processing, as in large database applications. They are mostly custom-configured for each customer, each server specifically assembled, and each system specifically configured to meet each customer's needs.

As computer manufacturing processes become more standardized, and computers almost commoditized, it becomes impractical to manufacture all system components in-house. To that extent, Compaq has gradually outsourced more and more of the functions, which, combined, are necessary to deliver finished product to Compaq's Alpha Server customers. For instance, as computer manufacturing technology progressed, it quickly became evident, that keyboard manufacturing can, and should, be outsourced to a contract manufacturer, which can achieve economies of scale and produce large quantities of standard keyboards at minimal cost. On the other extreme, Compaq has made sure to keep most of its core competencies in-house, in order to preserve its competitive advantage. The key question faced by Compaq today is which functions to preserve in-house, and which to outsource.

A new conceptual model for making this make or buy decision is presented. The purpose of this model is to raise the numerous issues at stake when considering outsourcing of a particular function, specifically when dealing with low-volume, high-complexity products, such as the Alpha Server. This model provides Compaq with a structured method of analyzing the various components that make up the finished product delivered to the customer, and deciding which *need* to be maintained in-house, which *should* be outsourced, and which of those *can* be outsourced. Initial model implementation was performed on the latest Alpha Server product family, dubbed *Miracle* for the purpose of this document.

Thesis Advisors:

- Stephen C. Graves, Abraham J. Siegel Professor of Management & Engineering Systems, Chair of MIT Faculty
- Joel Moses, Institute Professor, Professor of Computer Science and Engineering, Professor of Engineering Systems

Acknowledgements

I wish to acknowledge the MIT Leaders For Manufacturing (LFM) program for its support of this work. LFM is a graduate-level academic and research program sponsored by MIT's Sloan School of Management, the School of Engineering, and over 20 Industry Partners. LFM is part of the Engineering Systems Division, which develops academic and research programs that reflect the integrative aspects of engineering, complement traditional engineering science strengths and enable students to better understand complex systems. LFM's mission is to discover and codify guiding principles for manufacturing; to educate leaders for manufacturing companies; to infuse important principles and technologies into global manufacturing practice; and to improve the manufacturing excellence of its partner companies.

I would like to express my gratitude to the LFM program for granting me the privilege of enrolling at MIT. My tenure at this most prestigious institution was a time of immense intellectual and personal growth. I will always look back at my years at MIT with a smile. I especially would like to express my appreciation for LFM's flexibility in allowing me to accomplish my internship in an irregular time frame.

I wish to thank Compaq Computer Corporation for hosting my internship graciously during the past year. This thesis is the result of the experience I had during that time. I have learned much from Compaq employees, whether directly through my work at Compaq or indirectly, through informal conversations and cafeteria discussions. Thanks to you all, the experience has been both memorable and educational. I apologize to all those whom I cannot explicitly mention herein, and I hope that you will accept my gratitude for your help and friendship during the last year nevertheless. I managed to bid most of you farewell, yet some of you were absent or on vacation, and I was sorry that we did not have a chance to properly say goodbye. Fred Rosenblum, thank you for introducing me to the staff and "showing me the ropes" as my first supervisor. Paul Sturgis, thank you for being supportive as my final supervisor, and helping me through times when the project seemed "stuck". Frank Fallon and Doug Kellogg, thank you both for being cooperative and helping to provide more insight into the inner-workings of HPS. Keith Tenney, thank you for making me feel at home with the technical staff, and physically showing me around the Alpha platform. It was indeed a pleasure to work with you all.

Next, I wish to thank my thesis advisors, Steve Graves and Joel Moses, for their support and advice throughout the internship and during the writing of this thesis. Sometimes, even a short utterance from you gave me enough to think about for weeks, and changed the course of my internship project.

I wish to thank my parents and siblings for their advice and help throughout my internship and thesis-writing period.

Finally, I wish to thank my dear wife, Galya. I hope to be able to provide the same kind of love and support you gave me on my internship to you on yours.

Table of Contents

I. Introduction 7
  1. Project Description 7
  2. Project Selection 9
  3. Glossary 10
II. Project Setting and Background 15
  1. Company Background, Position and Outlook 15
  2. Compaq's High Performance Server Business Unit 15
  3. Compaq's Alpha Server 16
III. Past Research and Industry Trends 17
  1. Outsourcing Research 17
  2. Recent Trends in Outsourcing 18
IV. Sourcing Decision Model 21
  1. Introduction 21
    a. Assumptions 21
    b. Model Overview 22
  2. Core Competency Assessment 24
    a. Definition 24
    b. Product Component Hierarchy 25
    c. Core Competency Identification 26
    d. Examples 27
  3. Alternative Solutions for Non-Core Functions 28
    a. Financial Criteria 29
      (1) Activity-Based Costing 29
      (2) Capital Investment 30
      (3) Capital Budgeting 30
    b. Operational Criteria 32
      (1) Time To Market 32
      (2) Logistics 34
      (3) Inventory 34
      (4) Quality 35
      (5) Fixed Resource Capacity 36
      (6) Economies of Scale 36
    c. Strategic Criteria 37
      (1) Focus 37
      (2) Flexibility 37
      (3) Control 38
      (4) Double Marginalization 38
      (5) Employees 39
      (6) Market Perception 39
      (7) Technology Strategy 40
      (8) Plant Capacity 43
  4. Evaluation of Alternative Solutions 44
  5. Sourcing Decision 46
V. Conclusions and Analysis 47
VI. Bibliography 49
Appendix 1: Capital Budgeting Example 51
Appendix 2: Initial Model Implementation 54

Figures and Tables

Figure 1 - The sourcing decision model steps.... 8
Figure 2 - Compaq's Alpha Server, in a GS320 configuration.... 16
Figure 3 - The proportions of various functions being outsourced by companies.... 18
Figure 4 - The proportion of outsourcing of various functions within manufacturing companies.19
Figure 5 - Manufacturers typically maintain multiple suppliers when outsourcing.... 19
Figure 6 - Primary goals for outsourcing initiatives among manufacturing companies.... 20
Figure 7 - Expected growth of outsourcing budgets.... 20
Figure 8 - Flowchart of overall sourcing model process.... 23
Figure 9 - A sample high-level product component hierarchy diagram.... 25
Figure 10 - Core competency assessment process flowchart.... 26
Figure 11 - Alternative Assessment based on Capital Budgeting with Real Options.... 32
Figure 12 - Product lifecycle of Product X.... 33
Table 1 - Assessing the value of a technology-intensive function.... 41
Figure 13 - Make / Buy Flowchart based on Technology Criterion.... 42
Figure 14 - Outsourcing as a method of dealing with demand fluctuations.... 43
Figure 15 - Example of an alternative evaluation table, based on weighted average scores.... 45
Figure 16 - Flowchart of overall sourcing model process, with indication of completed model implementation.... 54

I. Introduction

1. Project Description

Compaq Computer Corporation's High Performance Server Business Unit (HPSBU) is struggling to make structured, comprehensive, objective sourcing decisions regarding various components that make up the Alpha Server. Compaq must consider a myriad of strategic and tactical motivations for and against outsourcing, resulting in a daunting decision process. In addition, low volumes make manufacturing of Alpha components unattractive to potential contract equipment manufacturers (CEMs). Finally, the high level of complexity of many of the components significantly limits the number of real outsourcing options available to Compaq.

The decision support model presented was developed by combining the works of various research papers and books from industry and academia in a novel manner. Its primary goal is to help Compaq make these decisions by providing a structured decision-making framework, as illustrated in Figure 1. Of course, this framework may be useful for other companies contemplating sourcing decisions regarding low-volume, high-complexity products as well.

This structured framework achieves three significant goals:

- The model necessitates examination of each sourcing decision in the perspective of the entire Alpha Server system as viewed by the customer, not as a self-contained decision regarding one specific component.
- The model places each component or function that is required to complete the product at the same level of consideration. This includes functions that would not necessarily appear in a bill of materials, such as product marketing or design.
- The model takes both strategic and tactical goals into consideration.

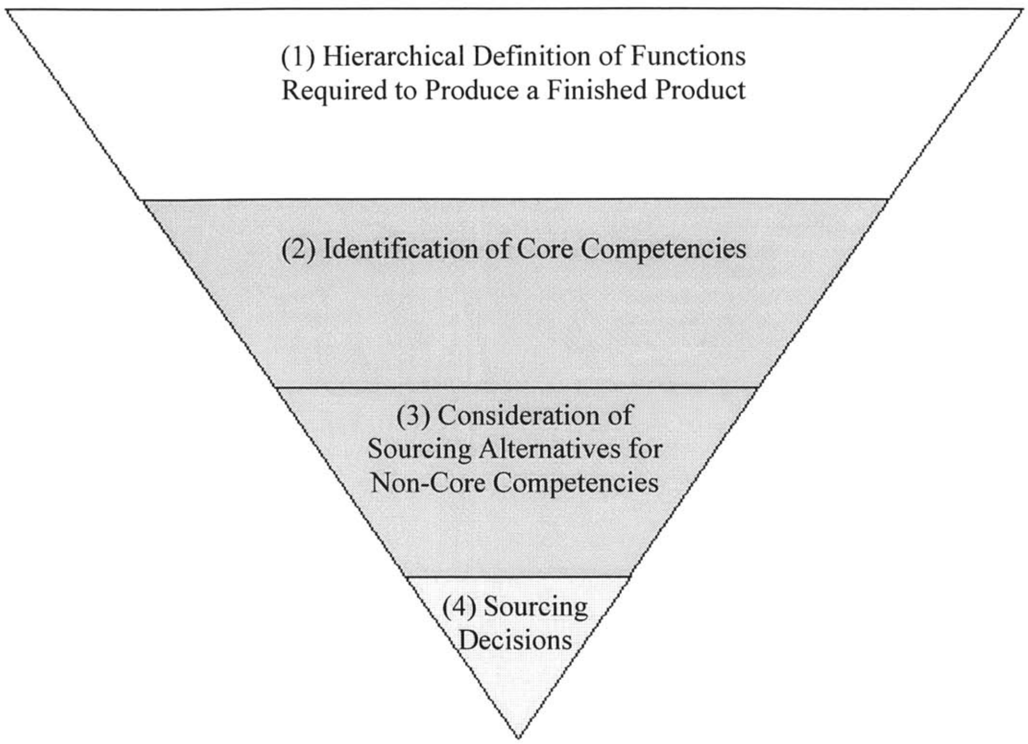


Figure 1 – The sourcing decision model presented consists of four steps: (1) Hierarchical representation of the functional product components, (2) Identification of core competencies, (3) Consideration of sourcing alternatives, and finally (4) The sourcing decisions themselves.

However, it is important to note that the model *does not* provide one conclusive, objective sourcing decision for each component. Rather, it should be used as a framework in which to consider make or buy decisions, not as a magic formula for solving these complex decisions. To that extent, the last step in the model, the sourcing decision, still requires a significant amount of subjective, managerial consideration. Different managers may come to different sourcing decisions using the same data and the same model, but such is the nature of a complex system. There simply is no one correct or optimal solution, and this framework merely helps present a comprehensive list of criteria to be considered in order to achieve an educated, calculated, and, hopefully, successful solution.

Implementation of this model has begun at Compaq, as it relates to the newest family of Alpha Servers, dubbed *Miracle* for the purpose of this thesis (see Appendix 2: Initial Model Implementation).

2. Project Selection

The project described herein has evolved significantly over the course of the one-year LFM internship at Compaq. At first, it seemed as if the most serious issue on the agenda was Compaq's newly forged relationship with one particular Contract Equipment Manufacturer (CEM). Indeed, this was Compaq's first attempt to outsource the manufacturing of a complex component called a Printed Circuit Assembly (PCA). In addition to relatively normal labor pains, such as problems that stemmed from lack of formalized communication between Compaq and its new supplier, Compaq found itself having to deal with global fluctuations in material supply, driving lead times for standard, simple components from days to months. This bitter experience ultimately led Compaq management to the decision to rebuild in-house manufacturing capacity for PCAs and subsequently discontinue the outsourcing relationship they worked so hard to establish.

Simultaneously, Compaq was experiencing quality problems from a supplier of fans for certain processor drawers. Despite the fact that the root cause was a simple fuse mismatch, Compaq found their supplier unresponsive, and was forced to replace entire fan systems for lack of a better fuse – or a better supplier relationship.

The High Performance Server Business Unit (HPSBU) was, just three years ago, a division of Digital Equipment Corporation, which was acquired by Compaq Computer Corporation in 1998. One outcome of this acquisition was a conflict of different corporate cultures. Regarding sourcing issues, Digital management was traditionally much more hesitant to outsource than was Compaq's. Historically, Digital once manufactured all components of its entire product line in-house, as a matter of principle. As time progressed, so did computer manufacturing technology, and Digital resorted to outsourcing the manufacturing of relatively standard components to contract manufacturers that had started to spring up like wildflowers.

Compaq, however, largely depended on these CEMs right from the start. As a high-volume PC manufacturer, Compaq had much to gain from developing long-term, high-volume relationships with these suppliers. The CEMs, on the other hand, manufacture these components in even higher volume, and supply these commodity components to multiple computer vendors, taking advantage of economies of scale that one single vendor could never achieve on its own.

After Compaq's acquisition of Digital, HPSBU began to adjust to Compaq's outsourcing strategy. However, HPSBU's low-volume, high-complexity systems posed different issues than those which led Compaq management to its outsourcing strategy, and the make / buy decision was not as trivial as Compaq believed it to be.

Project selection was based on a combination of Compaq's concerns listed above, as well as academic interest. The project was designed to be both useful for Compaq management, and educational, interesting, and beneficial for others faced with make / buy decisions in low-volume, high complexity manufacturing environments. The framework presented provides a novel method for contemplating the make / buy decision, by bringing both strategic and tactical issues to light. While each element or step of the model is based on previous research, as referred to specifically in each section of the thesis, the model framework represents a new approach to the make / buy decision.

Where Compaq is concerned, the model deals with the issues described above, whether directly or indirectly. Specific examples of potential model implementation at Compaq are presented as well.

3. Glossary

Activity-Based Costing (ABC) – Activity-based cost systems emerged in the mid-1980s to meet the need for accurate information about the cost of resource demands by individual products, services, customers, and channels. ABC systems enabled indirect and support expenses to be driven, first to activities and processes, and then to products, services, and customers. The systems gave managers a clearer picture of the economics of their operations.[1]

Alpha Server – A high-end computer server manufactured by Compaq Computer Corporation. Alpha Servers are designed to run Compaq Tru64 UNIX, Linux, or Windows NT operating systems, and are sold primarily for data-intensive applications or massive processing needs.

Appropriability – The environmental factors, excluding firm and market structure, that govern an innovator's ability to capture profits generated by an innovation. The most important dimensions of such a regime are the nature of the technology (whether product or process, tacit or codified) and the efficacy of legal mechanisms of protection (patents, copyrights or trade secrets).[2]

[1] Kaplan, Robert S. & Cooper, Robin, Cost & Effect: Using Integrated Cost Systems to Drive Profitability and Performance

[2] Teece, David J., "*Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy*"

Complementary Assets – Capabilities or assets necessary to be able to successfully commercialize an innovation, such as marketing, competitive manufacturing, or after-sales support. Complementary assets may be generic or specialized.

Contract Equipment Manufacturer (CEM) – These are the suppliers of components, equipment, and services to end product vendors, or OEMs. CEMs typically provide their products and services through long-term contracts, with the understanding that they waive branding rights. *Example*: Solectron Corporation.

Complexity – Complexity is defined by Boppe (2000) as "a measure of the difficulty we have working with something...Complexity typically increases when the number of attributes or situations that exist simultaneously increases." MIT Institute Professor Joel Moses, an advisor for this work, presents a similar definition of complexity as "the number of interconnections between the parts coupled with the intricacy of these connections", in a memo entitled "Complexity and Flexibility". He asserts that complexity is not "bad" - rather it is the currency to achieve real goals of a system such as functionality, efficiency and flexibility. However, if too much complexity has to be expended to achieve these goals, the system becomes increasingly less usable.

The words "complex" and "complexity" are used in this thesis in two different contexts:

- Complexity of the entire supply chain system in which Compaq is engaged.
- Complexity of some of the components that comprise the Alpha Server.[3]

Component – For the purpose of this thesis, a product component is defined, in the most general sense, as any function or physical part that is necessary in order to provide finished product to the end customer. Examples: a printed circuit board, product branding, transportation, quality control system, etc.

Core Competencies - The innovative combinations of knowledge, special skills, proprietary technologies, information, and unique operating methods that provide the product or the service that customers value and want to buy.[4]

HPS - This acronym is sometimes used to refer to HPSBU, Compaq Computer Corporation's High Performance Server Business Unit.

---

[3] This complexity does not constitute a complex system in the systems engineering sense; rather, it is an indication of the difficulty of designing and manufacturing the component, and is defined as the number of interconnections between the parts coupled with the intricacy of these connections, in this case physical interconnections on the part itself.

HPSBU – Compaq Computer Corporation's High Performance Server Business Unit. Based in Marlboro, Massachusetts, this business unit, previously a division of Digital Equipment Corporation, is responsible for the Alpha Server line of products.

LCM – HPSBU's Lifecycle Management Group, née Product Lifecycle Group. LCM is the group within HPSBU that supported the internship project associated with this thesis. LCM owns responsibility for the supply chain lifecycle of the various Alpha Server models, from design conception, through first revenue shipment (FRS) and volume production, to end of life, when a model is phased out of the market to make room for the next improvement to the Alpha series.

Leaders For Manufacturing (LFM) – The dual-degree program at MIT within which the internship that led to this thesis took place. LFM is a graduate-level academic and research program sponsored by MIT's Sloan School of Management, the School of Engineering, and over 20 Industry Partners. LFM is part of the Engineering Systems Division, which develops academic and research programs that reflect the integrative aspects of engineering, complement traditional engineering science strengths and enable students to better understand complex systems. LFM's mission is to discover and codify guiding principles for manufacturing; to educate leaders for manufacturing companies; to infuse important principles and technologies into global manufacturing practice; and to improve the manufacturing excellence of its partner companies.

Linux – An open-source computer operating system that holds 3% of the market share for servers worldwide[5]. Linux started as a "flavor" of UNIX, though was never supported by a specific software vendor. Rather, Linux is developed by volunteer contributors worldwide in an open source strategy.

Make / Buy Decision – A term that pertains to the sourcing decision of a certain part or function. *Make* relates to the decision to manufacture or otherwise accomplish a task or function in-house, i.e. within the organization. *Buy* implies outsourcing the component or function to a contract manufacturer or other service company.

Miracle – A disguised code name for the newest platform of Alpha Servers. The Miracle family is designed to replace all existing Alpha platforms.

Original Equipment Manufacturer (OEM) – The product vendor that brands and sells the end product, albeit through the help of equipment manufacturers and suppliers, CEMs, that are under

---

[4] Greaver, Maurice, Strategic Outsourcing
[5] IDC, March 2001

Operating System (O/S) – The core software at the heart of every computer system that allows other higher-level software applications to access resources such as files, directories, memory, processors, etc. Examples: UNIX, Windows, Windows NT, Linux, VMS, MVS, Palm-OS, etc.

Outsourcing – The act of transferring some of an organization's recurring internal activities and decision rights to outside providers, as set forth in a contract.[6]

In other words, when an OEM outsources work to a CEM, that OEM sets up a contract with the CEM in order to provide products and/or services to the OEM on a recurring basis.

PC – Personal Computer. The term Personal Computer was first used by International Business Machines (IBM) as a name for the computer that marked IBM's 1981 entry into the market for desktop computers (This market was previously dominated by Apple, Commodore, and Tandy, companies that had been marketing personal computers under other names since about 1975). Today, the PC platform represents the largest market segment of computer sales worldwide.

Printed Circuit Assembly (PCA) – A printed circuit board that is fully loaded with appropriate components. Sometimes referred to simply as *modules*, PCAs are the building blocks of computer hardware. PCAs range in complexity from relatively simple Operating Control Panel PCAs, which are used to control the basic on/off switch elements of the computer, to highly complex central processing unit (CPU) PCAs, upon which processors are placed to operate the main processing of the computer.

Printed Circuit Board (PCB) – A raw card containing electronic circuitry that, after placements of numerous electronic components, operates as a printed circuit assembly. Printed circuit boards are not generic; rather they are designed and manufactured to serve in specific printed circuit assemblies.

Server – A computer capable of supporting software applications on remote computers. Servers typically reside in central locations on the network, and are typically stronger machines used to support numerous applications or users on a computer network.

---

[6] Greaver, Maurice, Strategic Outsourcing

UNIX – A computer operating system that holds 48% of the market share for servers worldwide[7]. The term UNIX is used to refer to various similar operating system "flavors" (e.g. Compaq's Tru64, Sun's Solaris, IBM's AIX, and HP's HP-UX), based on software vendor.

Windows NT – A computer operating system sold by Microsoft that holds 23% of the market share for servers worldwide[8].

---

[7] IDC, March 2001
[8] IDC, March 2001

II. Project Setting and Background

1. Company Background, Position and Outlook

> *"Compaq Computer Corporation, a Fortune Global 100 company, is a leading global provider of technology and solutions. Compaq designs, develops, manufactures, and markets hardware, software, solutions, and services, including industry-leading enterprise computing solutions, fault-tolerant business-critical solutions, and communications products, commercial desktop and portable products, and consumer PCs that are sold in more than 200 countries."*[9]

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

Recently, a new corporate vision was unveiled, stating that Compaq will bring "Everything to the Internet". To that extent, new marketing plans were laid out, and the corporate strategy has evolved. Specifically, in June 2001, toward the end of the internship that led to this thesis, Compaq declared a strategic alliance with Intel Corporation, whereby Compaq will phase out of the Alpha microprocessor altogether, and will instead base all future products on Intel's Itanium chip. More on this initiative is discussed in the thesis conclusion.

2. Compaq's High Performance Server Business Unit

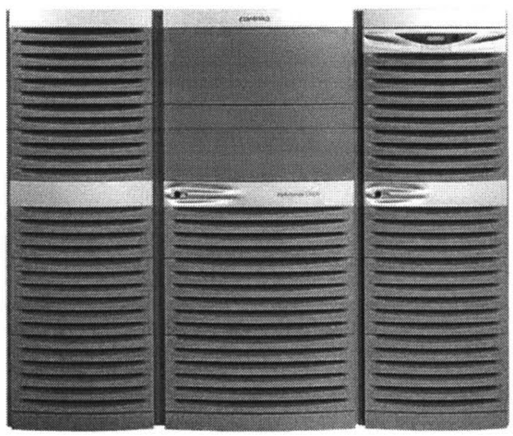
The work associated with this project was conducted at Compaq's Marlborough, Massachusetts facility and was sponsored by the High Performance Systems Business Unit's Lifecycle Management (LCM) Group, which has supply chain lifecycle management responsibility for Compaq's Alpha Server series. This group became part of Compaq after the 1998 acquisition of Digital Equipment Corporation by Compaq.

---

[9] "Compaq at a Glance", http://www.compaq.com/corporate/ataglance.html, August 8, 2001

For the most part, the HPSBU has not changed, culturally or administratively, as a result of this acquisition. To that extent, Compaq has left HPSBU's work methods and processes intact, and has managed to preserve employee loyalty to the core business unit. While this tactic proved successful at the business unit level, several cultural and strategic differences are apparent at the corporate level. These differences seldom erupt as internal conflicts, but more often expose different managerial styles, opinions about corporate strategy, or new work methods. Discussing and resolving these differences with an open mind leads to process improvement and strategy evolution. The difference in sourcing strategy views within corporate Compaq and within HPSBU emerged as an opportunity to question the essence of the decisions that make up the sourcing strategy. In many ways, this thesis is the result of this improvement process.

3. Compaq's Alpha Server



<u>Figure 2</u> - Compaq's Alpha Server, in a GS320 configuration.

Compaq's Alpha Servers are some of the fastest, most powerful computer systems on the planet. Used primarily by large organizations in need of heavy floating-point number calculations or intensive data processing, Alpha Servers support applications such as the Celera Genomics' role in the human genome project and the Pittsburgh Supercomputing Center, a joint effort of Carnegie Mellon University and the University of Pittsburgh together with the Westinghouse Electric Company. In addition to such high profile, computing-intensive applications, Alpha Servers provide significant value as application servers in businesses and other institutions, running their information systems on Compaq's Tru64 UNIX, Microsoft's Windows NT, or Linux operating systems.

III. Past Research and Industry Trends

1. Outsourcing Research

Extensive research has been conducted over the past two decades regarding sourcing strategy and the make / buy decision. Though the framework presented herein is novel, most of the elements that comprise this framework are directly derived from various industrial and academic sources. However, little reference is made in the literature to the specific concerns of the sourcing decision in low-volume or high-complexity environments. Many of the factors that are considered primary reasons to outsource in high-volume systems are different or simply not relevant in low-volume environments. Other factors are almost trivial to implement when dealing with simple components, yet become difficult or even infeasible when dealing with complex components.

The model presented herein is based on current research regarding outsourcing initiatives[10], primarily in, but not limited to, manufacturing companies. Specifically, in orderto build a framework for consideration of Compaq's make / buy decision, the most important factors were those that involved the motivation behind outsourcing initiatives and the stumbling blocks of those initiatives, once they were decided upon.

Many researchers agree that the motivation behind outsourcing is closely coupled with the concept of core competencies[11], which is discussed at length. Generally speaking, it is considered a strategic mistake to outsource a core competency, and thus one must first determine the organization's core competencies, before making any make / buy decisions.

---

[10] Greaver, Maurice, Strategic Outsourcing; Anderson, David, "The Seven Principles of Supply Chain Management"; Fine, Charles, ClockSpeed; Brück, Felix, "Make Versus Buy: The Wrong Decisions Cost"; Fine C. & Whitney D., "Is the Make-Buy Decision Process a Core Competence?"; Stuckey, John and White, David, "When and When *Not* to Vertically Integrate"

[11] Greaver, Maurice, Strategic Outsourcing; Fine C. & Whitney D., "Is the Make-Buy Decision Process a Core Competence?"; Rosenfield, Donald. Notes from "15.769 Manufacturing Strategy"

In addition, the following criteria, compiled from various sources (see VI Bibliography), were determined relevant for sourcing decision consideration, specifically when considering outsourcing of a non-core competency:

- Financial criteria: These include both variable and fixed costs that are affected by the sourcing decision.
- Operational criteria: These include changes in logistic systems, relationships with suppliers, and the effects of fluctuations in supply and demand.
- Strategic criteria: These include other long-term issues, such as company focus, reputation, and employee retention and motivation.

2. Recent Trends in Outsourcing

The following figure illustrates the recent increase in outsourcing worldwide. As effective, inexpensive, inter-enterprise communication becomes commonplace, transportation and logistics systems improve, and services industries become more consolidated, companies are able to take advantage of these advancements in order to focus on their core competencies and outsource non-core functions.

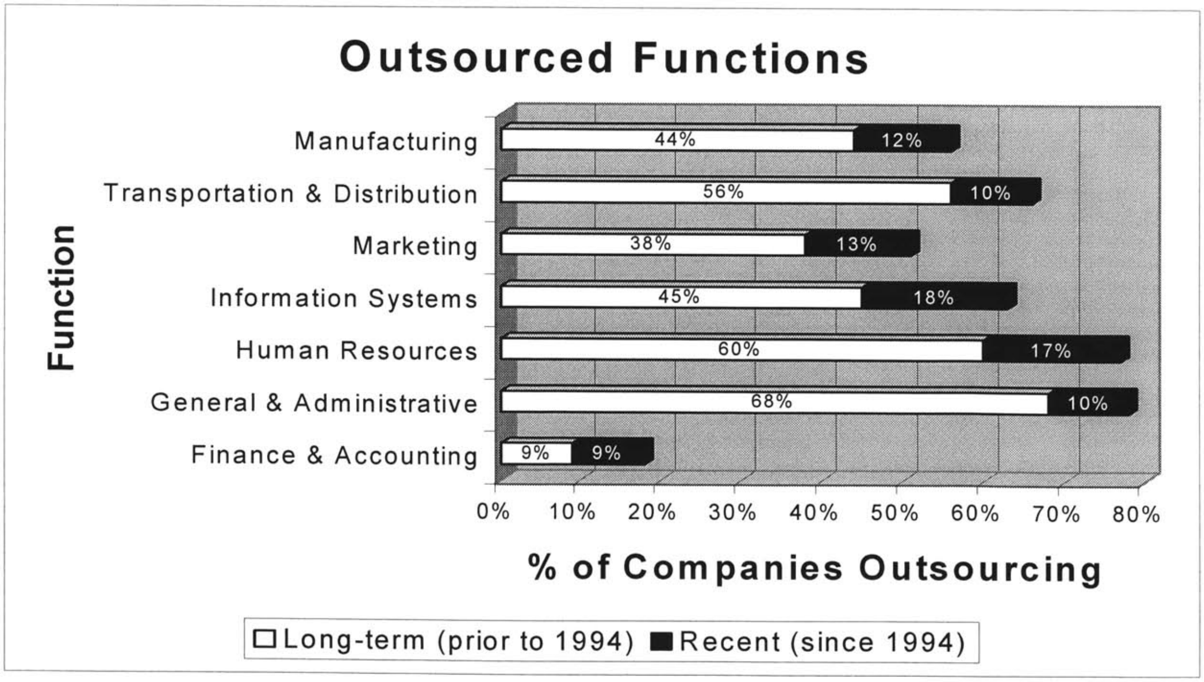


Figure 3 - **The proportions of various functions being outsourced by companies. (Source: American Management Association, 1997)**

Among manufacturing companies, outsourcing is a growing trend as well, and component production has become the most commonly outsourced function, as shown below:

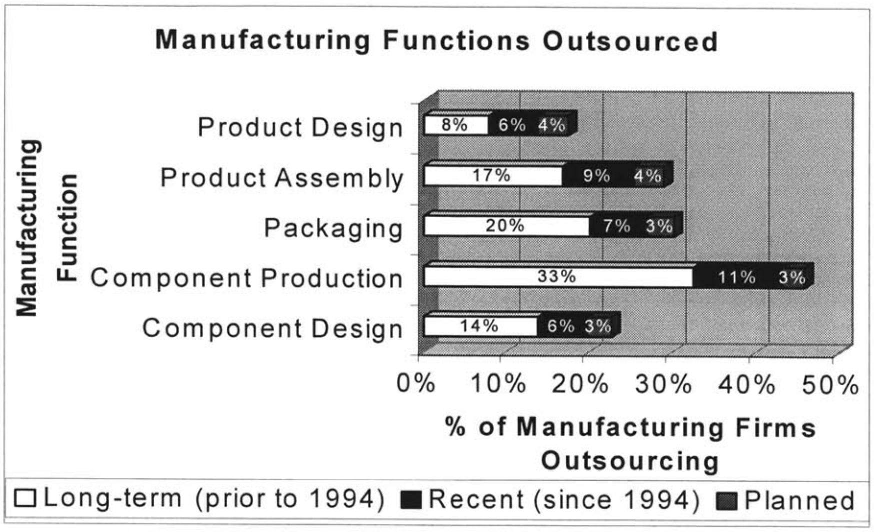


Figure 4 - The proportion of outsourcing of various functions within manufacturing companies. (Source: American Management Association, 1997)

Moreover, the following chart shows that outsourcing of these manufacturing functions is typically achieved by maintaining multiple suppliers:

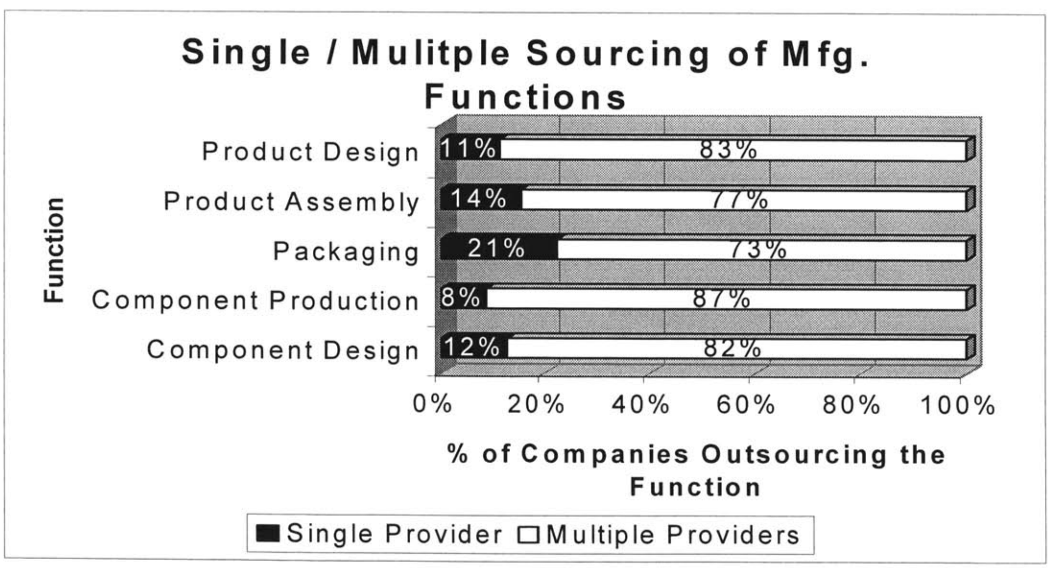


Figure 5 - Manufacturers typically maintain multiple suppliers when outsourcing. (Source: American Management Association, 1997)

The primary reasons behind outsourcing among manufacturing companies are cost and time reductions:

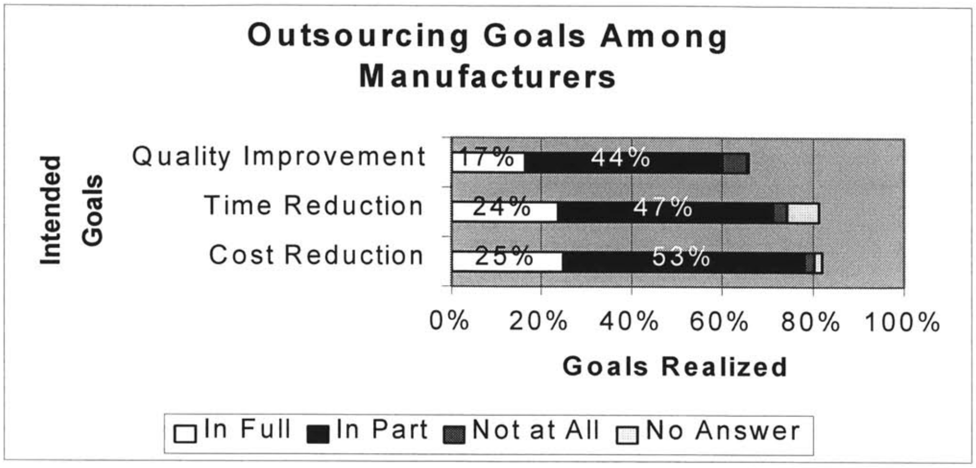


Figure 6 - Primary goals for outsourcing initiatives among manufacturing companies.

(Source: American Management Association, 1997)

The outsourcing trend is accentuated among electronics manufacturers, as shown below:

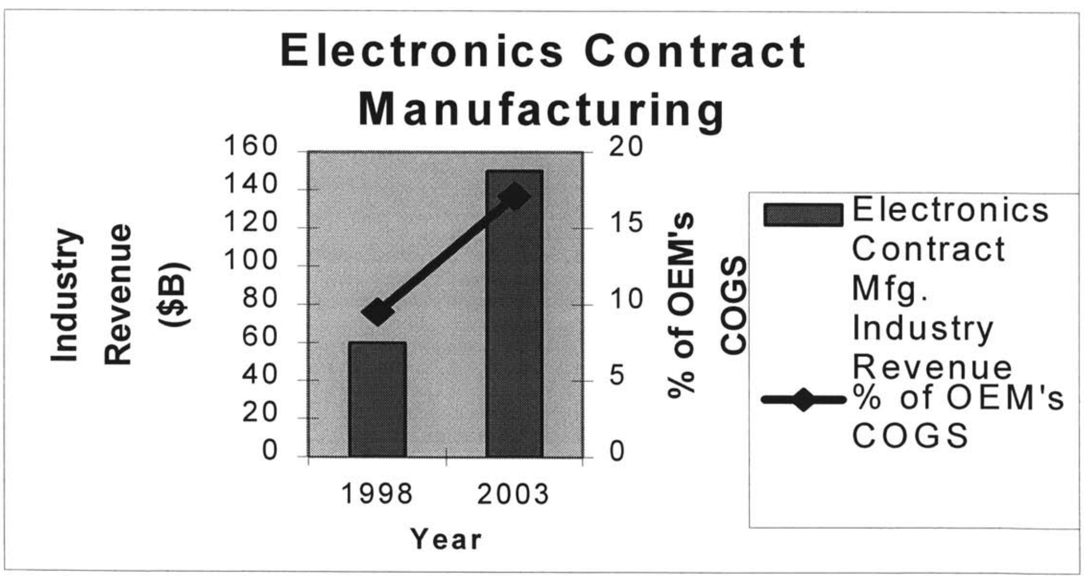


Figure 7 - Expected growth of outsourcing budgets as a percentage of cost of goods sold among electronics manufacturers.

(Source: Forrester / Technology Forecasters, May, 2000)

IV. Sourcing Decision Model

1. Introduction

The following model describes a framework of a suggested thought process to be used when contemplating sourcing or make / buy decisions for Alpha Server components. This model is based on the combination of industry and academic research, as well as specific Compaq needs and considerations. It was designed as a generic model, however, which could be useful for most any company contemplating the make / buy decision, and probably most helpful for those manufacturing companies faced with specific problems in outsourcing low-volume, high-complexity components, as is Compaq. The model structure (see IV.1.b Model Overview), as well as its focus on issues that arise in low-volume or high-complexity manufacturing environments, is what constitutes the model's novelty.

a. Assumptions

The following initial assumptions are established in order to build a generic, strategic model:

1. The Alpha Server platform, as a whole, constitutes a competitive advantage for Compaq, as a product that provides unique value to Compaq's customers.[12]
2. Customers will continue to base their buying decisions on criteria similar to those that they use today.
3. Compaq currently has variable in-house manufacturing capability, which may, at a measurable cost, be diverted to other activities, expanded, or eliminated altogether.
4. Several contract manufacturers also have variable manufacturing capability, which can be bought by Compaq in an outsourcing contract.
5. Compaq wishes to provide customers with an end-solution, consisting of hardware, basic system software, and optional integration services.

[12] A process of core competency assessment, similar to that described herein regarding component-level core competencies, could be conducted ahead of time at a corporate level across Compaq products in order to determine which products are indeed core competencies. In this case, the working assumption is that the Alpha Server is a core competency, and therefore provides competitive advantage to Compaq.

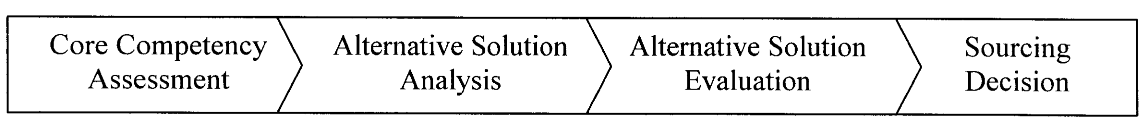
b. Model Overview

The model should be applied iteratively to each component or function that is performed in order to supply finished product to the customer, in a top-down manner. These components include both physical component manufacturing as well as more intangible elements, such as product design or distribution. In other words, the product, in its entirety, is first analyzed in order to determine a hierarchy of components and sub-components. Then, each component is analyzed separately, starting with the entire finished product, and ending with the nuts-and-bolts that make up the system. However, fear not – entire sub-systems will be exempt from further analysis upon determination of sub-system outsourcing, rendering the whole process practical.

The following steps constitute the process to be conducted for each component, and are described at length in the following chapters:

1. Core competency assessment
2. Analysis of alternative solutions for non-core functions
3. Evaluation of alternative solutions
4. Sourcing decision

The following bar is used throughout the model description to help the reader keep track of the various steps of the model framework – The relevant step is highlighted in the beginning of each section.



However, while discussion of these steps in the thesis is serial, model implementation is not. The following diagram illustrates how these steps are meant to be implemented:

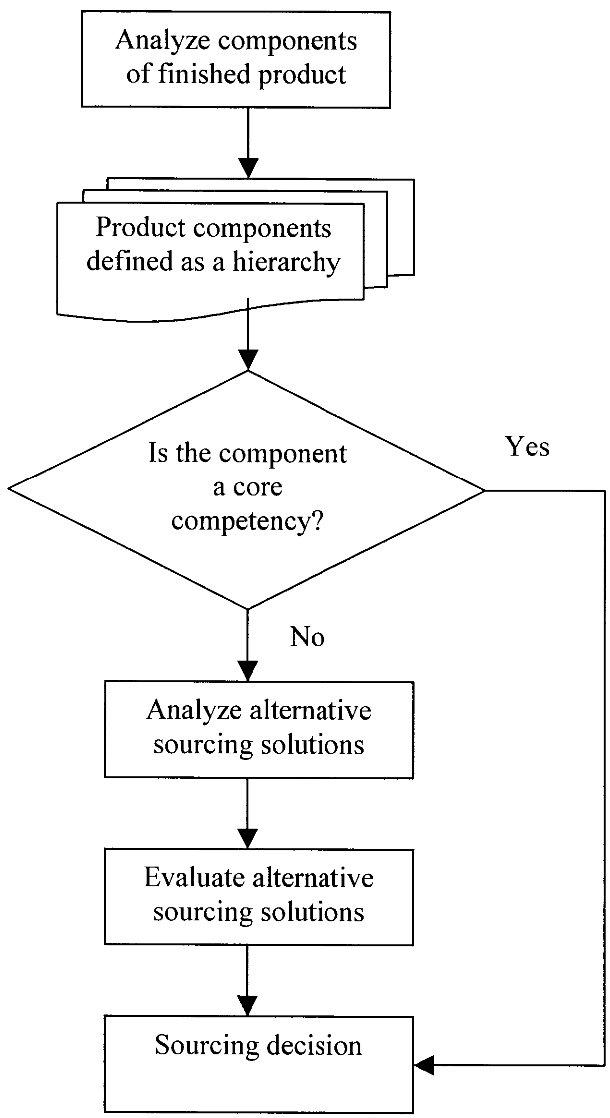


Figure 8 – Flowchart of overall sourcing model process.

2. Core Competency Assessment

Core Competency Assessment	Alternative Solution Analysis	Alternative Solution Evaluation	Sourcing Decision

a. Definition

Before delving into the subject of core competencies, a proper definition of the term is in order:

Core competencies are[13] –

- *"...the innovative combinations of knowledge, special skills, proprietary technologies, information, and unique operating methods that provide the product or the service that customers value and want to buy."*
- *"...what sets the organization's products and services apart from competitors' similar offerings."*
- *...not "fleeting [or] easily imitated."*

In other words, a competency can be considered core only if it satisfies two criteria:

1. It must provide a competitive advantage; i.e. it must contribute to creation of a product or service that customers see as distinguishably valuable and unique to the company.
2. It must be a sustainable competency.

[13] Greaver, Maurice, Strategic Outsourcing

b. Product Component Hierarchy

Figure 9 illustrates a sample product component hierarchy at its highest level. Each component is broken down into sub-components, unless an outsourcing decision is already made for that component. If an activity-based costing (ABC) method is implemented, this can help define the product component hierarchy, since the breakdown to specific activities is quite similar to this approach. Furthermore, costing data collected through ABC can then be used for evaluating the financial criteria discussed below. For the purpose of this thesis, a product component is defined, in the most general sense, as any function or physical part that is necessary in order to provide finished product to the end customer. Examples: a printed circuit board, product branding, transportation, quality control system, etc.

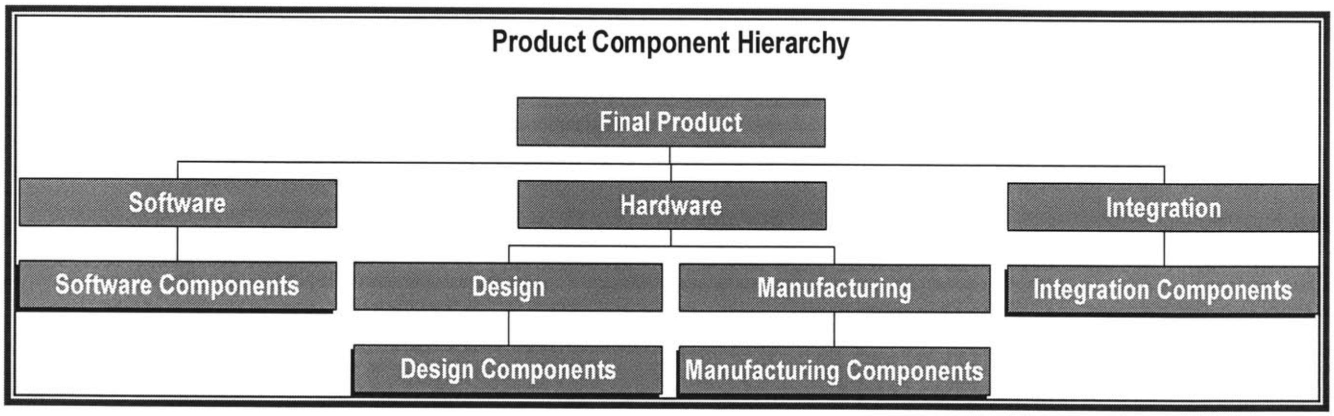


Figure 9 - A sample high-level product component hierarchy diagram.

c. Core Competency Identification

Outsourcing a core competency essentially means giving up a sustainable business method or function that directly provides unique value to the customer, and handing that business over to another company instead. Therefore, by identifying core competencies, one eliminates those functions as potential for outsourcing, thereby mitigating the risk of losing valuable business to contract manufacturers or other service providers. The only functions exposed to this risk are non-core competencies, which, by definition, do not contribute to unique customer value over the long haul in any case.

The following flowchart (Figure 10) describes the process of identifying core competencies, and should be applied to each function, or component within the product component hierarchy (as described in Figure 9):

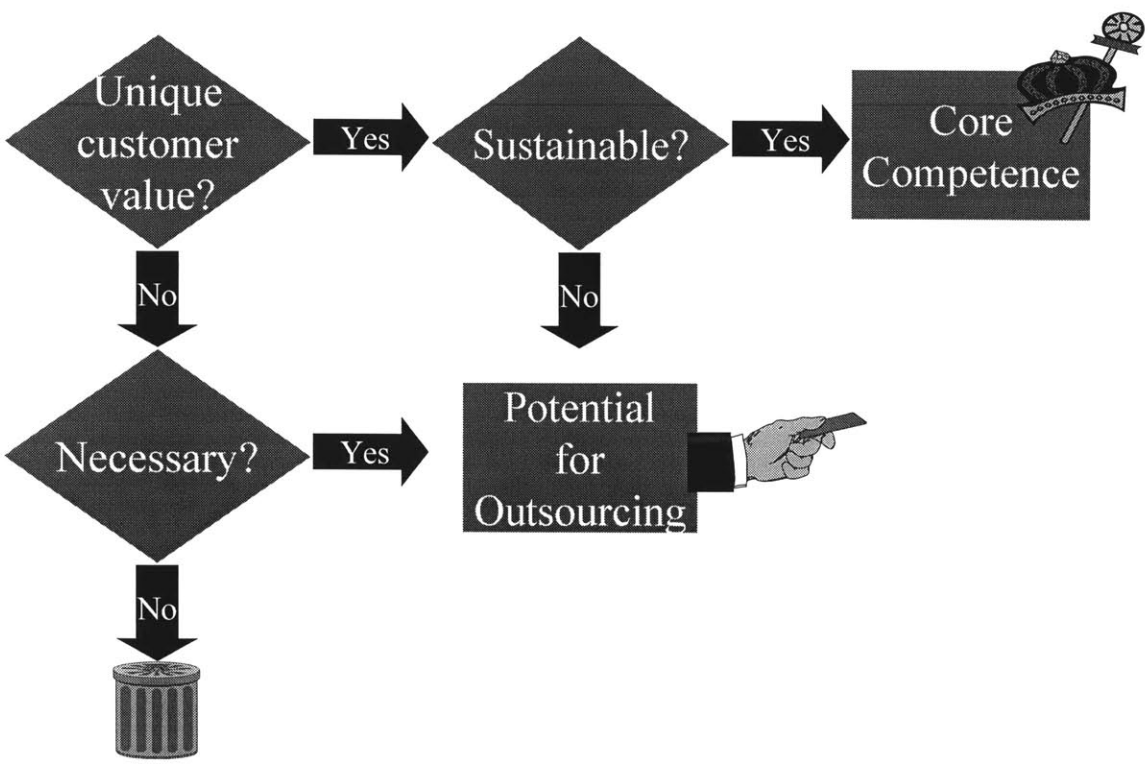


Figure 10 - Core competency assessment process flowchart: Non-necessary functions should be eliminated; Necessary non-core functions can potentially be outsourced; Core competencies should be regarded as sustainable revenue generators, and thus should be maintained, fostered, and guarded as crown jewels.

d. Examples

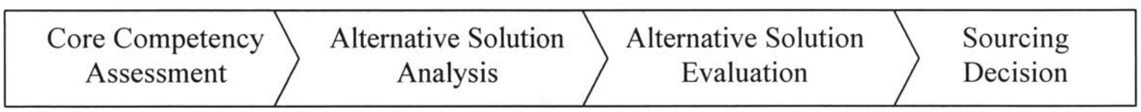
1. In a typical manufacturing company, the accounting department is crucial to the long-term survival of the company. However, when customers contemplate which product to buy, accounting competencies are rarely considered a factor, nor do they directly contribute to such a factor. To that extent, accounting methods, while necessary to the survival of the company, would not be considered a core competency, because they do not fulfill the first requirement – they do not contribute to **unique** customer value.

2. Let us consider another, less obvious example. *WidgetWare Corp.* has an extremely efficient quality control system. As a result of this system, *WidgetWare* was able to cut costs by a factor of 30%, and quality levels increased by 70%, far above competitors' offerings. One would think that *WidgetWare*'s quality control system must, therefore, be a core competency. However, that is not necessarily true. If customers are, perhaps, indifferent to the increased level of quality offered by *WidgetWare*, then their increased quality levels do not offer unique customer value. In addition, if *WidgetWare*'s prices were not affected by the lower costs, then customers did not receive value in this respect either. If no unique customer value was gained by implementing the quality control system, then that system cannot be considered a core competency.

3. In that case, one might say, assuming the customer in the previous example *did* appreciate the value of the increased level of quality in *WidgetWare*'s product, the quality control system could be considered a core competency. However, this statement is not necessarily true either. Let us assume that two key employees are responsible for the quality control system in its entirety. Their method and work processes are not documented, nor do their coworkers or superiors understand their function. Or, alternatively, what if the quality control system consists of a generic software package that was bought off-the-shelf for $199.99? In both cases, the appropriability of this function is considered weak. A competitor, *Better Widgets Corp.*, could easily acquire this competency, either by hiring these two individuals, or by purchasing this software. This would render the competency of no *unique* value to the customer, because *Better Widgets* would then offer comparable value as well. In this example, the competency is said to be unsustainable, and therefore is not a core competency either.

4. In another example, *Mobile Widgets, Inc.* has developed a new type of cellular phone that is significantly less expensive than other phones on the market, because it operates on a new communication protocol, for which *Mobile Widgets* has a patent. *Mobile Widgets* believes it has strong appropriability for this product as a result. However, when trying to penetrate the cellular market, *Mobile Widgets* finds it necessary to contract with wireless communication carriers, in order to begin deploying the product. It can be said that *Mobile Widgets* is dependent upon specialized complementary assets that are owned by the carriers, namely their relationship with their customer base and their ability to provide wireless communication service. *Mobile Widgets* would be wise to partner with such a carrier in order to commercialize their defendable technology, for without these complementary assets *Mobile Widgets* would not be able to achieve market penetration.

3. Alternative Solutions for Non-Core Functions



Once the core competencies are identified, and unnecessary functions are eliminated, the remaining components in the product component hierarchy are said to be non-core competencies. In the iterative process of drilling down through the product component hierarchy, these non-core competencies are the functions that should be considered for outsourcing. Outsourcing these functions carries minimal risk of conceding long-term value to contractors, since all functions that provide such value are, by definition, considered core competencies. In other words, **limitation of outsourcing potential to non-core competencies ensures preservation of those functions that provide sustainable unique customer value**.

However, it is not always feasible or advisable to outsource *every* non-core function. First, alternative solutions to in-house functionality must be assessed and compared with in-house solutions. When evaluating alternative solutions, it is appropriate to weigh the benefits and drawbacks of each alternative in regard to several critical factors, including, but not restricted to, cost. The following list of factors includes most major potential benefits and drawbacks of outsourcing a particular function, and can be used as a "checklist" for evaluating each sourcing alternative. The criteria are divided into three primary categories based on financial, operational, and strategic relevance.

a. Financial Criteria

Miguel Miciano, an LFM intern at Compaq in 1999, conducted a thorough analysis of financial criteria to be used for considering sourcing alternatives, in his thesis titled "A Tool for Sourcing Decisions". In his work, Miciano developed a comprehensive financial planning tool, based on Microsoft Excel, especially for conducting such cost-based decisions. The purpose of this work is not to "reinvent the wheel", so to speak, rather to provide some of the financial criteria as food for thought to be considered when looking at sourcing alternatives.

In a low-volume or high-complexity manufacturing environment, it is particularly important to differentiate between the fixed and variable costs associated with the production of each component. This is due to the fact that "fixed" plant, property, and equipment costs tend to be proportionally higher than in high-volume or low-complexity scenarios. Accordingly, sourcing solutions that have an effect on fixed resource allocation entail thorough financial analysis of relevant cost drivers.

(1) Activity-Based Costing

Breaking the finished product down to product components and functions allows us to look at the various activities involved in the entire production process. The activities-based costing (ABC) method similarly relates to activities and raw materials that make up the entire cost of the product. This paper does not go into depth describing ABC methodology, which can be found in a wide variety of accounting textbooks (perhaps the most commonly used is Kaplan and Cooper's "Cost and Effect", included in the bibliography of this thesis). Data derived from this cost analysis can help in performing capital budgeting analysis on the various alternatives for each function, since ABC allocates costs separately to each such function.

In this analysis, we will need to make certain assumptions about the future environment and its effect on these costs, in order to project the costs over the next few years. These assumptions include production volumes, product mix, inflation rates, labor rates, etc. The cost projections related to in-house production are then compared to the costs of the various outsourcing alternatives. Depending on the volatility and the impact of the assumptions made, sensitivity analysis may also be useful for these projections. For instance, if prices of raw materials depend on a shaky supplier, and that cost represents a significant portion of the overall cost of the function in question, sensitivity analysis based on the existence of that supplier, or on the cost of that material, is in order.

Miguel Miciano's LFM thesis work provides a tool that could be used efficiently in this capacity. ABC data can be used in the "input worksheet", and then the optimization framework suggested can be used to find the short-term costs associated with each sourcing alternative for the component.

(2) Capital Investment

Outsourcing allows OEMs to essentially turn fixed costs into variable costs. For example, by outsourcing manufacturing capability, production lines or even entire facilities can be closed down, sold, or transferred to production of other products. The plant, property, and equipment (PP&E) expenses, which are considered fixed costs, are thus eliminated. However, prices negotiated with contract manufacturers typically include these costs, as they are factored into the CEM's prices. In this manner, the fixed PP&E costs are "exchanged" for variable costs, paid to the CEM for services rendered.

It is often convenient to assume that outsourcing does not have an effect on such fixed costs, unless they are indeed eliminated, as described above. However, in most cases, this assumption is inaccurate. If the fixed assets are not specialized to one specific function, or are otherwise utilized as a result of outsourcing, this extra value should be taken into consideration. Moreover, Theory of Constraints (ToC)[14] would suggest, that if the total throughput can be increased as a result of this increased resource capacity, then the added value of that freed capacity is equal to the entire increase in throughput. See IV.3.b(5) Fixed Resource Capacity for more information about the value of alleviating capacity constraints.

(3) Capital Budgeting

In order to quantitatively evaluate the financial impact of the make or buy decision of a specific component, it can be helpful to consider each component as a separate project, and each sourcing alternative as an alternative to project execution. Capital budgeting analysis takes both the variable and the fixed costs described in the previous two criteria into account in order to compare the various alternatives. These criteria are discussed separately above, because it is important to be able to evaluate the impact an alternative has on fixed costs regardless of variable costs and vice-versa. However, the overall combined comparison obtained through capital budgeting is useful to get a feel for the combined cash flows of each alternative.

---

[14] Goldratt, Eliyahu M., The Goal: A Process of Ongoing Improvement.

The simplest way to go about capital budgeting is to conduct a discounted cash flow (DCF) calculation, taking real options into account. Free cash flows are calculated as follows:

$$FCF = OP \times (1 - T_c) + D \times T_c - I - \Delta WC$$

where:

FCF = free cash flow

OP = operating profit, or gross cash flow

D = depreciation

T_c = tax rate

I = investment

WC = net working capital (or inventory)

The net present value of an alternative equals:

$$NPV = \sum_{j=1}^{T} \frac{E(FCF_j)}{(1+r)^j}$$

i.e., the sum of the expected free cash flows over time, discounted according to the discount rate, r. In order to account for real options, the expected value of free cash flows must take the different possible outcomes of the alternative into account, including project deferral, project abandonment, or growth. See Appendix 1: Capital Budgeting Example.

Generally speaking, when contemplating an alternative that contains a significant element of risk, the following matrix is a useful way to think about the value of that alternative as a function of its expected net present value and its associated risk:

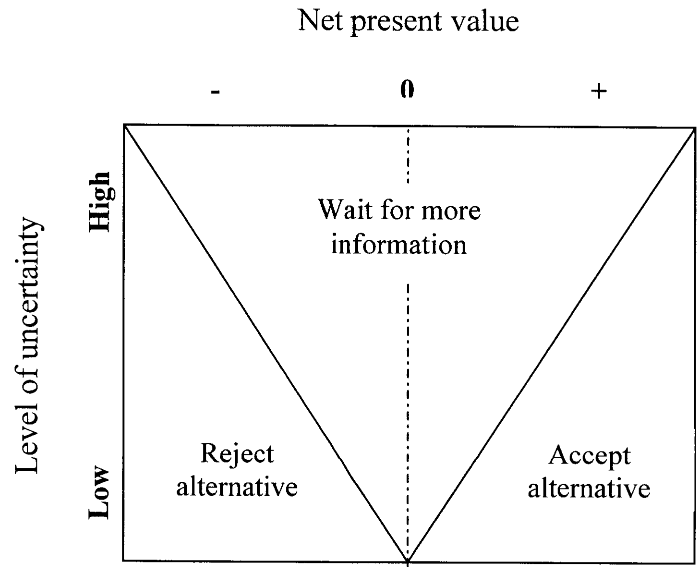


Figure 11 - Alternative Assessment based on Capital Budgeting with Real Options

b. Operational Criteria

(1) Time To Market

Outsourcing can have a significant impact on the period of time that elapses from product inception to first revenue shipment. This time to market is particularly relevant to technology intensive products, which are typically characterized by short lifecycles. For example, if Product X has a two-year product lifecycle, then a one-month delay in time to market of Product X will cause a decrease of over four percent ($\frac{1}{2*12}$) to the bottom line, assuming a constant revenue flow throughout the lifecycle. This assumption proves to be quite conservative, considering the fact that revenue is usually higher in the initial stages of the product lifecycle.

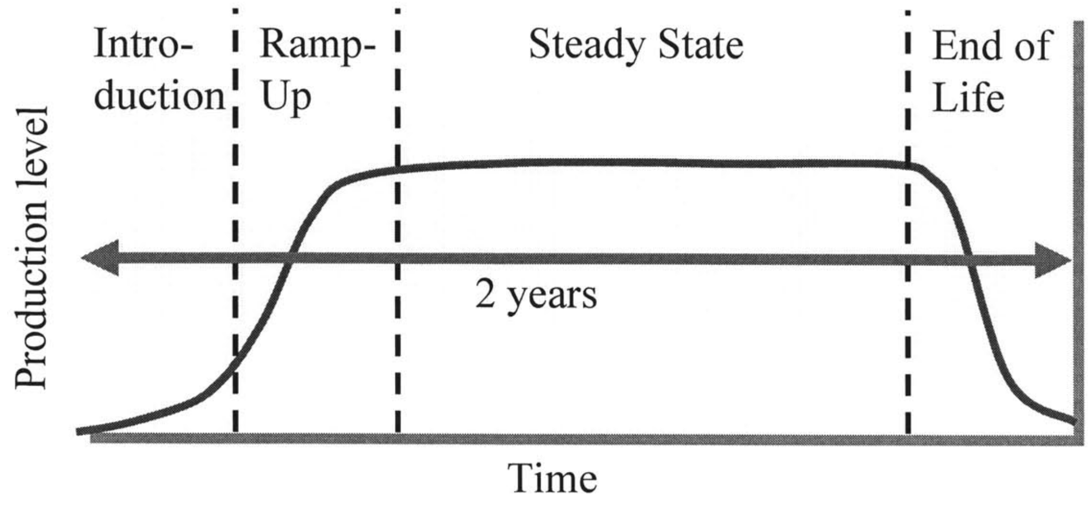


Figure 12 - Product lifecycle of Product X.

In this example, Product X has a lifecycle of two years. Since the end-of-life stage is typically determined by external market conditions and the competitive landscape, its timing is independent of the market introduction (first revenue shipment). Thus, delays in product ramp-up have a significantly detrimental effect on Product X's bottom line.

However, it is not always obvious whether time to market will increase or decrease as a result of outsourcing. The effect depends largely on the manufacturing capabilities in-house and within the potential suppliers, on the information flow between the OEM and the CEM, and on the incentive alignment between the different organizations.

If, for instance, in-house capabilities in procurement or production ramp-up are considered stronger than those of contract manufacturers, then in-house manufacturing might lead to shorter time to market, and vice-versa. Regarding high-complexity products, product-specific in-house manufacturing processes tend to be superior to those which can be obtained elsewhere. To that extent, prospective contract manufacturer learning curves must be taken into consideration.

More often than not, information flows between various business units within the organization are more efficient than those between an OEM and a CEM. Communication breakdowns between the supplier and the OEM can be quite detrimental to product lead times in the short term and to product lifecycles in the long term. However, internal communications issues have been known to arise in manufacturing organizations as well, typically between engineering and manufacturing. If these information flows are as weak as proposed inter-organizational ones, then in-house manufacturing loses this particular advantage.

Finally, incentives of manufacturing and engineering, wherever they may be (i.e. internal or external), must be aligned. Quite often, when dealing with external manufacturers, conflicts of interest may arise. For instance, such conflicts may lead to swifter handling of one competitor's order over that of another. Another example manifests itself in times of material shortage; contract manufacturers must choose among their clients or otherwise "ration" these materials and the products they comprise. This factor, when not carefully handled, could have a detrimental effect on time to market as well.

(2) Logistics

Site specificity[15] might be a significant determinant in the sourcing decision. For example, refineries are typically located near mines, in order to reduce transportation costs. In such a case, though numerous buyers and sellers may exist in the market, logistics costs or times may deem most options infeasible. This leads to a virtual oligopoly, based on location and access, which often can eliminate the luxury of choosing a sourcing alternative altogether.

In less extreme cases, site location may still be a determining factor, if logistics costs or times provide a significant advantage of one alternative over another.

(3) Inventory

Inventory carrying costs can severely impede a poorly planned supply chain. Different sourcing decisions entail different inventory capacities, lead times, and availability, thus it is important to estimate the effects that each alternative has on inventory carrying cost. When analyzing these costs, it is recommended to estimate the inventory carrying costs throughout the supply chain, and not just the costs that appear on one company's books. Despite the fact that outsourcing can help improve an OEM's cost structure by mitigating the risk of carried inventory through hubs established and owned by the suppliers, this risk, and the cost associated with its mitigation, still has an impact on the chain as a whole. The cost is merely shifted to a different channel. Therefore, when assessing the value of different inventory carrying options, one must consider whether the supply chain as a whole benefits from the option. For instance, if, by vertically

[15] Site specificity is a term coined in Stuckey and White's "When and When *Not* to Vertically Integrate", and refers to a situation in which buyers and sellers locate fixed assets in close proximity to minimize transport and inventory costs.

integrating with a supplier, only one buffer stock needs to be held (in one facility) instead of two (one in each facility), this is a certain benefit to the supply chain. However, if vertical integration maintains two facilities and two separate buffers, this integration has done nothing to save inventory carrying costs.

The more complex a component, the more sub-components it has, the more suppliers of those sub-components are involved, and the deeper the supply chain tends to be. Since each supplier adds value to the component along the way, complex components are also associated with relatively high inventory carrying costs. Robust supply chain design, involving modular activities conducted in parallel, can often reduce the depth of this chain, and, in turn, the inventory carrying cost of the complex component.

Numerous optimization models have been developed to analyze inventory carrying costs across a supply chain. Companies such as I2 Technologies and Manugistics offer such software packages, and Compaq owns the rights to an internally developed system with comparable capabilities, known as "The Optimizer".

(4) Quality

Sourcing decisions can have a huge impact on quality rates. This issue becomes especially tricky when considering low-volume, high-complexity components. On the one hand, low-volume OEMs can typically benefit from pooled resources that CEMs provide. In this manner, contract manufacturers, focused on manufacturing a specific component in relatively large quantities, can often achieve higher quality rates. Such economies of scale can lead to more efficient or precise work processes, or the ability to invest in quality control systems, for example.

On the other hand, CEMs are set up to provide high-volume service. Low-volume orders typically generate less revenue, and therefore receive less attention. A CEM that manufactures PCBs in high volume for the exploding cellular phone market sets quality standards, which are appropriate for $10 PCBs, used in $100 cellular phones. While it might make perfect sense to replace 1% of the defective phones as a result of low quality boards, high-end servers, which may cost over $1,000,000 per unit, cannot be readily replaced should a $10 PCB prove defective.

In addition, when considering complex components, sometimes contract manufacturers simply cannot provide the competencies required to manufacture the component within the expected quality metrics. In such cases, the contract manufacturer progresses on a learning curve. The OEM must take this into consideration, and anticipate lower quality levels at first.

(5) Fixed Resource Capacity

Fixed resource capacity can also have a bearing on the sourcing decision. It is not always clear how to distribute fixed plant, property, and equipment costs in the financial analysis of the various sourcing options. When considering these costs, one must look at the **opportunity cost** of one sourcing alternative versus another. If outsourcing the manufacturing of one small component does not seem to have an impact on fixed costs, one should ask if the fixed resources were utilized to their maximum or not. If they were, constraint theory[16] would suggest that outsourcing the component might free one or more fixed resources in favor of another constrained operation, thus increasing throughput and revenue. This additional revenue should, in this case, be added to the benefits of this option.

Such opportunity cost calculations tend to have a larger impact in low-volume scenarios. When dealing with low volumes, fixed resources are typically underutilized, making overhead costs relatively high. Reallocation of fixed resource capacity in this case may have a significant impact on bottleneck management, as well as on the bottom line. SeeIV.3.a(3) Capital Budgeting for more information on how to calculate the financial impact of these real option decisions.

(6) Economies of Scale

If contract manufacturers can effectively pool their resources in order to provide products to numerous OEMs, they can potentially benefit from economies of scale. This point is particularly relevant to low-volume manufacturing. For instance, Boeing, a low-volume airplane manufacturer, may require a part identical to another that could be found in a car. Let us assume that Delphi manufactures this part for General Motors in high volumes. It stands to reason that Delphi could manufacture this part at far lower cost than Boeing ever could, due to higher leverage with suppliers, more efficient volume-oriented manufacturing processes, and better equipment utilization. If this is indeed the case, Boeing might better procure the part from Delphi instead of manufacturing it in-house.

However, the large size of an organization or production volume does not always entail benefits of economies of scale. These efficiency improvements can only be gained if the larger scale can be successfully leveraged to achieve process improvement, cost reductions, or other logistical benefits.

---

[16] Goldratt, Eliyahu M., The Goal: A Process of Ongoing Improvement.

c. Strategic Criteria

(1) Focus

When all is said and done, every company should have a focus, a mission, and a goal. Conveying a clear vision that is focused on one outcome helps companies achieve that outcome. Employees relate to the focus and concentrate their efforts to achieve the goal. Clients associate the company with its vision, and thus a clear, focused vision helps brand the company as well. Strategic focus determines core competency development, and, in turn, core competency identification helps mold business strategy.

Sourcing decisions are strategic by nature, and thus are ultimately determined by business strategy, yet they also help create that strategy. Outsourcing non-core competencies is a method of announcing to the world – both internal and external to the organization – what the vision of the organization is. By choosing which functions to keep in-house and which to outsource, a company acts upon strategic goals, clarifies those goals publicly, and helps those goals evolve.

(2) Flexibility

OEMs often outsource manufacturing functions in order to gain flexibility. Outsourcing companies can react quickly to changes in the business environment, because they are not invested in fixed resources, rather their suppliers are. By switching from one supplier to another, an OEM can swiftly take advantage of new technologies that might take years to develop in-house.

In addition, instead of relying on one internal source, outsourcing companies can pick and choose solutions from multiple suppliers, and "play" one against the other, or simply keep one supplier as a "back-up" in case the main supplier does not live up to its promises. See Figure 5 on page 19.

Unfortunately, when considering complex low-volume production, multiple sourcing could pose a difficult problem, and is sometimes even an infeasible option. This is due to the lack of truly competent suppliers available to fill the function in question, as well as the lack of interest in dealing with low volume production.

(3) Control

Issues such as project scheduling, internal coordination and cooperation, and bridging the gap between functional teams are simpler and more effectively handled, by and large, when functions are kept in-house. There is a certain level of trust an OEM must place in the CEM in order to work together effectively. Ultimately, however, the make alternative clearly gives the OEM more control over the process than does the buy alternative. This is due to the fact that the CEM, by definition, ultimately reports to its own stockholders, and not to the OEM (contrary to the "customer always comes first" myth). Thus, when process control is a critical element of the function in question, it is recommended to keep the function in-house. If outsourcing is the chosen alternative, on the other hand, one must pay careful attention to information flows between the supplier and the OEM on all levels, to ensure maximal communication, which is the next best alternative to total control.

(4) Double Marginalization

When all is said and done, profit is the one factor that motivates each company in the value chain. By this rationale, the more fragmented the value chain, the more profit-takers exist within that chain, and the less efficient the chain overall. Thus, outsourcing can cause value chain inefficiencies by increasing the number of profit-takers, which typically increases the end-product cost. This phenomenon is called double marginalization, and is important to factorinto the final cost analysis when contemplating a sourcing decision.

In an efficiently aligned supply chain, suppliers along the channel will divide the entire supplier surplus in the form of profit throughout the chain. The existence of multiple competing channels drives these profit margins down, across the chain. However, low-volume, high-complexity products tend to be characterized by relatively unique channels, due to the novelty of such products. Thus, competition is low, supplier surplus is high, and profit margins tend to be higher, though more dynamic, across the chain. Double marginalization that may occur due to outsourcing in such a chain could indeed raise overall channel costs, thus decreasing supplier surplus. However, this strategy may still be beneficial overall, if other criteria, such as those described herein, provide other advantages. Thus, double marginalization is typically a more critical concern in more competitive, commodity-like products.

(5) *Employees*

The make/buy decision also encapsulates a human resources issue. If a function is outsourced as of one point in time, what is the fate of the faithful employees who took care of that function to date? Can their efforts be diverted to a core competency? Will competitors hire them and gain competitive advantage? Will massive layoffs create a distasteful environment, either within or outside of the organization?

When dealing with complex systems, this question takes on an additional facet: If the outsourcing strategy backfires for some reason, the OEM may not be able to revert to the in-house option, due to lack of available skilled employees. Training new employees would be expensive at best, and perhaps impossible within competitive time constraints.

Due to these situations, the employee criterion is frequently a factor that has a binary outcome regarding the feasibility in the make/buy decision – either outsourcing of the component is feasible or not feasible in terms of human resource issues.

(6) *Market Perception*

Market perception is not only relevant to assessment of core competencies (seeIV.3.c(1) Focus); it also matters when looking into the make/buy decision for non-core functions. First, it is necessary to estimate the market perceptions regarding the function at hand, and companies' capabilities within that function, for each alternative. In other words, when contemplating manufacturing of a certain widget, one must compare the market's reaction to in-house manufacturing versus manufacturing at supplier X. Partnering with companies that have widely-recognized market recognition for a certain function can go a long way to boost a company's market perception, and vice versa. If a company has a poor reputation as a manufacturer, and is better known as a system integrator for instance, perhaps a press release announcing the outsourcing of manufacturing to a strong production shop could improve the market's perception of that company as a whole.

(7) Technology Strategy

When assessing technology-intensive functions, technology strategy research[17] would suggest consideration of two key factors: appropriability and complementary assets. The following definitions explain these terms:

> Appropriability – *The environmental factors, excluding firm and market structure, that govern an innovator's ability capture to profits generated by an innovation. The most important dimensions of such a regime are the nature of the technology (whether product or process, tacit or codified) and the efficacy of legal mechanisms of protection (patents, copyrights or trade secrets).*[18]
>
> Complementary Assets – *Capabilities or assets necessary to be able to successfully commercialize an innovation, such as marketing, competitive manufacturing, or after-sales support. Complementary assets may be generic or specialized.*

By assessing the positioning of a company's technology regarding these two factors, one can conclude the next logical step in the preferred strategy to bring that technology to market or maintain a significant market position. The rationale behind this is that a company can sustain successful marketing of a technology if the company has cornered the intellectual property behind it and can somehow access the complementary assets necessary to connect that company to the market. If one of these factors is weak, the company should somehow find a way to fill the gap. Technology strategy analysis of this kind is especially relevant when dealing with products involving high complexity, since the intellectual property involved in creating such products typically has significant value, and is not readily reproducible.

For instance, Compaq's Alpha servers are based on the Alpha chip, a high-performance microprocessor that is designed and owned by Compaq. This defendable, heavily-patented intellectual property represents strong appropriability. Together with Compaq's access to complementary assets, such as manufacturing capacity and strong sales and distribution capabilities, Compaq can, and indeed does, bring the Alpha chip technology to market successfully. Compaq's recent decision to discontinue support of the Alpha chip and instead base

---

[17] Murray, Fiona. Notes from "15.393 Technology Strategy"; Teece, David, "Profiting from Technological Innovation"

[18] Teece, David, "*Profiting from technological innovation*"

the Alpha platform on Intel's Itanium chip significantly reduces Compaq's appropriability regarding chip technology. In order to maintain Compaq's market share, the company must develop and defend appropriability in other aspects of the system as a whole (e.g. marketing, software, etc). By leveraging Compaq's strong positioning regarding complementary assets, such as reputation, loyal client base, marketing savvy, etc., Compaq can maintain market share while developing such new appropriability.

The following matrix describes the value of a function based on these two factors:

	Poor positioning regarding access to complementary assets	**Good positioning regarding access to complementary assets**
Strong appropriability	Technology is defendable, but commercialization is a challenge without access to complementary assets.	Function is both sustainable and commercially viable.
Weak appropriability	Function cannot provide sustainable value.	Complementary asset positioning should be utilized to company's advantage (whether through in-house capability or through contractors) in order to secure market share before competition takes advantage of weak appropriability.

Table 1 - Assessing the value of a technology-intensive function based on the concepts of appropriability and complementary assets

At this stage of the process, analysis of alternative solutions for non-core competencies, we are dealing with functions that are not sustainable, unique competitive advantages. This being the case, exposure of the technology to competitors is not a strategic concern. If this is not the case, and there are reasonable concerns about appropriability, we must go back and reassess if this function is indeed a non-core competency.

On the other hand, however, much can be gained by taking advantage of cutting-edge technologies available on the market that might make this function more efficient, or give the component higher levels of quality or functionality. To that extent, by outsourcing to the most advanced supplier, the OEM stays on top of technology advancements.

The flowchart presented in Figure 13, taken from Teece's "*Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy*", describes a formal method for the make / buy decision, based on the appropriability regime and the complementary asset positioning. The notion of contracting for access relates to the act of forming alliances with other companies that have access to relevant complementary assets.

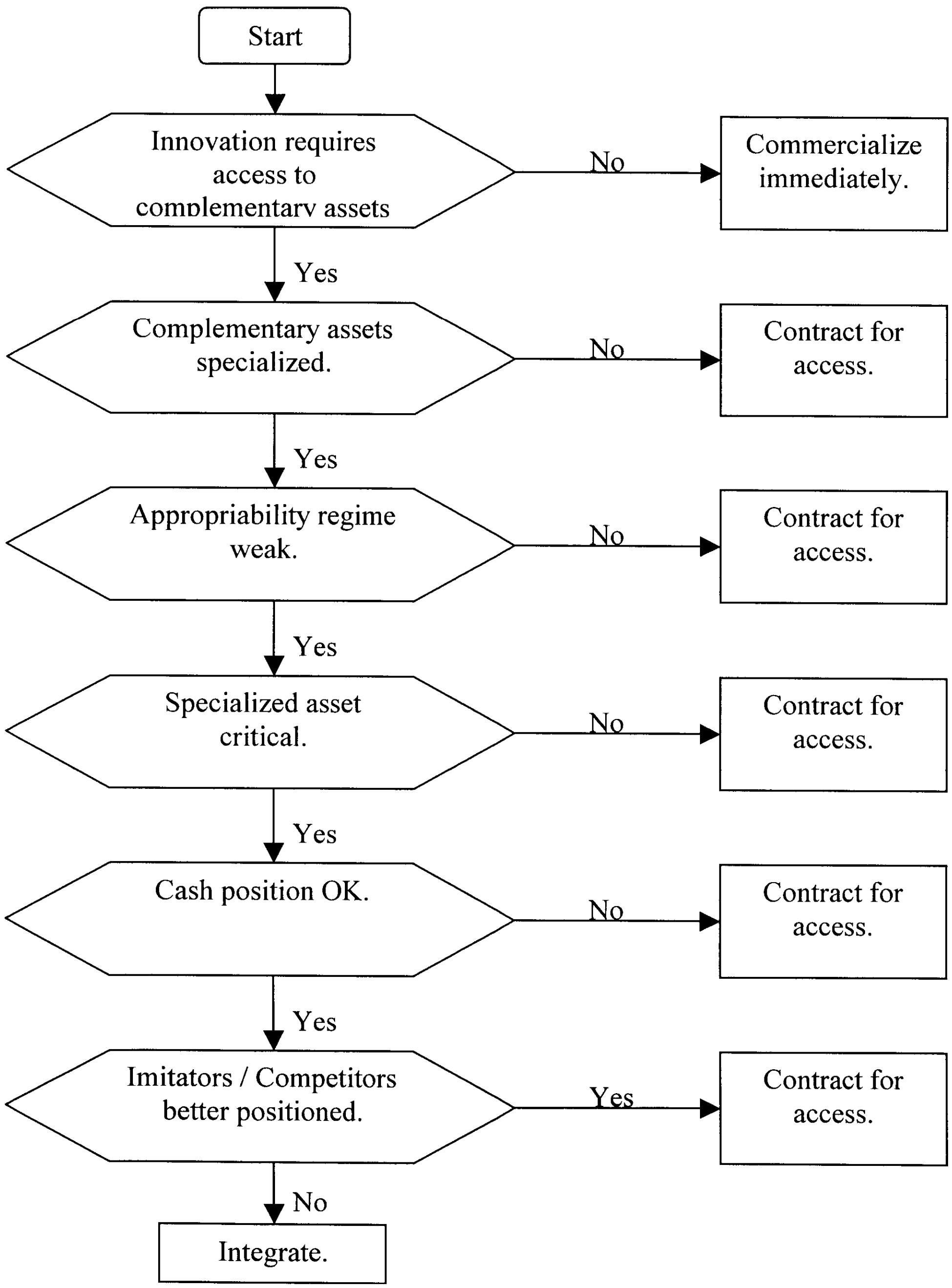


Figure 13 - Make / Buy Flowchart based on Technology Criterion

(8) Plant Capacity

Many manufacturers find outsourcing a good way to deal with demand fluctuations, without investing in additional plant capacity. See Figure 14 below.

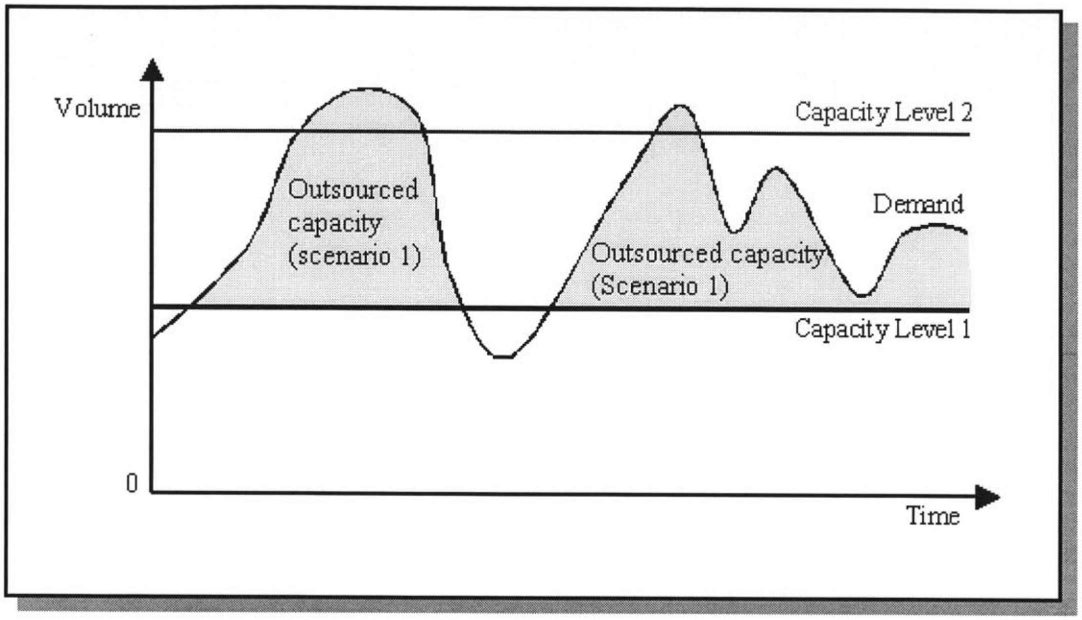


Figure 14 - Outsourcing as a method of dealing with demand fluctuations.

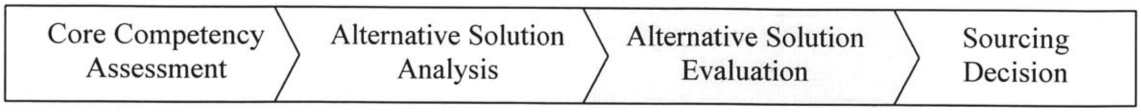
Two sample manufacturing strategies are illustrated herein:

1. **Manufacturing capacity level 1 is maintained in-house, and the remaining volume is supplied through contract manufacturers (shaded in light blue).**
2. **Manufacturing capacity level 2 is maintained in-house, and is the maximum available volume, since no manufacturing is outsourced.**

In these examples it is evident that, if outsourcing is feasible, a lower manufacturing capacity level can be maintained, which saves fixed costs. The added flexibility achieved through outsourcing is expressed in the ability to meet demand despite low capacity and despite demand fluctuations. Note that resource utilization would typically be higher in the fist scenario.

The caveat presented by low-volume production, however, is that this multi-sourced solution is often not feasible, and the make / buy decision is more of a binary decision. In such cases, the plant capacity criterion herein makes sense only if volumes can be aggregated among product lines or otherwise divided between sources.

4. Evaluation of Alternative Solutions



At this point, we are dealing with a function or component that is not a core competency, and we have analyzed the key criteria regarding the sourcing alternatives for this function. Now, we must evaluate the various alternatives, in order to make a wise sourcing decision. Although this process usually involves more art than science, a decision support tool can be useful for displaying the key findings of the previous analysis in a straightforward manner. To that extent, visual presentation of all criteria and alternatives in a condensed format is recommended. The table suggested in Figure 15 is an example of such a tool, this one using a weighted average, an arbitrarily chosen calculation method that can be used for a decision support.

In this example, there are three feasible sourcing solutions for non-core component X. These are dubbed Solution A, Solution B, and Solution C. Each sourcing solution was evaluated according to the financial, operational, and strategic criteria described above, and the relative importance of each criterion to that component was assessed as well. If a criterion was deemed utterly irrelevant for Component X, no further solution evaluation by that criterion was necessary. Furthermore, if a sourcing solution posed an insurmountable problem when considering a particular criterion, the entire sourcing solution was rejected. Finally, a weighted average calculation, consisting of a sum of solution evaluations multiplied by their respective importance scores, is presented.

When evaluating the various alternatives, one must not get "hung up" on arriving at an accurate, high-resolution score for each. In the absence of the ability to arrive at a score on a scale of 1-5, for instance, one might use a more conceptual scale, such as "-", "0", and "+". Likewise, one must not use this final table as a precise metric for determining sourcing decisions. As stated in IV.1.b Model Overview, the model presented herein is a conceptual model, and results should be evaluated with this in mind.

Evaluation of Component X	***Importance***	***Solution A***	***Solution B***	***Solution C***
Criterion	0 = Not at all 5 = Crucial	0 = Show-stopper 5 = Most beneficial	0 = Show-stopper 5 = Most beneficial	0 = Show-stopper 5 = Most beneficial
Financial				
Activity-based Costing	4	4	1	1
Capital Investment	0[19]			
Capital Budgeting	3	5	2	1
Operational				
Time to Market	5	3	4	1
Logistics	2	4	3	4
Inventory	4	4	3	2
Quality	1	3	2	1
Fixed Resource Capacity	2	5	4	2
Economies of Scale	4	5	2	3
Strategic				
Focus	5	5	4	2
Flexibility	5	3	1	4
Control	3	0	3	1
Double Marginalization	3	2[20]	2	2
Employees	2	3	4	2
Market Perception	4	5	3	4
Technology Strategy	1	4	3	3
Plant Capacity	1	4	4	4
Weighted average[21]		**3.73**	**2.71**	**2.27**

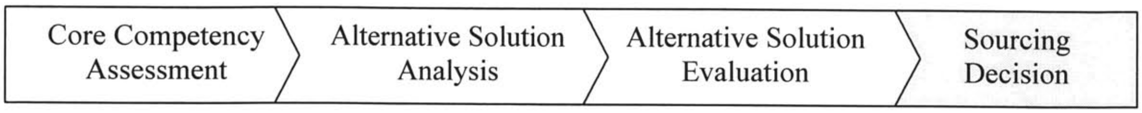
Figure 15 – Example of an alternative evaluation table, based on weighted average scores

[19] Since capital investment is not an issue regarding function X, there is no need to calculate solution scores for this criterion.

[20] In this example, the control criterion is a "show-stopper" for solution A. Thus, despite otherwise high scores, A cannot be chosen, and the scores in this column may be disregarded.

[21] The weighted average is the sum of the importance scores multiplied by the benefit scores, divided by the sum of the importance scores. Though solution B has the highest weighted average, the show-stopping score of the "control" variable suggests using solution A, with the next-highest score.

5. Sourcing Decision



On the one hand, reaching a sourcing decision based solely on these numbers would be a grave mistake. On the other hand, though, overlooking, underestimating, or overestimating, any of the above criteria can also lead to decisions that are misaligned with corporate strategy. The main objective of the model is to provide a framework that will help surface the issues that may deem outsourcing infeasible or sway the sourcing decision in a particular direction, whether it be make or buy.

To that extent, all core competencies, which directly contribute to unique customer value in a sustainable manner, should stay in-house. The residual components or functions are candidates for outsourcing, and should be considered separately, as described above. Separate consideration of these factors provides a "feeling" for the important criteria for leaving a component in-house or outsourcing it. However, in reality, we are dealing with a complex system, and pure optimization or even prioritization may prove to be an insurmountable task. The main reason for this is that each component of the product component hierarchy does not constitute an independent decision. More often than not, the sourcing decision of one component affects the decision criteria of that of another component. This being the case, evaluation of each component and criterion separately provides a conceptual model, and not a precise, optimal solution. It remains up to the manager to reach a business decision, based on these data. The model merely provides a tool for accumulating those data and presenting them in a manner that supports this decision process.

V. Conclusions and Analysis

Initial implementation of this model is currently being conducted at Compaq Computer Corporation's High Performance Server Business Unit (HPSBU), in order to determine which components of the *Miracle* series Alpha Servers should be outsourced and which should remain in-house.

Using this model, Compaq personnel view the Alpha Server system as a final deliverable, and have mapped every function that leads to system delivery as a component, whether tangible or intangible. Moreover, through model implementation, Compaq has identified several core competencies – components that provide unique customer value in a sustainable manner. Initial analysis of non-core competencies has surfaced several issues regarding the feasibility and benefits of outsourcing these functions, in comparison to manufacturing them in-house. Much additional work is necessary in order to complete this procedure according to the model described herein, and analyze each criterion for each sourcing alternative of each non-core component that is manufactured in-house. Such teamwork could very well be achieved by a future LFM intern together with a dedicated group of Compaq personnel.

Unfortunately, the timing of this project was a little late. Before significant headway in the model implementation could be achieved, a corporate decision was made to terminate the internal design of the Alpha chip – the key component of the Alpha Server responsible for much of Alpha's superior performance ratings. Instead, all future Alpha Servers designed after the *Miracle* series will be based on Intel Corporation's *Itanium* processor, which, with this announcement, became the de-facto industry standard, competing only with Sun Microsystems' proprietary processor platform.

Using the model presented herein, Compaq personnel could have seen the impact that the Alpha chip design component had on providing unique customer value. Assuming the design of the Alpha chip was a core competency, it would have been a mistake to let this competitive advantage fall into the hands of competition. Assuming this component was not a core competency, the model could have provided a useful tool to assess the feasibility and benefits of the various sourcing alternatives. In any case, many of the issues involved in outsourcing a critical component such as this would have surfaced by utilizing the model presented herein.

Similarly, numerous sourcing decisions will have to be made now that Hewlett-Packard Corporation has announced that it will acquire Compaq Computer Corporation. Fortunately, next time such a sourcing decision needs to be made, management at Compaq, "HewPaq", or whatever the name of the future entity is, will be armed with a new framework for making sourcing decisions regarding low-volume, high-complexity products, such as the Alpha Server.

VI. Bibliography

1. Greaver, Maurice F. II, Strategic Outsourcing: A Structured Approach to Outsourcing Decisions and Initiatives. AMACOM, 1999. This book is a must-read for managers contemplating outsourcing decisions. It provides a structured framework for strategic outsourcing decision-making.
2. Dell, Michael, Direct from Dell. HarperBusiness, 1999. Michael Dell provides revolutionary insight regarding his experiences in managing one of the world's most successful computer manufacturers, and one of Compaq's greatest competitors, Dell Computer Corporation.
3. Anderson, David L., et al. "The Seven Principles of Supply Chain Management." *Logistics Management and Distribution Report*, 1997. This document concisely describes seven important considerations for effective supply chain management.
4. Fine, Charles H., ClockSpeed: Winning Industry Control in the Age of Temporary Advantage. Perseus Books, 1998. Prof. Fine discusses how different industries inherently have different "clockspeeds", and how we can benefit from learning about supply chain management across industries.
5. Goldratt, Eliyahu M., The Goal: A Process of Ongoing Improvement. North River Press Publishing Corporation, 1992. This enjoyable, sometimes even humorous, book is considered the foundation of the Theory of Constraints (ToC), which looks at costing and inventory management from a perspective of throughput generation by easing the impact of systematic bottlenecks.
6. Kaplan, Robert S. & Cooper, Robin, Cost & Effect: Using Integrated Cost Systems to Drive Profitability and Performance. Harvard Business School Press, 1998. This book is considered the handbook for activity-based management (ABM).
7. Brück, Felix, "Make Versus Buy: The Wrong Decisions Cost." *The McKinsey Quarterly*, 1995, Number 1. This article provides a framework for making the make / buy decision based primarily upon the level of the product's technological differentiation.
8. Fine C. & Whitney D., "Is the Make-Buy Decision Process a Core Competence?" MIT Center for Technology, Policy, and Industrial Development, February, 1996. This article focuses on the importance of effective sourcing strategy in business strategy.
9. McKeefry, Hailey Lynne, "Special Report: Contract Manufacturing Quality Assessment." *Electronic Buyers' News*, September 7th, 2000. This report looks at the process of assessing a contract manufacturer in times of component shortages.
10. Ojo, Bolaji, "Blurring Supply Lines Force Module Makers to Adapt." *Electronic Buyers' News*, August 16th, 1999. This article describes how traditional module manufacturers have added supply chain management capabilities in order to provide an array of contract manufacturing functions.
11. Johnson, Eric, "Break It Up." *CIO Magazine*, May 15th, 2000. This article discusses how information technology enables new forms of supplier – customer relationships.
12. Hachman, Mark, "Components Shortage Squeezing Profits out of Supply Chain." *Electronic Buyers' News*, May 29th, 2000. This article describes how the shortage of hardware components has affected virtually all industry players across the supply chain.

13. Malone, Mitchell Abbott, "Analysis of a High-End Memory Supply Chain – DRAM Vendors to Final Assembly." Masters Thesis, Massachusetts Institute of Technology, June 2000. Malone's thesis preceded mine at Compaq HPS, and, although it pertained to mostly different aspects of the business, it proved valuable in learning HPS' supply chain environment.

14. Ryden, Carl Ashley, "Outsourcing in High Volume Electronics Manufacturing." Masters Thesis, Massachusetts Institute of Technology, June 2000. Carl Ryden's thesis discusses similar sourcing decisions at Qualcomm, albeit in a high-volume manufacturing environment.

15. Miciano, Miguel Manuel, "A Tool for Sourcing Decisions." Masters Thesis, Massachusetts Institute of Technology, May 1999. Miciano's thesis presents an analytical tool he developed for cost-based sourcing decisions at Compaq HPS. This tool could be used in the context of this thesis, when considering financial factors associated with the sourcing decision.

16. Stuckey, John and White, David, "When and When *Not* to Vertically Integrate." *Sloan Management Review*, Spring 1993. This article, part of the required readings for 15.769: Manufacturing Strategy, gives a concise, yet insightful, description of the dos and don'ts of vertical integration.

17. Teece, David J., "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy." *Research Policy*, Vol. 15, 1986, pp. 285-305. This article discusses the importance of understanding a company's position regarding appropriability and complementary assets.

18. Ante, Spencer E., "IBM Serves Up Some Surprises." *BusinessWeek*, August 13th, 2001, pp. 57-58. This article provided data about UNIX server revenue and the competitive landscape in general.

19. Jaffe, Sam, "Now Compaq is… a Software Company?" *BusinessWeek Online*, June 28th, 2001. The author of this article regards the recent decision to outsource the design of Alpha chips a mistake.

20. Shankland, Stephen & Wilcox, Joe, "Compaq Narrows Server Chip Competition." *C|Net News.com*, June 25th, 2001. This article discusses some of the perceived value of the Alpha chip design, compared to competitive offerings, in light of Compaq's decision to terminate the Alpha chip.

21. Martell, Duncan, "Alpha chip's demise shows best is not always first", *Reuters Business Report*, June 25th, 2001. This article describes Compaq's move to terminate the Alpha chip as another example of why technical superiority does not always result in competitive advantage.

22. Boppe, C. W. ESD.33J, "Systems Engineering" course notebooks, Massachusetts Institute of Technology. 2000.

23. Moses, Joel. Memorandum entitled "Complexity and Flexibility".

24. Rosenfield, Donald. Notes from a class entitled "15.769 Manufacturing Strategy", Massachusetts Institute of Technology, Spring 2001.

25. Murray, Fiona. Notes from a class entitled "15.393 Technology Strategy for New Enterprises", Massachusetts Institute of Technology, Spring 2001.

26. Strahan, Philip. Notes from a class entitled "15.401 Finance Theory I", Massachusetts Institute of Technology, Spring 2001.

27. Compaq Computer Corporation, corporate web site, www.compaq.com, August, 2001

Appendix 1: Capital Budgeting Example[22]

Discounted Cash Flows (DCF)

Suppose we have a project that costs $120 in year 0. The project is expected to produce the following revenues and costs:

Year	*Sales*	*Inventory*	*CGS*	*Dep.*
0	$0	$0	$0	$0
1	$100	$100	$50	$20
2	$100	$100	$50	$20
3	$100	$100	$50	$20
4	$100	$100	$50	$20
5	$100	$100	$50	$20
6	$100	$0	$50	$20

To compute the net present value (NPV), we need to compute free cash flows (FCF). In this example, we will assume the tax rate is 40% and the discount rate is 10%.

Year	*I*	*OP*	*Taxes*	*ΔWC*	*FCF*	*E*
0	-$120	$0	$0	$0	-$120	$0
1	$0	$50	$12	$100	-$62	$18
2	$0	$50	$12	$0	$38	$18
3	$0	$50	$12	$0	$38	$18
4	$0	$50	$12	$0	$38	$18
5	$0	$50	$12	$0	$38	$18
6	$0	$50	$12	-$100	$138	$18
			NPV	**(10%):**	**$11.04**	

[22] Strahan, Philip. Notes from "15.401 Finance Theory I"

Real Options

The DCF approach to making investment decisions assumes that firms are locked into their investment with no opportunity to change as circumstances evolve. However, in reality, firms have real options, for instance:

- Growth option: Expand the scale of a project if things go well.
- Abandonment option: Shrink a project or abandon it if things go badly.

Real options are valuable, since they lower the risk involved in a project, and thus raise the market value of investments.

Example of a growth option

Imagine a $150M R&D investment in a new drug with a 50% chance of very successful development, generating $200 million in FCF forever and a 50% chance of limited success, worth $50 million forever. It costs an additional $500 million to develop the drug next year. Assuming a discount rate of 20%, standard DCF analysis gives us a negative net present value, thereby suggesting project rejection:

$$NPV = -150 - \frac{500}{1.2} + \frac{0.5 \times 200 + 0.5 \times 50}{(0.2) \times 1.2} = -45.84$$

However, by incorporating the growth option, things start to look better. We start by putting ourselves in our own shoes next year, when we face the decision to develop the drug.

Next Year	NPV
Good State	$NPV = \frac{200}{0.2} - 500 = 500$
Bad State	$NPV = \frac{50}{0.2} - 500 = -250$

In conclusion, next year we will choose not to invest the additional $500 if the bad state occurs, and the net present value is really:

$$NPV = -150 - \frac{0.5 \times 500}{1.2} + \frac{0.5 \times 200}{(0.2) \times 1.2} = \$58.34$$

Example of an abandonment option

Imagine a project pays $180 million under good economic conditions (50% probability) and $60 million in bad times. The discount rate is 20% and the risk-free rate is 8%. Using DCF to value the project:

$$PV_{project} = \frac{0.5 \times 180 + 0.5 \times 60}{1.2} = \$100$$

Now, suppose you can buy insurance that will pay $100 in the bad state. The DCF calculation of the value of this policy fails, because we do not know which discount rate to use: 20% or 8%. In order to factor this policy into the project value, we consider the project with the insurance as riskless. Thus,

$$PV_{project+insurance} = \frac{180}{1.08} = \$166.67$$

and the policy itself is worth $66.67.

Appendix 2: Initial Model Implementation

Initial model implementation has been conducted at Compaq's HPSBU with regard to the Miracle platform of Alpha Servers. Figure 16 presents the current status of project implementation (model flowchart is identical to that shown in Figure 8, with added indication of Compaq implementation status).

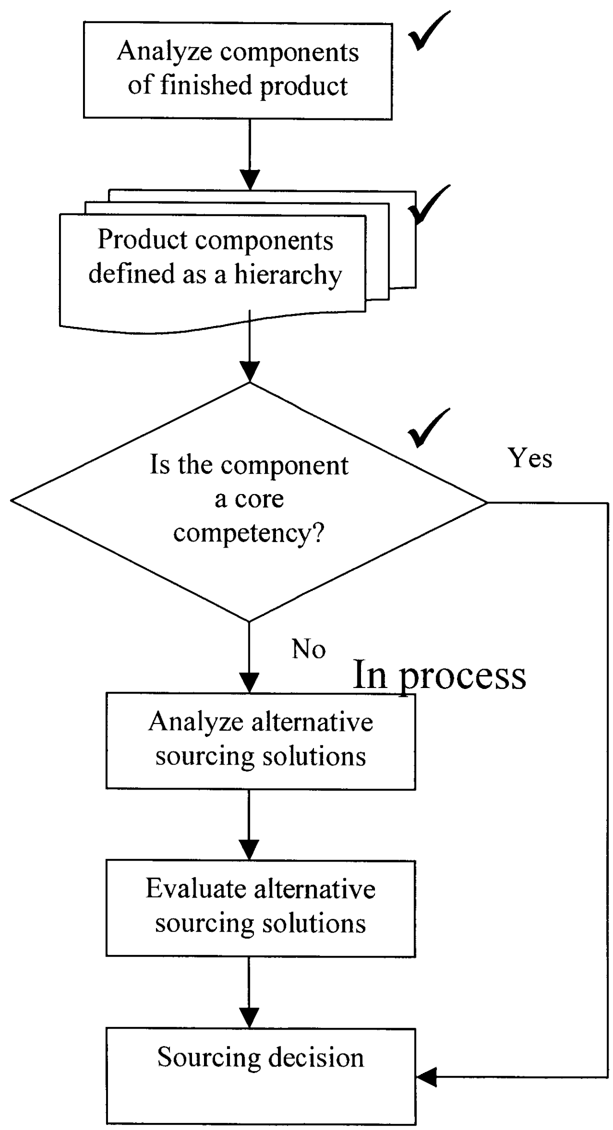
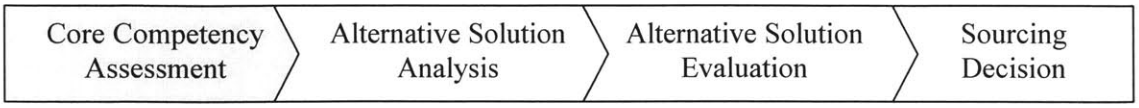


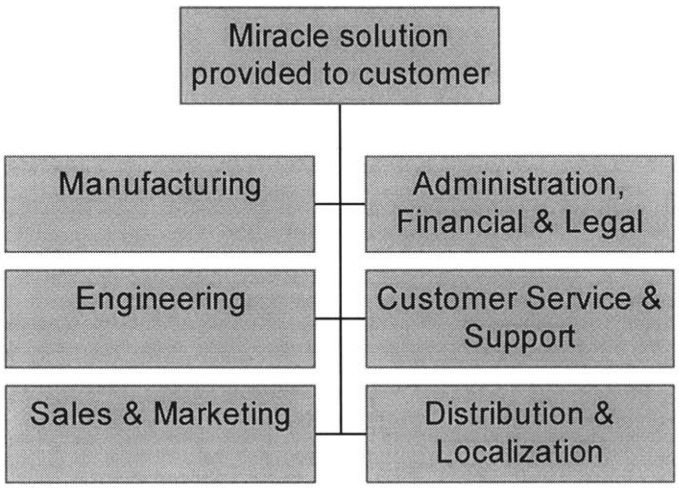
Figure 16 – Flowchart of overall sourcing model process, with indication of completed model implementation

Core Competency Assessment

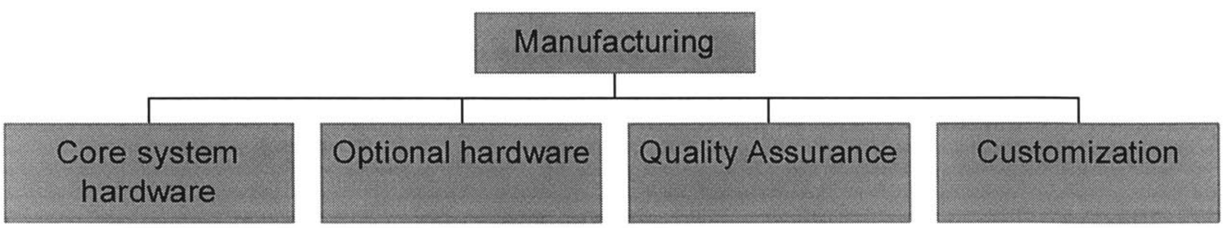


A high-level product component hierarchy is presented, with lower-level hierarchies corresponding to each block within.

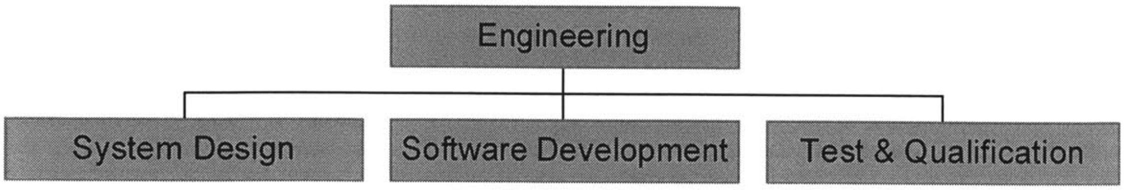
Miracle Product Component Hierarchy



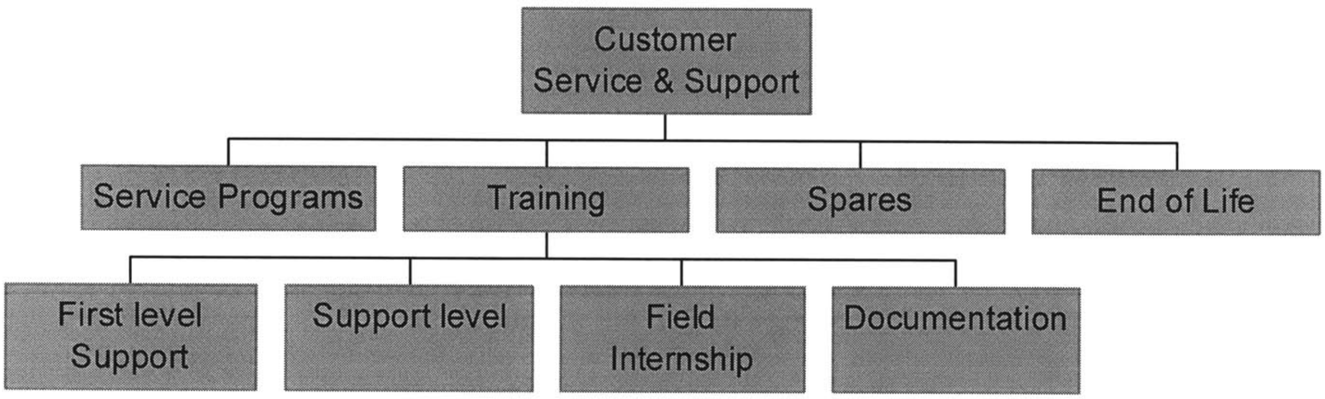
Manufacturing Component Hierarchy



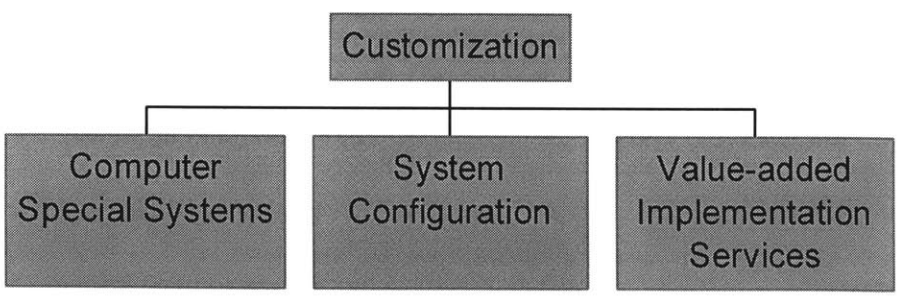
Engineering Component Hierarchy



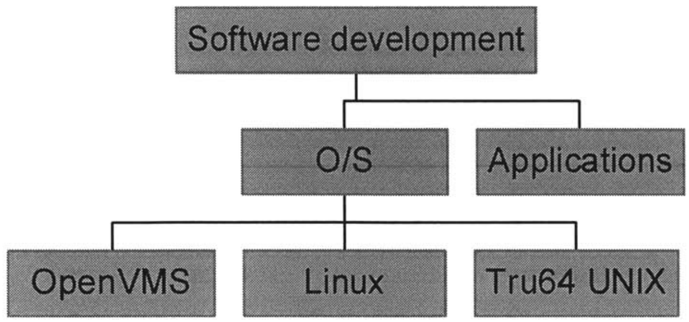
Customer Service and Support Component Hierarchy



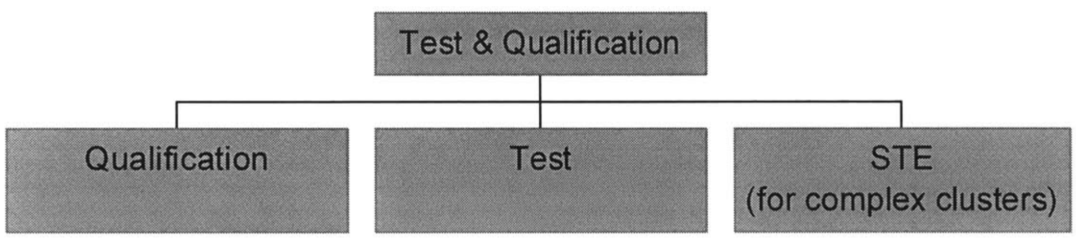
Customization Component Hierarchy



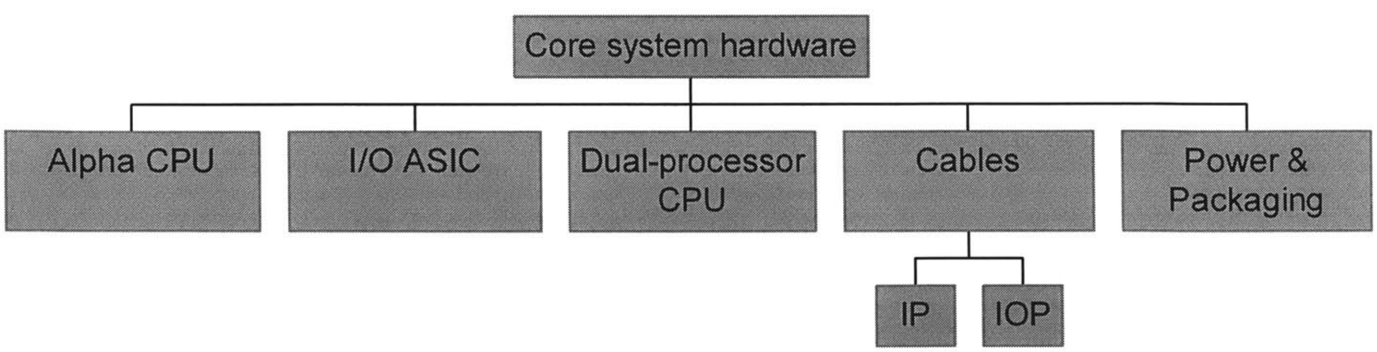
Software development Component Hierarchy



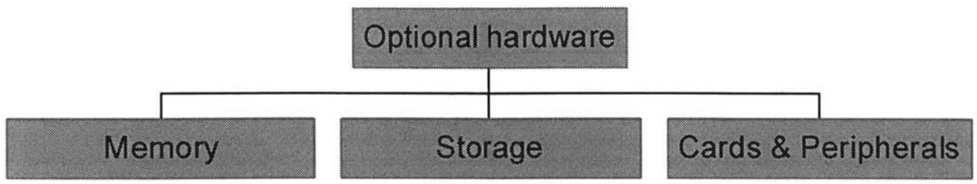
Test and Qualification Component Hierarchy



Core system hardware Component Hierarchy



Optional hardware Component Hierarchy

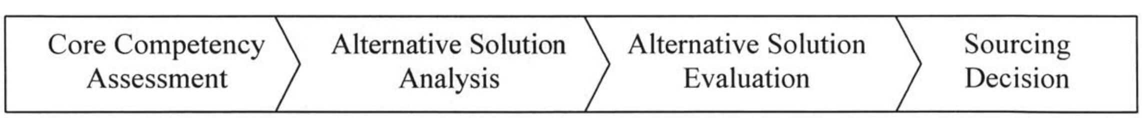


After laying out the entire product component hierarchy above, the Compaq team proceeded to analyze each component, looking for core competencies. This was based on comprehensive customer satisfaction and benchmarking data taken from the marketing department. Components that were thought to contribute to distinguishable customer value that could be sustained over time were considered core competencies. These were later denoted, on the product component hierarchy diagrams themselves, according to the following, simple and visually clear legend:

✓= Core Competency
✗ = Non-Core Competency

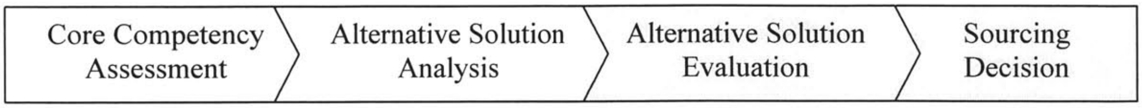
Next to each core/non-core indicator, a brief explanation of the decision was also noted. Non-core components were not analyzed or expanded further at this stage. Core competencies were expanded as deeply as possible, until it was clear precisely which sub-components provided the sustainable, unique, competitive advantage, and which could, potentially, be outsourced.

<u>Alternative Solutions for Non-Core Functions</u>



Further analysis of sourcing alternatives for non-core components is currently being performed, in order to determine which of the non-core components can be outsourced, and which cannot. To that extent, it seems that many non-core components that have not yet been outsourced really should not be, due to issues that each stem from one of the restricting criteria listed in IV.3 Alternative Solutions for Non-Core Functions.

Alternative Solution Evaluation and Sourcing Decision



However, some non-core components with viable sourcing alternatives are being uncovered, and, hopefully, will be successfully outsourced. Through a rigorous, structured decision process, such as that presented herein, managerially correct, albeit not necessarily mathematically optimal, sourcing decisions can be reached.