

Design Methodology for Products and Systems When Technology is the Enabler and Technology
Change is the Competitor

by

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Engr

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Philip Emile Jr.

Submitted to the Department of Civil and Environmental Engineering and the Sloan School of Management on March 21, 1996 in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Technology Applications to Systems Management

ABSTRACT

A design methodology is described, to be used when new technology makes the design possible, but the rate of technology change is the dominant factor affecting the design and limiting the useful life of the proposed product or system. The generic engineering design process is enhanced by incorporating two new elements called Goal-Charts and Technology Lemmas. Goal-Charts are x-y charts used to plot the system performance versus cost for various design options. When the results of system simulation or testing are plotted on the Goal-Chart along with the acceptable limits for performance and cost, the decision of which design option to implement is usually clear. Examples of the use of the Goal-Chart by designers, management and customers are given. The second new element, Technology Lemmas, four in number, are used during the design to consider: 1) When will the better, cheaper component be available?; 2) Is the margin between the component performance and the user requirements sufficient, stable, or changing?; 3) Can the design be made expandable for longer life?; 4) When are the users' advancing requirements going to make this technology ineffective or obsolete?.

Two design projects performed using this design methodology are described. The first project was a feasibility study using Active Control and Tuned Mass Dampers to limit the motion of a building during earthquakes or wind. In this project, the Goal-Chart was used to clearly identify the most effective arrangement. The second project involved the selection of components and the design of a Computer Aided Engineering System which provided a rapid simulation capability to be used in the design of certain complex electronic circuits. During the CAE system design and procurement process, the electronic circuit design process, the hardware and software capability and cost of the equipment were changing. The Goal-Chart was used as a vehicle throughout this process and applied to guide the decisions to select the specific CAE system at the end of the project. Use of the Goal-Chart to include incorporation of non-technical factors is demonstrated as well.

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Technology Change is the Competitor

A Thesis by Philip Emile Jr.

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PREFACE

The path to this thesis and to the Doctoral Program at the Massachusetts Institute of Technology has been a different one for me than the paths taken by most other candidates. After many years in industry, that included mid-management, top-level management, invention and technical achievement as measured by patents, publications and the chairing of seminars, (not to omit rearing five children through college and into adulthood) I got the opportunity to study at the Center for Advanced Engineering at M.I.T. The opportunity came in a back-door kind of manner. Briefly, I hired my replacement and my boss chose to use him to replace me and provide me another assignment in research, for a time. I said, fine, but I need to go to school to properly understand how to make progress in this new milieu. At a later point, after initial good results were achieved, this same boss encouraged me to tackle the formal Doctoral Program at M.I.T. Business fortunes later influenced his ability to continue financial encouragement and even my employment, but the fire was lit and there was no turning it out.

Most of my technical life has been spent at the leading edge of the Aerospace and Instrumentation industries. I have been fortunate to have made a few inventions and followed the path of technology from vacuum tubes to transistors to integrated circuits. The aircraft for which I have provided instrumentation, extend from the T-28 Jet trainer to the Boeing 777 which recently began revenue service. These aircraft also include the military variety that sometimes go undetected. The goal of my research was to locate some kind of a pattern or process which could be articulated to help in designing in the face of the vast and rapid technological changes taking place in our world. The Goal-Chart and Technology Lemmas have for me outlined an approach that can be helpful in this process. It is my hope that they will also be helpful to the reader in that regard.

ACKNOWLEDGMENTS:

The M.I.T. community starting with Dr. Paul Brown, Dr. Shaoul Ezekiel, Dr. Hazleton, Dr. Ernst Frankel, Dr. Edward B. Roberts, Pat Nixon were facilitators of my progress at many steps along the way. A very special debt of gratitude goes to Professor Jerome J. Connor who was willing to take a chance and go to bat for a very unconventional student who also had gray hair in spots. Without these people, my success would not be possible. I say thanks to one and all and also say thanks to the many others who were not mentioned by name in this brief acknowledgment.

Philip Emile Jr.

INTRODUCTION

Introduction

This thesis describes a methodology which can be used in the design of products and systems when Technology Change is the dominant factor in the process. The methodology employs a Performance versus Cost x-y plot called a **Goal-Chart** to compare alternative technology solutions. The difficulties in designing when technology change affects the product or system lifetime are represented in a series of **Technology Lemmas**, which are questions to identify when the effects of Technology Change need to be considered. Two development projects which were performed and aided in the development of the design methodology are described in some detail, to illustrate the application of the methodology.

Technology Change is a fact of life. The effects of Technology Change are experienced by all segments of the human environment. Technology Change provides an effective end to all useful product or system design applications through mainstream obsolescence. Mainstream obsolescence occurs when it is the perception of the user community that the product or system no longer serves as the most effective application vehicle for its initially intended task. In many instances this effective end is much shorter than the potential lifetime due to physical wearout limits which might govern, absent Technology Change. In some cases Technology Change can extend the useful life of an product or system.

Successful design when Technology Change is the competitor, requires consideration of the life cycle of the target product or system, time rate of change of the relevant technology and some measure of the probability of a spike or radical, new change of direction in the technology. The design process itself must also include some flexible means of accommodating the feedback from the Technology Change measurements received.

Successful design is herein defined as contributing some benefit for some useful period of time to the Health, Environment, Communication or Transportation factors in the human condition. The enterprise sponsoring the design is also likely to request and expect a monetary gain or profit on the manufacture, sale or implementation of the product or system as an additional measure of success.

Product and system design is a complex process without the factor of Technology Change. Attempts to improve performance, features or benefits in the design often rely on Technology as an Enabler. The questions of what technology should be used, how and whether or not it should be applied, involve cost-benefit, reliability, availability, safety, pollution, effectiveness, feasibility and other factors.

Standard engineering design approaches answer directly the questions of feasibility, availability, effectiveness and sometimes reliability and safety. Usually an estimate of cost is also given, but cost-benefit and the actual cost often go well beyond the factors within the scope or under control of the original engineering design as may be illustrated with numerous examples. Pollution, artifact disposal and the consequences of Technology Change have often been an afterthought if considered at all.

Thus, successful design or risk reduction in the presence of Technological Change is difficult and should be attempted with a method or process which makes the task easier.

The ultimate objective of this research is to provide engineering management with guidelines for determining how to assess the effects of Technology Change (TC) in the design process, and if the effects of TC are to be included, provide some methodology for making the design robust and flexible enough to cope with these effects.

In addition to looking at the engineering design process, it is important to review other fields to see how planning for design or investment is done. These include business planning, for example the "Michael Porter Method" for measuring the impact of "Five Forces" and the business concerns strengths, on the viability of a Product undertaking. The notions of

Constructors, Maintainers and Destructors are borrowed from the software field to help approach the general problems in designing products or systems which may become obsolete due to Technology Change. This leads to a recommendation of recycling for obsolete technology items.

The general patterns of Technology Change in an industry field will be reviewed. An example of rapid change is, of course, the personal computer industry. In particular, emphasis will be placed on the **rates of change and the timing**, history and projections. Comparisons between the technology applicable to the field and the historical rate of change in that business or engineering field will be included as a decision impact on the design.

The normal design approach generates a series of structures, systems or circuits which satisfy a set of design objectives based on costs, required performance and specifications and the implementation of the structure, system or circuit within the resources and time constraints available. The design process follows the so-called "waterfall" model from **initial specifications through requirements to analysis, modeling, implementation and testing.**

Often, using new or borrowed technology from another field will result in some improved performance feature in the artifact. Examples based on original work done for MIT courses are described and expanded in the research work.

A number of books have been written describing the advances of technology and managing the application of technology to product or system design. Among them are "Management of Technological Change" by Dr. Ernst Frankel and "Forecasting and Management of Technology" by Alan J. Porter et al. These publications outline the danger of overtaking technologies and estimate future impacts of technology, but stop short of suggesting a design methodology for dealing in advance with a probable technology change.

In the business arena, the common goals of sales, market share and profit have created a number of systems like the Michael Porter Method which can be used by any business which wishes to analyze their markets and products. A similar method to evaluate the effect of technology change and incorporate that information in a design method does not appear to have been articulated. Further, the **essential element of time**, is not strongly featured in many of these approaches.

System Dynamics and Game Theory do provide some consideration of time in that repeated trials cause the essential system performance parameters to be defined in terms of the system constraints. Where data from these can be applied to the problem at hand it will be incorporated. Transportation models also seem to be a rich area for parallelism to technology incidents. In transportation a large amount of the uncertainty and delays are due to incident.

Two very effective methods for sensitizing the design to future technology changes are expected to be: 1) Choosing an Architecture and Standards which allow changes, expansions and upgrades easily; 2) Providing a method of system upgrades which allow for x% of the system to be replaced over Y time. For example if the system obsolescence is deemed to be 3-5 years, then arrange to replace 25 -30% of the system yearly rather than make a massive change-out which will itself be obsolete in three years. This effectively spreads the cost and change impact over a period of time.

An example of a system which has incorporated improving technology by proper choice of Architecture and Standards is the Audio field where CD-ROM's, tapes, discs and direct broadcast coexist in a common network of amplifiers and speakers. They all provide outputs via standards-based interfaces to radios/tuners/amplifiers with audio outputs for the consumer. Other examples are the common railroad gauge across the US.; common highway markings and signs; and common procedures and controls for aircraft in departures, landing, and enroute procedures. Computer systems have also standardized on communication protocol and even operating systems and data transfer mediums for periods of time; for example, tape data and disk and diskette formats.

The thrust of the Thesis is that if the proper questions are asked and answered, then it is possible to design products and systems which have extended life and utility in the market despite the effects of technology change.

I pose that the following questions are key questions in "Designing Products and Systems When Technology is an Enabler and Technology Change is the Competitor".

1. Is there a standard which exists or which can be developed that the design can adhere to for wider acceptance and usage?

Examples are Railway Gauges, Highway Signs and Markings, Recording and Broadcasting Standards, Ball-point Pen Cartridges, Telephone System. The HP-IB instrumentation bus is an example where an industry initiative was adopted as an IEEE standard. Other engineering standards include ISO 9000, ANSI, and the communication protocols DECNET, ETHERNET, ISDN, etc..

2. Does the product or system benefit from a cluster effect because a major player has established a defacto standard and large market for the product or system?

Examples are AMD benefiting by cloning leverage from Intel's dominant computer chip series, Digital benefiting from IBM establishing a major computer presence umbrella.

3. Is the architecture of the product or system extensible so that upgrades adapting the product or system to new technology are possible, feasible and cost-effective?

Example as an operating system DOS is extensible, CPM is not very extensible.

4. Can the technology enabler benefit or enhancement be modeled in a way to illustrate the benefits in a quantitative manner?

Examples are Active Motion Control and Expert Systems to allow data to be extracted from an information source or data base in an efficient manner.

5. Are the quantified benefits from the model in 4, above, such that the customer has adequate cost -benefit not only for the service, but also for the change effort?

Example: Old car gets 15 miles/gallon; New car gets 25 miles /gallon. If the switching cost is \$10,000 the customer might not choose to change for this reason alone for a long time.

6. Is the technology entering a region where continued quantitative change (improvement) will result in a qualitative change in the use or lack of use of the product or system?

Examples: Sudden collapse of a dome roof when the snow load surpasses a triggering amount. Transportation examples; Walking will allow one to conduct business in person across the city of Boston; Driving will allow one to conduct business in person in Boston and in Springfield in the same day; A jet plane will allow one to conduct business in Boston and San Francisco in the same day; The electronic highway illustrated by the Internet, faxes, telephone and video-conferencing will allow business, almost “in person”, to be conducted around the world without one leaving their basic office area.

7. In the field to which the product design is to be applied, is the rate of technology advance such that a change of 30 to 40% of the applicable life of the product will be made obsolete by technology advancing?

Examples: a ten year old PC is not too valuable for anything today since the current software requirements exceed the hardware capabilities and speed of that equipment.

8. What is the projected useful life of the product or system (without scheduled replacement) given 7. ? Examples: Buildings of masonry 40-100 years; toothbrushes 2 months to 10 months; Christmas toys 3 months; Wall to wall carpet 8-12 years; House paint 5-7 years.

9. Is the useful life such that cost recovery and profit can be accomplished or are there other indirect benefits which make it worthwhile, spares, upgrades, follow-on or related services? Example: Give away the camera and sell the film. In the airline “instrument” business; sell the “parts at cost” and make the money on the higher cost aftermarket spares, since the cost of requalification of the aircraft to change vendor parts is huge.
10. Is there sufficient information about the projected product or system to inspire confidence in the answers to 1-9, barring significant unpredictable incident? If so, then the answers may be used to determine whether the design process must include factors allowing for shortened life due to possible predicted technological change. Then, the design guidelines apply.

Approaches to these questions are incorporated in the four Technology Lemmas which are described in Chapter Three (3).

Thus, the enhanced design process or methodology, which is described herein, adds the tasks of :

(1) defining the performance objectives and the cost elements in a goal-chart, (2) asking the relevant technology rate of change questions as captured in the Technology Lemmas,

(3) modeling or testing the design in a way to provide the necessary performance results and (4) capturing or updating, the results on a goal-chart with the maximum performance and cost limits defined, such that the appropriate design choices can be made.

The material covered in the chapters is as follows:

Chapter 1 describes the enhanced design process including the points where the preliminary goal-charts, the technology lemmas, and the final goal-charts are inserted in the design process. Chapter 1 also considers the example of the Michael Porter design process for business strategies as a similar process designed to identify the best products to pursue, given the external and internal strengths and obstacles.

Chapter 2 describes goal-chart construction and explains how it can be used by the designer, marketer, manufacturer, and customer.

Chapter 3 describes the four technology lemmas and illustrates how they affect the design choices.

Chapter 4 describes applications of the technology lemmas.

Chapter 5 describes applications of the goal-chart.

Chapter 6 describes the project "Design of Optimal Control for an 11-story Building" and shows how the goal-chart clarifies which approach provides the best options.

Chapter 7 describes the project of selecting components and designing a CAE system to provide advanced simulation capability for design of custom electronic circuitry. This chapter also includes ways to consider the effects of non-technical influences on the design decision.

Chapter 8 describes other technical projects which provide advantages, but are affected by exogenous (outside) non-technical factors which may cause the projects to be not feasible. CAS and Information Sharing Technologies are discussed.

Chapter 9 presents conclusions, recommendations and suggests subjects for further study.

Definition:

Throughout this thesis, the terms “product”, “system”, “products and systems”, “items”, are used interchangeably to designate and include both products and systems. The reader will recognize that some elements apply more readily to systems than to products, or vice versa, but in the authors’ view, most statements will apply to either products or systems in one discipline or the other.

CHAPTER 1

ENHANCED DESIGN PROCESS

Chapter 1. Enhanced Design Process

Designing products or systems where technology change is the dominant factor requires specifying objectives, understanding the advancing technology requirements of the user, making projections for the likely state of technology availability, and estimating the period the product or system is expected to be functional. The primary effect of technology change is to shorten product or system life by obsolescence, since the new products or systems offer better performance at the same or lower cost. Two components, 1) **Goal-Charts**, and 2) Technology Rate Considerations, designated in this thesis, as **Technology Lemmas**, are added to the standard design process to deal with the effects of technology change. Figure 1.1 shows the Enhanced Design Process with the new components incorporated in a Generic Design Roadmap.

The Enhanced Design Process starts with **Step (1)**, defining the objectives. This takes the form of mission statements, specifications and requirements. At this early stage it is recommended, **Step (2)**, to consider establishing performance measurements for a goal-chart. The proper choice of axes may not be obvious at this stage of the design. Also, the limits of acceptable performance in either the cost element or the performance elements may not be known since these may be derived quantities. However, beginning the high-level design thought process, will

shed light on the critical experiments and concepts necessary to provide the data for the later goal-charts where those items will be known.

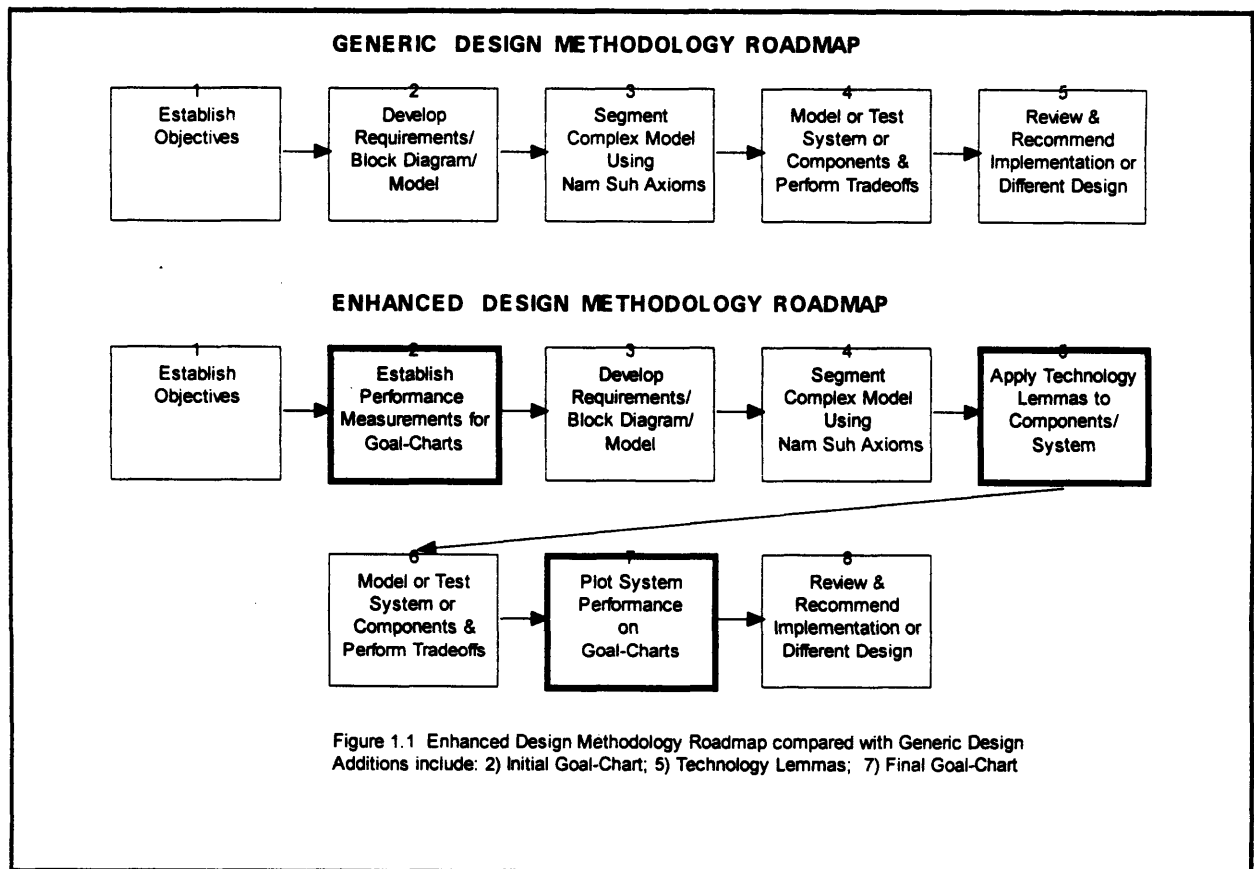


Figure 1.1 Enhanced Design Process including **Goal-Charts** and **Technology Lemma** insertion points

Goal-Chart Use Defined:

Goal-Charts primarily used to measure Performance versus Cost, are employed to compare the design options. The Goal-Chart serves as a means of capturing the objectives of the design in a simple form for presentation and decision-making. There will be an initial chart, one or more interim charts and a concluding chart when the design is simulated or tested. There may also be a chart which considers the weight of non-technical factors and has the axes of Cost of Performance versus Cost. This chart helps guide the final selection process of the design option to be implemented. Chapters 2 and 5 discuss the goal-chart in more detail.

Continuing the Enhanced Design Process:

The next step in the Enhanced Design Process, **Step (3)**, is to develop the requirements in a more complete form and support them with block diagrams, models and other implementations. If the product or system being designed is complex, then **Step (4)**, a method such as Nam Suh's axiomatic design (Ref. 16) can be used to segment the design into parts whose performance can be independently described as affecting the fewest possible functions, with the objective of one-to-one or eigen-vector construction for the matrix. Next, **Step (5)** the technology lemmas are applied to the various parts. This really consists of asking the technology questions at the component and then at the system level.

Technology Lemmas Defined:

Technology Lemmas are a means to consider the rate of change of technology and the advancing technology requirements driven by the users. This thesis presents those considerations in the form of four **Technology Lemmas**. In words, the four lemmas or problems to be dealt with are: **Lemma 1)** In a rising technology the newer product will reduce the sales of the earlier product when it becomes available; **Lemma 2)** An advancing technology need or requirement by the user community will very quickly obsolete a product or system which does not meet those needs; **Lemma 3)** Designing a product for expandability can sometimes extend its life; **Lemma 4)** There will come a time when the rising technology requirements by the users in a particular field will exceed the capabilities that can be furnished by the existing or customary technology in that field and a new technology or approach will be necessary. The four **Technology Lemmas** are described in greater detail in Chapter 3.

The term **Technology Lemmas** is introduced to describe the life-shortening effects due to improving technology and also the increasing demands on technology as the users insist on more features. Methods are described which reduce the effect of the Technology Lemmas by evaluating rates of technology change, adhering to or establishing new standards, and choosing proper timing. Designing for expandability or evolutionary replacement is also addressed.

These factors are used to support the reduced life or provide alternative benefits to the user to stabilize the product or system offering despite the technology changes.

Continuing the Enhanced Design Process:

Step (6) is to model or test the system by simulation or other means. **Step (7)** is to plot the system or product performance on goal-charts. **Step (7)** plots the results on the appropriate axes on a goal-chart. By this step, the performance limits and or cost limits may be known. In **Step(8)**, the goal-chart data is reviewed and the recommendation for implementation of one approach or another approach should be clear.

The **Goal-Charts** and **Technology Lemma** approaches come out of the authors' experience in both developing and reviewing products and systems where technology was a dominant factor. Two differing developments are described at some length in the thesis. The first development was a feasibility effort and the second was the design of a system to provide a state of the art analysis capability using CAE techniques.

The first development is entitled "Design of Optimal Control for an 11-story Building". The technologies involved are large force electrical or fast hydraulic actuators, Tuned Mass Dampers, sensors and advanced mathematical control algorithms. The problem posed was to use these

elements singly or in combination to control the swaying motion of a building to keep stress below damaging levels when the building is subjected to an earthquake or other forces.

The Goal-Chart Axes to evaluate the combinations are Control Performance Deviation from ideal (producing stress) versus Energy Required to limit motion to a particular deviation.

The proposals were modeled using MATLAB @. Once the resulting lines are plotted on the Goal-Chart, along with the stress limit line (approx. 9) on the Performance Index in Chapter 5, Figure 5.1, it is relatively easy to see which combinations of methods are to be recommended. This leads to a three step process. First, state the problem and objective; Second, Develop and Model the solutions; Third, Plot the results on the Goal-Chart and Choose the best solution(s). It is important to recognize that the goal-chart, though simple in appearance can have complex data inputs. For example the Figure 5.1 goal-chart is based on Matrix comparisons rather than simple numbers.

The second development, that of the CAE analysis system, has many parallels to very large projects. Specifically, there are at least six steps. See Figure 7.1 in Chapter 7. In the first step a need or problem must be articulated. In the second step a method for solving the problem using available or projected technology must be stated and modeled. The results of this modeling

should be presented in an interim Goal-Chart. The Interim Goal-Chart in words or pictures or both are useful in the third step, convincing the funding sources to provide funding in the form of Capital and Expense appropriations. Also, in this third step, the funding sources must be assured that the Return on Investment will be met. This forces statements based on existing technologies or at least evolving technologies to reduce risk. This third step can take months as in the case of the project described, and many years in the case of a project like the Central Artery in Boston. Meanwhile in both cases technology advances and changes and a new placement of the system on the Goal-Chart occurs. In the fourth step, assuming funding has been obtained, some pilot testing must be done before the final system implementation is undertaken. The fifth step is to plot the results on a Goal-Chart and include the effects of non-technical factors on a subsequent Goal-Chart. The sixth step is to implement the preferred system after convincing the funding sources that the differences between the system originally proposed and funded and the new one currently being implemented are really minor and very beneficial!! The Goal-Chart approach can be used to do this effectively in that it conveys the essence of the technical changes without bogging down the audience in the details.

In the CAE analysis system described, the problem is to speed up the analysis of circuits being analyzed under a Cadence software package called Verilog@. The Verilog@ package tests the performance of a circuit represented by a netlist and compares the performance with an idealized

mathematical model. The situation is that many circuits of interest could take as long as 2 years to fully analyze on slow machines, (Sun SPARC 2 or less as a reference) because of the many input and output combinations. Therefore only a representative sample can be analyzed unless much faster methods are available. Much faster methods involve hardware or software accelerators and faster Workstations. A proposed system must be designed with full justification for the expenditure and return on investment. By the time the project is approved, the latest new offerings from all the vendors must be reviewed and tested against the objectives and plotted on the Goal-Chart to pick a preferred solution. The non-technical issues must be and are also weighted and revise the axis of the Goal-Chart to a Cost of Performance versus Cost chart in the end. Also the new solution must be economically justified again.

The thesis also includes samples from other developments to illustrate the Technology Lemmas and to point out the effects of non-technical factors on the adaptation of otherwise desirable technical solutions.

The thesis illustrates a methodology which can be employed by others in the design of their products or systems when technology change is a dominant factor. This is accomplished by describing the Goal-Chart approach and by pointing out the dangers inherent in the Technology

Lemmas. The thesis also provides some guidelines for coping with the limitations posed by the Lemmas.

Perhaps the greatest benefit of the Goal-Chart approach is that one is required to quantify and define the overall project objective in simple terms translatable to people not in the particular field of expertise. The greatest benefit of the Technology Lemmas is that the designer is prompted to ask a series of questions in the beginning, about the project and about the technology status and rate of change. Those questions might not be asked and answered until later in the project when modification changes are more difficult.

A Companion Approach from The Business Community:

The field of business planning and has been helped by the contributions of Michael Porter in his offerings on strategy. The author was involved in the application of the "Five Forces" strategy activity with a \$100 million company over a six months period to develop and implement an effective product strategy. The five forces described by Michael Porter are, the supplier power, customer power, rivals power, threat of new entrants and the threat of new technology. See

Figure 1.2, The Five Forces Described by Michael Porter which Limit Profitability

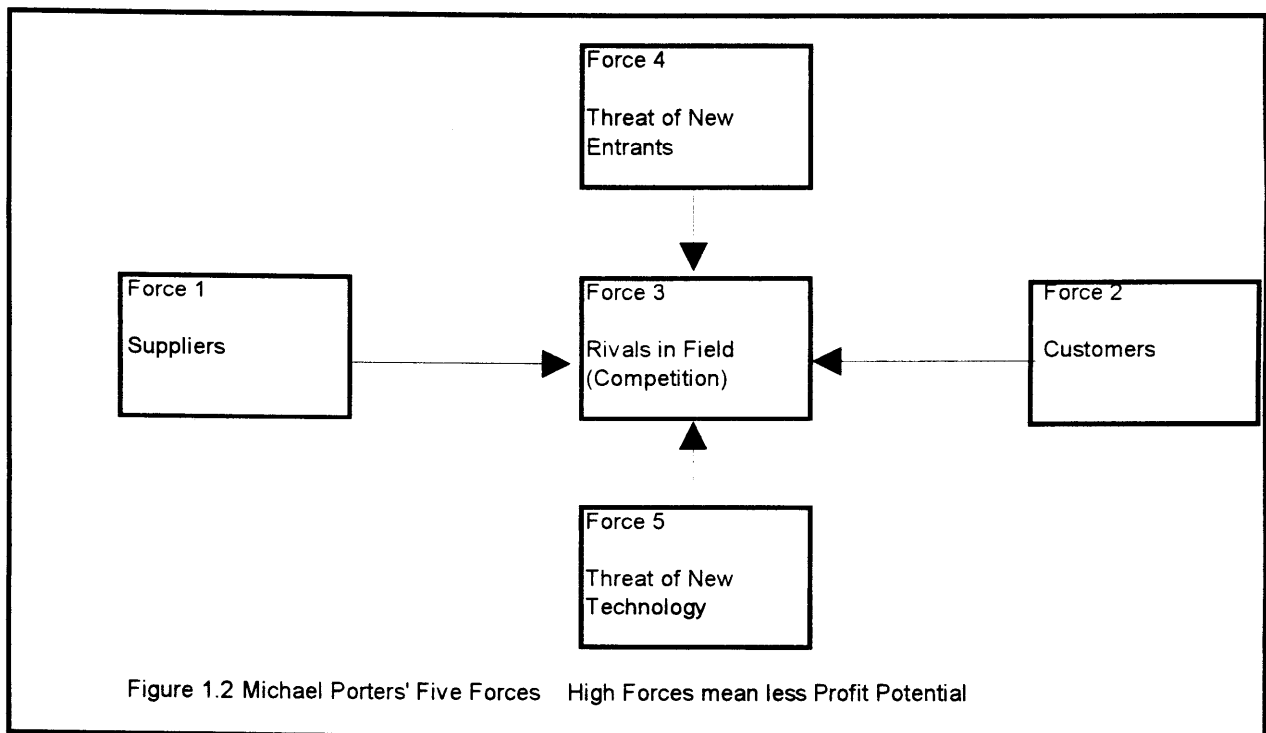


Figure 1.2 The Five Forces Described by Michael Porter which Limit Profitability

Figure 1.3, Michael Porter's Five Forces Methodology, graphically shows the planning process.

First, the business objectives must be clearly elucidated. Usually a mission statement or dedication to a field of expertise is part of that declaration of business objectives.

Second, the business elements must be separated into groups or segments which behave similarly under the effects of the five forces.

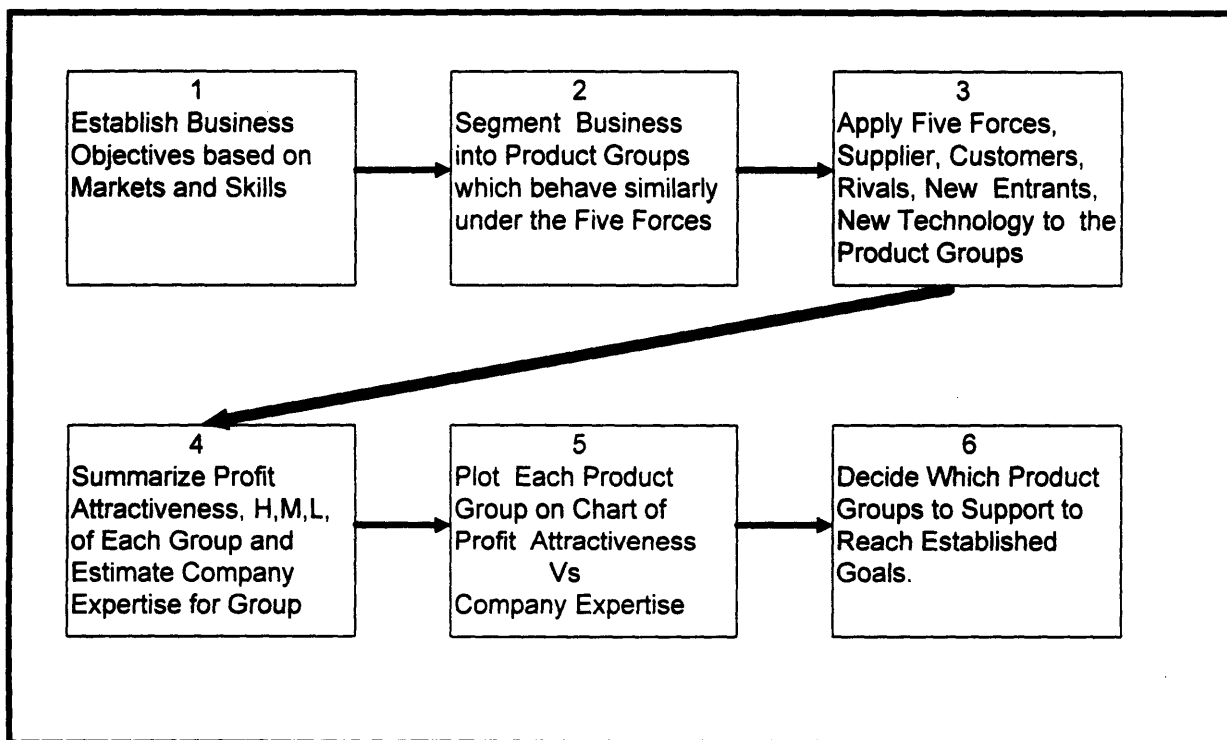


Figure 1.3 Michael Porter Five Forces Strategic Planning Methodology

Third, using information from various media, customers, suppliers, history and other sources, the effects of the five forces on the segments can be estimated and collected so that the profit attractiveness of that segment can be characterized in one of the categories, High, Moderate or Low.

Fourth, the expertise of the company and its' desired growth paths, based on market potential and company expertise, including Capital equipment and special tools or personnel skills are analyzed as objectively as possible.

Fifth, the company expertise is combined with the profit attractiveness of the products on an x-y chart which indicates the products which should be selected for emphasis or which will require more or less investment to be attractive products.

Sixth, usually a break-even line can be drawn on the chart to better indicate which products are most attractive to the company to support. The shape of the break-even line is often a second order curve in the first quadrant, products above the line can be made profitably, products below will require additional expenditure or development of higher priced markets to be made profitably by the company.

This Product attractiveness chart is in some sense a goal-chart identifying the most fruitful products. Figure 1.4, Product Attractiveness Chart illustrates the situation.

This is therefore an example of companion thought from the field of business.

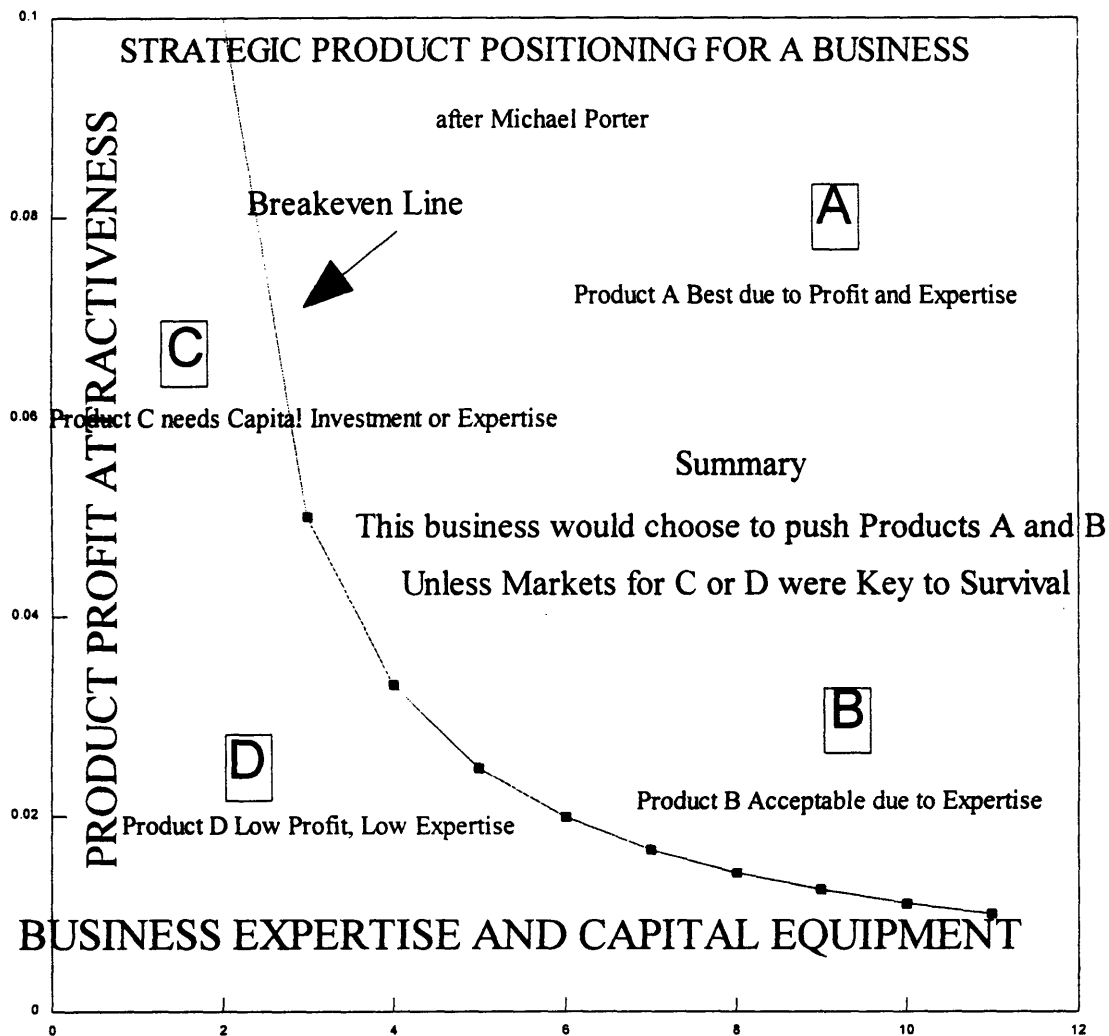


Figure 1.4 Product Attractiveness Chart after Michael Porter.

Chart illustrates products above the curve are attractive or profitable and products below the curve require expenditure of capital dollars or expertise or development of markets to be attractive or profitable.

CHAPTER 2

GOAL-CHARTS INTRODUCED

Chapter 2. Goal-Charts Introduced

Why The Goal-Chart?

The **Goal-Chart** and **Technology Lemma** approaches come out of the authors' experience in both developing and reviewing products and systems where technology was the dominant factor. Goal-Charts are an effective way to express the project objectives and product or system design results in a two dimensional x-y chart. Once the results are plotted on a properly formatted goal-chart, together with the limiting conditions, the comparisons indicating which methods are better, which options are feasible, which options meet the limiting conditions, can be easily made. Then the decisions for project implementation can be confidently approached.

Developing the goal-chart at the beginning of a project tends to identify key experiments and focus the project efforts toward gathering the data for the goal-chart evaluation and decision process.

The goal-chart is an effective means for the designer to communicate with both technical and non-technical audiences. The goal-chart also serves as an evaluation tool for the customer or user community, for management and the designer. With the limit conditions in place and the simulation or testing results plotted, guidelines for the designer, customer, and management will be easily discernible to all of the interested parties.

The preparation of the preliminary goal-chart at the beginning of the project is an excellent discipline for the design effort. Frequently, the project goals are stated in one-dimensional terms. It is later, sometimes near the end of the project, that the two-dimensional or multi-dimensional aspects of the project emerge. What is meant by the multi-dimensional project goals?

Multi-dimensional Project Aspects:

Engineering is the art of compromise between diverse goals. One set of goals is often the triad of 1) performance, 2) cost, and 3) schedule. (This gives rise to the engineers' dilemma, "I can give it to you Good, or Fast, or Cheap; Pick any two!"). Another set of diverse goals is 1) performance, 2) size (often cost-driven), and 3) weight. A third set of multi-dimensional goals is 1) performance, 2) feasibility, and 3) time or schedule. For example, this project can be done as soon as a new steel or plastic is available which has tensile qualities ten times better than anything we have today and I think it will be available in three years. Sometimes a performance specification change of 20% can mean failure or success, complexity or a simple design.

This thesis emphasizes the importance and value of setting out the multi-dimensional aspects at the beginning of the project. By defining these aspects up front, the critical experiments to be

performed can be identified. The identification of the data which it will be necessary to develop, in a form suitable for the goal-chart, can also be made.

Goal Chart Defined:

The Goal-Chart is a two-dimensional (x-y), projection of the system Performance versus Cost, based on multi-dimensional testing or modeling results from various design options, used to compare these system design options. The final Goal-Chart, used for decision-making among alternatives, includes the limit conditions on Performance or Cost or both which define the area within which any satisfactory system design solutions must be contained. The Goal-Chart concept can be extended to include the effect of exogenous and non-technical events by changing the Performance axis to one which is based on the Costs of Non-performance. Alternatively, the position of the projection on the Goal-Chart may be modified to show extra cost or less efficient performance to reflect the effect of the non-technical factors. Figure 2.1 shows the Basic Goal-Chart which will now be explained.

The axes of the Goal-Chart of Figure 2.1, are Performance Measures on the Y axis and Cost Measures on the X axis. In the typical x-y chart, performance is assumed better in the direction away from the x-y origin. However, this thesis chooses the performance

measures to be better in the direction toward the x-y origin. The cost measures are also chosen to be better in the direction toward the x-y origin. Therefore, the x and y axis arrows are drawn pointing toward the x-y origin.

THE GOAL CHART

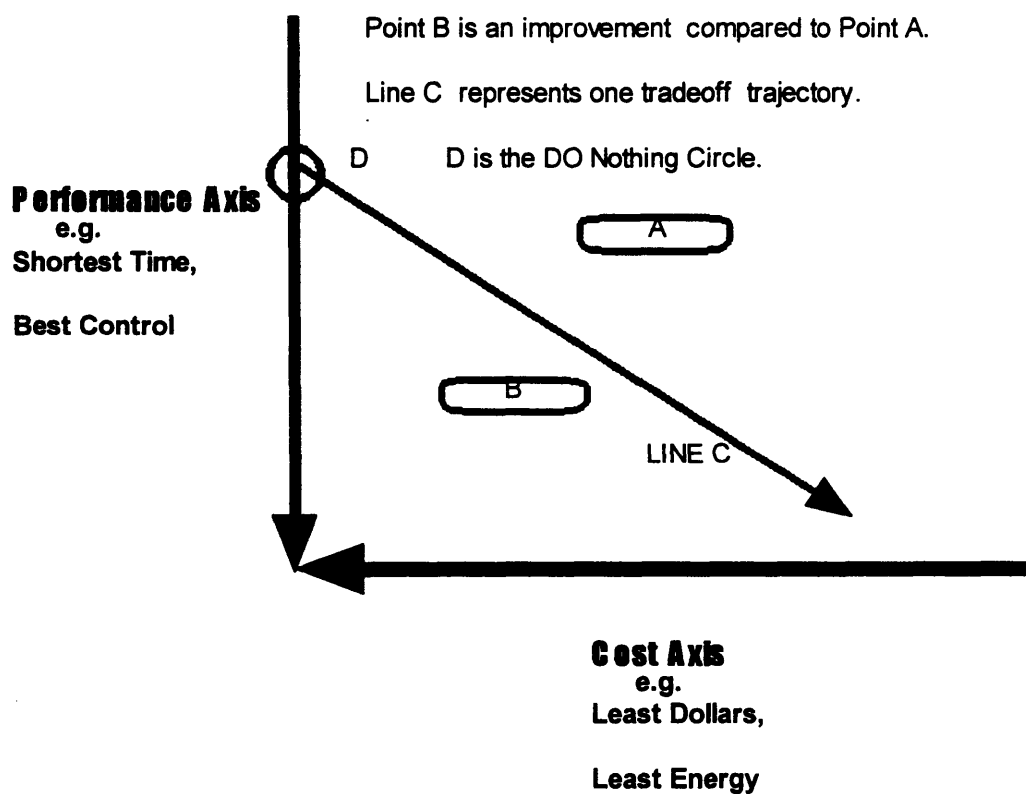


Figure 2.1 The Goal-Chart

Performance is better toward the x-y origin. Cost is better toward the x-y origin. Therefore, Point B is a better design solution than Point A. The Point D is placed on the y axis to represent the “Do Nothing Option”, neglecting maintenance costs. Line C shows one possible performance improvement trajectory, by additional investment cost..

There are three reasons for choosing the performance axis to be better in the direction toward the origin. First, this choice allows the performance goals to be bounded more easily, that bound being the x-y origin. Second, when the upper limit of acceptable performance line and the upper limit of acceptable cost line are plotted on the goal-chart, they form a box or region, together with the x and y axes, defining the acceptable performance-cost area of the design. Third, when the performance measures are converted to the Cost of (Non) Performance and plotted on a goal-chart showing the Cost of (Non) Performance versus Cost, for funding considerations by management (or by voters or the legislature on large projects), the origin direction for better performance is preserved.

A further clarification of these reasons follows: Considering Reason One, the x-y origin bound; The optimum point for the design, given these goal-chart axes, would be at the origin. A design point at the origin would give perfect control, for example, with no cost expenditure in dollars or energy. Obviously, that will not occur. However, the closer to the origin the system design

solution lies, the better the performance-cost value for the user. In general, the design solutions will lie along families of hyperbolic curves in the first quadrant. These curves will be asymptotic to the positive x axis. That is to say, there will be no value of Cost in dollars or energy which can guarantee perfect control (perfect performance). The asymptote in the y axis direction could lie in the first quadrant, the second quadrant, on the y axis or it could have no practical meaning. For example, the D or “Do Nothing” solution is shown on the y axis, given that the maintenance of this item is ignored. Should the D solution disappear, the Performance deterioration would go to some possibly indeterminate limit. Also, for some excursions, the tradeoff investment curves may be close to linear for some range of values.

Considering Reason Two, the upper limits of acceptable performance and acceptable cost:

An upper limit on the performance will clearly be indicated by some faucet of the design.

Otherwise, there is probably no value in performing the design. There may be an upper limit on the cost also. This can be a firm limit, (e.g. the budget) a limit set by severely diminishing benefits or a limit set by feasibility factors. The upper limit of acceptable performance or cost may not be known at the beginning of the project task since it may be a derived quantity. Also, one or the other of the upper limit lines may have no effect on the design choices. It is sufficient to realize that if the limit lines exist, as they do in most practical cases, they will proscribe the suitable design area, i.e. form the boundaries of the acceptable design solutions.

Considering Reason Three, the cost of non-performance:

An example of the cost of non-performance might be the height of a levee to hold back water.

There is a concept in civil engineering where the history of a river overflowing its banks is kept, and the various amounts, by which it extends outside its banks, are known, respectively, as the “ten year flood”, the “fifty year flood”, and the “hundred year flood”. If a levee is designed to hold back the “ten year flood” because that is cheaper or all that can be done at a particular time, and in fact the “fifty year flood” or the “hundred year flood” comes, then the damage done to the community in lost homes, property or lives is a cost of non-performance of the levee.

In some system or product design cases, the risk of non-performance is quantifiable and justifiable. In other cases, everything humanly possible must be done to avoid the catastrophe which can result from non-performance.

Other Goal-Chart Characteristics:

Linear axes are preferred for the goal-chart unless a logarithmic measure provides better clarity for the comparisons to be made. The performance measures themselves may be the results of matrix products, integrations or other complex procedures. In order to meet the criteria of the goal-chart being employed, the performance measures must relate to the objectives at hand and be measurable, calculable or observable. The cost measures must be derivable, known or estimable.

Figure 2.1 shows a basic goal-chart with a few elements plotted on it. First, the axes are shown with large arrows pointing toward the origin to indicate that better performance and lower cost, both desirable, are in the direction of the origin. In Figure 2.1, since Performance is better toward the origin and Cost is less toward the origin, Square "B" represents a better Performance - Cost value than Square "A" which is both higher cost and less good performance. Therefore, Square "B" would represent the result or option to be chosen instead of Square "A", if this is the final goal-chart.

One might ask, "why can't I just move from point A to point B and improve both cost and performance rather than move along a product trajectory like line C?". The answer is that the movement toward the origin is the development of new technology, through design and discovery. This may not be directly purchasable through money alone.

The circle "D" represents the present performance of a product or system. If no improvement is done, that is what the performance remains. If that performance is within the acceptable performance limits now or going forward for the near future, there may not be a need to do anything, the so-called "do nothing" option. It is important to realize that the output of a goal-chart analysis for a project addressing the incorporation of new technology, may reveal that the correct answer is "Do Not Incorporate This Technology" or "Do Not Incorporate This Technology Now". The models and simulation developed to produce the performance data must

be good enough to simulate and produce the data which says "Do Not Incorporate This Technology" as well as to describe the performance which will be achieved if the technology is used.

The Line "C" shows one possible trajectory for the Performance - Cost line, if cost is added to improve the performance of the product or system at circle "D". The actual trajectory or family of trajectories will be derived from the simulation model of the product or system by measurement, calculation or observation.

Figure 2.2 shows performance and cost limit lines added to the goal-chart and product positioning or simulation results on a possible trajectory. This goal-chart is provided to show how market positioning may be done through goal-chart analysis.

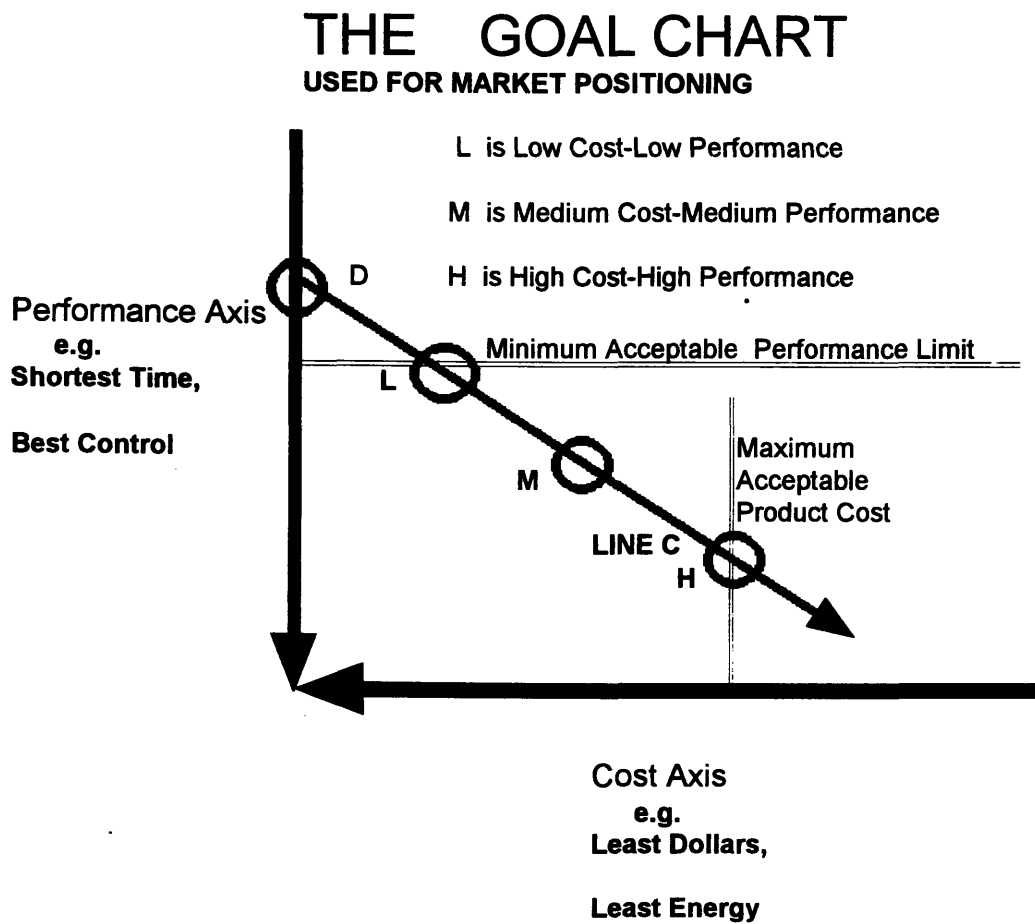


Figure 2.2 The Goal Chart used for Market or Product Positioning. The chart has limits added for the worst acceptable performance and the highest acceptable cost for the markets involved. This leads to a Low range, Mid range and High range product assignment. Both the marketer and customer can use this chart for their own purposes.

The goal-chart in Figure 2.3 re-emphasizes that many functions can use the information for their purposes. Marketing can use the information to position the product or system at the "L" point providing minimally acceptable performance at the lowest possible cost. Alternatively the product can be positioned at the "M" medium performance, medium price point. Finally the product can be positioned at the "H" point where the highest performance consistent with a maximum price is provided.

In the chart shown, the "D" circle the "do nothing option" has been ruled out as outside the range of acceptable performance. For the designer as well as the marketer, the rate of technology advance can affect the decisions. Products designed at "L" will likely fall out of the acceptable range quickly in a field where the technology is advancing rapidly. Products designed at "H" will move into the "M" region and new "H" products will take their places. Understanding the technology lemmas, described in Chapter 3, will help the decision-making in these areas. As will be seen, on the next chart, products at "M" will probably attract the most customers.

THE GOAL CHART

USED FOR CUSTOMER DECISIONS

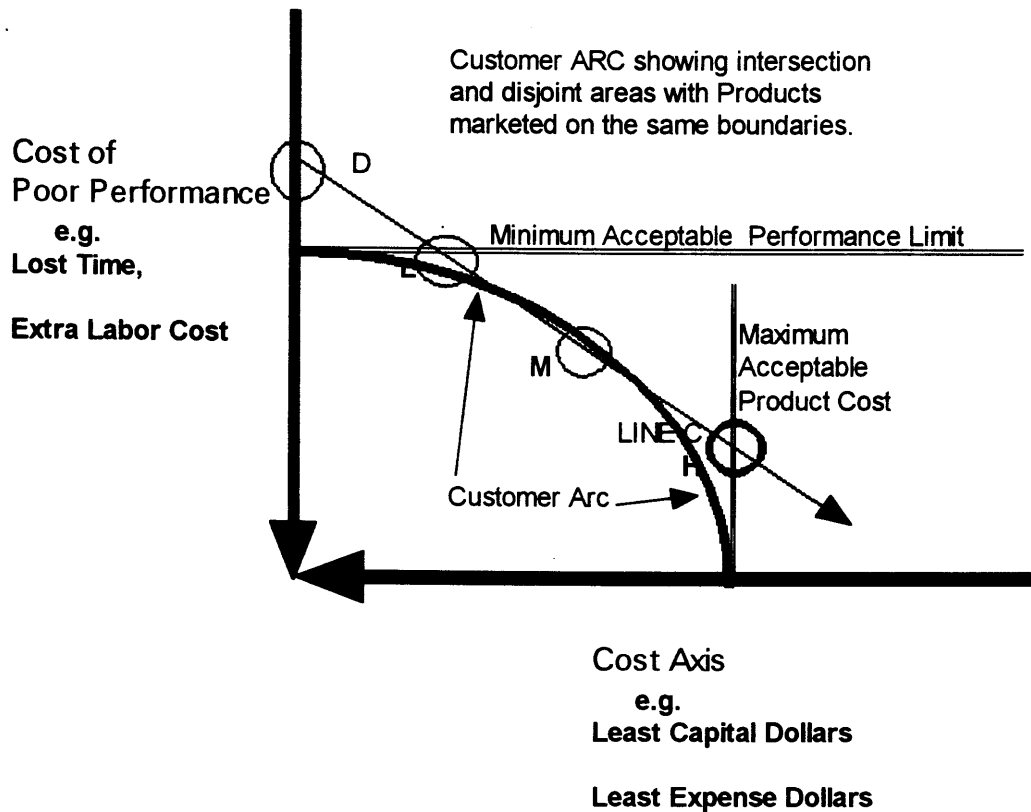


Figure 2.3 The Goal-Chart , Used for Customer Decisions

This chart suggests that the customer is more likely to purchase the Mid range product unless he has high performance requirements or is focused on the least expensive solution from a short range viewpoint. Figure 2.3 shows the Customer Arc added to the Goal-Chart. The customer is also looking for products positioned near the x-y origin. Note that some kind of curved surface within the acceptable limits of performance and cost will proscribe the customers' interests. Note

also the Y-axis of the customer is the cost of poor performance, not performance alone. The curved surface which has been named the Customer Arc comes about as follows: If necessary, that is to say, no better solutions exist, the customer is prepared to pay the maximum acceptable price for the poorest acceptable performance. This is the point at the intersection of the limit lines of Cost and Performance. However, most customers will be very watchful for the opportunity to gain better performance at the same price or the same performance for a lower price. Therefore the chosen options will move away from the limits toward the origin if any solutions exist within the cost/performance bound limits. Thus a curved arc within the limit rectangle will describe the loci of acceptable solutions for the customer, unless this is an empty set.

Summary of Goal-Chart Introduction:

Goal-Charts with the axes of Performance versus Cost have been introduced in this chapter. The Goal-Chart performance measures are chosen to show performance better in the direction of the x-y origin. The design solutions are plotted on the goal-chart so that comparisons can be made by the designers, marketers, users and managers. The notion of Product trajectories on the goal-charts was also introduced with further discussion to follow in Chapter 5. The acceptable area of design solutions was also addressed by adding the respective limits of performance and cost to the goal-chart. It was clarified that the correct answer to the incorporation of new technology could be “do not incorporate this technology now”.

CHAPTER 3

TECHNOLOGY LEMMAS INTRODUCED

Chapter 3. Technology Lemmas Introduced

Technology Lemmas Defined:

Technology Lemmas is the name given to a series of questions which should be asked and answered by designers and users of products or systems in fields where technology change is a dominant factor. The questions concern: 1) the rate of change of technology in the field and the consequent shortening of the functional life (or obsolescence) of the product or system; 2) the rate of change of the users' perceived or actual need for new features in the product or system as compared to the capability of the product or system; 3) the tradeoff of making the product or system expandable for longer life, versus the additional cost of the expandable product; 4) the certain fact that whatever product or system is offered, one day advances in technology and the advancing needs of the users will make it obsolete. Although the series of questions can be asked and answered in many ways, this thesis considers that most of the questions can be categorized in the previous four statements. This chapter 3, therefore, discusses the Four Technology Lemmas. **Lemma 1 is named Technology Driven Obsolescence, TDO. Lemma 2 is named User Driven Obsolescence, UDO. Alternatively, Lemma 2 which involves perceptions, can be called Market Driven Obsolescence, MDO. Lemma 3 is named Expandability Delayed Obsolescence, EDO. Lemma 4 is named Limiting Technology Obsolescence, LTO.**

Background:

Figure 3.1 entitled "Technology at a Point in Time", shows some basic relationships underlying the Technology Lemmas. At a given point in time the technology performance measure of a particular product or system may be divided into Low-range performance items, Mid-range performance items and High-range performance items as shown in the figure. This grouping moves to the right as technology advances. The High-range performance of today becomes the Mid-range performance of tomorrow. The Mid-range performance of today becomes the Low-range performance of tomorrow, The Low-range performance of today becomes unacceptable performance for the original markets. Thus it disappears, experiences a severe price reduction, or is directed to another, usually different, market, also generally at a lower price.

The slope of the technology line affects the movement of the performance groupings to the right on the figure. The rate of technology growth is therefore a key item for designers or users to observe when planning a product or system design or acquisition. If the technology slope is still positive as is shown in the figure, the markets for the products are expanding, otherwise there would not continue to be an incentive to develop the technology for those products. This has other implications addressed in Technology Lemma 4 later in the chapter.

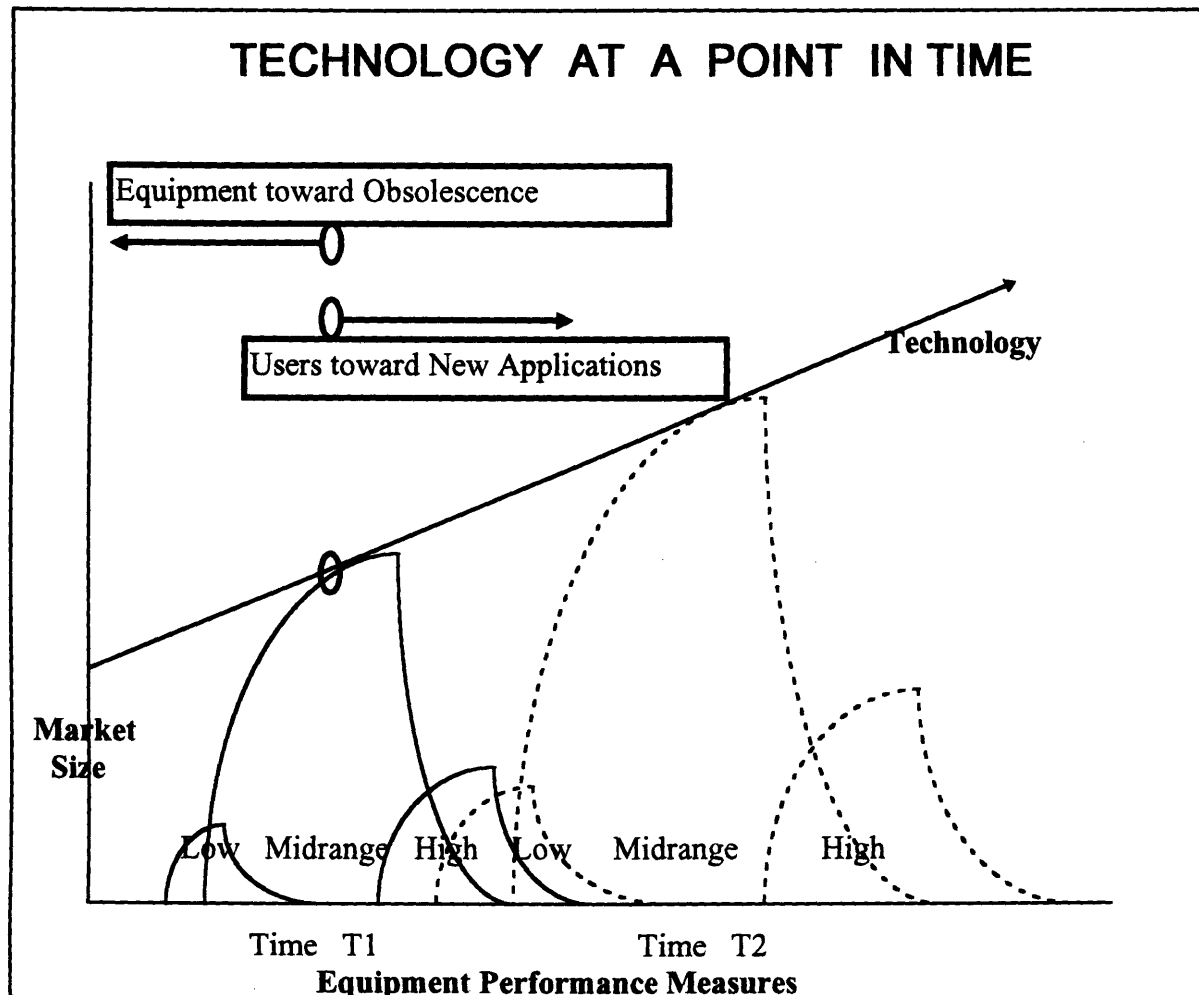


Figure 3.1 Technology at a Point in Time

Figure 3.1 also includes an arrow pointing to the left and labeled "Equipment toward Obsolescence". This suggests that all the equipment we use is heading toward replacement by some other equipment (TDO). Equipment upgrades can provide a step function to delay the obsolescence process (EDO), but the process starts again as soon as the upgrade is complete.

Further, in technology intensive product fields, upgrades of one to two steps are often viable, but beyond that point, the characteristics of the system, equipment, or operating milieu change so much that replacement with a more advanced product or system is a much more cost -effective and efficient option.

Another arrow on Figure 3.1 points to the right and is labeled "Users toward New Applications". (This is one basis of UDO or MDO.) This also suggests that people are directed toward the application of the equipment, rather than the equipment itself. This is an important distinction because it further suggests that users who become wedded to their equipment are themselves tending toward obsolescence in the main stream of events. This arrow is representing that the main stream users tend to develop applications and advance to the level of their equipment and then push for more applications and performance. This is UDO which can lead to LTO.

The trend of equipment toward obsolescence, planned (Vance Packard circa 1960) or otherwise, has other implications as well. For example, this suggests that all the cars, computers, and many other things of today are destined to become junk, refuse, pollution or ashes. The poet said, "All the rivers flow into the sea, but the sea is not full", (Ref 19). However, the poet neglected to point out or perhaps did not wish to consider that the seawater recycles as rain, sometimes as hurricanes and floods. Therefore, nature

has shown the basic process of recycling to be an important part of a continuing, viable, sustainable process. It will be important for technology purveyors to also discover ways to implement the planned destruction and recycling of the ever larger collection of obsolescent products before the Technology Equation can be brought into balance. Otherwise this generation may be known as the “Landfill Age” in the flow chart of technology.

Technology Lemmas Described:

Technology Lemmas are a means to consider the effects of the rate of change of technology and the advancing technology requirements driven by the users. The primary effect of rising technology is to reduce the life of current products because the new products or systems offer better performance value for the same or less cost (TDO). Users of new products or systems based on technology enhancement will soon find ways in which the product or system could be improved to better meet more of their needs or allow them to do new functions or be more user-friendly (UDO). When this need or requirement becomes crystallized, it will be necessary to modify or replace the system with one which meets the newly emerging or advancing technology requirements.

This thesis presents those considerations in the form of four **Technology Lemmas**. In words, the four lemmas or problems to be dealt with are:

Lemma 1) In a rising technology, the newer (later) product will reduce the sales of the earlier product because it will offer better performance, often at the same or lower cost; Thus, Technology Driven Obsolescence, TDO.

Lemma 2) An advancing technology need or requirement by the user community will very quickly obsolete a product or system which does not meet those needs; Thus, User Driven Obsolescence, UDO, or MDO Market Driven Obsolescence.

Lemma 3) Designing a product for expandability can sometimes extend its life, but the additional cost of an expandable product compared to a simpler, non-expandable product must be traded off against the possible life extension gain in sales or use; Thus, Expandability Delayed Obsolescence, EDO.

Lemma 4) There will come a time when the rising technology requirements by the users will exceed the capabilities of the customary technology in that field and a new technology or approach will be necessary. This can come from technology limits or an increased user capability requirement or both. Thus, Limiting Technology Obsolescence, LTO.

The four **Technology Lemmas** are graphically illustrated on the following pages. Note the effect on the sales of Product A (at the bottom of the illustration **Lemma 1**) when the new product B is introduced. As will be shown later in **Lemma 2**, the sales reduction of Product A is even more drastic when the performance capability of Product A no longer meets the Advancing Technology Requirements of the users and the performance of the new product, Product B, meets or exceeds those requirements.

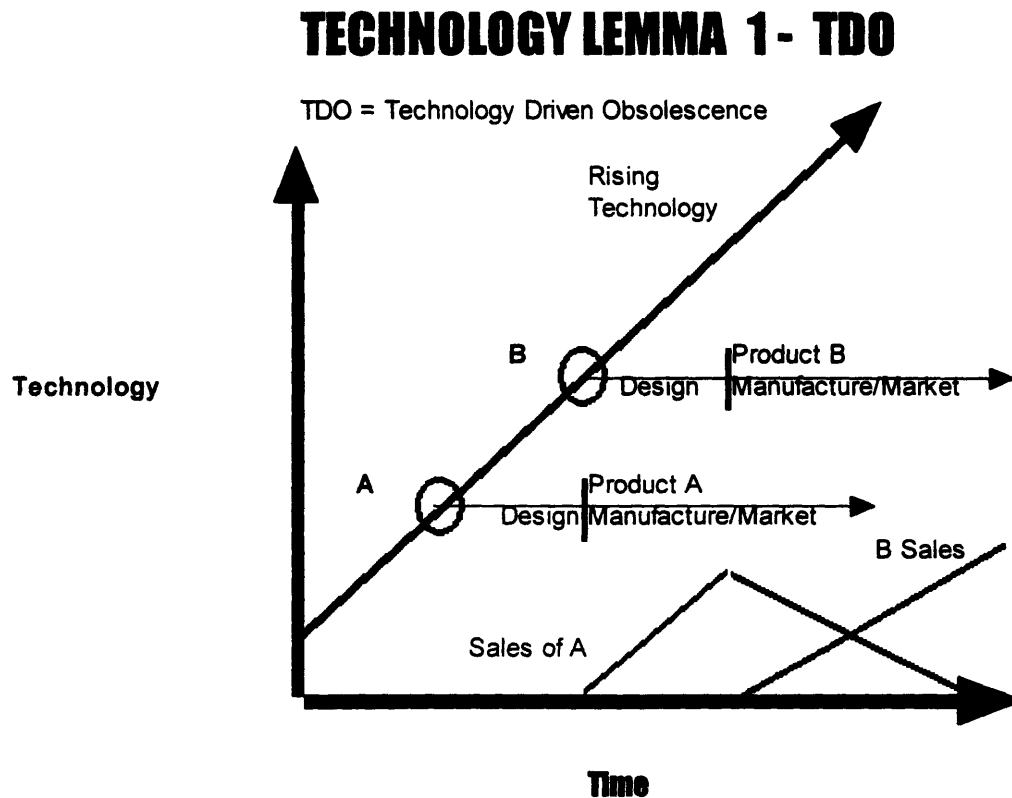


Figure 3.2 Technology Lemma 1, Technology Driven Obsolescence, TDO.

LEMMA 1 Described:

Figure 3.2 entitled LEMMA 1 illustrates a line rising at a 45 degree angle which will be considered the improving quality or capability of some element of technology. A practical

example of an element of technology to be considered in a design is the growth in the amount of hardware memory which can be addressed by a single microprocessor in a Personal Computer (to be addressed in detail in Chapter 4). The person designing the product or system using this improving technology has to decide at what point to take a design baseline, let us say at "A", and begin the design process.

This is illustrated by a horizontal bar proceeding to the right from a chosen point "A", on the Lemma 1 technology line. Once the design process is complete, the horizontal bar proceeds through manufacturing and marketing, hopefully generating enough revenue and profits to repay the design , manufacturing and marketing investment. Some level of investment is necessary to start the process and carry through to manufacturing and sale before positive revenue and profits are achieved. Typically, a projected date will be calculated at the time of the start of the design process , which will be the date at which the payback, break-even, or profitability point is achieved for the product or system. This projection takes into account the market size and expected rate of sales and the total sales for some period of time.

Even at this early stage, the initial impact of Technology Change begins is felt. The basic fiscal analysis assumes that the sale price of the product or system is some determined fixed value

sufficiently above the costs and maintenance to produce a positive revenue situation. The desired positive revenue should be of sufficient magnitude and duration to recover the investments and provide as much profit as possible. However, the emergence of other, more advanced products, presumably at a later time, will offer a better value to the user or customer because the new product will have increased capability in a desirable direction at the same or reduced cost.

Thus the manufacturer who begins at "B" on the technology curve will have a technology advantage over the manufacturer who began at "A". The solution often employed by the "A" manufacturer is to reduce prices to deplete his inventory (dumping is one practice) or maintain some market share as long as possible. The limit, of course will be influenced by the lowest costs which the "A" manufacturer can produce the product or system and sell it against the improved technology. Clearly, the improvement of technology and the entrance of other manufacturers at "B" and "C" and beyond will end the product or system life of the "A" manufacturer sooner than for a product where technology was not improving rapidly.

Making the timing choices to pursue or abandon products in the areas affected by a high rate of technology change is not unlike driving a race car competitively or making choices in the stock

market. In both these cases, information, skill and knowledge of the field and consistent strong efforts (e.g. the parallels to dollar cost averaging), can be valuable assets.

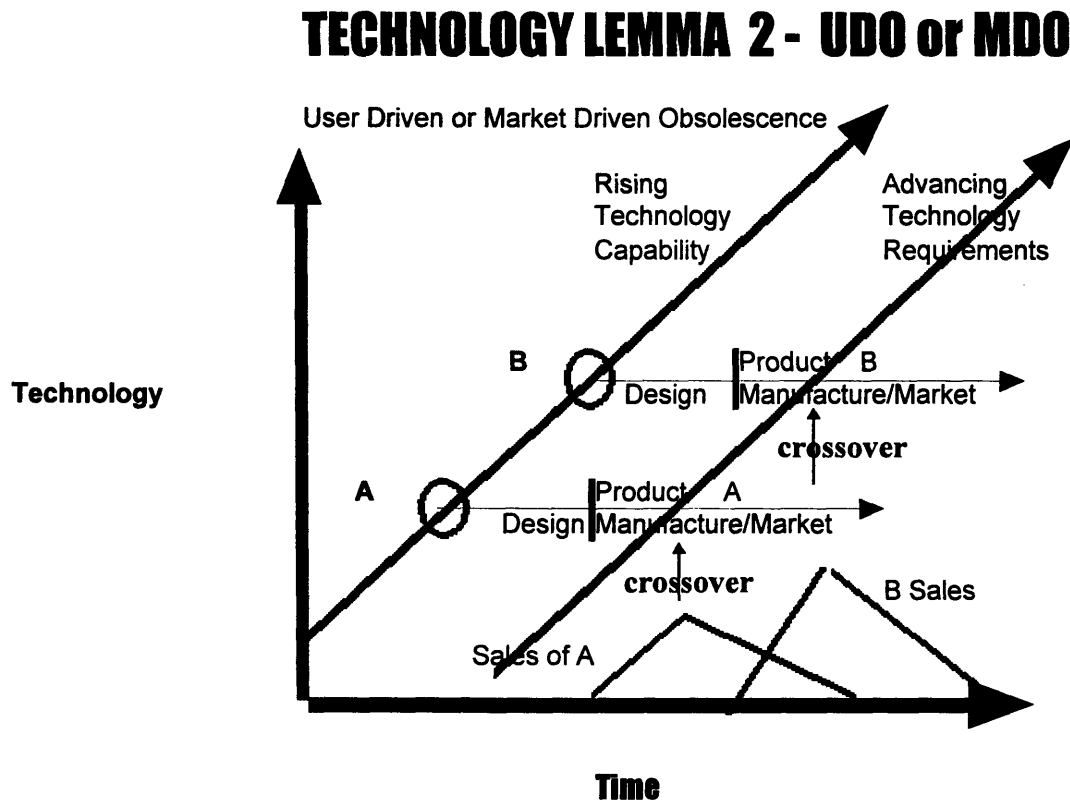


Figure 3.3 Technology Lemma 2 User or Market Driven Obsolescence

Technology Lemma 2 Described:

Technology Lemma 2 shown in Figure 3.3 poses an even a bigger problem than Technology Lemma 1. The user has requirements which are expanding and changing at some rate. This

expansion can be driven by advertising, convenience, a national event, or just "an idea whose time has come". (In modern times, ISDN and the Internet for example). For whatever reason, the users' advancing technology requirements dictate whether the manufacturers products or systems will solve the need (=sell well). Nothing can reduce the sales or use of a product faster than the perception by the user that it no longer fills a key need or is hopelessly "obsolete".

Figure 3.3 shows a line called Advancing Technology Requirements. This line can be parallel to, divergent from or be on an intersection path with the technology capability line and represents the users' changing technology needs.

The greatly reduced total sales of Product A shown in Figure 3.3 in comparison with the total sales in Figure 3.2, the Lemma 1 figure, illustrate this defining effect. The narrow range, between the hardware capability limits and the software or user requirements, in which the manufacturer of technology intense products must operate, is shown in more detail in Chapter 4.

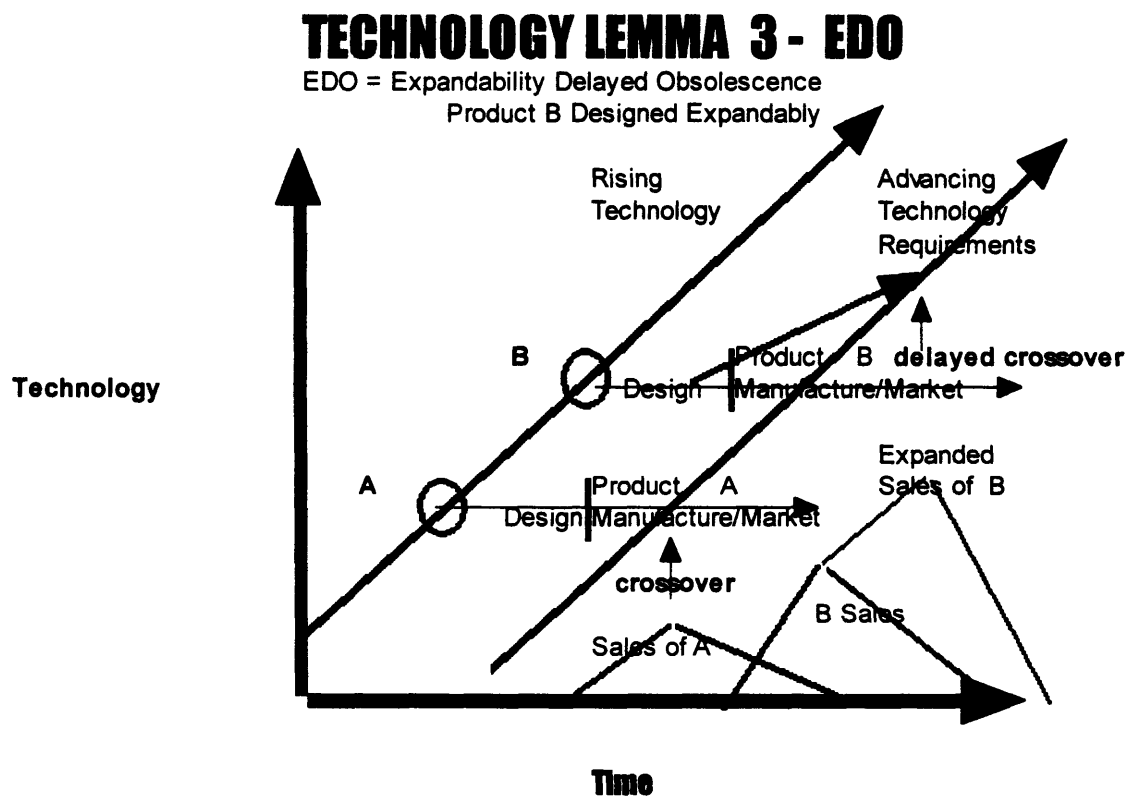


Figure 3.4 Technology Lemma 3 Expandability to Extend Product Life or Delay Obsolescence

Technology Lemma 3 Described:

Figure 3.4 Technology Lemma 3 addresses the approach of making a product or system expandable to increase life or utilization. The chart illustrates manufacturer "B" who, by designing in expandability to the product extends its useful life which would otherwise have been earlier, cut short by the advancing user requirements. The expanded product serves the users' requirements for a much longer time as the chart suggests by the delayed crossover arrow. Therefore, the market available to the manufacturer is much larger. The cost of the expandability as a market-price effect must be considered.

In the design of Workstations, Sun has been a strong performer in providing upgradeable products. Many versions of its Workstations can be upgraded by several steps as faster hardware becomes available. See Chapters 5 and 7. Many PC products are also upgradeable by replacing the base processor or circuit board. The large IBM mainframes, for example, were more of a replace-and-obsolete item rather than an upgrade item. Automobile upgrades are not so available; once again the manufacturers prefer to sell new.

Lest the reader think that upgrades and expandability apply only to computers, a few examples of other fields will be mentioned. Circa 1940, the Bell Telephone Company built a building in downtown Indianapolis, Indiana. In the mid- fifties, they needed extra space and after research

decided they could safely add five stories to the masonry building and did so, avoiding moving to other quarters.

The George Washington Bridge connecting Manhattan to New Jersey was built as a single roadway crossing. When additional traffic capability was needed a second roadway span originally dubbed "Martha" was hung under the first roadway.

There have also been famous examples of insufficient capability in the building design. One of the most famous, the extra structure stiffening required in the John Hancock Building in downtown Boston, MA.

The decision to add expandability cannot of course be done lightly, because usually the inclusion of expandability comes at extra cost. This is what must be traded off against the market value of expandability. Again a chart comparing product trajectories in Chapter 5 speaks to this matter.

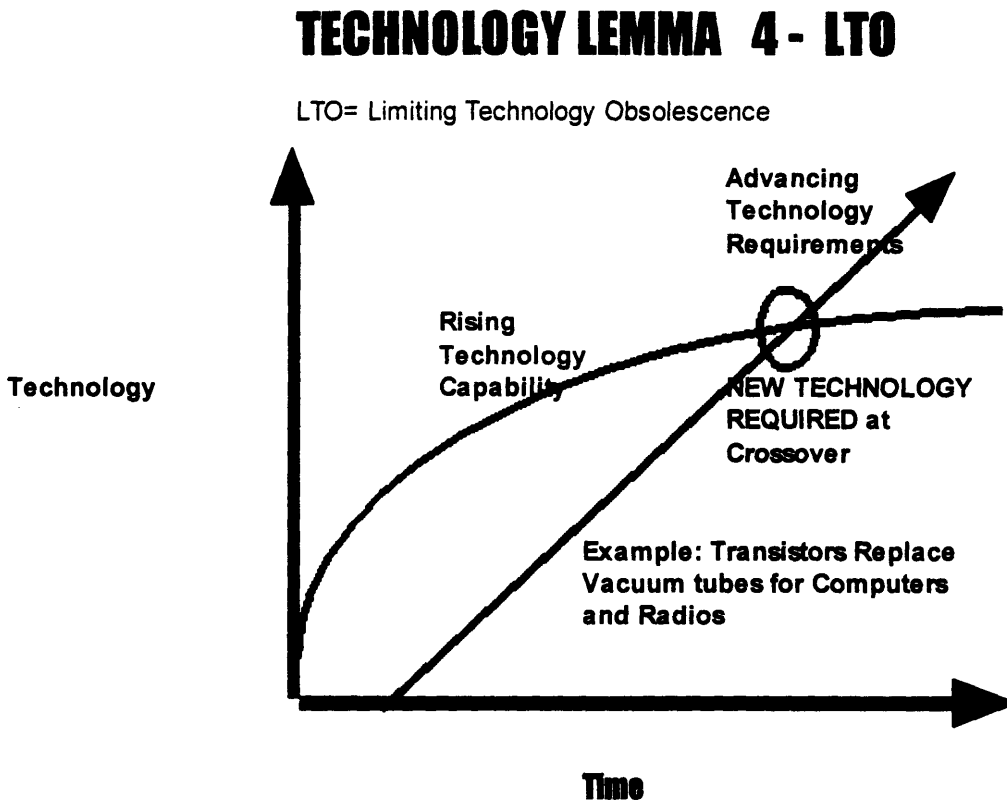


Figure 3.5 Technology Lemma 4, User Requirements Exceed Technology Capability

Technology Lemma 4 Described:

Figure 3.5 Technology Lemma 4 illustrates the “fate” which at some point will befall all technologies. The user requirements expand beyond the capability of the technology to perform from a standpoint of size, weight, speed, flexibility, effectiveness or some other desirable

parameter. The manufacturer hopes to anticipate this point and be ready with a new product. Sometimes the cross-over point in Figure 3.5 is gradual and sometimes the change is overnight in effect. Each enterprise or designer needs to spend some time thinking about the logical replacement of the product or system which he is designing, manufacturing or using. Sometimes, that thinking needs to be extended to an illogical, i.e. creative, innovative or non-traditional alternative, replacement as a trigger for the new technology method.

In the example given, one finds it hard to imagine vacuum tubes giving us the small calculators and powerful computers and communication devices we enjoy today. Yet, the transistor and integrated circuits are less than fifty years old in 1996, having been first constructed in 1948 at Bell Laboratories in the search for smaller, lower power, communication devices.

The other factor in the limiting technology case, LTO, is that the incremental expense to advance along the now-flattened technology curve is likely to inhibit advances, while the users' needs and expectations continue to increase. Using the vacuum tube example, it might be possible to make a vacuum tube, the size of a straight pin or needle, but the cost would be very great with known technologies.

Brief Summary of Technology Lemmas:

The term **Technology Lemmas** is introduced to describe the questions to ask about the rates of technology change to identify the product life-shortening effects due to improving technology and also increasing technology demands as the users need or demand more technology features. Designing for expandability or evolutionary replacement is also addressed. The four Technology Lemmas discussed are named: 1) Lemma 1, TDO for Technology Driven Obsolescence, which represents that less expensive, higher performance devices or systems will replace current items in a rising technology field; 2) Lemma 2, UDO or MDO for User Driven or Market Driven Obsolescence, which represents that the increasing requirements of the users by need or perception will cause current products or systems to become obsolete over time; 3) Lemma 3, EDO for Expandability Delayed Obsolescence, representing that sometimes making a product or system more flexible or expandable, usually at extra cost, may delay the obsolescence and provide a longer useful life or more sales of the product; 4) Lemma 4, LTO for Limiting Technology Obsolescence, representing that eventually a particular technology will provide only limited growth in capability, that this incremental growth will be costly and finally, that the user's requirements will exceed the capability of the technology, ushering in the need for a new technology. The requirement is for the designers, manufacturers, and entrepreneurs to project this intersection or crossover and have new technology products or systems available to serve the needs of the market and users.

CHAPTER 4

TECHNOLOGY LEMMAS - APPLIED EXAMPLES

Chapter 4. Technology Lemmas Applied

Technology Lemmas comprise the questions to be asked and answered to determine whether the effects of Technology Change must be considered in a design. If the effects of Technology Change are to be considered, the answers to the Lemmas suggest METHODS to enhance the design process to mitigate risk and help in evaluating design directions and goal-chart decisions.

The key issues are that the product or system is destined for obsolescence by one means or another even as it is being designed, and that the rate of Technology Change affects the product functional life before obsolescence. The reader may recall, from chapter 3, that the four Technology Lemmas were classified as: Lemma 1, Technology Driven Obsolescence, TDO; User Driven or Market Driven Obsolescence, UDO or MDO; Expandability Delayed Obsolescence, EDO; and Limiting Technology Obsolescence, LTO.

The methods to be used to answer the questions which have been previously posed are described in the following pages.

METHODS TO BE USED

The following methods address the problems posed by the Lemmas:

- 1) Evaluate the trend, rate of improvement of HW (SW) Technology in field, based on TDO, Lemma 1 (UDO or MDO, Lemma 2).
- 2) Evaluate the existing standards for products or systems in the field based on TDO, Lemma 1.
- 3) Consider related markets, applications and products or systems for technology transfer or new system or product applications. based on TDO, UDO, MDO.
- 4) Evaluate the trend, rate of advancement of technology requirements (usually, SW driving HW) based on UDO, MDO, Lemma 2.
- 5) Evaluate whether the system architecture can be (economic tradeoff) designed to support the advancing technology requirements by expansion, EDO, Lemma 3.
- 6) Evaluate the potential that the rate of advancement of technology requirements will outdistance or punch-through the limits of the current technology in the field requiring a new medium of expansion for meeting the development needs based on LTO, Lemma 4.
- 7) Based on 1-6 decide the window of opportunity or system or product life for the primary system.
- 8) Decide the window of opportunity or system life for the expanded system or product if feasible or useful by EDO, Lemma 3 (answer to method #5).
- 9) Plan the necessary allocation of resources to assure system design and acceptance.

- 10) Make the Return on Investment or other suitable calculations, given the estimated product market and life limited by technology, and either implement the project or decide to allocate the resources to alternate projects.

METHODS DETAILED:

- 1) Evaluate the trends and rate of improvement of the product or system hardware (software) which is relevant to the product or system design. Project backward and forward considering the product trajectories of the main stream players and any peripheral systems which are nearby or have an effect on or strong relationship with the field which the new or enhanced design will enter. Use this information to help gauge the period of time the product or system will likely be effective before price reductions will become necessary or functional obsolescence precludes its use. These sound like tall orders (difficult problems), but it seems in practice that many times the answer for these types of questions can be found or estimated closely enough, if only the questions are asked. Resources such as trade magazines, surveys, the Internet, specialized research articles, can all be used as guidance. As an example, Figures 4.1-4.3 taken from Reference 20, provide a collection of data and trends on Personal Computers (PCs). Figure 4.1 shows the rate of growth for working memory addressed by personal computers as a function of time. Figure 4.2 shows the price behavior for various families of PCs. Figure 4.3 shows new market development for PCs. These charts were intended to guide a manufacturers' product profile decisions (Ref. 20).

2) Evaluate the existing Standards and Architecture for the product or system as to maturity, obsolescence, new approach needed, limited flexibility, existence or non-existence. The rate of both hardware and software growth are jagged in that plateaus develop and step functions occur. Lemma 1 in Chapter 3 shows an average smooth curve, but the difference in launching a product just after a standards plateau has been reached or after the standard has been abandoned for a more advanced standard that the new design cannot meet, can mean a much shorter life for the latter product. In Figure 4.4, (Ref. 20) observe that the horizontal distance between the Hardware Memory Limits and the Computer Software Memory Requirements is not constant, but varies considerably over the period of time shown on the chart. The horizontal distance is related to the effective life of a product before its capabilities intersect the advancing requirements of the user, UDO, and it experiences a market reduction. The hardware limits are driven by the change of microprocessors from 8 to 12, to 16 to 32 bits and more. The software steps are driven by advanced word -processing software and software packages like Windows, among others.

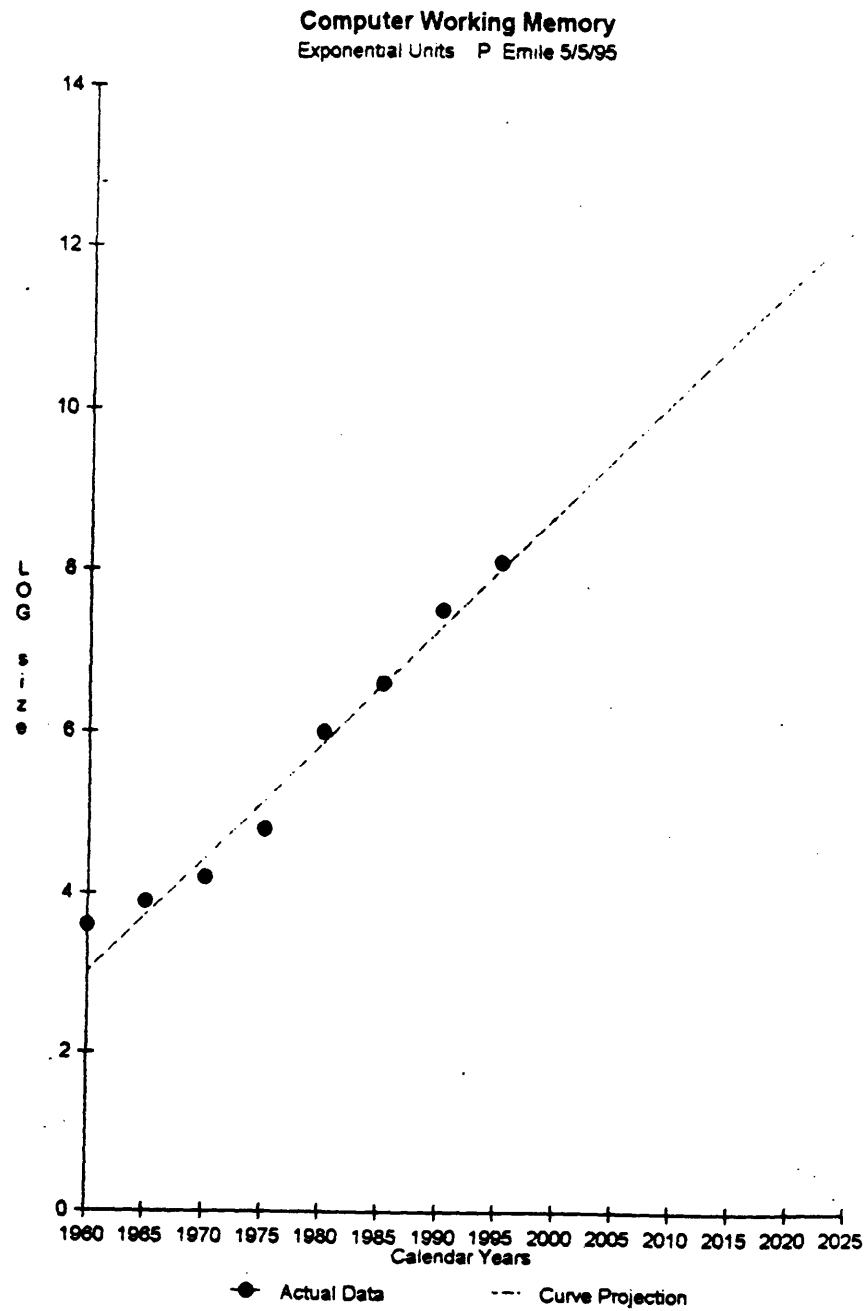


Figure 4.1 Working Memory Addressed by Personal Computers versus Time

An illustration of rising technology.

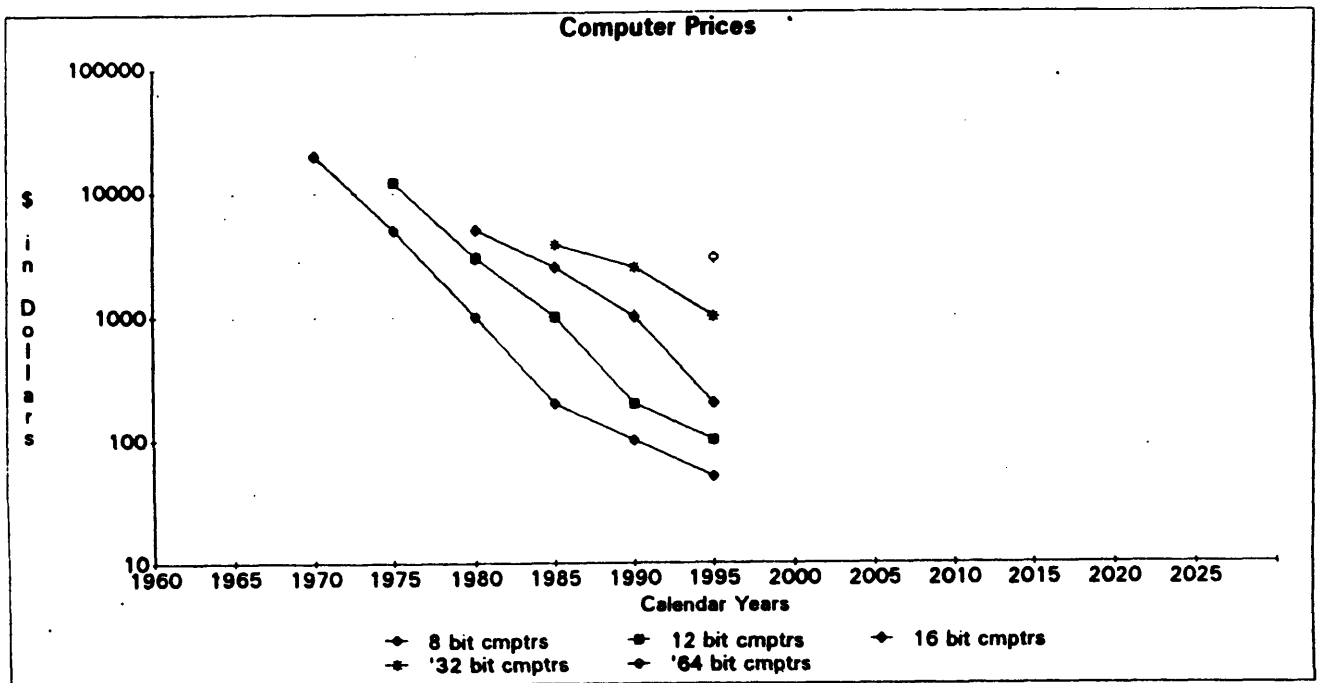


Figure 4.2 Price Behavior of Families of Personal Computers versus Time

Illustrating the declining prices for older models as newer models emerge.

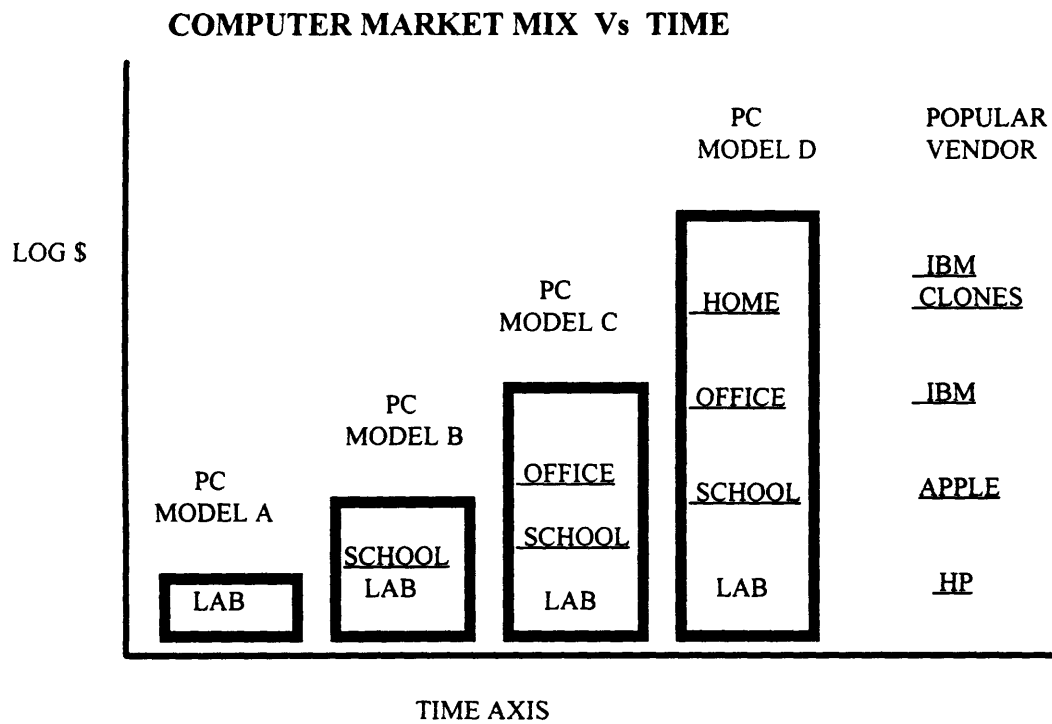


Figure 4.3 Market Development for Personal Computers

Illustrating Growth and Diversity With Differing Requirements and Suppliers

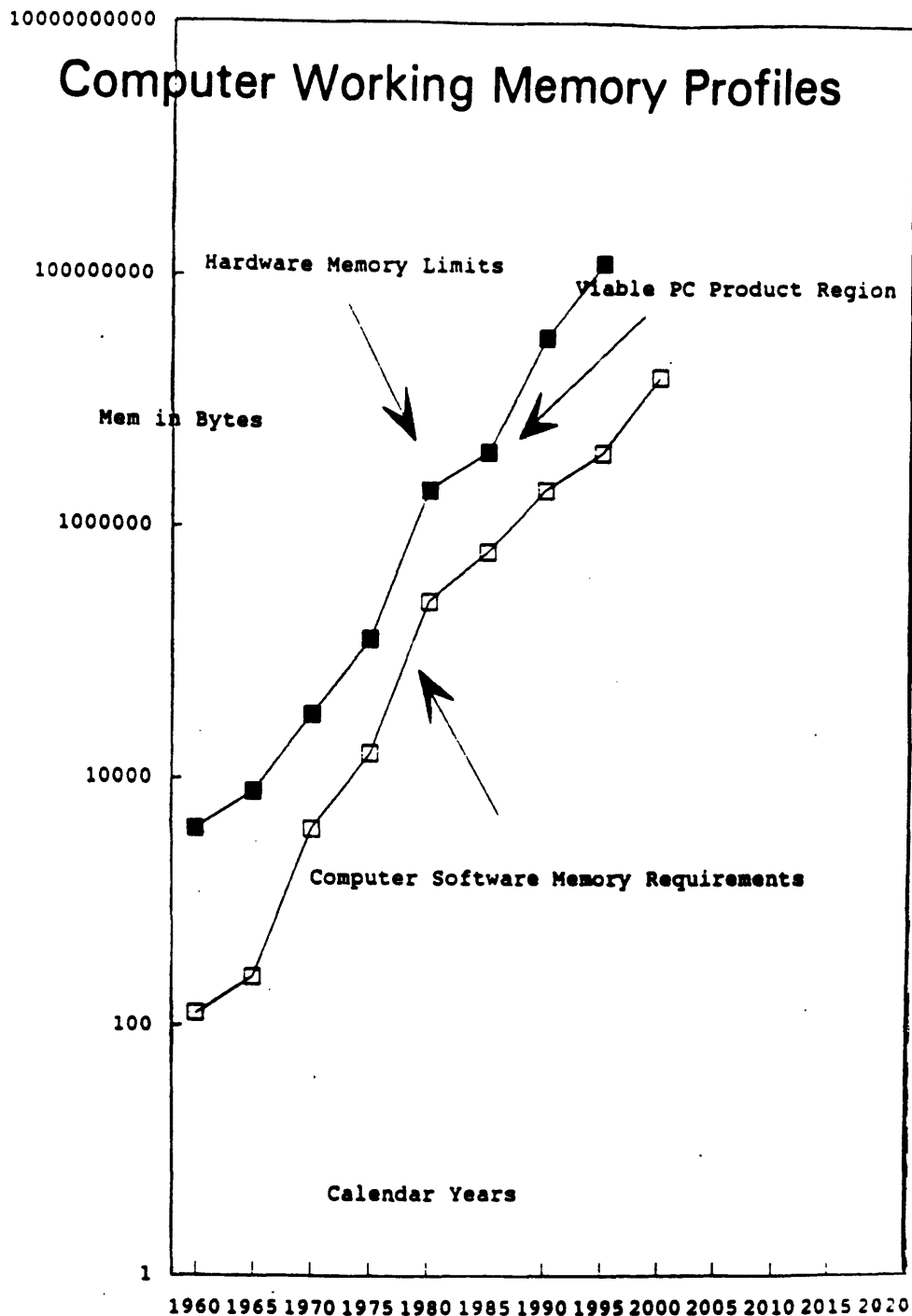


Figure 4.4 Narrow Range for Successful PC Products as User Requirements Increase.

In designing systems where Technology Change is the dominant factor, there are other hazards. These include strategic choices, (which may override technical superiority), regulatory factors, accumulation of collateral assets or capture of a large customer base by one or more major players. Professor James M. Utterback, in "Dominant Designs and the Survival of Firms", Reference 4, considers the effects when a design becomes "dominant", i.e. a de facto standard, where the economies of scale (increased production at lower cost) can be leveraged to increase the barriers to entry for new firms and thereby reduce the survival chances for new competing firms. The status of a proposed new product needs to be viewed in the light of these types of considerations.

Professor John Gero, of the University of Queensland, Australia, (an early reviewer of some of the original material in this thesis) addresses the issue of estimating product life, by saying, "Note when the increase in quantity of a particular factor becomes critical enough so that the kind of action or result is qualitatively different". One example is to consider the region over which one can carry out face-to-face communication in one day, given various means of transportation. A person walking could reasonably meet and talk with people twenty miles apart in a single day if he chose to make the effort. The same person using an automobile could comfortably meet and talk face-to-face with people 200 miles apart in the same day. Given access to a modern jet aircraft, the same person could meet and talk face-to-face with people 2000 miles apart in the same day. (Crossing the International Date Line into tomorrow or yesterday is not being

countenanced in this example.) Thus, the scope and type of affairs that could be considered by the person in this example would vary by a large amount depending on the transportation he had available to him. Of course, the hazards he would likely face would also increase. These would include, worldwide weather patterns, wars, political elements, currency changes, language and custom barriers and many others.

Providing the person in the previous paragraph with a video phone would allow near face-to-face contact throughout the world we call earth. Contacts to the moon inhabitants with the 8 second delay would be annoying and face to face video with persons as far away as the sun would get positively annoying with delays approaching twenty minutes between responses. Some new technology is needed to approximate face-to-face contact with inhabitants as far away as the sun, no doubt. One possibility might be extended thoughts or telepathy. Has anyone tracked the speed or range of a thought?

3) Evaluate the trends and rate of advancement of technology requirements. Many times this takes the form of software or system requirements to do more than in the past. For example, consider the introduction of the Microsoft Windows software when the Model 286 computers were comfortably coping with word-processing, spreadsheets and a number of other functions rather successfully. Within months it became clear to a large number of users that only a more powerful processor with more memory capability would be capable of dealing effectively with this

new and attractive functionality. Enter, the Model 386 and the faster Model 486 and the Pentium and Windows 95, and.. Anybody need a very inexpensive 286, cheap!? Figure 4.4 illustrates the narrow region for successful PC products as both technology and technology needs or advancing technology requirements proscribe the boundaries of useful products.

Let us look at a totally different field, that of automotive transmissions. In 1941, the automatic transmissions which existed on cars were considered by many to be expensive to repair, poor on gas mileage, more complicated and less effective than manual transmissions and in some cases not suitable for a "real man". By circa 1970, cars without automatic transmissions suffered badly at resale or trade-in since no one wanted a car without an automatic transmission. (trucks and sports cars being the last to make the shift.) The automatic transmissions are much better in performance today, but the real factor is that the users want the automobile to be as automatic as possible while their time is spent listening to the CD player, talking on the Cellular phone or enjoying the surroundings. "Let the car do the shifting, I'll tell it when to stop or go." Did someone say Car-Following or Automatic Cruise Control?, see Chapter 8.

4) Evaluate the potential that the Rate of Advancement of Technology Requirements will outdistance or punch-through the limits of the HW (SW) technology requiring a new medium for expansion. This is the LTO, Lemma 4 for which the designer must be watchful. Projections must be made and critical experiments conducted to determine when it is not feasible to accomplish the

goals with the present processes. The search for a new or different way should begin from the projections and be verified by the critical experiments. From wartime , one can think of Star Wars requirements, ballistic missiles guidance, submarine detection and communication and others. From NASA, one can think of new ablative materials and methods for manned reentry vehicles. One can think of advanced communication and the choice of the famous "Slingshot Orbit" which would guarantee the return of the Apollo Space Capsule to Earth orbit by Lunar gravitation, should the Retrofiring to enter lunar orbit not be successful.

On the Central Artery Project a critical element was fire in the tunnel. To resolve what methods would be required to deal with such an eventuality, the Project leased a mining tunnel in the mountains of Pennsylvania to experiment with all types of fires which might be expected to arise under whatever circumstances. The Fire project drew worldwide interest as many countries posed problems and sent personnel to gain knowledge and information. Fire project cost, \$39 million; project knowledge worth, safety for millions of tunnel users through the next fifty years.

As indicated in the LTO, Lemma 4 chart, the communication, computation and electronic conveniences we enjoy today would not be possible without replacing the vacuum tubes with semiconductor devices, first born at Bell Laboratories and later evolving into integrated circuits at Harry Diamond laboratories and Texas Instruments and most recently into powerful

microprocessors at Intel and IBM. The next frontiers which limit the possible progress should be considered in any major new project.

5) Evaluate whether the system architecture can be designed to support the advancing technology requirements by expansion. This is a trade-off process by the designer on one hand and by the user on the other hand. It can be taken as a given that a product designed to do one thing only can be designed to do that one thing less expensively than a product designed to do more than one thing. If that one thing is valuable, required in large volume and needed for a relatively long time, then economics may favor the “one trick pony”. However, if the product is required to do more than one thing to serve a larger market or a changing market then some other approach may be the economic choice. Further, from the users’ standpoint, an expandable or more flexible product may last longer as his needs change. Thus, the market/user /product cost/product expandability parameters should always be considered in the design of a product in a field where technology change is occurring. If there is a low cost way to achieve expandability, then the scales favor incorporating the expandability from both the maker and user standpoint based on the experiences of manufacturers in fields where technology is changing at a significant rate. Examples of manufacturers who have successfully chosen this path include Sun with Workstations and Intel with computer chips.

6) Evaluate the potential that the rate of advancement of technology requirements will outdistance or punch-through the limits of the current technology in the field, requiring a new medium of expansion for meeting the development needs based on LTO, Lemma 4. The usual shape of the growth curve for a new technology approximates the cumulative probability distribution for the Normal Curve. At the onset the advances in the technology are incremental. As time passes, if the technology is seen to be beneficial and there is continued interest in development, the advances continue at some increased rate. After a longer time, the advances come more slowly and at greater cost. Finally, the cost of further improvement in the technology is prohibitive unless a survival issue is present. Meanwhile, the users of the technology discover the enlarged capabilities and the perceived or actual need for enhanced features increases at some rate. The problem of LTO occurs when the users needs continue to increase after the technology advances have become much more difficult or limiting. It is up to the designer to observe if this effect is happening in a number of disciplines which affect his system or product design and look for non-limiting alternatives.

7) The window of product opportunity is obtained by extrapolation of the items reviewed in methods 1-6. Briefly, one estimates the duration of the window of opportunity by observing the rate of change of the technology and the rate of market growth. The rate of technology change sets the timing of the next product step and the market behavior sets the number of products which can be expected to be sold before and during the early life of the succeeding product.

8) The window for the expanded product or system is also determined by extrapolation of the previously discussed methods. In this case, the issues are the sensitivity of the market to the cost associated with including the expanded capability in the initial product, compared against the potential gain in product performance from the users' standpoint and the additional product sales during the extended life from the manufacturers' standpoint.

9) and 10) involve applying standard business design algorithms and will not be discussed in this chapter. However, the Capital Acquisition Request described in Chapter 7 gives answers to the many questions which are asked by the finance and management people.

Summary of Technology Lemmas Applied:

Methods are described which mitigate the effect of the Technology Lemmas by evaluating rates of technology change, adhering to or establishing new standards, and choosing proper timing.

These factors are used to support the reduced life or provide alternative benefits to the designer or user to stabilize the product or system offering despite the technology changes.

CHAPTER 5

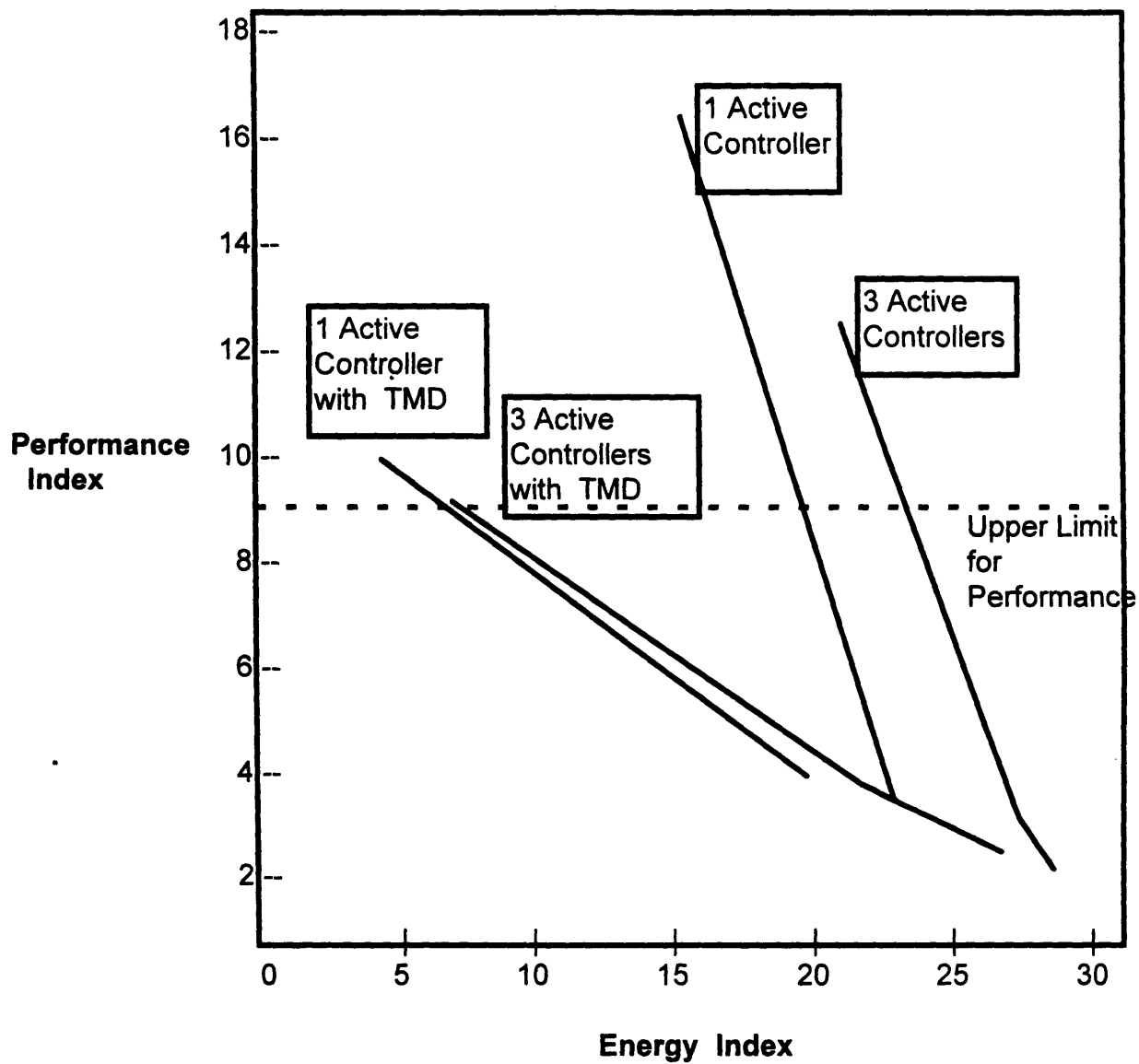
GOAL-CHARTS - APPLIED EXAMPLES

Chapter 5. Goal-Charts, Applied Examples

Goal-Charts Revisited:

Goal-Charts were introduced in Chapter 2. The goal-chart was defined as an x-y plot of Performance versus Cost. The Cost or x- axis was taken as dollars or energy and better in the direction of the origin. The Performance or y- axis was also taken as being better in the direction of the origin. It was discussed that the Performance axis could in some cases be the Cost of Non-Performance or Poor Performance. The goal-chart was further identified as a two-dimensional projection of a multi-dimensional project solution result. The goal-chart was identified as a method to communicate technical results to a non-technical audience or a technical audience in another technical field.

With this background information re-established , the reader is directed to Figure 5.1, a project goal-chart from a project to be discussed in chapter 6. First it can be observed that there is a performance limit horizontal line at about 9 units on the Performance or y-axis. Therefore solutions above this line will be unacceptable. One can observe that points on the the lines labeled “1 Cont w TMD” and “3 Cont w TMD”, which lie below the acceptable performance limit require less energy or “Cost” than points on the lines labeled “1 Cont” or “3 Cont” which lie within the acceptable limit shown. Thus, one who does not know the procedures or details

GOAL-CHART for ACTIVE CONTROL

5.1 A Project Goal-Chart to discuss Communication with non-technical personnel.

of the project can easily digest the results and understand the decision-making elements. This is an example of the goal-chart being used to communicate to a different technical audience.

Never-the-less, the chart is also useful to the designers to compare results and guide decision-making. The chart will be more fully explained and developed in Chapter 6.

Once the goal-chart ideas of Performance versus Cost and Cost-of-(Non) Performance versus Cost, are understood, some interesting strategies and tactics can be illuminated from the plots on the goal-chart. Further, connecting data points on the goal-chart to describe Product Trajectories and applying the Technology Lemmas can provide helpful guidelines for decisions by manufacturers, management and customers.

Product Trajectories On Goal-Charts:

Figure 5.2 Product Compromise Trajectories, shows a circle on a goal-chart aligned on a 45 degree angle from the origin. The basic product being discussed is assumed to lie at the center of the circle. The 90 degree swath from 0 degrees, (aligned parallel to the x-axis in a positive x direction) to 90 degrees, (aligned parallel to the y-axis in the positive y direction) is identified as favorable to the product manufacturer. This swath allows a lower performing product to be sold at the same price, 90 degree position, or allows a product with the same performance to be sold at a higher price, 0 degree position. All positions of related products from 0 degrees to 90 degrees

therefore favor the manufacturer from a profit benefit standpoint, other things being equal. On the other hand, products developed in the directions from 180 degrees to 270 degrees favor the customer. In these directions the customer will get the same performance at a lower price(cost) 180 degrees, or will get the improved performance, closer to the $y=0$ ordinate at the same price (cost).

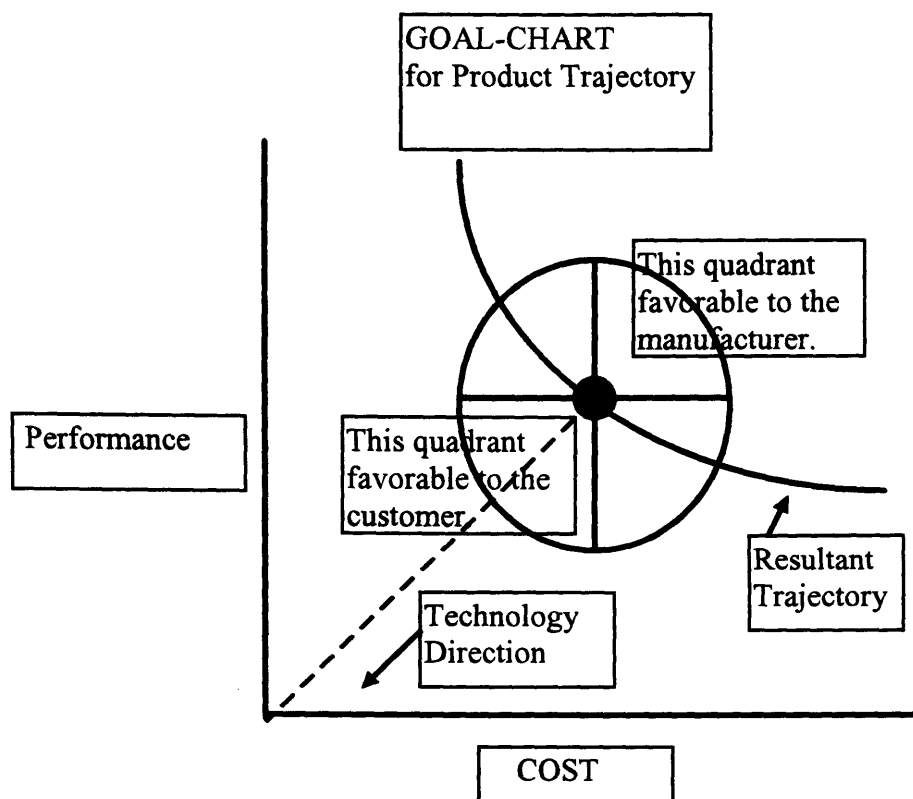


Figure 5.2 Product Compromise Trajectory - Compromise Direction based on both Manufacturer and Customer needs.

As might be expected in a case where opposite directions benefit two parties doing business, a compromise situation may exist, where similar products developed lie along a line at right angles to the 45 degree line through the origin. This may continue to be the case until the next technology step toward the origin, e. g. the next microprocessor development.

Performance Category Pricing Strategy:

Let us consider the situation of a PC Manufacturer, and his potential customer an Information Systems selection specialist who must project the purchase of computers over one to three years in the future. Both know that the performance of available machines will improve in the future, and that the costs for a particular series of machines will decrease. They also know that the requirements for their customers or users will continue to increase and exceed the capabilities of the current machines. Neither party really knows the rate of change of the technology three years into the future. What to do?

Management and financial planners look for certainty to commit dollars and the previous paragraph incorporates a reasonable amount of uncertainty. Both the PC Original Equipment Manufacturers, (OEM), or Assemblers, Gateway, for example, and the Information Systems selection specialist have come up with compatible strategies to deal with this situation. Gateway

has divided its Product lines into High Performance, Moderate Performance and Economy Sectors. For the sake of discussion, the High performance sector always costs the same amount, \$5000. The moderate Performance sector always costs \$2500. The Economy sector costs, \$1000, (or \$999.95 to be just under the limit to charge expense dollars rather than capital equipment dollars These are treated differently for financial purposes.).

However, the contents of the High Performance system will vary as the technology advances. For instance, at one point in time the high performance system will be a 486DX-66 (Computer Processing Unit) , CPU, with a 424 Megabyte Hard Disk Drive, HDD, 8 Megabytes of Random Access Memory, RAM, and a combination of floppy disk drives, FDD. The Moderate performance system will be a 486DX-33 CPU with a 200 Megabyte HDD and 4 Megabytes of RAM and a single FDD. The Economy system will be a 386SX-20 CPU with a 100 Megabyte HDD, 4 Megabytes of RAM and one FDD.

Eighteen months later, the high performance system will be a Pentium 133MHz with a 1 Gigabyte Hard Drive, 16 Megabytes of RAM, one FDD and a Quad (4X) CD-ROM drive. The Moderate performance system will be a 486DX-66 CPU with a 730 Megabyte HDD and 8 Megabytes of RAM. The Economy system will be a 486DX-33 with a 200 Megabyte HDD and 4 Megabytes of Random Access Memory.

During the time between Central Processor Unit performance quantum improvements or changes, the base system price is declining and the PC Manufacturer pads out the value of each class of system with added peripherals such as more memory, a larger hard drive, larger or better display, CD-ROM, or other items with the goal of keeping the system price the same and providing the value to the customer within the range he has chosen to operate. This strategy provides a more consistent predictable, product movement.

The Information System selection specialist divides his purchase requirements into high performance, moderate performance and low or economy performance models depending upon his user base. One strategy for a company with a large proportion of high tech, high performance users is to purchase only high end systems and subsequently to cascade the older systems down to users with less requirements. Eventually, the older low performance systems will be scrapped or auctioned.

In a company with a more distributed mix of users or a population which is undergoing major changes, a less expensive method might be to approximate the purchases over the user need base more directly. In this case one may spend less to optimally equip his user population. In all cases major jumps, like Windows, Networking, Windows- 95, Windows-NT, the information

systems specialist must gauge what proportion of his systems will be connected and used and in what configurations to keep an integrated seamless, computing environment.

Goal-charting and technology tracking will be helpful for both PC Manufacturer and the information system specialist. Figure 5.3 Low, Medium and High Performance systems Aligned by Constant Price as a Strategy describes the process using Computer Pricing and User Category Allocations versus Time.

Computer Pricing and User Category Allocations vs Time

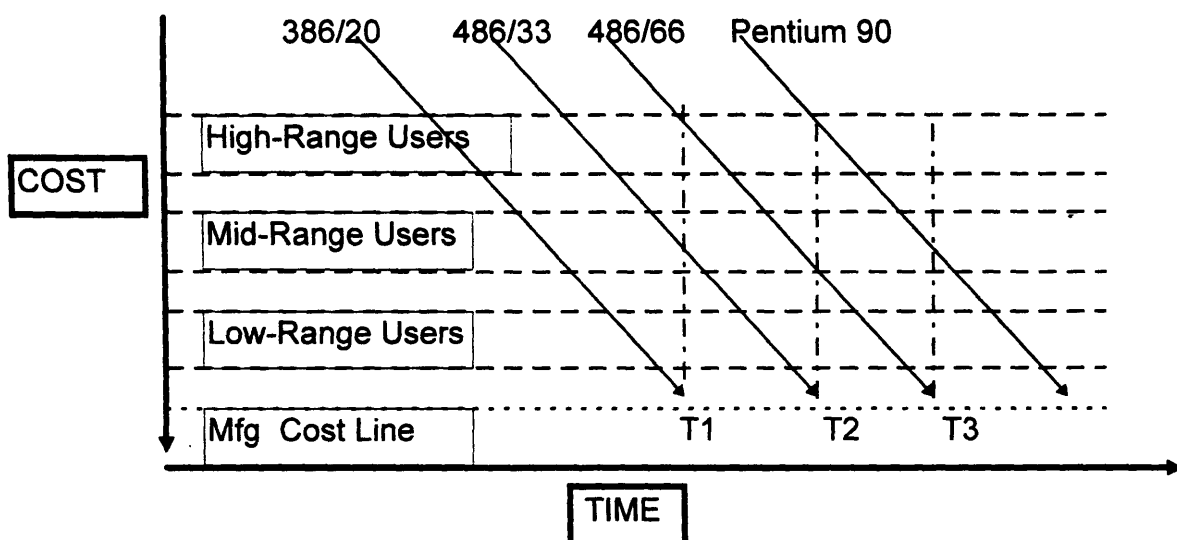


Figure 5.3 Low, Medium and High Performance systems Aligned by Constant Price as a Strategy

At time **T1**, the High-Range User gets a 486/66 with Minimum Extras or a loaded 486/33.

The Mid-Range User gets a 486/33 and the Low-Range User gets a 386/20.

At time **T2**, the High-Range User gets a Pentium 90 with Minimum Extras or a loaded 486/66.

The Mid-Range User gets a 486/66 or a loaded 486/33. The Low-Range User gets a 486/33.

At time **T3**, the High Range User gets a loaded Pentium 90 or the next Upgrade to a

P-133. The Mid-Range User gets a Pentium 90. The Low Range User gets a 486/66.

Market Implications of Goal-Chart Product Positioning:

The product group positioning or product trajectories on a goal-chart may have market implications which the customer can use to help his decision-making. See Figure 5.4.

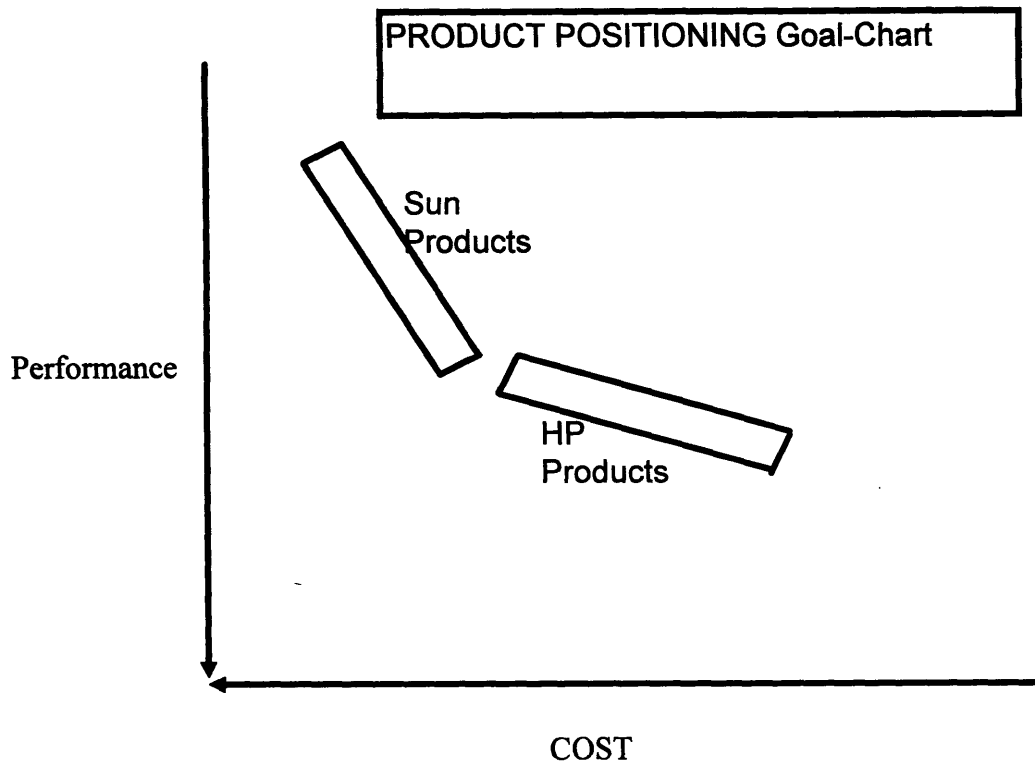


Figure 5.4 Market Implications of Product Positioning Goal-Chart

This figure shows that the Sun Products, Workstations, are positioned to cover the range from Low Cost, Low Performance to Medium Cost, Medium Performance. The HP Products are positioned to cover the range from Medium Cost, Medium Performance to High Cost, High Performance. There is still a Price-Volume Curve to which the market responds. Therefore the Sun strategy will lead to a larger volume of Products being sold.

Figure 5.4 and 5.5 support the application of Goal-Charts is to review the Product Trajectories of different manufacturers to see which of their sets of goals and trends best serve your needs as a

customer. Figure 5.5 shows the performance metrics of two Workstation manufacturers studied in the CAE project described in Chapter 7. Notice that the product trajectory of Manufacturer Sun, covers a wide range of performance and is generally lower in cost than the offerings of Manufacturer HP. The offerings of Manufacturer H are clustered in a small high performance range although various versions offer a significant price difference. Unfortunately for Manufacturer HP, it also appears that the high end performance of Manufacturer Sun will cross the performance line of Manufacturer HP very soon. Then, unless Manufacturer HP offers some quantum change in technology, the product may be at a disadvantage in the marketplace. The placement of the customers' minimum performance line or maximum cost line will have a large bearing on what choices are viable and most attractive. Non-technical factors, such as users experience, training and expertise will also come into play in decisions like these as will be further discussed in Chapter 7.

An interesting item on the chart of Figure 5.5 is the placement of the SPARC 5 110 Workstation by Sun. This Workstation appears to be placed on a possible trajectory which would fall inside the SPARC 20 Workstations and be favorable to the user in Performance vs Price. However, the memory type is different from the other Sun Workstations and the SPARC 5 does not support multiple users as well as the larger Workstations (Chapter 7).

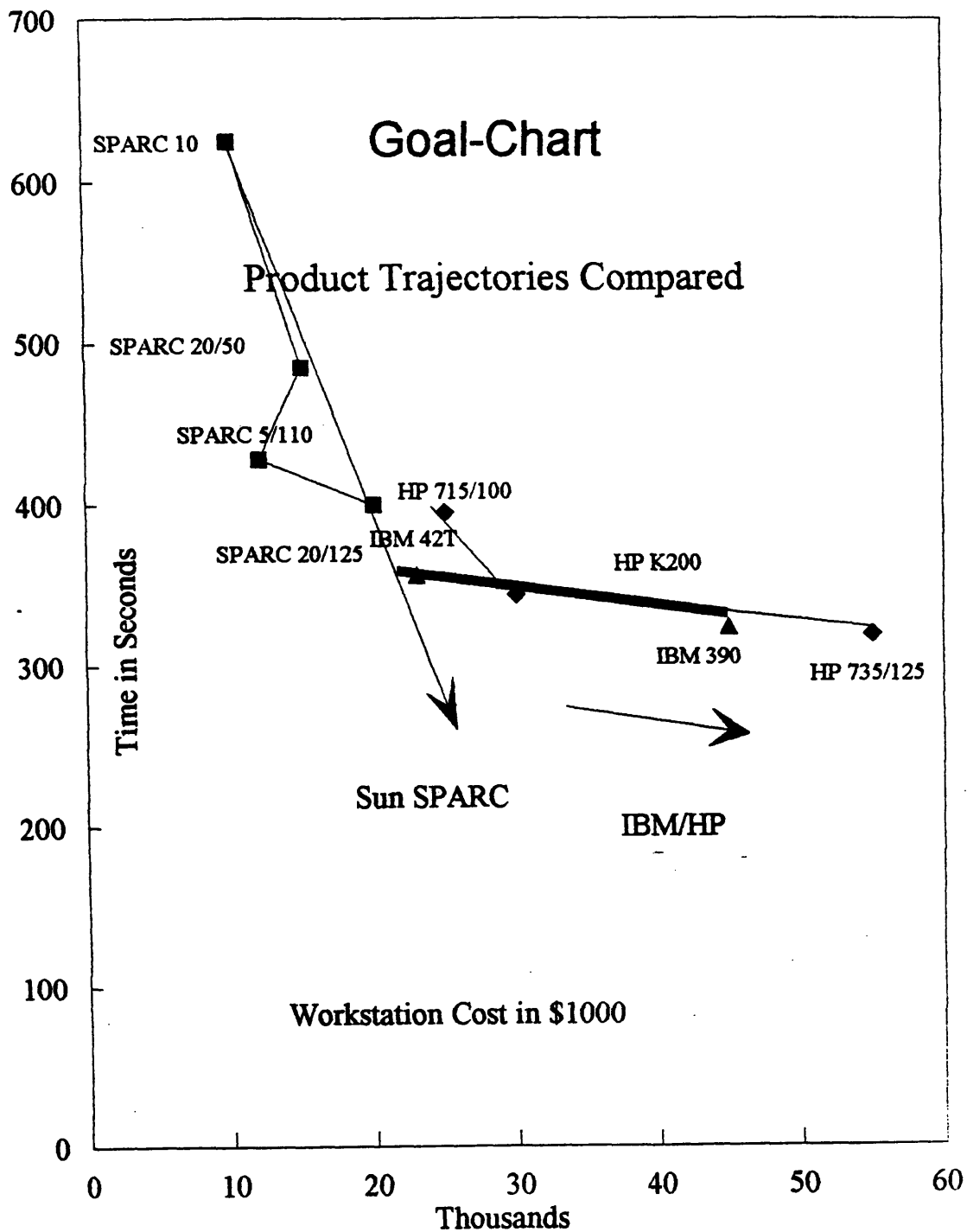


Figure 5.5 Goal Chart Illustrating Product Trajectories with Simulation Results.

If one is making a large purchase of new equipment and the individual Workstation performance is more important than the shared response, the SPARC 5/ 110 would appear to be an exceptional buy. It should be noted that MIT replacing its aging DEC machines and some SPARC 10's chose the SPARC 5/ 110 for many of these replacements.

Summary of Goal-Chart Applications:

After reciting the goal-chart principles, this chapter covered a number of the practical applications of goal-charting to technical, marketing and customer problems. The goal-chart was shown to be an effective flexible tool in this regard.

CHAPTER 6

PROJECT 1. DESIGN OF OPTIMAL CONTROL SYSTEM EXAMPLE

**Chapter 6. Design of Optimal Control for an 11-story Building,
A System Example Illustrating the Goal-Chart**

The Goal-Chart and Technology Lemmas did not suddenly appear full-blown, but are the result of the author wrestling with the problems of understanding, designing, communicating and guiding decision-making on projects where the incorporation of technology was expected to make an improvement in the performance of a system or product. In this chapter 6, the paper "Design of Optimal Control for an 11-story Building" is encapsulated between an introduction to the process of applying technology to a systems management problem and a conclusion detailing a discussion of the interpretation of the final goal-chart. The presentation is made in this way so that the reader can experience some of the "AHA!" which the author experienced as the goal-chart process was evolving. The introduction is of a general nature, while the paper is focused on a particular set of problems and technology.

The particular set of problems and technology are the application of Active Control and Passive Control, see Figure 6.1, to limit a building's motion under the effects of wind and earthquakes. The limits would be such that the inter-story shear strain is below a level which will damage or weaken the building's structure. The building selected for evaluation was a medium height, 11-story building. In buildings above 30 stories, the wind effects are the major factor, while in medium height buildings earthquake effects are the major factor (Ref. 12, Housner).

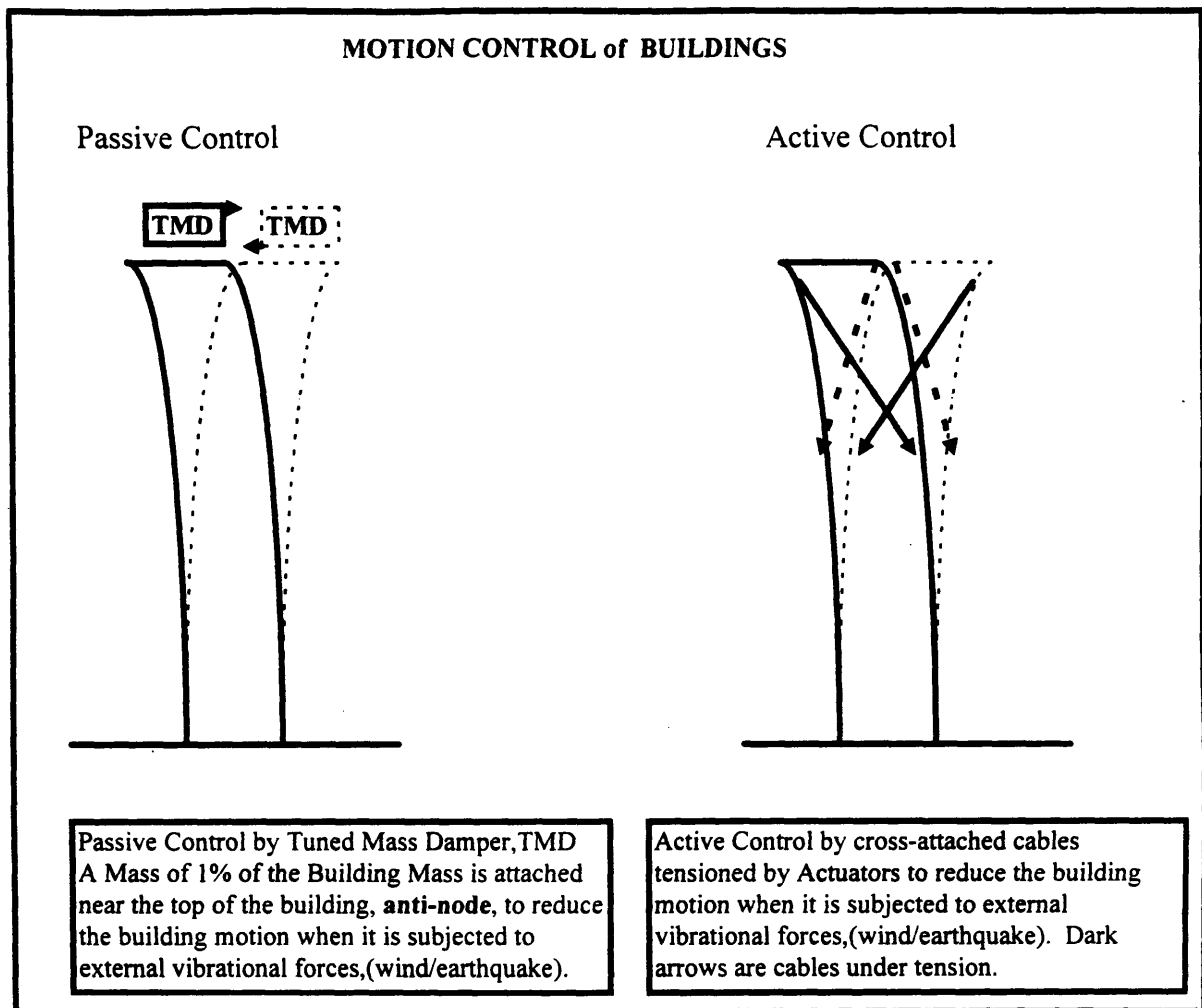


Figure 6.1 Passive, Tuned Mass Damper, TMD, and Active, Cable-Tensioning Actuators; Two Methods for Controlling Building Motion due to external wind and earthquake vibrational forces.

The building was modeled as lumped masses of 70,000 kilograms for each floor. The availability of suitable Active Control algorithms and Actuators was assumed, based on the current and improving state of the art in both these areas. The availability of a variety of Passive

Control methods is also known. These include Tuned Mass Dampers, as well as absorptive joints and couplings. Tuned Mass Dampers are currently used in the John Hancock Building in Downtown Boston and the Citicorp Building in Manhattan, New York to name two applications. Passive absorptive joints (10,000) are used in the World Trade Center Buildings, also in Manhattan, New York. Active control is used in a number of buildings in Japan.

The Control algorithm employed is the so-called Least Cost Method after Riccati. This is one of the methods embedded in MATLAB®, a program for manipulating matrices for analysis and design. This method usually produces results which are stable and realizable.

Next, we will address the general considerations for applying technology to a systems management problem before goal-charts are specifically identified. This is illustrated in the "waterfall" type process in Figure 6.2 entitled "Roadmap for Technology Application to Systems Management Problems". The roadmap includes the six steps of : 1) stating the system management problem; 2) choosing the technology to be applied; 3) modeling the process; 4) describing the findings and projections from the modeling (this became the entrance point for the goal-chart); 5) verifying the performance data in some manner; 6) accepting or rejecting the new technology choice.

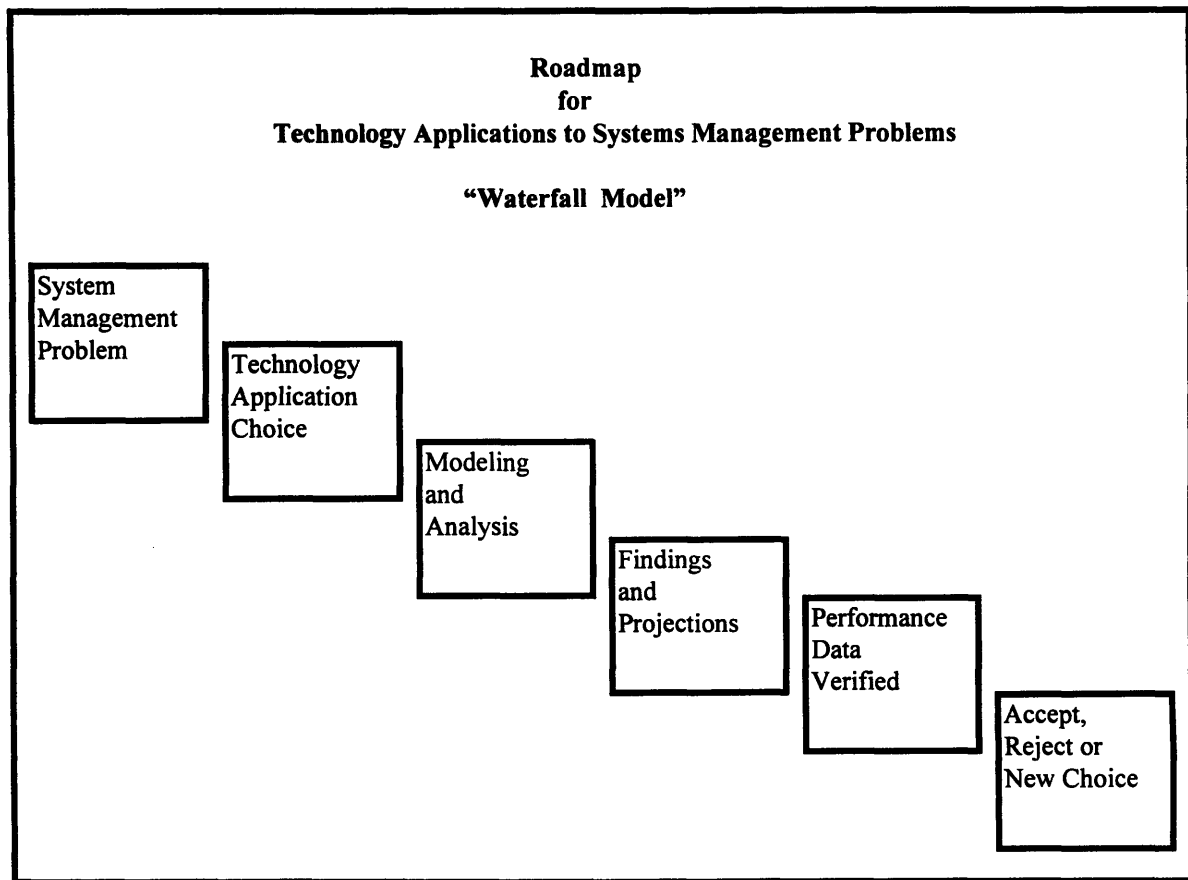


Figure 6.2 Roadmap for Applying Technology to a Systems Management Problem

In the "Design of Optimal Control ..." paper, the systems management problem is to control the building motion during the El Centro earthquake. The control needed to be applied to limit the inter-story strain to a known safe limit. The technologies of passive control with TMD, active control of both the TMD and the building structure in various combinations, were the technologies of choice to be examined. The modeling was done with conventional matrix analysis tools and control algorithms. The findings and projections were to be done in a manner

which would allow comparisons of the various methods and permit a recommendation of the best method or methods. The last two steps, those of performance verification through test and final acceptance of the choice directed to a construction activity were not part of the process in the paper.

Under the Findings and Projections step, the single-dimension performance goal, that of keeping the inter-story strain below 0.004, was extended to include the force feasibility and energy “costs” of obtaining the goal under various scenarios. This led to more extended simulations. Thus, the multi-dimensional aspects of the goal were recognized and addressed.

We now proceed to the encapsulated paper (10 pages), wherein the Appendix A. has been relocated to the end of the chapter 6.

DESIGN OF OPTIMAL CONTROL FOR AN 11-STORY BUILDING

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ABSTRACT

Passive and Active Control is applied, using the tool of numerical simulation under MATLAB®, to an 11-story building with an objective being to limit the maximum interstory shear strain to 0.004 when the building is subjected to the El Centro earthquake. An additional design objective is to minimize the necessary control forces and energy while meeting the design constraints. The two passive methods used are; 1) a quadratic variation of the stiffness floor by floor, and 2) a Tuned Mass Damper (TMD) near the top of the building. Five Active Control combinations are considered; 1) an Active Tuned Mass Damper (ATMD), 2) a single active control near the top of the building, 3) three distributed active controllers near the top of the building, 4) a single active control with TMD, and 5) three distributed controllers with TMD. All of the active combinations used the passive quadratic stiffness variation.

Active Control methods; 3) three distributed controllers, 4) a single control with TMD and 5) three distributed controllers with TMD meet the design constraints. Active Control methods 4) and 5) use less energy and require a smaller maximum force. Two indices selected to provide a measure of the control system are Eindex, and Pindex. Eindex is the integration of the product between control force and displacement throughout the time history. Pindex is the integration of the displacement throughout the time history. A constant in the linear quadratic cost function is given discrete values of 0.1, 0.25, 0.5, 1.0, 1.5 to develop a family of curves to compare the control systems.

The design analysis suggests that the combination of a passive TMD and an Active Controller applied near the top of the building requires less energy and a smaller maximum force and is therefore recommended. The Active Control algorithm is based on an optimal control theory using the Riccati equation.

1. INTRODUCTION

Passive and active controls were applied to an 11-story building based on numerical simulation in MATLAB®. The control methodology includes the following two passive approaches:

- 1) variation of the stiffness of the building, floor by floor, to minimize undesired response,
- 2) a Tuned Mass Damper (TMD) near the top of the building to minimize the first mode vibration.

The active control methodology includes five (5) approaches:

- 1) Active TMD (ATMD),
- 2) a Single active control near the top of the building,
- 3) Three (3) distributed active controllers near the top of the building,
- 4) a Single active controller with TMD,
- 5) Three (3) distributed controllers with TMD.

The active control algorithm used is based on the Riccati equation.

The desired response is a constant shear strain of 0.004 throughout the height of the building when the building is subjected to the ground excitation of the El Centro earthquake.

A listing is available with the project.m file for MATLAB® with comments which will allow simple modification by an informed user.

2. PASSIVE CONTROL METHODOLOGY

2.1 Stiffness variation The desired curve on a graph showing inter-story strain by floor is a vertical line at 0.004. Figure 1 shows the maximum strain curve of the uncontrolled building response when subjected to the El Centro earthquake. Figure 1 also shows the maximum strain curve when the building is controlled by a single active controller at the top. The controlled curve is on the left, while the uncontrolled curve is on the right. The building in Figure 1 has a stiffness decreasing quadratically from the bottom to the top. The choice of the stiffness variation can be shown to minimize shear strain variation of the building, Connor et al. (1993).

Figure 2 shows the uncontrolled and controlled response curves of the building when the stiffness is constant throughout the building.

The curves in Figure 2 show a large variation in maximum shear strain from the top to the bottom of the building. This is undesirable because of the potential uneven damage to the building structure. Therefore the comparison of the response curves in Figure 1 and 2 shows that the quadratic stiffness variation is a better alternative.

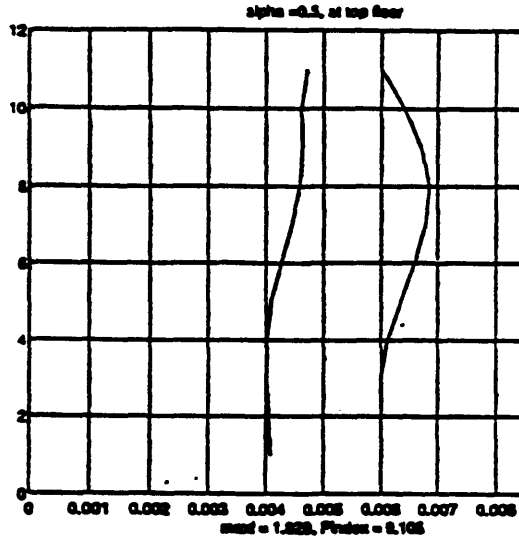


Figure 1. Controlled and Uncontrolled Response to El Centro

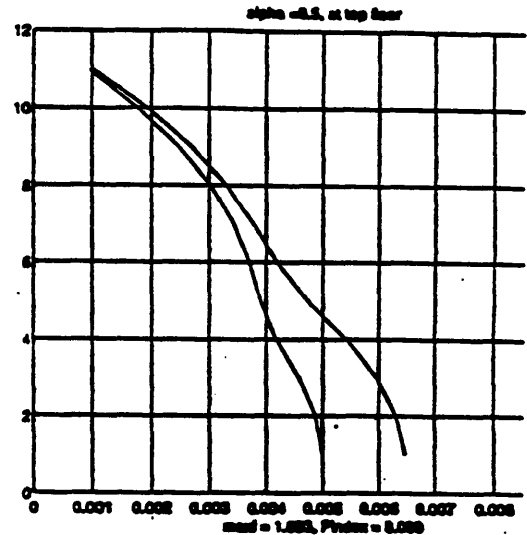


Figure 2. Response with Constant Stiffness

2.2 Tuned Mass Damper -TMD

Figure 3 shows the typical first 3 vibration modes of the building. It can be shown, Housner et al. (1990), that the first mode is usually the dominant mode under the earthquake excitation. The most effective way to reduce vibration is to apply the out-of-phase force at the antinode. In the building case, the antinode is at the top of the building. Therefore we will apply the control force at that location. The dominant mode has an associated period, or frequency. The control force will be chosen or 'tuned' such that its frequency matches the dominant frequency of the building and is out-of-phase. This is the basis of the TMD. Connor et al. (1993), also shows how the stiffness, damping, and mass of the TMD can be chosen to most effectively damp the dominant mode of the building vibration.

Figure 4 shows a TMD installation from the Citicorp Center, New York City, H.H.E. Liepholtz et al. (1986). The mass of the TMD is the order of 1-2 % of the mass of the total building (op. cit.). In the simulation, the building has 11 stories and is modeled as a 11-lump-mass structure weighted 70,000 kg each. Therefore the mass of the TMD is selected to be 7,700 kg. The dominant frequency of the building is 0.2835 Hz, or 1.7813 rad/sec. Using $k = \omega^2 m$ gives the stiffness of the TMD to be 24,432 N/m. The damping ratio of the TMD is chosen to be 2 %.

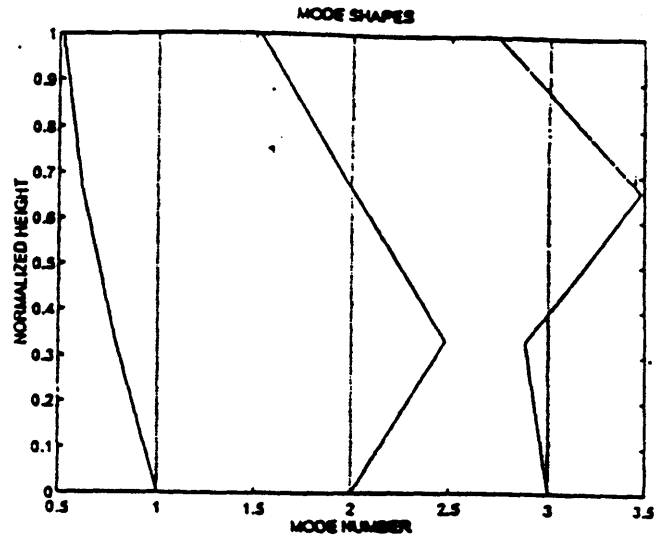


Figure 3. Vibration modes of the building

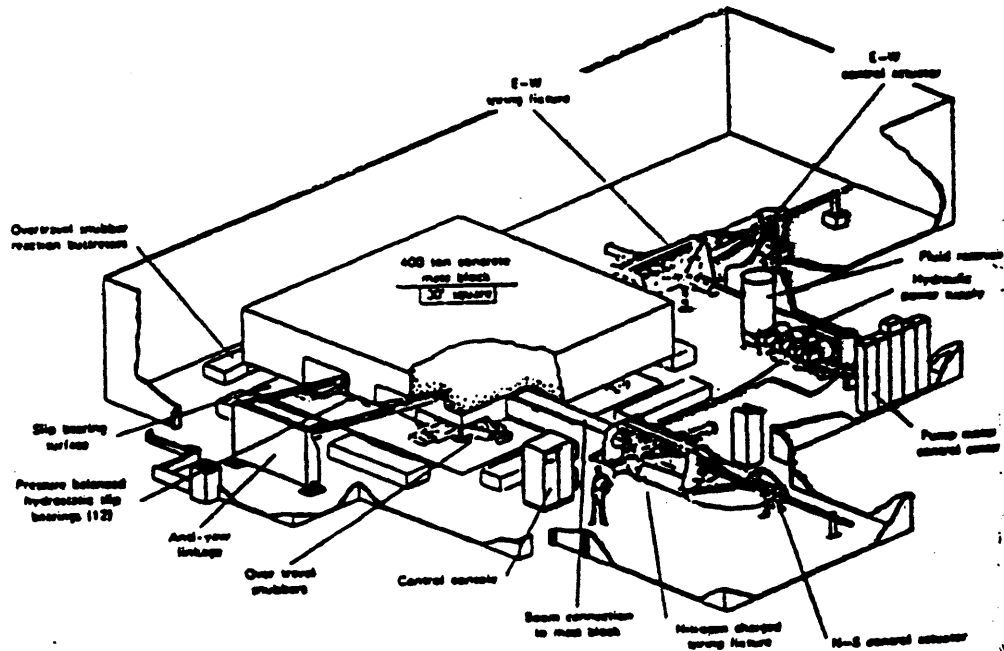


Figure 4. TMD Installation at Citicorp Center, NYC ,H.H. Liepholz (1986)

Figure 5 shows the response of the building with the TMD. The use of the TMD reduces the maximum strain from approximately 0.0065 in Figure 1 to 0.0045 in Figure 5.

The TMD and the quadratic stiffness variation have effectively reduced the maximum strain and make it close to the desired constraint, but the constraint of 0.0004 has still not been met. The next step is to apply active control in order to achieve the desired response.

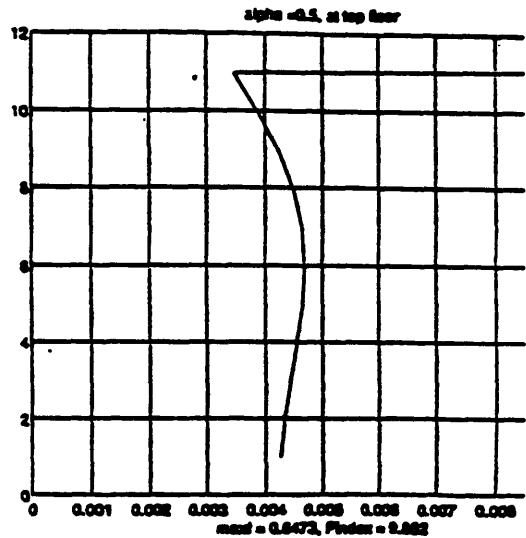


Figure 5. Building Response with TMD

3. ACTIVE CONTROL

3.1 Active Tuned Mass Damper (ATMD) The control force was applied directly to the TMD. Figure 6 shows the response of the TMD with and without the active control force. The excursion of the TMD is reduced by the application of the control force.

The important thing is that the effect of the active control applied to the TMD is no different than the TMD acting passively alone in terms of the building response under the El Centro earthquake. This is shown in Figure 7 where the lines of the controlled and uncontrolled response using a passive and active TMD are identical. No further consideration was given to the ATMD for the purposes of this paper.

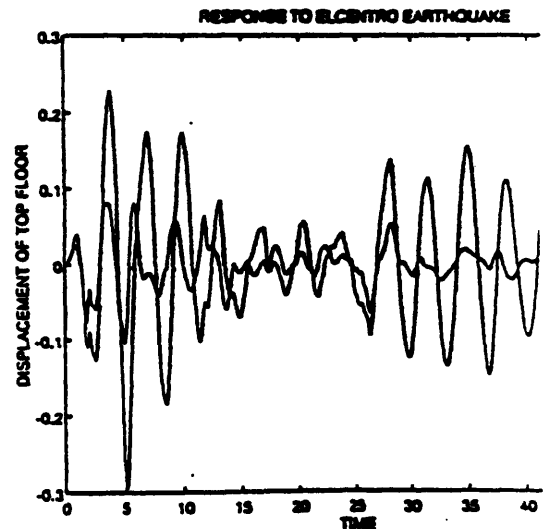


Figure 6. TMD response with and without Active Control (ATMD).

3.2 Single Controller Near the Top

The building response with a single controller applied to the top is shown in Figure 8. The controlled response does not meet the desired response, but does come close. In all examples the quadratic stiffness variation is employed.

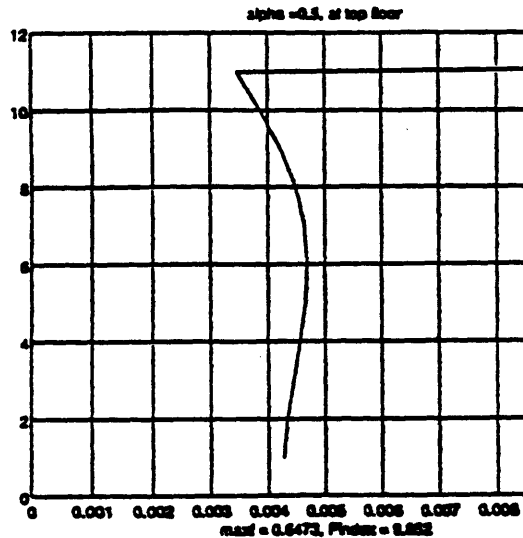


Figure 7. Building Response with TMD or ATMD.

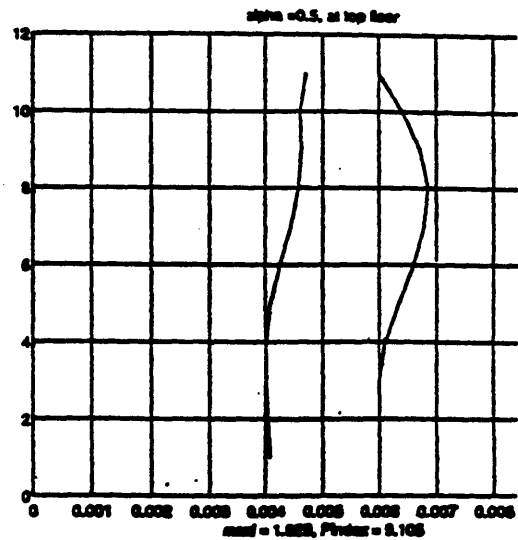


Figure 8. Building Response with Single Controller, no TMD.

3.3 Three Distributed Controllers Near the Top (Floors 11,10,9)

The building response using three controllers near the top is shown in Figure 9. This control design satisfies the .004 constraint. The single controller only came close.

The next steps are to use active control with the passive TMD to see if energy or force to control the building can be reduced and whether a more optimum response can be achieved using the TMD in conjunction with the two active control scenarios.

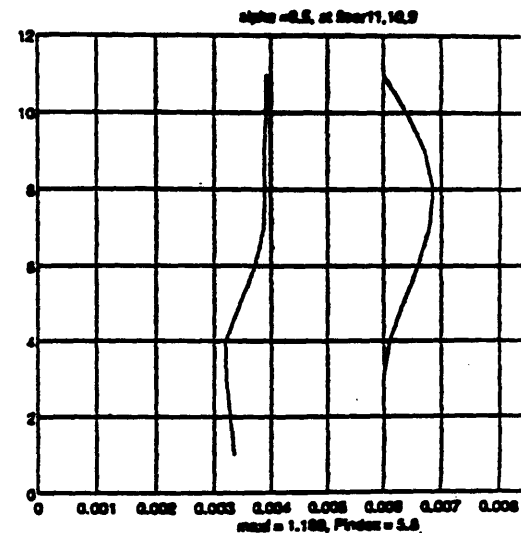


Figure 9. Building Response with Three Controllers, no TMD.

3.4 Single Controller Near the Top with TMD

The single controller was placed at the top of the eleven story building with the TMD on top of the building. This configuration gave the response shown in Figure 10. The response is within the constraint.

3.5 Three Controllers Near the Top with TMD

The three controllers were placed near the top of the building with the TMD on the top of the building. The response is shown in Figure 11. It can be noted that the response is within the constraints. Also there is sufficient margin to the constraint that one can look to save energy or reduce the maximum controlling force by changing the factor "Alpha" in the active control algorithm. This brings us to the heart of this paper.

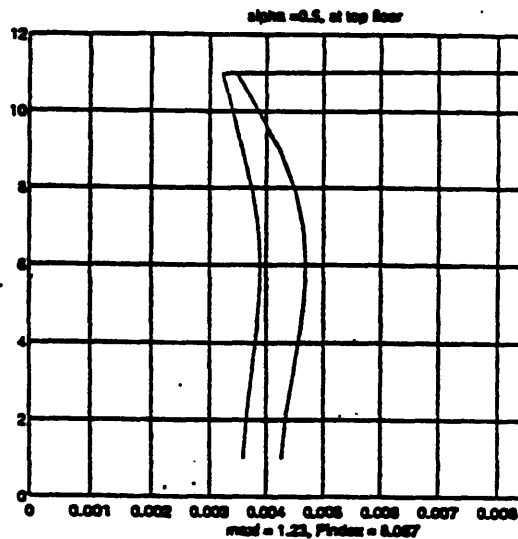


Figure 10. Building Response with Single Controller and TMD.

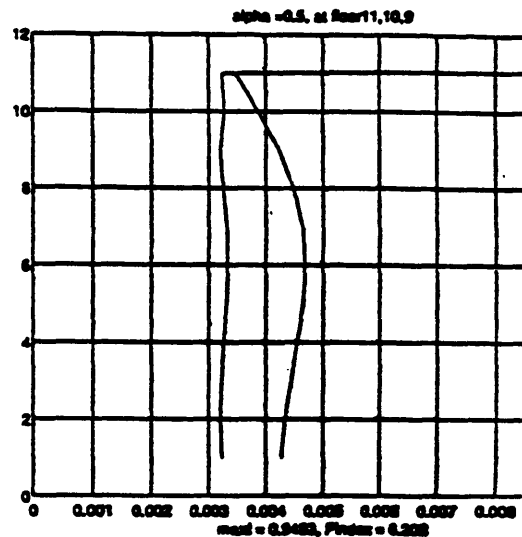


Figure 11. Building Response with Three Controllers and TMD.

4. OPTIMAL CONTROL CONFIGURATIONS

Data was taken with varying Alpha under the four conditions of Single controller near the top with and without TMD, and Three Controllers near the top controlling with and without the TMD. The quadratic stiffness variation was used in all cases. The results of these data appear in Figures 12,13,14,15.

4.1 Energy vs Alpha -Figure 12

The data in Figure 12 show that energy applied in the active control decreases as Alpha is increased in the control algorithm. The squares show the places on the four control configuration lines where the constraint of .004 is just met. In other words, if a larger Alpha is selected, the constraint in general will not be met. On this basis it is seen that the single control with the TMD meets the constraint for Alpha = 0.5. The three controllers with TMD meet the constraint for any Alpha less than 1.5. We note that the Eindex at which the constraint is just met is approximately the same for the two cases.

The Single controller without the TMD comes close but does not meet the constraint at Alpha = 0.25. The Three controllers operating without the TMD meet the constraint at Alpha = 0.5. However the Energy index is approximately 33 as opposed to approximately 11 when the TMD is included. Therefore, the use of the TMD affords a clear energy savings. It therefore may make possible, control parameters which are not feasible without the TMD.

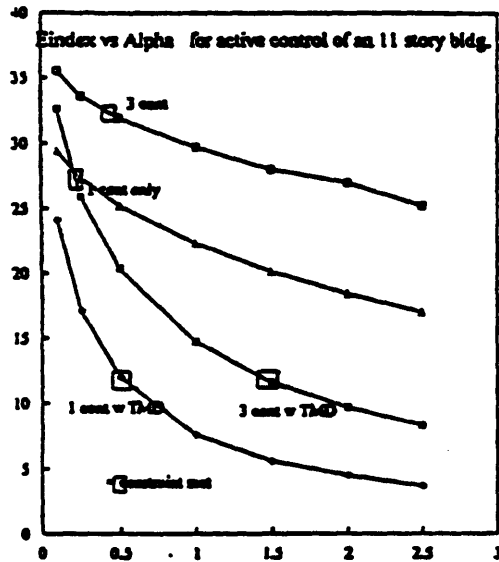


Figure 12. Eindex vs Alpha

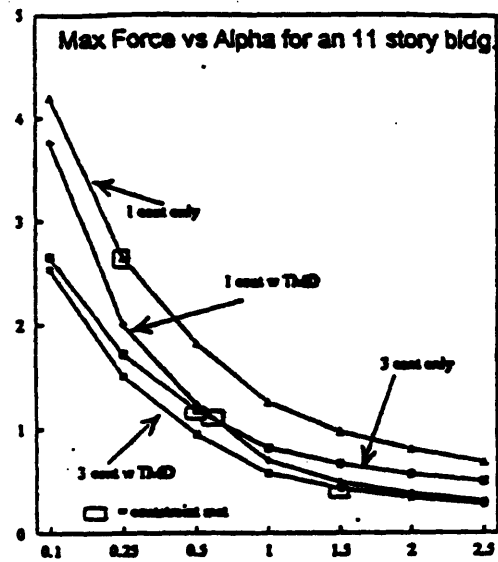


Figure 13. Maximum Force vs Alpha

4.2 Maximum Force vs Alpha- Figure 12

The maximum force needed to control the building response is shown to decrease as Alpha increases. In both the case of the Single controller and the Three controllers the use of the TMD reduces the maximum force required to control the building response.

The Three controllers with the TMD require the the lowest force, followed by the Single controller with the TMD. Very close to the Single controller with the TMD is the Three controllers with no TMD. The single control control with no TMD requires a large force to come close to the constraint.

4.3 Pindex vs Alpha - Figure 14

Pindex is a measure of the control effectiveness in terms of deviation from the desired position. Therefore smaller values of Pindex are better than large values generally. Both the Single controller with TMD and the Three controllers with TMD are at approximately the same Pindex. The Three controllers without the TMD achieve

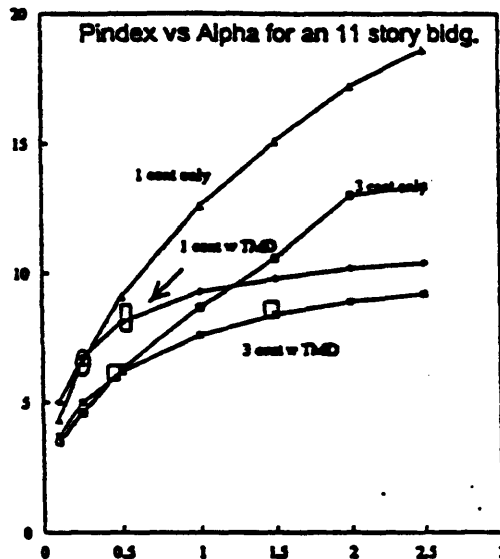


Figure 14. Control Deviation Pindex vs Alpha

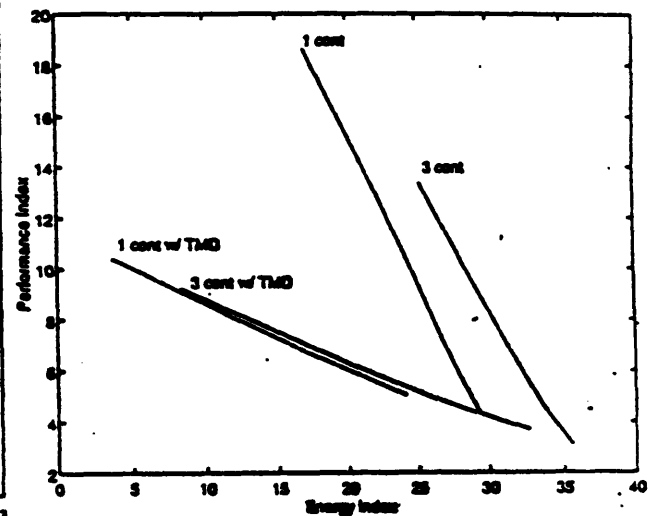


Figure 15. Control Deviation vs Control Energy Pindex vs Eindex

a lower Pindex, as does the Single controller without the TMD. This can probably be attributed to the delayed response caused by the TMD and the lower energy and forces which are being used in the control arrangements which include the TMD.

4.4 Pindex vs Eindex -Figure 15

The measure Pindex vs Eindex indicates the relation of control effectiveness to energy expended. The two lower curves indicate that the Single and Three controller systems using the TMD's are much more efficient than the controllers without the TMD.

5. SUMMARY

The interstory shear strain response of an eleven story building subject to the El Centro earthquake excitation, has been examined. Active motion control to limit the interstory shear strain was applied in accordance with the Riccati equation implemented through numerical simulation on MATLAB®. The best results were obtained by combining the TMD and quadratic stiffness variation, passive approaches, with active control based on the Riccati equation, applied at multiple points near the top of the building. The use of an active TMD, ATMD, for this application did not improve the building response results over the passive TMD in this simulation.

6. ACKNOWLEDGEMENTS

Professor Jerome J. Connor encouraged the submittal of this paper to the conference. Also, Professor Jerome J. Connor Jr., Instructor John Thomas, and Mr. Boutros Abboud Klink furnished an information base through MIT Course # 1.964, Large Scale Systems which allowed us to make the connection between the TMD and Riccati equation control.

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2. Connor, Jerome J. and Klink, Boutros S. Abboud (1993), "Motion Based Design Methodology for Buildings," Technical Report R93-18, Oct. 1993 Intelligent Engineering Systems Laboratory, Dept. of Civil and Environmental Engineering, Massachusetts Institute of Technology
3. Housner, George W. et al. (1990), *Selected Earthquake Engineering Papers of George W. Housner*, American Society of Civil Engineering, NYC
4. Liepholz, H.H.E. and Abdel-Rohman, M. (1986), *Control of Structures*, Martinus Nijhoff (Kluwer Academics)

DEVELOPING THE GOAL-CHART

Figures 12, 13, 14 and 15 from the paper were the germ of the goal-chart idea. These figures were obtained by varying a coefficient parameter, "Alpha", in the simulation model, to determine the slope or trends of the functions with respect to each other.

The first curve, Figure 12, plots the energy index, E_{index} , versus "Alpha". The point along the curve that meets the constraint is determined by repeated simulations noting the inter-story shear strain as a result of the simulation. The point along each of the curves, that meets the constraint (inter-story shear strain ≤ 0.004), is indicated by a square box around the point. As noted in the paper, and as can be seen in Figure 12, the constraint is met at a lower energy index when the Tuned Mass Damper (TMD) is employed, than when the Active Controls are used without the TMD. The difference is between about 11 with the TMD and 27-33 for the Active Controllers without the TMD.

Figure 13 shows the Maximum force required versus "Alpha". This series of simulation curves was drawn to determine if the maximum force required was even in the capabilities of the some reasonable number of Active Controllers. The data suggest that some reasonable number of the advanced Active Controllers could supply the maximum forces required. However, the maximum force required is less if the Active Controllers are used with a TMD.

Still looking at Figure 13, the maximum force necessary to meet the constraint for the three controllers with the TMD is about 0.5 on the vertical scale. The maximum force for one Active Controller with the TMD and for three Active Controllers without the TMD is about 1.0 on the vertical scale. The energy required for the three controllers is more as indicated in Figure 12, since there must be force applied to all three controllers. Finally, the maximum force that must be applied to one Active Controller working without the TMD is about 2.8 on the vertical scale, as indicated in Figure 13. This discussion provides a sanity check to be sure that the results shown in the curves hang together in a consistent manner.

Figure 14 shows the Control Deviation versus "Alpha". The theoretical best point would be at the zero point on the vertical scale. This would correspond to the building not flexing when subjected to the earthquake forces. That phenomenon would, of course, require an infinitely stiff structure or perfect control forces, neither of which is available.

The curves in Figure 14 show that the single Active Controller and the three Active Controllers operating without the TMD can produce a smaller Control Deviation than the Active Controllers operating with the TMD if the "Alpha" parameter is allowed to become very small, about 0.25. Thus, in the limit, the Active Controllers operating alone can do a better control job if that is the only parameter.

However, referring back to Figures 12. and 13, it is seen that small values of the "Alpha" parameter lead to higher energy costs and require that larger maximum forces be generated by the controllers to effect such control. Thus, both energy and force is minimized for larger values of the factor "Alpha", in the range of 0.5 to 1.5, with 1.5 requiring lower maximum forces and less energy. Another fact on Figure 14 that should be noted is that the inter-story shear strain constraint, shown by the boxes, is not met when the Control Deviation, Pindex, is above about 9. This sets an upper limit for the satisfactory operation of any combination of the control systems that meet the inter-story strain goal.

The next step is the Goal-Chart of Figure 15, where the Control Deviation, Pindex is plotted versus the Energy index, Eindex. Once these matrix simulation results are placed on the chart in Figure 15, the efficiency of the Active Controllers working with the TMD is clearly evident. The transformation of Figure 15 from the paper to Figure 6.3 (and Figure 5.1, shown back in Chapter 5), only requires adding the maximum upper limit line that Pindex be 9 or less for the basic constraints for the building motion to be satisfied.

As a sanity check it is useful to explore what is happening at the limits in Figure 15 or Figure 6.3, where the Active Controllers without the TMDs are seen to be finally becoming more efficient than the Active Controllers with the TMDs at small values of Pindex.

GOAL-CHART for ACTIVE CONTROL

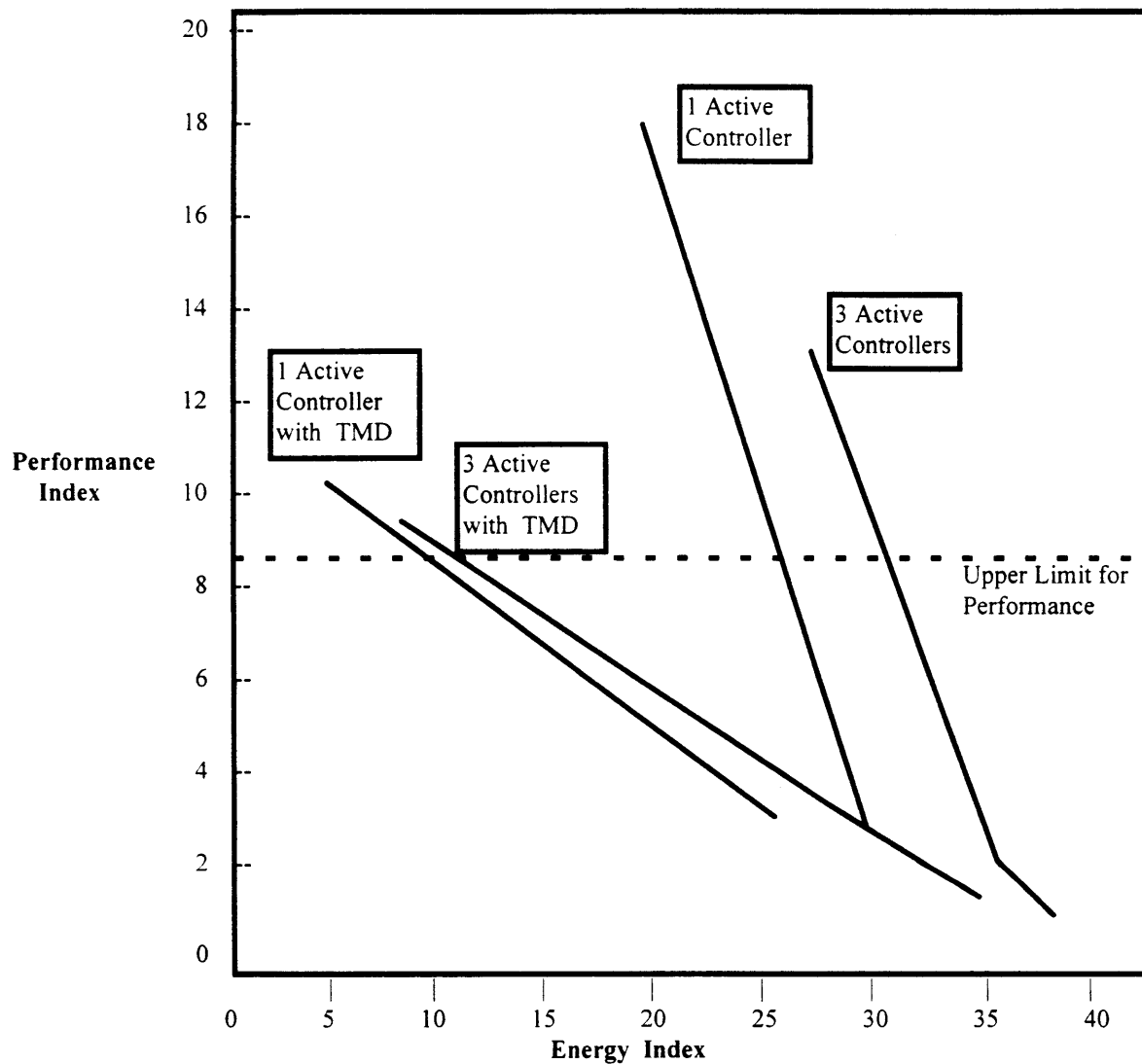


Figure 6.3 Goal-Chart Comparing different options of Active Control

From "Design of Optimal Control for an 11-story Building by P. Emile and C. Peetathawatchai".

Axes are Control Performance Deviation, Pindex (Y) Vs Energy, Eindex or Cost (X)

The TMDs are effective by providing anti-resonant forces in opposition to the induced building motion. At the point, where the Control Deviation, Pindex is very small, the resonances of the Tuned Mass Dampers become part of the problem rather than part of the solution. The Active Controllers are then working against the induced motion of the TMD as well as against the induced motion of the building.

Therefore, the placement of the Pindex limit on the goal-chart becomes a deciding factor in what means can be used to effect the building control and meet the limits. Further, if the energy (or cost) available limit is placed on the chart, that may also determine what means can be used to effect the building motion control within the constraints. The previous figures, Figures 12,13,14 provide feasibility answers for energy, force, and control deviation that can be incorporated in the Goal-Chart, Figure 15 or Figure 6.3.

If the Goal-Chart concept is considered at the beginning of a project, then determining the necessary limits, feasibility and defining experiments can be orchestrated such that the proper intermediate and final data will be available to make an easily understood, effective presentation goal-chart for decision-making guidance.

Summary of System Design Example:

The Goal-Chart concept, developed in this chapter will be shown to have application in other diverse areas where technology is to be applied. The application to the design of an electronic system for CAE simulation is shown in Chapter 7.

A Technology Lemma question was also indirectly addressed in this chapter and answered in the negative. That question was, “Given the availability of powerful electrical, and fast-acting, mechanical actuators, should they be used exclusively to control the motion of the building.”

The answer given by the goal-chart in Figure 6.3, is that they should be used to supplement, but not supplant other passive means such as TMDs, unless the finest precision of control is required, and there is a large supply of energy available for the controls.

Appendix A from “Design of Optimal...”

% PROJECT.M LISTING

% DISTRIBUTED ACTIVE CONTROL w/ TMD

% STEP 1: SPECIFY EXCITATION :

% ~~~~~

nstories = 12;

ndof=12;

bldg_height=42;

story_height = bldg_height/nstories;

damp_ratio = 0.02000 ;

% STEP 2: SPECIFY THE EXCITATION (m/s/s) :

% ~~~~~

z0_elcen

E=ones(nstories,1);

% STEP 3: FORM THE MASS MATRIX :

% ~~~~~

M=diag(70000*ones(12,1),0:12);

M(1,1) = 7700; % mass of TMD

% STEP 4: FORM THE STIFFNESS MATRIX :

% ~~~~~

%k1 = 9e7;k2 = 9e7;k3 = 9e7;k4 = 9e7;k5 = 9e7;

%k6 = 9e7;k7 = 9e7;k8 = 9e7;k9 = 9e7;k10 = 9e7;k11 = 9e7; % average stiffness

k1=24432;k2=3.0506e7;k3=5.1254e7;k4=6.6134e7;k5=7.7851e7;k6=8.792e7;
k7=9.7177e7;k8=1.0610e8;k9=1.1469e8;k10=1.2240e8;k11=1.2829e8;k12=1.3149e8;

K = diag(zeros(12,1),0:12);

k1 = 24432; % stiffness of TMD

K(1,1) = k1;

K(2,1) = -k1;K(1,2) = -k1;

K(2,2) = k1+k2;

K(3,3) = k2+k3;

K(4,4) = k3+k4;

K(5,5) = k4+k5;

K(6,6) = k5+k6;

K(7,7) = k6+k7;

K(8,8) = k7+k8;

K(9,9) = k8+k9;

K(10,10) = k9+k10;

K(11,11) = k10+k11;

K(12,12) = k11+k12;

K(3,2) = -k2;K(2,3) = -k2;

K(4,3) = -k3;K(3,4) = -k3;

K(5,4) = -k4;K(4,5) = -k4;

K(6,5) = -k5;K(5,6) = -k5;

K(7,6) = -k6;K(6,7) = -k6;

K(8,7) = -k7;K(7,8) = -k7;

K(9,8) = -k8;K(8,9) = -k8;

K(10,9) = -k9;K(9,10) = -k9;

```

ylabel('DISPLACEMENT OF TOP FLOOR')
title('RESPONSE TO ELCENTRO EARTHQUAKE')
hold

% STEP 25: OPTIMAL CONTROL (RICATTI EQUATION) - SPECIFY CONTROL LOCATIONS :
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

n1 = 11;
n2 = 10;
n3 = 9;

%Bric=[zeros(ndof,ndof);eye(ndof)]; % Controls at all floors

Bric=[zeros(ndof,3);zeros(ndof,3)]; %control at 3 floors
Bric(2*ndof+1-n1,1)=1;
Bric(2*ndof+1-n2,2)=1;
Bric(2*ndof+1-n3,3)=1;

%Bric=[zeros(ndof,1);zeros(ndof,1)]; %control at 1 floor
%Bric(ndof+1,1)=1; % control at top floor

% STEP 26: SPECIFY FUNCTIONAL PARAMETERS :
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

alpha=input('Enter value of alpha'); % Scaling Factor
Q=eye(2*ndof);
R=alpha*eye(3,3);

%R=zeros(ndof,ndof); % control force no floor
%R(ndof+1-n1,ndof+1-n1) = alpha; % control force on n1 th floor
%R(ndof+1-n2,ndof+1-n2) = alpha; % control force on n2 th floor
%R(ndof+1-n3,ndof+1-n3) = alpha; % control force on n3 th floor

%R=alpha*[1]; % only one control force

% STEP 27: DETERMINATION OF GAINS :
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
[Kgainr,Sgainr,Egainr]=lqr(Au,Bric,Q,R);

% STEP 28: CALCULATE NEW SYSTEM MATRIX :
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Acr=Au-Bric*Kgainr;

% STEP 29: DETERMINE THE CONTROLLE RESPONSE TO ELCENTRO EARTHQUAKE :
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
[Ycr,Xcr]=lsim(Acr,Bu,Cu,Du,ACC,Tacc);

% STEP 30: PLOTTING DISPLACEMENT OF TOP FLOOR VS. TIME :
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
plot(Tacc,Xcr(:,1),'w')
xlabel('TIME')
ylabel('DISPLACEMENT OF TOP FLOOR')
title('RESPONSE TO ELCENTRO EARTHQUAKE')

```



```

hold

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

maxf=max(max(abs(Kgainr*Xcr)))

Pindex=0;
X = Xcr;

for q = 1:2500
    pindex = Xcr(q,:)*Q*X(:,q)*0.02;
    Pindex = Pindex + pindex;
end

Pindex

Eindex=0;
Ucr = Xcr*Kgainr; % control force
X = Xcr;
N = ones(3,24); % no. of controller = 3

for q = 1:2500
    eindex = Ucr(q,:)*N*X(:,q)*0.02;
    Eindex = Eindex + eindex;
end

Eindex

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
bout = input('input any number to continue');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

xx = 0.004*ones(1,12);
yy = 1:12;
plot(xx,yy)
axis([0 0.01 0 12])
grid
hold
plot(max(abs(Yu)/38.5*12),12:-1:1,'-')
plot(max(abs(Ycr)/38.5*12),12:-1:1,'.')
title(['alpha = ',num2str(alpha),', ', 'at floor',num2str(n1),', ',num2str(n2),', ',num2str(n3)])
xlabel(['maxf = ',num2str(maxf),', ', 'Pindex = ',num2str(Pindex)])
hold

```

CHAPTER 7

PROJECT 2. DESIGN OF CAE ANALYSIS SYSTEM EXAMPLE

Chapter 7. Project 2, Computer Aided Engineering System Example

The Computer Aided Engineering Analysis System project was performed by the author over a nine month period between February and October 1995. As with many projects, there were multiple objectives and constraints to be satisfied. The prime objective was to provide a CAE system which had the capability to carry out simulations of the specialized electronic circuitry being designed, in a real-time fashion, so that the results could be used interactively, in the design process for the circuits. To illustrate the magnitude of the simulation problem, consider one of the simpler circuits, a sixteen by sixteen multiplier with signed inputs (plus or minus), thirty two outputs and four mode (0,1) input lines. Completely evaluating such a circuit requires 68.7 billion events. (See Illustrative Example later in chapter.) A Sun SPARC 2 Workstation achieves an evaluation rate of about 6000 events/second. This leads to 132 days for a complete simulation. A faster Workstation such as an HP735 at 30,000 events/second will still require about 26 days to fully evaluate the circuit. The initial system consisted of Sun Workstations like SPARC 2's with a few SPARC 10's. Thus a serious improvement in hardware capability was necessary.

A second objective was to solve the problem of insufficient numbers of workstations to support the engineering force requiring access to simulation capabilities. More engineers were needed

than workstations available. A way was needed to increase the number of workstations as well as allow access capability to the existing workstations to use advanced simulation capabilities.

A third objective of the project was to identify design blocks that could be reusable in other design situations, thereby reducing the need to process a complete simulation in every instance. As part of this approach, it would be necessary to train the electrical engineering staff in the use of a high level, hierarchical design methodology to achieve the proper results from the expensive software applications needed to implement this objective.

A monetary constraint on the cost of the new hardware existed, in that the maximum budget for the hardware had been previously set. Time was also a critical factor in completing and implementing the project since a number of design activities had been scheduled and costed based on the availability of an enhanced system and the resultant increase in engineering design efficiency. If the new hardware were not available in time, customer-driven design goals would be missed.

Technology Change:

As the standard companion problem in applying new technology in the rapidly changing CAE field, new Workstation hardware offerings were appearing in market in about six month cycles.

Each cycle offering promised increased performance and/or reduced cost. Sometimes the increased workstation performance came at the expense of incompatibility with previous software designs and would require expensive conversions of older design files, data and calculations to newer platforms.

As a further complication some design software will not run on all candidate workstations or is supplied at a later date on some platforms as the software vendors try to maximize their profit potential on the target workstation. For example, since there are more Sun (Unix) Workstations installed than HP or IBM, the software vendors first develop the applications for Sun. Typically, the HP and IBM or DEC versions are developed later, if at all. Sometimes special arrangements are made to limit the software access to one platform to provide a vendor advantage to a special group. As two examples, LSI design support is only available on the Sun workstations; the Cadence company has not seen enough justification to warrant developing the Verilog@ code for the DEC platforms.

The particular Operating systems and display menus and formats, sometimes called Graphical User Interfaces (GUIs), are different for each of the major vendors. The differences are enough that user re-training and re-acclimation is necessary, see Table 7.2 User feedback, later in this

chapter. Thus sensitivity to the user must be an important part of the non-technical (not directly machine performance) aspect of the evaluation.

The binaries or base code for a software package are also different for each vendors' system.

Therefore multiple sets of binaries and extra disk space is necessary if a system is to combine the workstation products from two or more vendors on the same network, even if they are running the same design software.

Caveat Emptor!!

The test and evaluation process must address the specific design problems to which the company expects to apply the equipment. This is important, since each of the proposed vendors will present evaluation data which will show their equipment to be a superior value to other vendors' equipment in some set of benchmark tests. These tests may, or may not be relevant to the specific design application needing resolution.

System Development

The development of the CAE Analysis System, has many parallels to very large projects. Specifically, there are at least six steps. See the Top-Level CAE System Design Methodology Roadmap shown in Figure 7.1. In the first step, a need or problem must be articulated. In the second step, a method for solving the problem using available or projected technology must be stated and modeled. The results of this modeling are presented in an interim Goal-Chart. The Interim Goal-Chart, in words, pictures or both is useful in the third step, convincing the funding sources to provide funding in the form of Capital and Expense appropriations. Also, in this third step, the funding sources must be assured that the Return on Investment will be met. This forces statements relying on existing technologies, or at least evolving near-term technologies to reduce risk. The waiting and justification process between the third and fourth step can take months as in the case of the project described, and many years in the case of a project like the Central Artery in Boston. Meanwhile, technology advances, changes and a new placement of the system on the Goal-Chart occurs. In the fourth step, assuming funding has been obtained, some pilot testing must be done before the final system implementation is undertaken. The fifth step is to plot the results on a Goal-Chart for making trade-offs. The sixth step is to include the effects of non-technical factors on a subsequent Goal-Chart for decision-making.

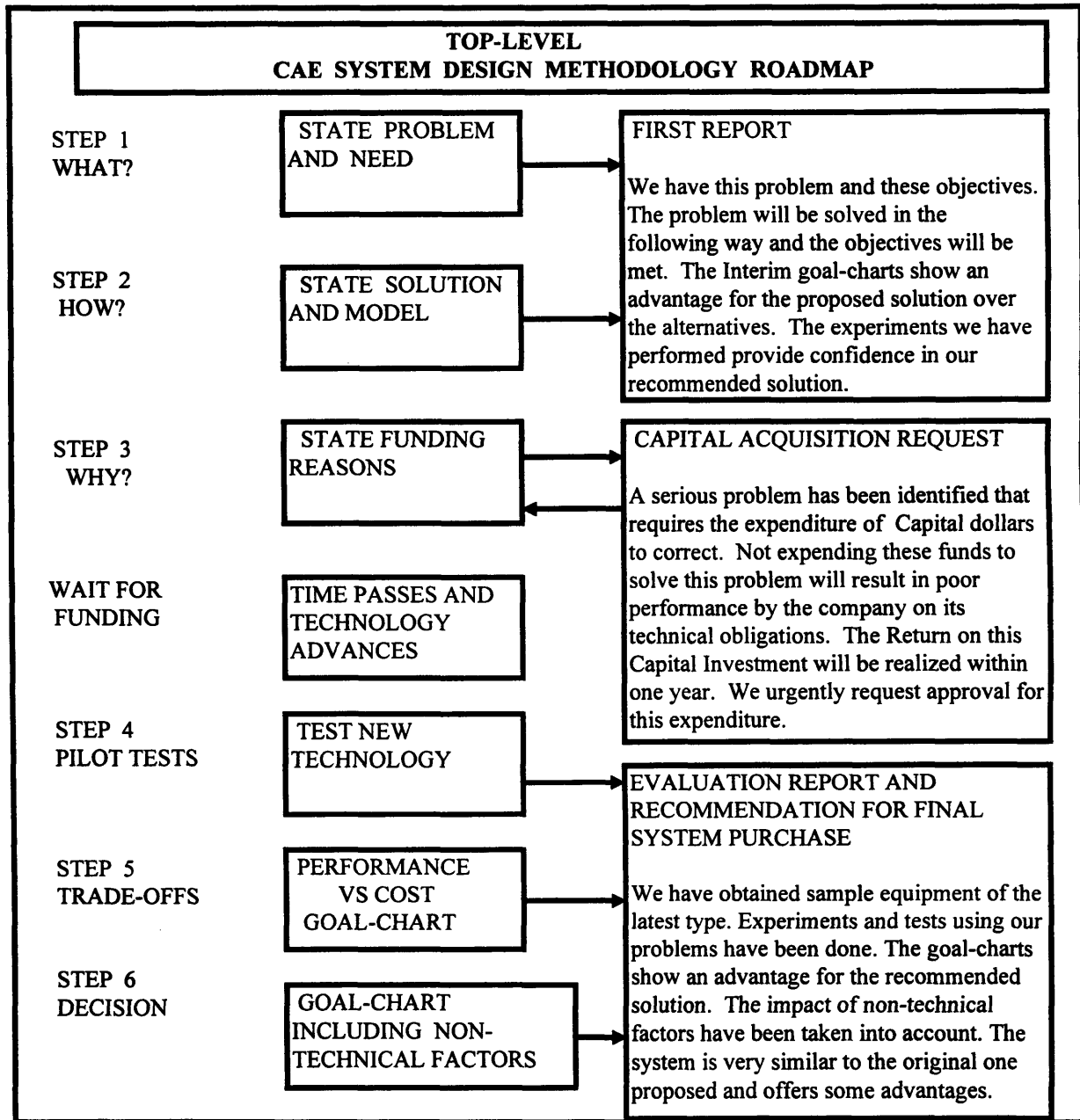


Figure 7.1 Top-Level CAE System Design Methodology Roadmap

The preferred system is then implemented after the funding sources are convinced that the differences between the system originally proposed and funded and the new one currently being implemented are really minor and very beneficial!! The Goal-Chart approach can be used to do this effectively in that it conveys the essence of the technical changes without bogging down the audience in the details.

In the CAE analysis system described, the problem is to speed up the analysis of circuits being analyzed under a Cadence software package called Verilog@. The Verilog@ package tests the performance of a circuit represented by a netlist and compares the performance with an idealized mathematical model. The situation is that many circuits of interest could take as long as 2 years to fully analyze on slow machines, (Sun SPARC 2 or less as a reference) because of the many input and output combinations. Therefore only a representative sample can be analyzed unless much faster methods are available. Much faster methods involve hardware or software accelerators and faster Workstations. A proposed system must be designed with full justification for the expenditure and return on investment. By the time the project is approved, the latest new offerings from all the vendors must be reviewed and tested against the objectives and plotted on the Goal-Chart to pick a preferred solution.

The non-technical issues must be and are also weighted and revise the axis of the Goal-Chart to a Cost of Performance versus Cost chart in the end. Also the new solution must be economically justified again.

The necessary steps were captured in a series of three reports for the CAE System Design Project as shown in the chart in Figure 7.1. The first report was prepared March 31, 1995 and described four items:

- 1) The Testing, Evaluation and Comparisons of various X-Windows software to make Workstations remotely accessible to engineers from their desktop PC's when the large screen capability of the dedicated workstation was not required.
- 2) The various Verilog@ simulation accelerators available including cost-performance.
- 3) Equipment projections and recommendations
- 4) Performance and cost data for the systems evaluated.

The next report was prepared May 8, 1995 and was a full-blown Capital Appropriations Request (CAR) with:

- 1) Executive Summary of need, cost and schedule justification and payback analysis.
- 2) Simple graphics to illustrate engineers vs workstations before and afterward.
- 3) Consequences if the appropriation is not approved
- 4) Detailed cost breakdown for the new system including maintenance and SW expense.
- 5) Past spending history on such systems and future multi-year plans.
- 6) Alternative solutions including leasing, do nothing, borrow equipment from other locations.
- 7) How long will the requirements be valid?
- 8) What are the costs and arrangements for training the personnel to effectively use the equipment?
- 9) Planned deployment of equipment in buildings with necessary facility improvements if any.
- 10) Planned personnel use of the equipment by name.
- 11) Planned use of older equipment being replaced.
- 12) Detailed quantification of cost avoidance and re-emphasized project need.
- 13) Detailed project description and implementation plans.
- 14) Appendices with all necessary current quotes and descriptive material.

The final report was a Workstation Evaluation and Recommendation completed on August 25, 1995 which included:

- 1) Background and Introduction to the problems.
- 2) Evaluation Plan and Evaluation Implementation.
- 3) Results including numerical, human factors and software limits.
- 4) Trade-offs based on the results, Specs and tests; equipment costs, time efficiency, improved design confidence by increased testing coverage.
- 5) Possible scenarios for purchase.
- 6) Situation changes and technology changes.
- 7) Recommendation for equipment and software purchase.
- 8) Conclusions with goal-chart support for technical and non-technical factors.
- 9) Appendices with quotations, users comments, and evaluation data.

Based on this work, a series of six Workstations was ordered and six more Workstations were upgraded to SPARC 20 Model 100 level performance. The project was fully operational in October of 1995. Training for the new high level software utilization began in November 1995. Since the final system was based on Sun hardware, with which most of the key users were already familiar, hardware training required was minimal. The project was concluded successfully.

The following sections of this chapter capture the substance of the three reports in more detail.

The first report captured the basic problem and need and proposed solutions with some performance and cost data corresponding to Steps 1 and 2 in the Top-Level CAE System Design Methodology Roadmap of Figure 7.1. The report summary follows.

ELECTRICAL TOOL EVALUATION REPORT

by
Philip Emile Jr.

March 31, 1995

OUTLINE

Project Objectives

- I X-Windows Evaluation**
- II VERILOG@ Simulation Accelerators**
- III Equipment Projections and Recommendations**
- IV. Appendices**

Project Objectives:

The project objectives were to

- 1) Evaluate X-Windows on PC as an alternate means of access to Workstations.
- 2) Evaluate VERILOG@ Simulation Options including accelerators.
- 3) Develop a Proposal recommending resource allocation.

The project plan included three phases for the first two items. The phases were:

- A) Vendor Survey, Reference Checks with users.
- B) Tests at Vendors
- C) Document Results/Proposal

Brief Summary of Project Results

The use of X-Windows allows engineers to access workstations from the PC terminals at their desks, rather than traveling to a central area. The access to multiple workstations from a single point is also an advantage. This may reduce the total number of Workstations required for processes like CONCEPT for circuit design.

Three X-Windows PC packages were examined and used successfully to access the Cadence CONCEPT Schematic Capture and VERILOG@ Digital Simulation Software. Discussions were held with the Information Systems personnel on methods to deal with the increase in network traffic expected as X-Windows becomes more widely used. Equipment requests for a number of 17 inch monitors to improve the displays for X-Windows users were also generated.

Two simulation scenarios were generated to test VERILOG@ simulations. One was ported to an external platform and tested. Two vendors of Accelerator hardware and software were contacted. Porting the test simulation to their platforms is in progress, but that work is incomplete and the results will require further efforts in the next fiscal year.

The present and proposed organization of Workstations and primary users based on the results of this burden project are shown as part of the Equipment Projections and Recommendations Proposal. As part of that projection it is proposed to upgrade a number of the Analog design PCs to Pentiums for greater speed in running PSPICE. PSPICE has previously been determined to be the Analog Design Analysis software of choice.

I X-Windows Evaluation

The X-Windows on PC packages examined directly or indirectly included "eXceed", by Hummingbird of Canada; "eXcursion" by Digital Equipment Corporation and "eXodus" by White Pine Software. Other packages such as "pcXware" are also available, but were not part of this evaluation based on the time available and the experience of the user base at the company.

Characteristics considered in the evaluation were:

- 1) Features
- 2) Ease of Use
- 3) Robustness
- 4) Intuitiveness
- 5) Speed
- 6) Ease of Installation
- 7) Flexibility
- 8) Cost per user.

The design packages, CONCEPT and VERILOG@ have been successfully operated on Sun and HP workstations using the X-Windows Hummingbird software . Also Mail, ftp, rlogin and other UNIX functions have been performed successfully.

There are ten current users of the Hummingbird eXceed4 X-Windows package. One user has indicated an interest in conducting a training session and acting as trouble shooter to users of eXceed4. EXceed4 does not run on the Macintosh.

There are several current users of eXodus on the Macintosh. The eXodus software was originally available on the Macintosh and is now available for the PC.

There are two current users of eXcursion.

There are a number of differences between the X-Windows packages. To start, eXceed4 comes on eleven 1.44 M disks, takes 21.1 M of hard disk space and has many features. The eXodus system is essentially complete on one disk, takes 4.7 M of hard disk; three other disks are used for special fonts only. Only one of these was required for the default font installation. EXcursion comes on seven disks and consumes 5.3 M of hard disk .

The knowledge and procedures necessary to install the X-Windows packages also differs from package to package. For example, eXcursion modifies the autoexec.bat file, sometimes deletes path information and leaves a TSR in memory. EXodus also modifies the autoexec.bat file and requires direct knowledge of the IP number of the resident PC, (obtainable from the PC/TCP .INI file). One user reports difficulty in getting the eXceed4 package to work properly with the DEC VAX system. None of the installation and startup procedures is completely user-friendly, but eXceed4 is most closely related to Microsoft Windows, icon-driven processes and appears most flexible of those examined.

The robustness of the packages also differs. Apparently, eXcursion is more finicky about the versions of TCP/IP with which it will operate properly.

At the present time, most Company PC user experience (5-8 users) centers around the Hummingbird "eXceed", with the White Pine "EXodus" on a few Macintoshes and the Digital Equipment "eXcursion" on a few PC machines.

Based on the features of eXceed4, the tests with Cadence SW, and the user familiarity, a set of ten licenses for eXceed4 has been purchased and will be available through a combination of network metering on the Vines network; and individual copies on the EE network. The cost per user for eXceed is higher than eXodus, for example, and further evaluation will be necessary at a later point to determine if eXodus or another, less expensive, X Windows package will be adequate for the company's needs.

PC X-Windows usage will be monitored to determine the effects on the network traffic. Methods to reorganize heavy traffic users, if necessary, have been discussed with network personnel.

A summary of results comparing the three items under evaluation are shown in Table I.

Number	Characteristic	eXceed4	eXodus	eXcursion
1	Features	17 direct icons plus ind. W/S	8 direct icons W/S avail.	4 direct icons plus hierarchical
2.	Ease of Use	Multi-Path, Direct	Single Path Direct	Multi-windows Indirect
3	Robustness	Operates w/o TSR	Limited data	Requires TSR & modified autoexec file
4.	Intuitiveness	Windows Icons	Multi-step	Hierarchical
5.	Speed	Setup time long, Hummingbird reinforcement	Quick setup	Multi-level
6.	Ease of installation	Direct Installation 11 disks, 21.1M	Quick 1 1/2 disk Install., 4.7M	Autoexec mod 7 disks, 5.3M
7.	Flexibility	Many direct operations, very flexible	Few options	Moderate options
8.	Cost/User	\$417.00	\$190.00	\$522.50

Table 1. X-Windows Comparison

II. VERILOG@ Simulation Accelerators

The number of the simulations necessary to simulate functional and timing performance to verify the new designs requires a significant amount of simulation in elapsed or calendar time to complete all the permutations of stimulus and responses. There are Hardware and Software Accelerators provided by a number of vendors which can execute this simulation process in a shorter time than a single workstation. The use of these accelerators can therefore allow more design iterations or indirectly allow less total workstations and licenses to be purchased.

References to approved vendors of Verilog@ accelerators were sought from Cadence, the manufacturer of Verilog-XL@. In addition trade magazines and advertising literature were consulted. Two vendors were invited to make presentations and submit approximate quotations for accelerators which would be effective on circuits using the number of gates characteristic of the new designs.

Both vendors suggested that accelerators of the size to handle the new designs would be a minimum of \$90,000 considering HW and SW and a maximum of \$180,000. The expected simulation speed gains would be the order of 10x to 20x for most cases. Speedups of 100x or more could be obtained in cases where both the stimulus and the gate structure could be fully ported to the parallel processors.

The accelerators operate by using parallel processors to provide gate level simulation. The chassis with the parallel processors, (a minimum of four scaling upward to 8, 64 or some other number) is connected to the S-Bus of a dedicated Workstation. Special software is invoked to port some or all of the Verilog@ simulation to the chassis containing the parallel processors. One company, IKOS, calls their parallel processor box an NSIM and the special software Gemini with Precedence.

A circuit simulation of the size and type to be of interest to has been prepared and tested by both Company and Cadence engineers. Preparations are under way to have the simulation tested using hardware at the vendors' location and determining what measured gain in performance is achieved.

Continuation of this effort is needed to confirm the actual gain by using these accelerators.

A trade-off must also be made considering the rapidly increasing processing rates of pure Workstations which continue to close on the performance of previous accelerators. Further, there is the cost of the accelerators and the projected requirement for gate level simulation where accelerators perform more effectively as contrasted to VHDL and HDL behavioral simulations where full featured Workstations perform better.

An Illustrative Example

A significant portion of the time and effort in this burden project went into determining a suitable circuit simulation and applying that simulation to the various platforms available at the company and elsewhere. In the process a critical evaluation of the hardware platforms, some Verilog@ software features and the software operating systems of the various platforms were examined and exercised. The results of that evaluation provide guidance for the recommendations for resource allocation.

The simulation program mentioned earlier consisted of a 16 bit by 16 bit multiply cell which could have signed inputs and 32 outputs. The cell also had four mode input lines for a total of 16 modes. The cell inputs and outputs were compared with the outputs from a behavioral model with the same inputs. The mathematics follow:

$$65,536 \text{ times } 65,536 = 4,294,967,296 \quad \text{or } 4.3 \text{ Billion}$$

$$16 \text{ times } 4.3 \text{ Billion} = 68.7 \text{ Billion}$$

One day has 86,400 seconds. Therefore a process which executes this simulation at 12,000 events/ second e.g. SPARC 10, would take

$$68.7 \text{ Billion divided by } 86,400 \text{ divided by } 12,000 = 66 \text{ days}$$

Should a faster process be available, say 30,000 events/second , e.g. HP735, the elapsed time decreases to

$$66 \text{ days divided by } 12,000/30,000 = 26 \text{ days}$$

A process which takes almost a month of continuous running is probably not productive or effective in the engineering design cycles with which the company is faced. Nevertheless, full evaluation is necessary to eliminate risk (Pentium example). Therefore the need for some kind of accelerator is apparent for the design tool arsenal if a number of gate level simulations of this type are to be run. For the present, sampling methods are being used as a basis and as much simulation time as can be accomplished during the program is done.

Unfortunately, some of this simulation is now being done on platforms which achieve only 6000 events/second e.g. SPARC 2 or IPX. Therefore one of the recommendations is to provide faster workstations to these designers.

Initial work with this simulation process produced puzzling results on the Sun Workstation platforms. The simulation proceeded with an inner loop and an outer loop both cycling from 0 to 65,536. However, the elapsed time for succeeding steps in the outer loop seemed to increase as the process continued. In some cases, the process crashed. This led us to call upon Cadence to verify that their software process was robust enough to perform this simulation and explain why the process elapsed time appeared to be increasing as the outer loop continued.

A Cadence application engineer made a trip to the plant to work with us on these problems. A number of very positive things came out of that visit. First, he provided us with up to date patches for the software for Verilog@ and suggested that to make the simulation independent of the VERILOG@ library we could load a later revision of VERILOG@ and use a switch which would include the library binaries. He also suggested that we add some Sun patches to the Sun OS which would be helpful. Next, working together, we changed the simulation to use a seeded random number to determine if elapsed time variation was real or an artifact of the linear simulation process. Lastly, we included a calculation of events/ second as a printed output and a saved file. Thus, the comparison of various workstations could be done on a relative basis.

At a later point, the Cadence application engineer provided us with the sorted run of the simulation taken on a HP735 platform. On an average, the HP 735 averaged 30,000 events/sec. The simulation ran for about two days simulating 2,610 lines or about 4% of 65,536.

Internally, the memory utilization of a Sun OS station "Merlin" was examined using the vmstat command. The station had been operating continuously for fourteen days and apparently the available memory had shrunk by some 30 megabytes due to fragmentation. When the station was rebooted, full memory utilization was apparent. This suggested some less than desirable memory "leak" which may be due to the Sun OS UNIX software when various tasks are being swapped over a period of time.

Using the X-Windows platform from my PC through eXceed, I examined the performance of a variety of Workstations on the Engineering network running the random seed simulation to determine the performance in events/second. The results are listed in the Table 2.

Number	Station Name	Type	Events/Sec.	Elapsed Time	Ratio to SPARC 2
1	MORDRED	IPX	5,948	7 min	0.89
2	CALVIN	SPARC 2	6,669	6 min	1
3	MERLIN	SPARC 2	6,669	6 min	1
4	IGRAYNE	SPARC 10	12,419	3 min	1.87
5	LEON	SPARC 20	19,415	2 .25 min	2.91
6	PEKING	HP735	27,000	1.5 min	4.05

Table 2. Simulation Performance Interim Goal-Chart Tabular Data

It is expected that Digital Equipment Hardware using the AXP chip or faster HP units such as the HP755 or faster Suns such as the 100 MHz unit would improve on the performance shown in Table 2. Other aspects of the various workstation platforms must also be considered. For example, the order of New software release, according to Cadence is 1) Sun, 2) HP, 3) IBM, 4) DEC. Thus Cadence is following the market density which favors Sun. They then follow with the established performance leader HP.

Also the system experience and compatibility of a particular network or network personnel is a factor in the actual equipment performance results. For example it is reported that the Sun interface with plotters is less troublesome than the HP interface. DEC has to overcome the late entry and convince both the users and third party software suppliers that it is worthwhile to devote the necessary time to write for the AXP platform.

Looking down the road from a users' perspective full interoperability between all the systems is most desirable since then the best platform for the given purpose can be selected.

III Equipment Projections and Recommendations

The following set of equipment projections and recommendations are the results of this burden study and related inputs:

Digital:

- 1) Purchase High End Workstations compatible with systems and system knowledge in place to increase average performance.
- 2) Use Verilog@ Simulation on Workstations with PC X-Windows link to Workstations for CONCEPT Schematic Capture. Upgrade PC displays to 17 inch monitors where appropriate.
- 3) Purchase One or more accelerators to provide ultra high speed simulation to reduce design risk and number of licenses required.

Analog:

- 4) Use PSPICE Simulation on P5-90's with 17 inch monitors and X-Windows link to Workstations for CONCEPT Schematic Capture.

General:

- 5) Find ways to interoperate over platforms, e.g. common UNIX structures such that HP & Sun or other Workstations can operate on the same network..
- 6) Encourage the use of PC platform extensions such as X-Windows for enhanced performance capability and location independence.
- 7) Develop a policy of staged equipment upgrade with vendors so that up to date high level performance equipment is continually available to design engineers.

Charts listing the present and proposed allocation of Workstations by name and the present and proposed allocation of High Performance PC's were included in the Electrical Tool Report.

IV

Appendices

- Appendix A. Descriptions and Quotes for X-Windows
Hummingbird - eXceed, White Pine eXodus, DEC eXcursion.
- Appendix B. Descriptions and Quotes for Accelerators
IKOS and ZYCAD
- Appendix C. Performance Comparisons and Quotes for Workstations
Sun, HP, DEC.
- Appendix D. PSPICE Comparison Article
- Appendix E. Sorted Simulation run of test circuit by Cadence from HP735

These Appendices are not included in the thesis summary to save space.

The Executive Summary, Project Description and Questions and Answers from the second report, the Capital Acquisition Request (CAR) are included on the following pages with editing to eliminate company or project specific references.

Capital Appropriations Request
for
EE Workstations for Digital Design and Simulation

Executive Summary

The company is a supplier of high performance, high tech equipment including sensors, instruments and systems for the demanding space environment, to NASA, DOD and other organizations. The company's success and business advantage hinges on its ability to develop state of the art instruments within budget, within schedule, and meeting all of the customer's requirements. Digital Simulation of the chip or circuit operation is vital to ensure that the operational goals of the device are met.

Digital Simulation requires that the company take full advantage of Computer Aided Engineering Hardware and Software and the best available technical talent to achieve this success.

The acquisition of this series of high end Workstations and supporting Software and peripherals is absolutely essential for the business success of the company to mitigate the financial, schedule and technical risks the current and continuing series of programs. The plan shown on the attached Figure 7.2 envisions adding 10 EE Workstations so that a total of 36 engineers will have access to 16 Workstations whereas, now, 28 engineers share 6 Workstations.

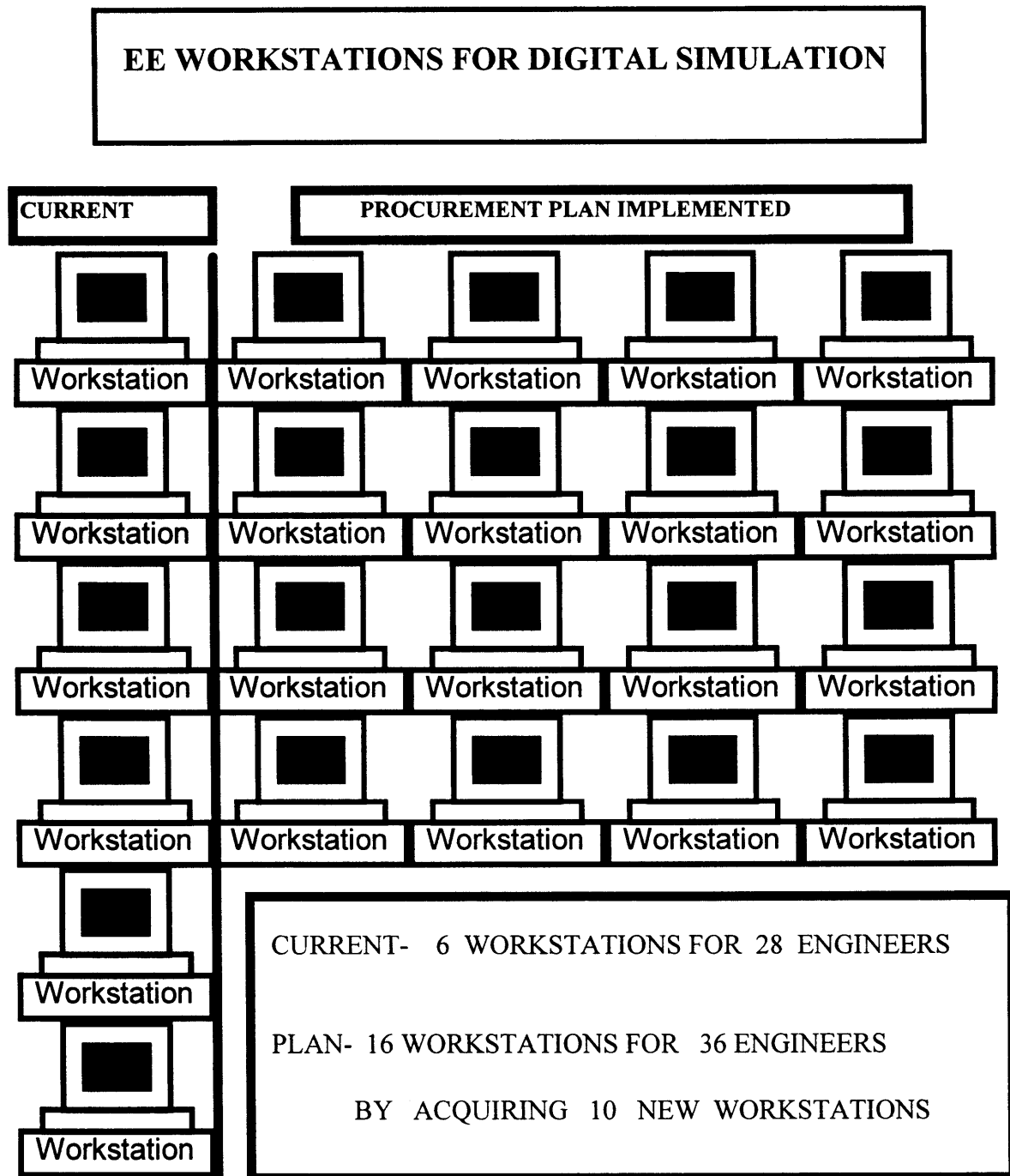


Figure 7.2 Illustration of Workstation Plan to Support Executive Summary
Entitled "EE Workstations for Digital Simulation"

Capital Appropriations Request
for
EE Workstations for Digital Design and Simulation

Project Description

This Capital Appropriations Request is submitted to buy ten high end Workstations to provide equipment so that the design engineers have the necessary hardware to perform the design tasks in accordance with the contract schedules.

At the present time, 28 engineers are assigned to perform design tasks in the mid to late 1995 time-frame. The available hardware is limited to six workstations and these are inadequate in terms of processing power to perform the simulation tasks. PC X-Windows has been purchased to expand the Workstations to engineers beyond a one-to-one basis.

However, more engineers must be assigned to complete the current project tasks. Therefore, more Workstations must be obtained for this to happen. Figure 7.2 entitled EE Workstations for Digital Simulation illustrates the current and planned situation. The plan is to provide a total of 16 Workstations supporting 36 engineers to meet the project needs. The ongoing work projection indicates that these Workstations will be needed for the foreseeable future, but without their availability schedule slip on the current projects is unavoidable.

The Capital Appropriation Request also lists Software and Maintenance. The purchase of additional copies of Verilog@, Concept and other design tools listed in the CAR are necessary to have the hardware function in a legal manner.

**CAPITAL APPROPRIATION REQUEST
QUESTIONS FOR JUSTIFICATION**

CAR NO. _____

TITLE __ELEC. ENG WORKSTATIONS FOR DIGITAL DESIGN _____

A. DESCRIBE THE PROBLEM AND SOLUTION

- 1. WHAT IS THE PROBLEM, NEED OR COMPELLING SITUATION THAT CURRENTLY EXISTS AND IS PROPOSED TO BE RESOLVED BY THE EXPENDITURE OF THE REQUESTED CAPITAL FUNDS?**

Currently, the manpower being hired as required to support some projects does not have a sufficient number of workstations and software licenses to do their work. Also the available workstations are much too slow to perform the required design and simulation tasks in a timely manner.

Digital Simulation is a critical activity to verify all paths in a complex circuit. Otherwise, fiascoes like the recent Pentium problem can occur.

Further, the cost the chip design and fabrication is substantial. One pass through the fabrication process costs approximately \$125,000. The design cycle cost is about \$400,000 and several months. Therefore, any steps to shorten the process and guarantee the design is right the first time, is cost avoidance savings.

- 2. WHAT IS PROPOSED TO RESOLVE THE EXISTING PROBLEM, NEED OR COMPELLING SITUATION?**

The proposal is to purchase ten Sun SPARC 20 Workstations with the Super SPARC Processors and copies of the required software to provide the tools so that the personnel can support the projects. This represents a good compromise between software availability and compatibility with our current system.

3. WHAT OTHER ALTERNATIVES WERE CONSIDERED AND WHAT WAS THE RATIONALE FOR SELECTION OF THE SOLUTION?

Other alternatives considered were:

- a) operating the current machines longer hours,**
- b) seeking surplus equipment from other locations and,**
- c) sending work outside to service bureaus.**
- d) use of hardware accelerators.**

Alternative a) This is being done to the maximum extent possible.

Alternative b), Locations which are downsizing have been contacted to see what systems are available. No satisfactory systems have been located.

Alternative c) The support to send designs to service bureaus is high for the preparation of the work, the duration of the work and the follow-up after the work is complete.

Alternative d) This introduces another level of software, and introduces the difficulty of pinpointing problems, but will be further evaluated.

4. WHAT ARE THE SPECIFIC PROGRAMS REQUIREMENTS FOR THE REQUESTED ITEM/SYSTEM? WHAT, IF ANY, CONTRACTUAL REQUIREMENTS ARE INVOLVED?

A number of specific programs require new designs. The schedules are such that much of the design must be done in parallel necessitating the additional workstations.

5. WHAT IS THE IMPACT ON THE DEPARTMENT/COMPANY IF THE REQUESTED ITEM/SYSTEM IS NOT ACQUIRED DURING THE CURRENT FISCAL PERIOD?

The allotted time for circuit design will be exceeded and the currently required project schedules will not be met. The financial risks of missing schedules include reduced award fees.

B. DISCUSS THE ITEM/SYSTEM UTILIZATION

1. HOW MANY OF THE SAME OR SIMILAR ITEMS ARE CURRENTLY AVAILABLE AND WHERE ARE THEY LOCATED?

Five systems are currently available and in continuous use beyond a single shift. A sixth system is shared with on a half-time basis.

2. HOW ARE EXISTING ITEMS UTILIZED AND HOW WILL REQUESTED ITEMS BE UTILIZED?

Current systems are used for design and simulation. The additional systems are intended to increase capacity to the necessary level.

3. HOW MANY OF THE SAME OR SIMILAR ITEMS ARE PLANNED FOR THE FUTURE?

There will be a requirement for five additional seats over the next two years. Refer to the Three Year Plan.

4. HAVE USERS OF EXISTING EQUIPMENT/SYSTEMS BEEN CONTACTED TO PROVIDE EQUIPMENT/SUPPORT FOR THIS REQUIREMENT? DESCRIBE CONTACTS AND RESPONSE.

Locations which are down-sizing have been contacted. No satisfactory systems have been located.

5. HOW LONG WILL THE KNOWN REQUIREMENTS FOR THE REQUESTED ITEM/SYSTEM LAST?

The project requirements are expected to continue beyond the year 2001.

C. DISCUSS FINANCIAL CONSIDERATIONS

1. IS THE REQUIREMENT INCLUDED IN THE CAPITAL BUDGET FOR THE CURRENT FISCAL PERIOD? IDENTIFY THE BUDGET NUMBERS AND DESCRIPTION.

The project is included in the capital budget for the current fiscal period.

2. WHAT OTHER COSTS ARE INVOLVED TO SUPPORT THIS REQUIREMENT (I.E. OPERATING COST, MAINTENANCE COST, TRAINING, LICENSE FEES, ETC.)?

Some training for the new hires will be needed and this is included in the CAR. The software includes training credits of four weeks for one person for each copy purchased. The operating and maintenance costs are in the Engineering Administration budget. The licensing fees are included in this CAR.

3. HOW WERE THE PRICES DETERMINED? ARE QUOTATIONS OR PRICE LISTS ATTACHED?

The prices were obtained from quotations. Quotations are attached.

4. WHAT WARRANTY IS INCLUDED WITH PRODUCT?

The product is warranted for one year. The parts exchange portion of the warranty runs up to five years for some parts such as 1 Gigabyte disk drives. A copy of the Sun Product Warranty is attached.

5. WILL THE ACQUISITION OF THIS CAPITAL ITEM/SYSTEM RESULT IN SAVINGS TO THE DEPARTMENT/COMPANY? QUANTIFY THE SAVINGS IN TERMS OF DOLLARS AND DEVELOP THE PERIOD OF TIME REQUIRED FOR THE SAVINGS TO PAYBACK THE CAPITAL EXPENDITURE. WHAT BUDGET ACCOUNT/S WILL REFLECT THE SAVINGS?

The work which will be accomplished, both in time and quantity. Therefore, the only relevant comparison is the cost of obtaining the design by subcontract means. This will add the costs of managing and coordinating an outside supplier, some turnaround delays and coordination delays. Over the course of a one year project or series of projects this is expected to add approximately 25 to 30% to the Design costs. Thus, the yearly cost increase will approximately $0.3 \times 10 \text{ stations} \times 1700 \text{ hrs} \times \$100/\text{hr} = \$500,000/\text{year}$. This neglects the fact that it may not be possible to accomplish the task within the contract requirements by such subcontract efforts.

6. **WILL THE ACQUISITION OF THIS CAPITAL ITEM/SYSTEM RESULT IN A COST AVOIDANCE TO THE DEPARTMENT/COMPANY? DESCRIBE THE COST AVOIDANCE AND IDENTITY THE BUDGET ACCOUNT THAT WILL BENEFIT FROM THE COST AVOIDANCE.**

The equipment is necessary to accomplish the tasks. the alternative is not to perform. This is a contract cost which is not easily quantified in terms of future contracts, credibility and all the factors which led the customer to choose our company originally.

D. **SUPPORTING DOCUMENTATION**

1. **PROVIDE PICTURES, DRAWINGS, LITERATURE, ETC., OF THE ITEM/SYSTEM WHERE POSSIBLE AS ATTACHMENTS TO THE CAR.**

Literature describing the Workstations and the Software is attached.

(Only brief data on this is included in the Thesis to save space.)

2. **PROVIDE COPIES OF PRICE LISTS, QUOTES OR RATIONALE AND SOURCE DOCUMENTS TO SUPPORT THE REQUESTED CAPITAL FUNDS.**

Copies of quotations for the workstations and software are attached.

3. **PROVIDE PRODUCTION SCHEDULES AND/OR IMPLEMENTATION SCHEDULES IN MATRIX AND/OR GRAPH FORM WHEN APPLICABLE.**

The work stations and software will be placed in immediate use. In fact the hiring process is on hold until the workstations can be obtained.

4. PROVIDE LOCATION AND LAYOUT DRAWINGS OF INSTALLATION OR CONSTRUCTION AREAS WHEN APPLICABLE.

The workstations will be located in the Design Center in the place of stations belonging to another function which are being moved to another area due to expansion requirements.

5. FOR CAPITAL REQUESTS THAT CANNOT BE FULLY EXPLAINED ON THE CAR DOCUMENT, AN EXECUTIVE SUMMARY IS REQUIRED THAT PROVIDES A BRIEF OVERVIEW OF THE PROBLEM, SOLUTION AND JUSTIFICATION. IT SHOULD SUMMARIZE THE KEY POINTS MADE IN THE CAR PACKAGE AND REFER TO OTHER ATTACHED DOCUMENTATION FOR THE SUPPORTING DETAILS.

E. CAR'S FOR \$100,000 OR MORE

IN ADDITION TO THE INFORMATION ABOVE, ALL CAR'S FOR \$100,000 OR MORE WILL BE ORGANIZED INTO A PROJECT PLAN FORMAT CONTAINING THE FOLLOWING SECTIONS PRECEDED BY A TABLE OF CONTENTS.

- A) EXECUTIVE SUMMARY**
- B) CAR APPROVAL DOCUMENTS**
- C) QUESTIONS FOR JUSTIFICATION**
- D) PROJECT DESCRIPTION**
- E) IMPLEMENTATION PLANS**
- F) FACILITY SITE PLANS**
- G) FINANCIAL ANALYSIS**
- H) SUPPORTING ATTACHMENTS**

The value of the CAR for this project was close to \$1,000,000 well above the limit, so the report format followed the requested format above. For illustration, a simple chart which supported the Executive Summary is included as Figure 7.2. A brief summary of section E. follows.

Capital Appropriations Request
for
EE Workstations for Digital Design and Simulation

E. Implementation Plans

This Workstations will be placed in immediate service the instant they are available. Trained people are in readiness to begin their tasks. Hiring of other needed people is being done at a slower than needed pace since there is not equipment and software for them to begin their tasks.

The switching network has been upgraded to accommodate these new machines. Space is being vacated in the Design Center with the move of another group and there are alternate plans if this space is not immediately available.

Currently, there is a large backlog of design work which makes it imperative that this equipment is received immediately. The revenue projections for theses new products over the next four years indicate modest growth. The current trends in our industry include:

- decreasing "time to market"
- increasing chip complexity
- increasing need for flexibility gained from additional digital circuitry
- increasing electronic content in our products
- increasing requirement for first pass success in product design.

These trends dictate an increasing reliance on Computer Aided Engineering on high powered Workstations. The company will need and fully utilize these workstations for at least the next five years to remain competitive in the market.

The third and Final Report in this CAE System Design effort is entitled EE Workstation Evaluation and Recommendations. The essential parts of that report follow.

EE Workstation Evaluation & Recommendations

by Philip Emile Jr.

Outline

1. Background
2. Introduction
3. Evaluation Plan
4. Evaluation Implementation
5. Results
 - Numerical
 - Human Factors
 - Software Limits
6. Tradeoffs based on Results
 - Purchase by Spec Integer (Int) and Test
 - Duplicate SW and Equipment Costs
 - Use by Time Efficiency
 - Improved Design Confidence by Additional Testing
7. Possible Scenarios
8. Scenario Commentary
9. Recommendations for Purchase
10. Conclusions
11. Appendices
 - A. Evaluation Forms
 - B. Users Comments
 - C. Users Data
 - D. Sun Quotations
 - E. HP Quotations
 - F. IBM Quotations
 - G. Sun Evaluation Data
 - H. HP Evaluation Data
 - I. IBM Evaluation Data
 - J. Original CAR Quotation

EE Workstation Evaluation & Recommendations

1. Background

The goal of this evaluation task was to confirm or modify the choices of Workstations selected and approved in the Capital Authorization Request #YYY entitled "EE Workstations for Digital Simulation and Design". The Digital Simulation referred to was simulation under Verilog-XL@. The task was to be performed by comparing workstations from major vendors Sun, HP and IBM in real-time and benchmark situations to determine performance metrics. The desired outcome was a recommendation for Workstation purchase. The evaluation task is now complete with the issuance of this report.

2. Introduction

The task implementation included requesting Workstations for evaluation from the vendors, Sun, Hewlett-Packard and IBM. Sun provided a SPARC 20 Model HS21 and a SPARC 5 Model 5/110 for the evaluation process. Hp provided a Model 735/125, a Model 715/100 and a Model 9000 K200 multi-processor unit without a local graphics monitor. IBM provided a Model 390 and a Model 42T for the evaluation.

An evaluation plan was laid out as described in Section 3. The data from the evaluations was presented in performance measures as shown in Table 7.1 and in written narratives. Meetings were held with the users and the Technical Lead Personnel to discuss the ongoing evaluation and make recommendations. The outcome of one of these meetings was to proceed with an order for three (3) Sun SPARC 20 Model HS21 machines while awaiting the completion of the evaluation process. This was done since some of the software in use by the EE design team is only available on the Sun platform. One example is support for LSI logic design for ASICS.

The evaluation hardware was made as compatible as possible with the existing Sun Network. For example the TCSH software was installed on all machines rather than the less user-friendly CSH which comes as standard on some machines. The automount method was used to load software just as is done in the operating Sun Network. Vendor Application Engineers were present on many occasions to answer questions and deal with special problems. The users have learned how the machines handle their work problems and have also become aware of differences other than performance and have been vocal about those differences in Table 7.2.

3. Evaluation Plan for Workstations

Purpose: Choose Workstations for Purchase under CAR considering Performance and Cost.

Duration: Over two month period ending not later than August 18;

1. Compare Workstations from major vendors, Sun, HP, IBM in real-time and benchmark simulation and other environments to determine performance metrics.
2. Compare usability, software function, support, limitations on applications.
3. Discuss futures, upgradeability with vendors and users.

Using Purchasing Interface:

4. Obtain pricing on appropriate configurations.
5. Evaluate applicability of various vendor inducements, e.g. trade-ins, maintenance, special discount policies in conjunction with purchasing and finance.
6. Re-check ongoing requirements, and technology driven lease-buy.
7. Make purchase recommendation including quantities and types by preparing necessary requisitions based on assumption that CAR is approved and requirements are still firm.
8. In subsequent effort, acquire, install and integrate new stations with support of IS.

4. Evaluation Implementation

1. Acquire Representative Workstations, Two from each vendor and with IS help, integrate and make SW transition as seamless as possible for user community.
2. Design forms for data collection.
3. Run benchmark tests (Overhead \$) and a variety of user applications (Program \$).
4. Prepare tabular and graphic results of Tests in 3.
5. Allow and arrange vendor presentations or seminar presentations on Workstations, present and future plans.
6. Get answers and support from vendor AE's as necessary.
7. Return non-selected equipment at end of evaluation.

5. Results - Numerical

The numerical results of the evaluation in the order of running Verilog@ Simulations summarized from Table 7.1 follows:

1. Order of speed in Running Verilog@ Simulations.

HP 735/125	Baseline
IBM 390	+5-8%
HP K200	+10 - 15%
IBM 42T	+10%
Sun SPARC 20/125	+30%
Sun SPARC 5/110	+44 - +90%
Sun SPARC 20/50	+50%
Sun SPARC 2	+300%

2. Other factors

ASIC Support for LSI Logic only on Sun
User and Administrator Training favors Sun

Performance Vs Cost (Price from the users' standpoint)

At this point it became relevant to consider the Cost part of the Performance -Cost of the Workstations, The Goal-chart labeled "Comparison Graph for Workstations based on Vidphil2.typ Test" shows how the various Workstations position themselves on a Cost Performance Grid based on initial price quotations.

The most desirable region in the goal-chart is near the Origin. Workstations located far up the Y axis will be too slow for Verilog@ use. Workstations located too far out on the X axis will be too costly to provide the number of seats required, given the limits on funds in the CAR.

Observation of the graph suggests that the IBM solutions and the SPARC 20/125 offer the best value with the initial prices quoted. The SPARC 5/110 is also closer to the Origin than some other solutions.

Requotes placed the K200 box very near the IBM 42T. Quotes on the HP 735/125 did not bring it into line with the K200. Various combinations were considered in the Tradeoffs section.

Table 7.1 Comparative Workstation Performance on Simulations under Verilog@

2-Aug-95										
Workstation Type	Name	Simulation #1								
		7_18_95 Vidphil2.typ				8_1_95 Simulation #2				
		Compile	Link	Simulation	Total	Compile	Link	Simulation	Total	
HP 735/125	Mercury	4	46	319	369	7	159	1537	1703	
IBM RS6000/390	Jupiter	7	57	324	388	12	195	1625	1832	
HP K200	Neptune	5	53	344	402				0	
IBM RS6000/42T	Pluto	6	43	356	405	10	152	1782	1944	
Sun SPARC 20/125	Mars	7	58	400	465				0	
HP 715/100	Venus	5	75	395	476	10	204	2217	2432	
Sun SPARC 5/110	Saturn	10	93	428	531	19	366	2510	2896	
Sun SPARC 20/50	Leon	7	92	485	584				0	
Sun SPARC 10	Perceval	11	107	615	733	20	347	3280	3647	
Sun SPARC 10	Guenevere	11	131	638	780					
Sun SPARC 2	Calvin	23	251	1211	1485					

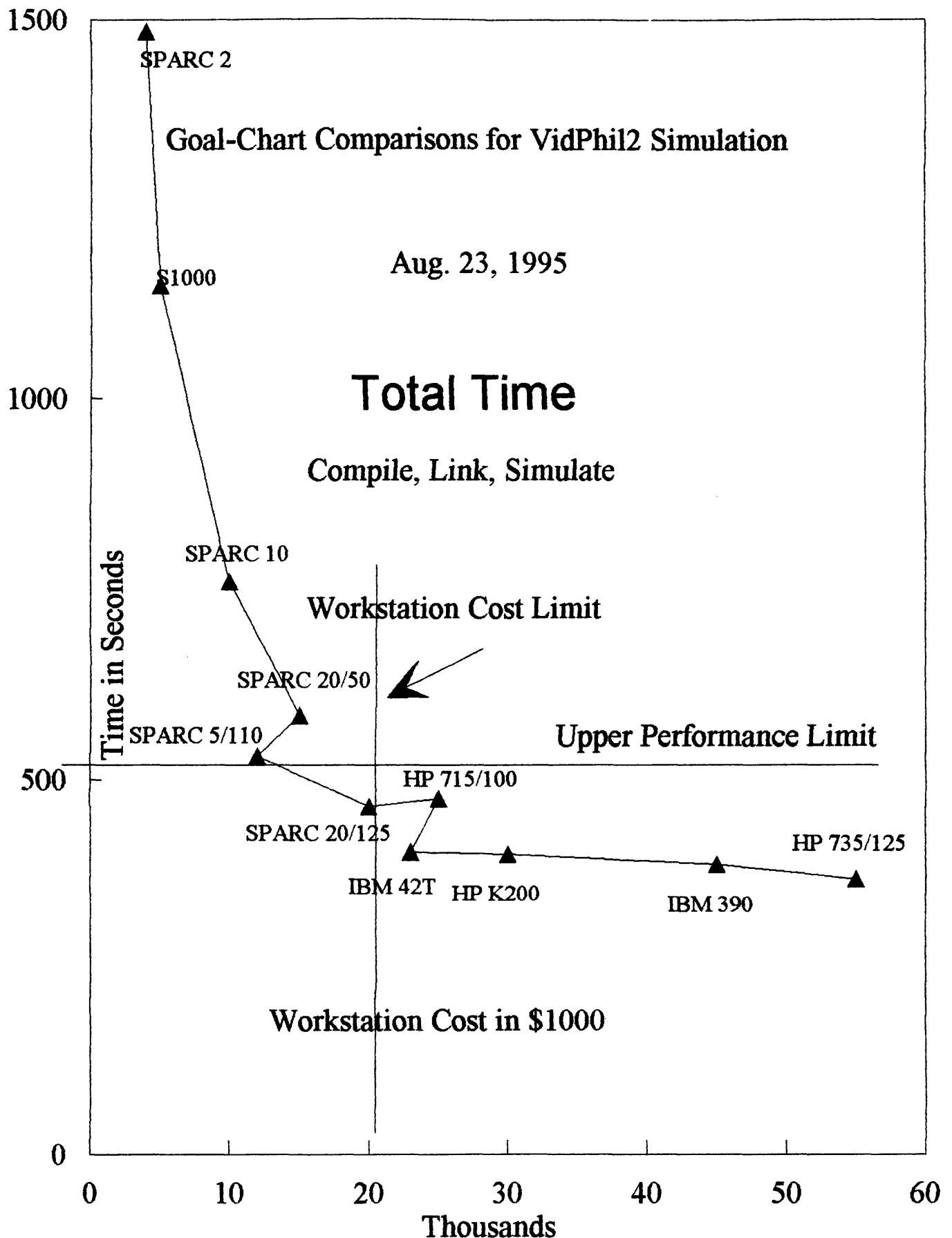


Figure 7.3 Goal-Chart Comparison Graph based on Vidphil2.typ

5. Results-Human Factors

There are differences in the presentation features in the HP, IBM and Sun Workstations. Thus, users who are used to one type of Workstation, strain and are annoyed at the features of another presentation. See Table 7.2 for some comments. Further, the versions of UNIX are somewhat different between the various systems. Some commands are absent and many keystrokes work differently. Thus moving back and forth between platforms is inefficient unless there is a compelling cost or performance advantage.

HP broached a partial solution to this problem when they brought in the HP 9000 Model K200 machine. This machine has no graphics display, only a console terminal. It can contain up to four processors of the PA7200 series. As can be seen in the Comparative Performance Table 7.1, these processors are close to the HP735/125 in performance.

The HP K200 unit can handle batch-type or interactive jobs where the users' display, be it Workstation, or PC can influence the protocol, once the K200 is properly set up. At a later point, both Sun and IBM described and quoted "headless", (no graphics display) units.

The IBM unit is described as a G30 and was offered as a "four-way", or an "eight-way, by the number of processors. Sun offers the S1000 and S2000 models in four and eight processor series. The Sun S1000 is unfavorably positioned on the Cost-Performance Grid based on the tests shown in Figure 7.3. A possible performance issue with the S1000 may be related to the use of the Solaris 2.X operating system according to reports from field users and third-party vendors. This was not confirmed in the work here and is reported as hearsay only.

The Workstation box with multiple processors is therefore one new solution which arose after the original CAR was prepared. Another clear item is that some users will put up with discomfort to use the fastest system available. The HP 735/125 was always the first choice for the power users.

5. Results- Software Limits

Sun represents the largest installed base of Workstations by a considerable amount. Therefore Software vendors often target the Sun Platform before other platforms and in some cases do not prepare the software for the other platforms at all. This is especially true for vendors who have co-operative agreements with Sun. To a smaller extent, this is also true with some HP software vendors. The difficulty in the environment with an installed Sun Network is that some specialized software is being used and if other Workstations are purchased, they will not be fully flexible in running all of the Network software.

Table 7.2 Excerpts from Users' Written Comments

User 1. As per your request, I have run one of my larger simulations on each of the machines listed below, with the results as shown. My criterion for measuring system performance was based on the use as a remote server.

From a remote login perspective, both the HP and IBM machines were downright unfriendly compared to the Sun "Open Windows" environment I have used for years. I tried the HP windowing environment and must say that it is far from intuitive, which is the goal of a windowed operating system. Further, I have personally experienced the pains of trying to work across multiple operating systems and would strongly recommend against it. If some machine offers a sufficient cost-performance advantage to switch en mass, then that is a different story. My results do not show enough advantage to switch. The results are:

HP 735/125	2 hrs... 1 min.
IBM RS6000/390	2 hrs... 16 min
HP K200	2 hrs... 25 min
Sun SPARC 20/125	2 hrs... 51 min
HP 715/100	2 hrs... 44 min
Sun SPARC 5/110	3 hrs... 56 min
Sun SPARC 20/50	3 hrs... 14 min
Sun SPARC 10	4 hrs... 39 min

User 2. Wants the performance and multiple processors that the K200 has. Does mostly Verilog@ batch mode and this works for him.

User 3. Has used the HP window interface exclusively over the past few weeks and gotten used to it. However, it is so different from the Suns that he recommends that we not purchase any HP machines unless they were cheaper and faster such that the overall user education would be worthwhile.

User 4. Concerned about the user interface.

This table suggests that the majority of users would not recommend a change requiring them to learn a new interface unless a major benefit was seen.

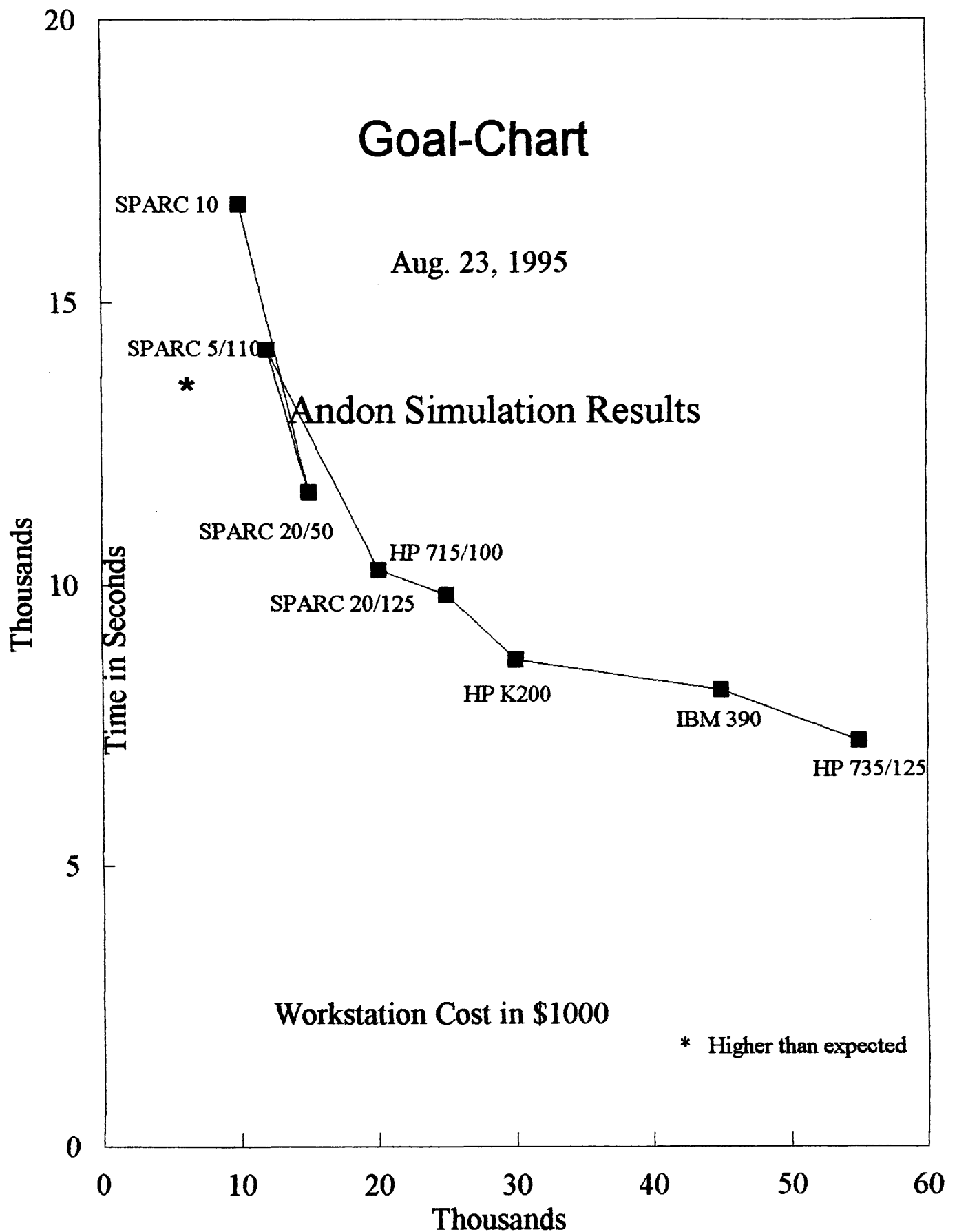


Figure 7.4 User 1 Goal-Chart (Andon) Performance Vs Cost Chart

6. Tradeoffs and Cost Metrics

There are several elements of cost affecting the ownership of Workstations and especially mixed environments (HP, Sun, IBM) and some of these will be discussed here. First there is the Performance -Cost or Goal-chart for making a relative comparison of the value of speed for the initial purchase. Second, there is the quantity of time the equipment is in use and adds idled manpower costs or reduced efficiency because of insufficient speed. This is an operating cost delta from the fastest available machine. Third, there is the delta equipment cost in memory or hard disks to store duplicate SW binary masters, if there is a mixed machine environment. Fourth, there is a delta efficiency in percent due to training or multi-operational system inefficiency which can be translated to man-hour costs in dollars.

Design Costs and Risks

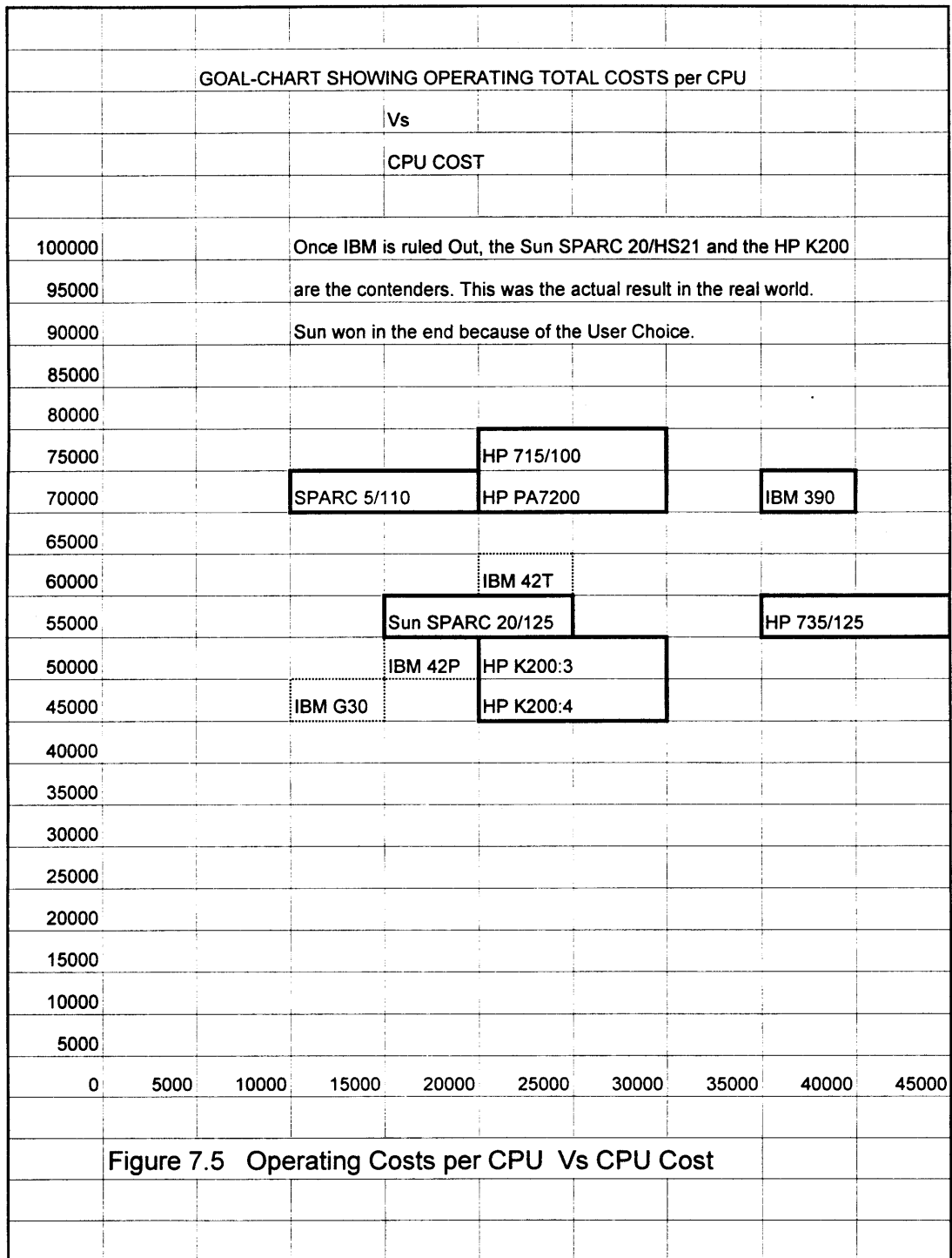
From a design standpoint, there is a tendency to develop confidence by simulation of the design. If a faster simulation method is available, more simulations might be run to assure that the design is correct the first time. The problem with the inability to run simulations to the requisite extent is that this lack may lead to an undiscovered flaw and the field failure of the design. If that design is an FPGA, there is one level of cost (circa \$50,000). If that design is an ASIC, there is in general a much higher level of cost for a repeated design cycle (circa \$400,000).

The spreadsheet labeled in Table 7.3 labeled Overall Workstation Cost Metrics has data and assumptions to address these factors. The results are expressed in the column labeled "Total per CPU 1K hr Cost". This data would be used for a Cost of Performance Vs Cost Goal-Chart. By this table, the untested IBM G30 solution looks least costly followed by the IBM 43P and the HP K200 solutions. The HP 735/125 and the Sun SPARC 20 HS21 solutions are similar.

7. Possible Scenarios

The original CAR called out 10 Sun Seats with what would have been an equivalent Verilog@ Seat power of 6.3 Seats compared to the HP 735/125. The testing experience has indicated that more RAM memory and Hard Disk space is necessary to carry out the simulations successfully. Therefore, only eight Workstations would have been purchasable with a net Verilog@ Seatpower of 5.12.

Table 7.3		Overall Workstation Cost Metrics										P. Emile 8/24/95				Total	# syst	fund
Type of Workstation	Time in Seconds for Vidphil Simulation	Perf. Ratio	per CPU Cost	Number of CPU	Delta	Delta Equipment Cost	Delta	Delta Efficiency %	Delta Efficiency Cost	Delta Confidence Cost	Sum of Costs	Delta effciency X 1000 hrs	Perf Ratio-1 X 5000	Costs	# syst for \$88K	fund balance \$		
					Operating Cost		User Learning	Cost	Cost	Cost								
HP 735/125	369	1	37,000	1		0	4000	20	16000	0	57000				2	14,000		
HP 9000/K200.3	402	1.09	24,667	3		2385	8000	12	9600	4472	49123				1	14000		
HP 9000/K200.4	408	1.11	21,000	4		2114	10000	12	9600	5285	47998				1	4000		
HP 715/100	476	1.29	23,000	1		23198	4000	15	12000	14499	76696				3	19000		
HP PA7200 *est	440	1.19	27,000	1		15393	4000	15	12000	9621	68014				3	7000		
IBM 390	388	1.05	38,555	1		4119	4000	25	20000	2575	69249				2	10890		
IBM 42T	405	1.1	24,000	1		7805	4000	20	16000	4878	56683				3	16000		
IBM 43P *est	400	1.08	19,000	1		6721	4000	20	16000	4201	49921				4	12000		
IBM G30 *est	415	1.12	13,250	4		2493	10000	15	12000	6233	43796				1	35000		
Sun SPARC 20/HS21	465	1.26	22,000	1		20813	0	0	0	13008	55821				4	0		
Sun SPARC 5/110	531	1.44	12000	1		35122	2000	0	0	21951	71073				7	4000		
Sun S1000E	1171	3.17	13750	4		43469	8000	15	12000	108672	185891				1	33000		



Further, the evaluation committee met and put forward a purchase request for three (3) Sun SPARC 20 Model HS21 Workstations based on need and software compatibility. Therefore, there is only a net of \$88,000 to devote to other hardware solutions. The scenarios under the Extended Overall Cost Metric are listed with those factors in mind. Although the IBM solutions are attractive, they cannot be recommended at this time because of the third vendor introduction without a substantial performance advantage, no strong local vendor interest in our location, because of small size, and limited or no compatibility with the IBM Workstation knowledge base at this company location.

Scenarios based on upgrading the Sun Workstations already owned by the company were investigated. It was not economically advantageous to upgrade the SPARC 2 machines, because the upgrade cost was about \$10,000 each, a considerable portion of the cost of a new machine. However, there was an upgrade offered by Sun to upgrade the SPARC 10 machines to SPARC 20 Model H11, SPARC 20/100, by changing the Processor Board at a cost such that 6 machines could be upgraded for \$16,000. This was seen to be very attractive.

9. Recommendations for Purchase

A particularly attractive scenario is to purchase a total of six (6) SPARC 20 Model HS21 125 MHz machines and Upgrade six (6) SPARC 10 units to Model HS11 100 MHz units with the balance of the CAR dollars.

Another attractive scenario is to purchase the HP K200 with three (3) processors for use as a crunch engine and file server, take the balance of the funds after the purchase of the 3 Sun Model HS21 Workstations and use them to Upgrade six (6) SPARC 10 Workstations.

These two scenarios seem to offer the best use of funds, provide maximum capability and compatibility and it is, therefore, a choice between these options which is being recommended.

The changes in the immediate project situation and the continuing changes in design and tool technology will be best served by one of these scenarios.

10. Conclusion

Once, one or the other of the above recommendations is accepted, the equipment should be ordered and this evaluation is complete.

SUMMARY OF CHAPTER 7. Project 2 CAE System Example

The goals of the CAE System Design were to provide a system with enhanced, i.e. faster, digital simulation capability and make that system available to a larger group of engineers. Constraints included funding limitations, approval processes, users' knowledge base, system administrators knowledge base, and required project completion times.

The System Development followed the CAE System Design Methodology Roadmap. First , the project need and proposed solutions were stated in an Electrical Tool Evaluation Report. Second, the Capital Authorization (funding) Request with its' group of financial and technical questions were answered. During the waiting period for funding authorization, the technology was advancing, some system solutions becoming more capable and in general less expensive. When project approval appeared imminent, a detailed evaluation process was implemented and reported. This report was called "EE Workstation Evaluation and Recommendations". The report included goal-charts for both performance and performance weighted by other non-technical factors. The output of this report was a purchase recommendation for the most applicable current technology based on the data from the test and evaluation process.

CHAPTER 8

NON-TECHNICAL FACTORS LIMIT ADOPTION OF TECHNOLOGY CHANGE
BIOLOGY, COLLISION AVOIDANCE, INFORMATION TECHNOLOGY ISSUES

Chapter 8. Non-Technical Factors Limit Adoption of Technology Change

Biology, Collision Avoidance Systems, Information Technology Issues

Background Perspective:

Technology Change impacts many diverse areas, one might even be able to say all areas. The response to a technology advance is often very different in one field compared to another. There are many reasons for this widely varying response. In human biology, for example, there is fear of unleashing a serious disease, or designing a “master race”, or eliminating a species which may later be found to be vital for the survival of Homo-Sapiens. In wartime technology, there is fear of unleashing a physical or biological destruction of the planet or many of its’ inhabitants. For example, in the book “The Manhattan Project” (Ref. 17) it is stated, that the scientists proceeded to detonate the first atomic device after they concluded that the probability of the earth’s’ atmosphere sustaining combustion was less than three in one million. Now it is recognized that the early atomic tests although destructive locally and generating harmful radiation, were on nature’s scale very puny in that many lightning storms can generate much more energy.

In plant biology and small animal experimentation, there seems to be more willingness to employ any advances in gene modification or growth alteration to gather knowledge for future application to other areas.

In computer technology there has been a thirst for the next wave which has devoured the slow of foot and created and supplanted companies and entire industries as the various technology waves surged forward.

In the auto industry, alternate fuels and radically changed designs would threaten a huge established base of suppliers, although there is some of this happening for environmental or other reasons.

Chapter Topics:

In this chapter two areas will be briefly addressed. The first area involves the advances in technology which could be applied to reduce deaths and injury in automobile chain collisions or “fender-benders” as they are often called. The reasons the technology is not applied has more to do with litigation fears than the ability to introduce the technology effectively and economically.

The second area is that of information technology, or more specifically, the selection of desired information from the great masses of data available through various means, e.g. books, manuals,

the Internet. There is a brief discussion of the application of Expert Systems to aid in this process. Many systems of varying degrees of sophistication are being employed to address this information problem at present.

**Collision Avoidance by use of a
Commuter Assisted Braking System (CABS)**

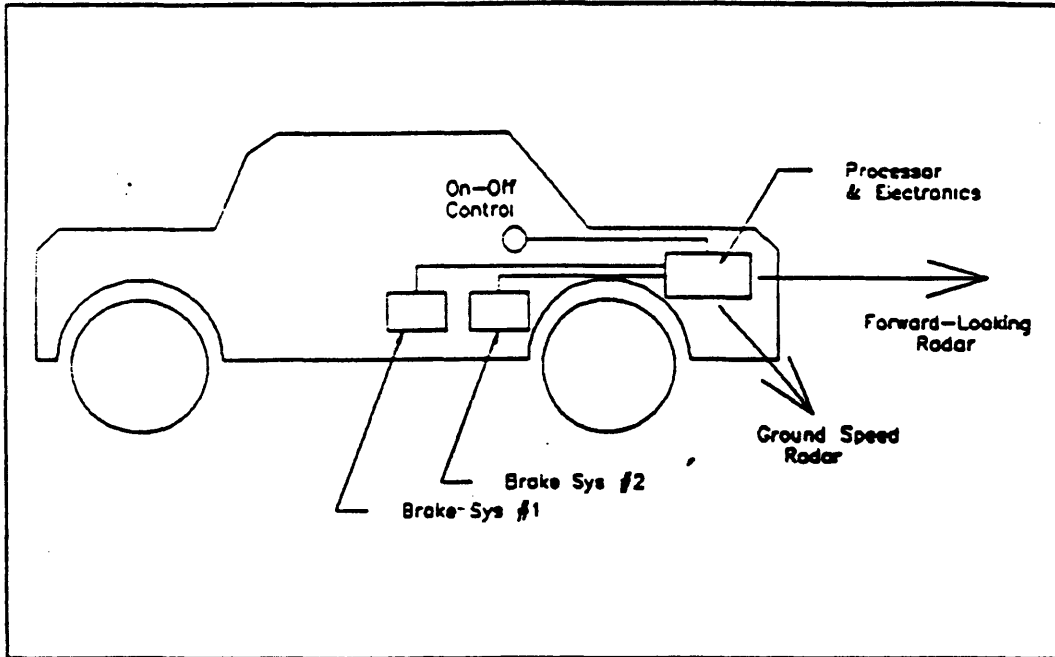
Figure 8.1 entitled “Commuter Assisted Braking System shows a passenger vehicle which contains a forward-looking and down-looking radar device. The radar device or devices provide information on ground speed of the vehicle and closing distance and closing speed on a vehicle or object to the front of the automobile. The information is processed by an on-board computer system which may also have information on the current weight of the car and its cargo as well as the road conditions. Given this information the computer can apply algorithms to achieve vehicle braking such that a safe distance is preserved between the vehicle and the car or object in front. The algorithms also allow the braking activity to be carried out in a manner which subjects the occupants to least stress during the stopping process.

The figure also shows the controls available so that the driver can turn off this system and operate the car braking in a normal manner.

The savings in vehicle damage and personal injury might be enormous if such a system were available to commuters' vehicles for rush hour use in places like California, New York and Boston to name a few high-density commuting corridors. The drivers would arrive home more relaxed and this might also contribute to an improved quality of life for regular commuters.

COMMUTER ASSISTING BRAKING SYSTEM (CABS)

ILLUSTRATION DIAGRAM:



OPERATION:

Ground Speed Radar Measures Forward Motion.

Forward Looking Radar measures distance and relative motion of hard target (vehicle or obstacle in front).

Processor Computes and automatically applies proper braking to avoid impact, using vehicle and other characteristics.

System is automatically activated at engine start, but can be disabled by driver.

Figure 8.1 Commuter Assisted Braking System Illustration

As part of an MIT design project, I carried out a design cost estimate for such a system. With the technology available today, it is estimated that a CABS system could be implemented for \$500 - \$700 per vehicle in large quantities. Small Doppler radars have been available since the early 1950's. They were used by scientists at the Harry Diamond Laboratories to measure the speed of thrown baseballs during an open house demonstration. In a published article in October, 1994, the Ford Motor company, Dearborn Division, described a small car mountable radar suitable for identifying objects as small as a rabbit more than 100 feet ahead of the car in total darkness,. Computer processing power and the availability of current items such as the automatic electronic braking systems, currently installed on many cars, make the discussion of the electronic and electromechanical portion of the equation merely a decision to act. Technology invention to incorporate Commuter Assisted Braking Systems is not necessary.

As part of another MIT course in New Product Innovation, the customer interest and feasibility of the CABS was investigated. It was concluded that a system for use on large buses and trucks might be the best introduction method for such a system. Such a system could cost as much as \$15,000 and still be of interest because of the large losses if cargo and vehicle were damaged in a collision. In fact, as part of the research, we did identify that the Greyhound Bus company had installed a proximity warning system on some of their buses. this system will sound a buzzer alarm if the bus is too close to a vehicle to its front.

Many major manufacturers come to MIT for recruitment and product discussion purposes.

During one of these occasions, the Ford Motor company team came and we were able to discuss the merits of a system such as CABS from their standpoint and gain some insight into their plans and thoughts in this area.

Litigation Fears:

Briefly, the Ford team recognized the feasibility of CABS. However, they were very concerned about the litigation liability if such a system were to fail to apply the brakes and the car was involved in an accident. Even if the occupant did not have the system in an “On” or operating mode, but said that he did, much cost and time would be lost in litigation. Their approach to the problem was to extend the notion of an Auto-Cruise Control to allow the proximity warning, of whatever kind, to reduce the gasoline supply to the engine or interrupt the ignition and thereby slow the vehicle. Thus, the responsibility for braking the vehicle would clearly rest with the driver and this Auto-Cruise Control would clearly only be an available assist to the driver.

Such an Auto-Cruise Control may be available on vehicles if further study indicates that consumers want and are willing to pay for it. However, the more effective process is for the moment lost, until some other time, due to the litigation fear by the automobile manufacturers.

Information Technology Examples

Car Repair Example:

Figure 8.2 and 8.3 illustrate an information selection process which is used to determine what the price of repairing a car will be, given several classes of damage. The process also will guide the user to the answer as to whether the car should be repaired at all, if the cost is beyond some percentage of the value of the present car or the cost of a new car of the users' choice. Among the criteria used are whether the damage must be repaired at a dealer or a garage or the part can be purchased at a parts store. It also includes questions to determine if the user is a "Fixer", i.e. is willing and has the knowledge, skills and desire to repair his own vehicle. If necessary, the choices of the user in a replacement vehicle will be included to provide the recommended repair answer.

These diagrams are part of an Expert System Program developed for an MIT course in Knowledge -Based Systems. The particular shell in which this system was developed is called VP Expert. The goal of such a system is to allow the desired answer to the question "what will it cost me to fix or repair my vehicle" to be provided with the fewest number of questions to the system user. For example, if the repair is a light bulb, the system should quickly proceed to the cost answer without asking "what are the new vehicle choices" of the user. On the other hand if

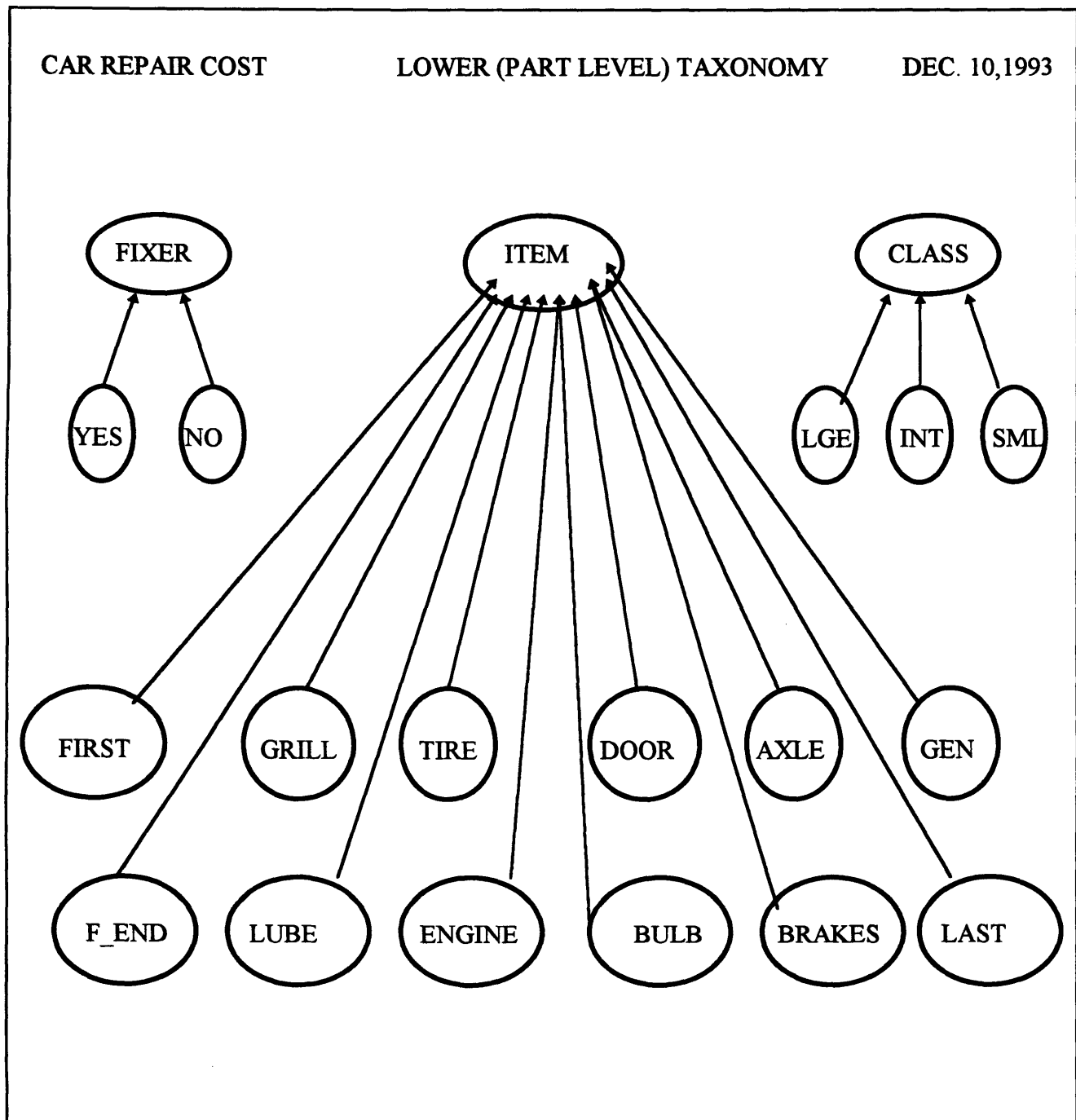


Figure 8.2 Part Failure Level Diagram for Expert Car Repair Cost System

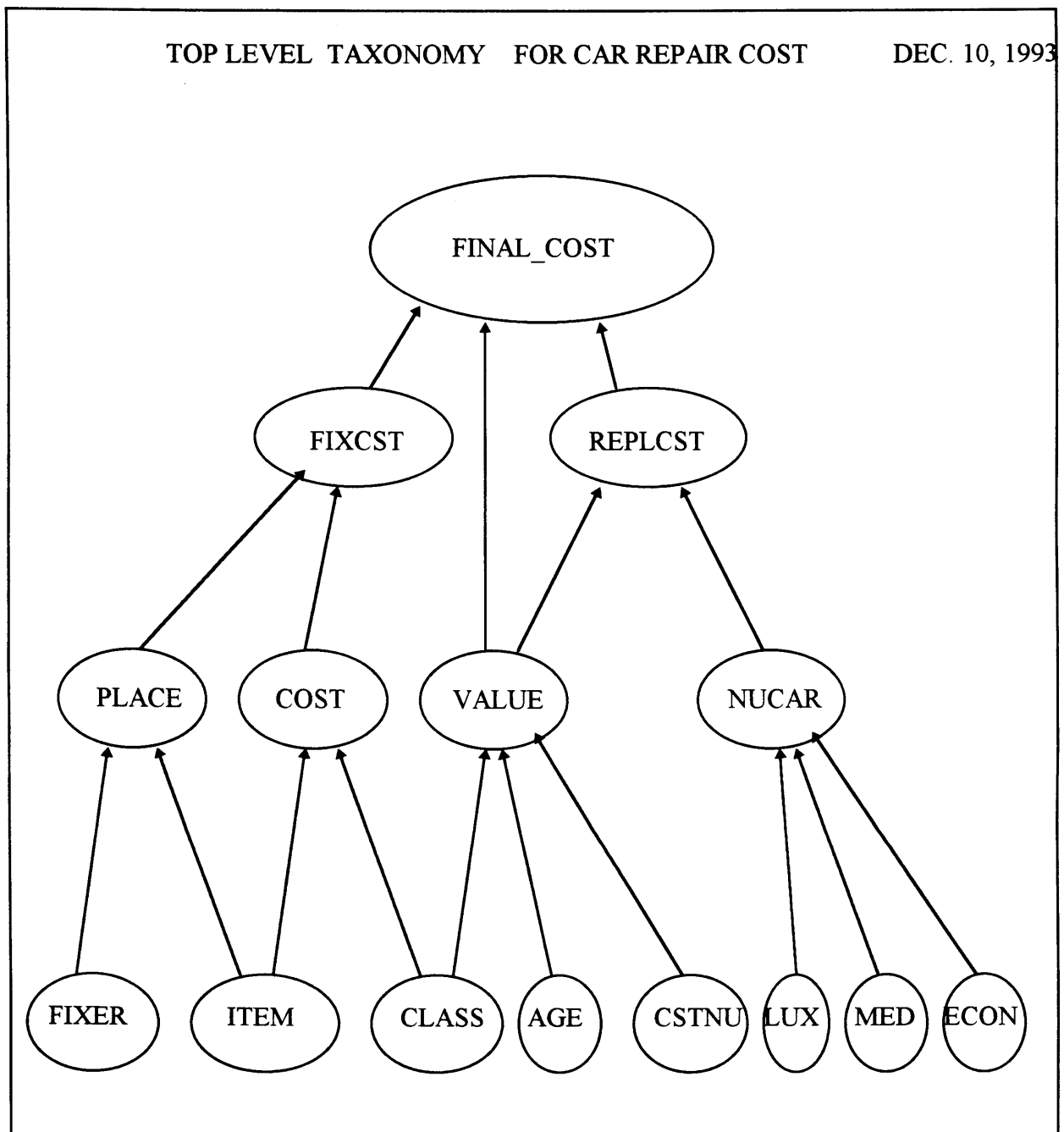


Figure 8.3 Top Level Diagram for Car Repair Cost System

the repair is major, an axle or front end, the place of the repair and the ability of the user to help himself by implementing part or all of the repair is a significant factor in determining the final cost of the repair.

The system presented in the diagrams is a so-called “back-chaining” system where the system designer has programmed in the relationships and knowledge. The user should experience a shorter time and less number of interactions to get his desired results than if all the possible scenarios and configurations had to be considered, in some kind of binary fashion, to achieve the desired answer.

This is a rudimentary example to show that Expert Systems are one method to make information retrieval more efficient for the user.

Information Sharing Example:

The rapid growth of the Internet, Web Pages, and retrieval software suggest that many people want to share and have access to up-to-date relevant information. Netscape, a retrieval software, provided explosive growth to the company when the stock became available because the enormous potential was recognized by many. This methodology may prove so powerful that it is replicated in volume on more local scales, now called Intranet, for controlled access networks within companies. Alternative schemes such as Lotus Notes have been recognized by IBM and others to have tremendous potential for providing information sharing.

An engineer, one Ian MacLennan, proposed a method for providing trade-offs for information sharing (Locally published communication) within a technical design environment. With some modification those trade-offs could probably be applied to many other areas. His trade-off chart is shown as Table 8.1. entitled "Information Sharing Trade-offs". At the bottom he develops a score to enable comparisons of the various options which he feels serve the technical environment of interest. The reader may have different views of the subjective rating numbers listed in the chart, as do I, but the comparison provides a forum to consider the information sharing process within ones' own environment.

Information Sharing Trade-offs

score matrix 0=poor, 5=excellent	group drive	e-mail	newsgroup	web page site	local bulletin board	Lotus Notes
PC viewable	4	4	4	5	5	5
topic categories	2	0	2	4	5	4
date/subject sort	2	0	0	3	5	4
posting	5	5	2	3	5	3
enclosures	5	4	2	4	5	3
archive	2	0	3	4	4	4
threading	0	0	1	4	5	2
access	3	3	3	4	4	4
security	0	3	3	3	3	5
internal only	3	3	3	4	4	3
graphical	1	1	1	4	5	3
low cost (scale 0-10)	10	10	8	8	2	1
admin support (scale 0-10)	9	8	6	7	2	1
score	46	41	38	57	54	42

Table 8.1 Information Sharing Trade-offs in a Technical Environment

Information -Sharing Pitfalls:

As many others, I have e-mail and voice-mail. At the beginning of the week, I reduce my on-screen e-mail messages to less than twenty (20) by archiving or deleting messages. However, by Wednesday my messages are usually up to 100 or so and it is necessary to delete or archive another group of messages. Since it is so easy to notify people by e-mail, once a proper setup is established, it also becomes easy to flood the system and memory capacity with less important messages to a large number of people.

Similar memory consumption occurs on the voice-mail side although the actual numbers are lower. At one company with which I am familiar, the voice-mail system had an automatic destruction date of about ten days for voice messages unless they were actively resaved by the user. There was further, an final automatic destruction for all messages which remained on the system for more than thirty days regardless of whether the user resaved them. By this means, the former company was able to keep their system relatively clean and reasonably sized while still maintaining the main benefits for a voice -mail information -sharing system.

This situation once again identifies the need for the technology innovation process to provide for Design, Construction, Maintenance, and finally Destruction or Recycling in a useful way, whether the material is physical or merely re-assignable storage space on a medium. The need for intelligent (artificial or otherwise) means to discriminate against the less important in favor of the needed data is also inferred.

Summary of Chapter 8.

Technology which can be beneficial is sometimes not adopted out of fear. The commuter assisted braking system is presented as a case in point. Information sharing is a very desirable goal. Methods for doing that effectively are being developed in many areas. Expert systems may serve some role in providing selectivity. An information sharing trade-off table is provided to stimulate the comparison process for ones' own information needs. The tendencies to be inundate users both by data and information and to accumulate stored data are discussed as problems to be attacked by system designers by considering the destruction and recycling part of technology resource reuse equation.

CHAPTER 9

CONCLUSIONS, RECOMMENDATIONS AND SUBJECTS FOR FURTHER STUDY

Chapter 9. Conclusions, Recommendations and Subjects for Further Study

Technology Change affects products, systems and disciplines in many fields. The capability to provide robust designs and estimate whether the project will be financially successful in terms of life and period of use includes the requirement to estimate and quantify the effects of technology change. There is also the need to decide between technological alternatives. This requires developing models which are good enough to provide the negative answer as well as assess the features and benefits of the technology application. This thesis suggests incorporating Goal-Charts and considering the Technology Lemmas in the Generic Engineering Design Process to achieve an Enhanced Design Process which can effectively deal with the effects of Technology Change.

The **Goal-Charts** and **Technology Lemma** approaches come out of the authors' experience in both developing and reviewing products and systems where technology was a dominant factor. Goal-Charts are an effective way to express the project objectives and results in a two dimensional x-y chart. The usual axes of the goal-chart are Performance Measures on the Y axis and Cost Measures on the X axis.

Once the modeling and testing results are plotted on a properly formatted goal-chart, the comparisons indicating which methods are better, which options are feasible, which options meet the limiting conditions can be easily made. The decisions for project implementation can then be confidently approached. Developing the goal-chart at the beginning of a project tends to streamline project efforts.

The Technology Lemmas deal with the effects of the rate of change of technology and attempt to pose the questions which will have a bearing on the product or system life and feasibility in terms of financial payback and use. Posing the technology lemmas is intended to ask the related questions at an early time in the design process, so that modifications in direction can be made at least cost.

Recommendation:

The Enhanced Design Process including the goal-chart and technology lemma questions is recommended for projects where Technology Change is expected to have a significant effect on the life, use or feasibility of the product or system.

Subjects for Further Study:

As the CAE System Design Example in Chapter 7 indicates, the design choices when technology is changing rapidly during the period of design and waiting for funding, are complex and subject to a variety of constraints. In the Design of Optimal Control for an 11-story Building, Chapter 6, there was MATLAB@, a comprehensive program which could handle the relationships and accept parameter modification such that a goal-chart could easily be drawn once the need was understood.

In the CAE Example a similar simple matrix-based system of expressing all the relationships so that directly quantifiable objective results are produced may not be available at present.

Therefore judgment and expertise play a significant part in obtaining good results. Thus, as I see it, there may be a need for something I will call an Operational Technology Calculus (OTC) to handle this situation. This Calculus must combine the Matrix qualities of a MATLAB@, the interrelationships of a Systems Dynamic program like I-THINK@, the gamesmanship matrices to deal with marketing options, possibly a Decision Analysis option and be moderated with a probability link to consider the uncertainties, risks and wide variations in the timing of technology applications by the designer and others. Combining all of these in one is a

formidable task. Therefore a series of intermediate steps in this direction are probably all that can be recommended for now.

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SUMMARY: Senior Engineering Manager with in-depth technical management, product development and strategic planning experience. Strong background in physics, mathematics and computer analysis and design tools. Special expertise in applying the new technologies in semiconductors and embedded microprocessors to enhance product performance and gain market advantage. Demonstrated successful track record in developing products for commercial, industrial and military markets. Conducted on site international negotiations and presentations.

EXPERIENCE:

1982-1994 AMETEK Aerospace Products, Inc., Wilmington, MA
(formerly General Electric)

MANAGER, ADVANCED DEVELOPMENT (1991-1994)

- Oversaw the R&D Programs across the Engineering Department.
- Developed fundamental patents under the R&D program which have been licensed to others, including competitors.
- Developed Engineering Technology Plan in conjunction with marketing and product groups to open new product markets.
- Initiated Strategic Alliance with MIT, Lincoln Lab and Draper Lab to ensure the availability of leading edge, high temperature sensors and electronics into the 21st century.
- Guided selection of CAE hardware and software tools and systems to improve efficiency and reduce expense.

MANAGER, CONDITION MONITORING ENGINEERING (1987-1991)

- Created initial design and proposal for Boeing B777 Airborne Vibration Monitoring Unit (AVM). Product offering unseated two competent long term Boeing suppliers because of its advanced features; won sole source supplier status into the 21st century.
- Designed and developed condition monitoring products for the Grumman E2-C, General Dynamics F-16, Lockheed P-7, Northrop B-2 (Stealth bomber) and Boeing Helicopter V22 Osprey. Products received world wide recognition based on operational cost savings, and increased pilot and aircraft safety.

MANAGER, INSTRUMENT SYSTEMS ENGINEERING (1982-1987)

- Designed and developed a variety of instruments, sensors and systems currently flying on the B-1B, C-5B, KC-135, DC-10, B-747, DC-9 and other aircraft.

1977-1982 Weston Instruments, Newark, NJ

CHIEF ENGINEER

- Directed design of state of the art microprocessor-based digital multi-meters.
- Ensured high quality instrument results by effective liaison with semiconductor suppliers.
- Produced instruments in large volume which were sold internationally and used by key corporations, such as 25,000 Xerox field service meters.
- Conducted International Symposia on measurement instruments in conjunction with the IEEE and New Jersey Institute of Technology.

1973-1977 Emile Technical Group, Roseland, NJ
(Consultants and Designers)

PRESIDENT AND GROUP DIRECTOR

- Provided Navigation studies for FAA and the Naval Air Station.
- Redesignated Blood Analysis machine for Warner Lambert Company.
- Designed factory system to grow Gallium-Arsenide Crystals for Allied Chemical Co.
- Designed child-proof cassette-tape machine for Appleton-Century Crofts, NYC.

1970-1973 Logical Technical Services Corp., New York, NY

EXECUTIVE VICE PRESIDENT

- Provided full financial and administrative management during extended absence of founding president.
- Supplied key efforts in business growth from three to more than 75 employees through successful proposal writing and contract management.
- Managed corporate portfolio of \$500,000 by purchases of commercial paper.
- Won NASA contract to prepare Technology Transfer Publications.
- Supplied technical teams to Litton for Electronic Counter Measures design on destroyers and Bendix for design of SW in ERTS and ALSEP satellites.
- Won and managed OEO contract for administrative and medical oversight of methadone maintenance program in Maryland.
- Supplied technical teams to IBM at Time-Life for design of software for worldwide material purchasing arbitrage.

1967-1970 Monsanto Electronics Technical Center, West Caldwell, NJ

ENGINEERING MANAGER

- Directed 80 technical people in the design of oscilloscopes, counters, frequency synthesizers, pulse generators and digital scan converters.
- Won contract and delivered to the US navy the first low frequency oscilloscopes with switching power supplies.

EDUCATION/TRAINING:

1995 Candidate, Ph.D. Technology Applications to Systems Management Problems,
Massachusetts Institute of Technology, Cambridge, MA

M.S. Solid State Engineering, Catholic University, Washington, DC
B.A. Physics and Mathematics, Earlham College, Richmond IN
General Electric Management Courses, Crotonville, NY
Professional Engineer, New York #41155

PROFESSIONAL AFFILIATIONS:

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SELECTED PUBLICATIONS:

"Design of Optimal Control for an 11-story Building" (to resist winds and earthquakes) First World Structural Conference, Pasadena, CA

"Airborne Condition Monitoring Systems", Avionics Magazine

Articles in book "Microminiaturization of Electronic Assemblies" published by Hayden

TECHNICAL SYSTEMS TRAINING:

Total Quality Management
Design for Manufacture
Statistical Process Control
Extensive PC knowledge and skills

OTHER:

Twelve Issued Patents
Taught graduate level transistor course at National Bureau of Stds. (NIST)
Expert Witness for Securities and Exchange Commission on Semiconductor products
TV appearance describing the operation of computers, Washington, DC
Allocations Chairman for One Million Dollar United Way, Montclair, NJ, 1981
Chairman of the Children's Committee in the UN Year of the Child, 1979
National Vice President for Resource Development for the Mental Health Association, Washington, DC, 1979-1980