DEVELOPMENT OF A STRATEGIC CAPITAL-EXPENDITURE DECISION MODEL INCORPORATING THE PRODUCT ABANDONMENT OPTION

by

Bechir Nacer Ouederni

Dissertation submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Industrial and Systems Engineering

APPROVED:

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May 1992

Blacksburg, Virginia
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(ABSTRACT)

The worldwide technological explosion has dramatically changed the basis of international competition. The accelerated rate of change in product engineering and process technology has led to decreasing product life cycles and made equipment obsolescence a primary concern to U.S. manufacturers. Researchers in academia, industry, and the government have unanimously agreed on the primary role that the investment in advanced manufacturing technologies (AMT, e.g., Flexible Manufacturing Systems) can play in meeting the challenges of the new global business environment. However, U.S. manufacturing technology is still lagging far behind U.S. innovation, and many U.S. firms are practically unable to justify the needed modernization.

Many authors have written about the necessity to account for strategic, long-term benefits associated with acquiring new AMT’s in order for U.S. manufacturers to justify more easily, and more realistically, their investment decisions. However, most of these authors have overlooked the fact that the decision to acquire a new AMT is most likely to displace existing resources, and that unless manufacturers are offered a tool to evaluate the impact of abandoning obsolete or less-than-profitable products and/or processes and justify such a decision, the needed modernization process will continue to be hindered.

The objective of this research is bifold. First, the product/process abandonment problem is reformulated from a new perspective which is congruent with the requirements of the new global business environment. And second, a global decision model (GDM)
incorporating the product abandonment option into the company's overall strategic planning and control system is developed which seeks to help U.S. manufacturers make world-class capital expenditure decisions. To this end, an extensive taxonomic analysis was first conducted to investigate the product abandonment analysis topic as treated in the literature of engineering economy, financial management, management accounting, marketing, strategic management, and corporate organizational and behavioral sciences. The product abandonment problem is then reformulated in view of both the strengths and shortcomings of traditional models and the requirements of the new business environment. Finally, the developed solution methodology is described, implemented as a computer program, and illustrated through an actual case-study.

The GDM is governed by an abandonment algorithm and a multi-attribute decision module (MADM) which are interfaced in a highly interactive mode. The proposed abandonment algorithm uses a recursive dynamic programming search method to determine at each decision point in the project life cycle whether it is more profitable to abandon a product or to continue its operations for one more time period. The MADM translates various strategic objectives of the company, financial and non-financial, into quantifiable performance measures and ranks alternative improvement portfolios. Production simulation techniques and activity-based costing (ABC) are suggested to collect the needed input data for the model. Preference ordering theory is used to account for management's attitude toward risk and make trade-offs between project profitability and riskiness. Once a course of action is selected, its performance must be continuously monitored and controlled in view of prespecified strategic performance targets.

The results obtained from the analysis of the case study confirmed the economic validity of the philosophy underlying the developed solution methodology as well as the ease of application of such a methodology to a wide range of real-life problems. They also demonstrated the benefits that a company can forgo by ignoring the abandonment option throughout the product life cycle.

In conclusion, the developed model is believed to be a sophisticated, yet practical, tool which can help engineering managers reach more informed, and therefore more competitive, decisions about their firms' portfolio of products. Furthermore, pertinent recommendations were made to direct future research regarding this subject matter.
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I DEDICATE THIS DISSERTATION TO MY YOUNGEST SISTER MONIA, TUNISIA’S HOPE FOR A BRIGHTER TOMORROW.
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CHAPTER 1
INTRODUCTION

1.1 RESEARCH BACKGROUND: THE CHANGING BUSINESS ENVIRONMENT

Competition in the world business arena is becoming as fierce as it has never been before. Both consumer requirements and production technologies are changing at such an accelerated pace that many companies find themselves fighting for survival rather than simply searching for excellence. The challenge these companies face has two dimensions. On one hand, consumers worldwide are becoming more informed, are increasingly gaining a stronger bargaining position and are, therefore, expressing more stringent requirements on product functionality, price, quality, and timely delivery to the market. On the other hand, the current explosive technological innovation rate presents a serious threat to the company's competitiveness by continuously down-grading the value of either its products or its production technology, if not both. How American industries have responded to the new requirements of such a dynamic environment have taken much of policy makers' and corporate executives' time and efforts during the late 1980's.

1.1.1 Manufacturing and National Competitiveness

Late in 1986, the Massachusetts Institute of Technology established the Commission on Industrial Productivity to determine whether there actually are pervasive weaknesses in U.S. industrial practices.[Berger et al., 1989] The commission took a
bottom-up approach in their study focusing mainly on the nation's production system. Industries from eight major sectors of the economy (automobiles, chemicals, commercial aircraft, machine tools, steel, textiles, and the closely related industries of computers, semiconductors, and copiers) were studied. After two years of careful investigation, the commission came up with evidence strong enough to dispel the myth that macro-economic trends and high-level policies are the sole factors behind U.S. industrial performance decline. The commission stated this as follows:

"From our industry studies, we have concluded that the setbacks many firms suffered are not merely random events or part of the normal process by which firms constantly come and go; they are symptoms of more systematic and pervasive ills. We believe the situation will not be remedied simply by trying harder to do the same things that have failed in the past. The international business environment has changed irrevocably, and the United States must adapt its practices to this new world."[Dertouzos et al., 1989]

Instead, the commission emphasized the role that manufacturing can play as a primary factor in enhancing U.S. “industrial productivity”, as implied by their statement below.

"For now, it will suffice to say that we believe manufacturing is crucial to the nation’s economic well-being. ... However, most of the evidence we have gathered points to the manufacturing sector as the area where the American advantage in cost and quality has been most severely eroded."[Dertouzos et al., 1989]

Other studies, too, have confirmed the above conclusions. [Bloch 1985, Dornbusch and Summer 1988, Skinner 1985, Wheelwright and Hayes 1984, Wheelwright and Hayes 1985, Hall 1987, and Business Week 1986] For instance, the members of the National Coalition for Advanced Manufacturing strongly believe that manufacturing matters. They have asserted that:
"It must be recognized that competitiveness and productivity are inextricably related. In advanced industrial societies, manufacturing productivity is the primary engine of economic growth and a prime determinant of a nation's standard of living. Thus without growth in manufacturing productivity, the standard of living of the American people will markedly decline."[National Coalition for Advanced Manufacturing, 1990]

The case for manufacturing in the United States is strongly supported by numbers, as well. In fact:

- The U.S. manufacturing industry generates approximately one fourth of the gross national product (GNP) in this country.
- As a segment of the goods producing sector of the economy, which altogether generates approximately 37% of the GNP, it produces 65% of what may be called the primary, real, tangible wealth of the nation.[Bloch, 1985]
- In 1987, gross U.S. exports of services, excluding income from overseas investments and overseas sales of government services, were worth about $57 billion, whereas the total value of goods and services imported into the United States was about $550 billion. Also, in 1987, the total value of manufactured goods purchased in the United States was about $1 trillion, nearly 20 times the volume of services exported.[Dertouzos et al., 1989]

Yet, the U.S. manufacturing sector is still not taking as much attention as it deserves from both policy-makers and industrial producers. In fact, by migrating to service industries, the United States is increasingly losing its manufacturing capacity to its Western European and Asian competitors. Akio Morita, chairman and co-founder of the Sony Corporation coined this issue as follows:

"American Companies have either shifted output to low-wage countries or come to buy parts and assembled products from countries like Japan that can make quality products at low prices. The result is a hollowing of American industry. The United States is abandoning its status as an industrial power."[Business Week, 1986]
Furthermore, American manufacturing is still lagging far behind American technological innovation. The Commission on Industrial Competitiveness's final report to the President contained:

"The relative neglect of process technologies places American industry at a competitive disadvantage, since Japan's prowess in process technology is the basic reason why Japanese industry can manufacture, at higher quality and lower cost, products which were first designed and commercialized in the United States"[President's Commission on Industrial Competitiveness, 1985]

Erich Bloch, then-director of the National Science Foundation, has noted that:

"The one essential reason for the loss of U.S. position in vital high-growth technology markets is that the United States has failed to apply its own technologies to manufacturing."[Bloch, 1985]

1.1.2 Attaining Manufacturing Excellence

Peter Turney defined manufacturing excellence as follows:

"Manufacturing excellence is the deliberate and continuous improvement of all activities within a manufacturing company with the goal of achieving a competitive advantage. Continuous improvement takes place within the framework of a competitive strategy that uses market, environmental, and technical opportunities to achieve a favorable competitive position in an industry."[Turney, 1989]

Although an increasing number of American companies are recognizing what it takes to attain a world-class manufacturing status [Wiater 1985, Kearns 1984, Main 1981, Meadows 1980, and Miller 1988], many U.S. firms have not yet realized that they have to make far-reaching changes in the way they do business. To this end, they have to adopt new ways of thinking, organizing, and managing both their technology and human resources. Central to this change process is a good understanding of the nature of the ever-
changing business environment and of how to make their firms respond effectively and efficiently to the market's new requirements.

Depending on the nature of their operations, different industries are affected to different extents by new trends in manufacturing. Yet, to sustain a leadership status in manufacturing, companies must account for the combined effect of all such trends and strive to use them to their "competitive advantage". Only then, can U.S. companies fulfill the prerequisites to attaining manufacturing excellence, and only then can U.S. manufacturers make world-class product decisions.

1.1.3 Product Decisions and the Product Life Cycle Concept

Traditionally, the factory used to be viewed, analyzed, and evaluated on a compartmental basis. Jobs and reports were passed from one individual or function to the next serially with everyone focusing only on his or her own internal problems. Upper management usually kept distance from the shop floor depriving it from any strategic guidance and have typically encouraged the fragmentation of the factory down to the single-machine level by appraising each person based on his or her individual performance and each unit based on its individual utilization. This approach would lead, at best, to suboptimal results.

In contrast, the new "integrated-systems approach" views the factory as a whole composed of individual elements, plus any interaction among them, all combined to achieve a common objective or set of objectives.[Solberg, 1988] Accordingly, all cross-sectional dependencies among various activities and functions within the entire "system" are accounted for. Similarly, more vertical interaction between the corporate level and the shop floor must be established. This integration process should reach even beyond the physical
boundaries of the factory to involve both vendors and customers in all product and process
decisions (i.e. buy vs. make, purchase vs. lease, product design, material purchasing,
process planning, product manufacturing, pricing, marketing, distribution, customer
support, and finally product abandonment).

Thus, product manufacturing, for instance, is no longer viewed as the sole
responsibility of the manufacturing department. Instead, representatives from all functional
areas within the company must sit around the same table, all under the same hat of a unified
corporate strategy, and interactively make any product decision, be it its design,
manufacturing, marketing, or abandonment.

The “product life cycle” (PLC) concept provides a good framework to analyze and
evaluate products under such integrated-systems philosophy, commonly referred to, in this
context, as “simultaneous engineering”. By following the product from its initial inception
until its disposal, the PLC provides for a more complete assessment of various costs and
benefits incurred or generated throughout the product’s entire physical life. This concept
confirms very well with the integrated-systems approach and allows the decision-maker to
account for the pertaining trends in the business environment. [Harrigan, 1980]

Typically, most products follow a four-stage life cycle including: product
introduction to the market, sales growth, market maturity, and sales decline as shown in
Figure 1.1. During the introduction stage, the product is still new to the employees and its
image is not well established in the market yet; therefore, extra employee-learning time and
product marketing expenses are required making the company’s profit margin negative or
very thin at best. As the product becomes familiar to both employees and consumers, its
production becomes more efficient and its sales volume grow rapidly causing the profit
margin to reach its peak. During the maturity stage, the market reaches its saturation level
requiring the producer to spend more funds on product modifications, among other
Figure 1.1 Product Life Cycle
marketing mix expenditures, in order to maintain market position. Hence, the product's profit margin starts to decline. Finally, unless major modifications are brought to the product, either consumers will, with time, look down to its value, or new entrants will profit of its mature market and compete to share as much as possible of it. In both cases, sales volume will go downhill and the profit margin will disappear.

1.2 RESEARCH PROBLEM: THE PRODUCT ABANDONMENT DECISION

Throughout the post World-War II management era, corporate focus has greatly changed from one stage of the PLC to another. However, two main characteristics have marked this managerial phenomenon:

1) Neglect of the late stages of the PLC;

Management focus has, typically, been skewed towards early stages of the PLC. Namely, management emphasized research in product design and development (introduction stage) and in manufacturing cost reduction (market growth stage). That is, product research and decisions regarding the market maturity and decline stages (i.e., continuous product differentiation, after-sale product support, or product abandonment) have taken the least attention from corporate executives as well as researchers and academicians. For instance, in a 1985-study commissioned by the National Association of Accounts (NAA) and the the Society of Management Accounts of Canada (SMAC) to
explore the decision process used by managers when making product abandonment decisions, Stephen Landekich, then director of research at the NAA, stated that:

"According to the results reported here, product abandonment is considered to be relatively unimportant as compared to other product related decisions. Only twenty percent of the firms participating in the survey had a formal (written) policy with regard to product abandonment." [Lambert, 1985]

(2) Lack of integration among different stages of the PLC:

Only recently, with the renaissance of "strategic planning" schools, have PLC advocates and, to a lesser degree, a few managers realized the importance of integrating product decisions with respect to different stages of the PLC. But, here again, most of the work has been done with respect only to the early stages of the PLC (i.e., concurrent engineering, design to cost, design to manufacturability, etc. [ASME, 1989]).

During the immediate post-World-War II decades, the negative impact of such managerial practices was greatly obscured by a growing market for U.S. manufactured goods. Economies of scale were the way to sustaining market growth, and technological stability made it a given for U.S. manufacturers not to worry about their production processes or about foreign competitors who might threaten their leading market position. Starting early 1970's, it became obvious to U.S. manufacturers that business globalization is a truth and that market growth is no longer a given. Decreasing PLC's made it a must for manufacturers striving to survive in such a new business environment to reposition their managerial focus on their production processes and the ever-changing consumer needs, at least, as much as they used to do regarding their products. In a 1986-report submitted by the Manufacturing Studies Board to the National Research Council (NRC), the Commission in Charge wrote:
"There is substantial evidence that many U.S. manufacturers have neglected the manufacturing function, have overemphasized product development at the expense of process improvements, and have not begun to make the adjustments that will be necessary to be competitive."[National Research Council, 1986]

To this end, managerial focus cannot but be extended to encompass the late stages of the PLC. Accordingly, a given product is viewed, analyzed, and evaluated from a broad perspective including various PLC stages plus any interaction among them. Thus, abandoning a product, a process, or even a whole business unit might prove to be the most rewarding course of action; and therefore, must be considered as a strategic option during the PLC analysis. Dr. Douglas M. Lambert, of the Graduate School of Business Administration at Michigan State University, has affirmed that:

"Increased sales can no longer be relied upon as a means of improving profits. Increasingly, companies will find it necessary to determine the contribution generated by each product and prune the product line of losers. The climate of the 1980's makes product abandonment a decision area of major importance to U.S. industry, and the need for research in this “underdeveloped” area of management is great."[Lambert, 1985]

1.2.1 Why abandon an ongoing concern?

In a global environment marked by inflation, soaring energy costs, hardly predictable currency-exchange rate fluctuations, political instability in many regions of the globe, and high uncertainties about the dynamics of international factors of production, one can think of more than one factor causing the demand for a given product to decline and, therefore, its PLC to decrease. Similarly, one can think of more than one reason to explain why a company might be better off abandoning an ongoing concern or product rather than continuing its apparently unprofitable operations. These causes of demand decline and reasons for product abandonment can both be grouped into three broad categories: (1) product-related, (2) process-related, and (3) business- environment-related causes and reasons.
1.2.1.1 Product-related causes and reasons

Generally speaking, the PLC literature is unclear concerning the causes of decline in the demand for a product. However, one can enumerate several primary factors contributing to the early transition of a product from its maturity to its decline phase. Those which are product related include, but are not limited to:

- Functional Obsolescence;
- Substitute Products, and
- New Entrants with Marketing Advantages.

At the other end of the product abandonment decision are the reasons for, or potential benefits from, such a decision. It is part of the rational economic wisdom that in order for a firm to increase its value, at any point in time, decisions should be made which generate the highest long-term reward to its “stakeholders”. Accordingly, the firm cannot afford to tie up its funds in investments that are either below acceptable standards (efficiency perspective) or less attractive than alternative uses of these funds (effectiveness perspective). Dr. John J. Clark, professor at the Business School at Drexel University, has noted:

“Failure to abandon projects that are no longer desirable could be very costly. By the same reasoning, failure to abandon projects that could make funds available for substantially better investment opportunities might also be costly from an opportunity standpoint.” [Clark et al., 1978]

That is, management must identify and eliminate products that represent a drain on corporate resources with no promise for future payoff. By doing so, not only does the
company avoid sustaining chronic losses but it, also, releases committed funds to more profitable uses. In fact by abandoning a "sick" product:

- First, the company saves the extra time and resources required to produce it, expedite its deficiencies, and get it to a more resistant customer. Dr. Robert W. Eckles has noted:

  "In addition to the obvious costs associated with weak products, there are a number of hidden costs. For example, weak products may consume a disproportionate amount of managements time, require costly short production runs, and incur higher marketing and physical distribution costs than profitable products. Failure to abandon weak products also may delay the aggressive search for replacements, thereby threatening the company's future profitability."

  [Eckles, 1971]

- And second, the company is likely to generate positive cash flows as tax effects for depreciation write-offs, sale of equipment, return of working capital, and the use of space, time, and funds for more profitable products.

  [Aggrawal and Soenen, 1989]

1.2.1.2 Process-related causes and reasons

Technological innovation is, obviously, the most visible acting force which influences the shape of a nation's manufacturing competitiveness. The accelerated rate of technological improvements and innovation in manufacturing processes has greatly contributed to the trend of decreasing PLC's. The associated decline in market demand for the product can be caused by any of the following process-related factors:

- Technological Obsolescence;
- Physical Obsolescence, and
- Lack of Process Flexibility.
For example, by failing to abandon their antiquated production technologies at the right time, U.S. steel industries are still paying the price of such a mistake. In their report on the U.S. steel industry performance, the MIT Commission on Industrial Productivity have noted:

"In the postwar decades, the domestic integrated producers lost their technological lead. They failed to adopt quickly the newest technologies, such as the basic oxygen furnace (BOF), continuous casting, and computer controls, as they became available in other parts of the world. And when the advantages of the new technologies became apparent, their adoption was delayed by financial commitments to existing plants and a shortage of investment capital." [Dertouzos et al., 1989]

1.2.1.3 Environment-related causes and reasons

The list of factors, exogenous to the company, which can cause the life cycle of a given product, or its demand in the market, to decline can be very long. Among the primary factors, one can cite the following:

- Changing Consumer Habits;
- Demographic Changes;
- Regulatory Policies;
- Changes in Major Supplier or Customer Technologies;
- Entry of Aggressive Competitors, and
- General Market Uncertainties.

1.2.2 The dilemma

As competition intensifies and technological change alters both product and process characteristics, uncertain economic growth and decreasing PLC's can no longer obscure
less-than-competitive, let alone erroneous. business decisions. U.S. manufacturers are increasingly recognizing this fact and trying hard to change their manufacturing technologies, as well as their managerial philosophies, so that they can meet the challenges of such new business environment. Unfortunately, a significant number of them found themselves in an intriguing dilemma:

_**On one hand,**_ their existing facilities were developed for a different business environment. Postwar-era strategies, such as economies of scale, were based on the assumption that repetition, experience, and homogeneity of tasks are the key factors to promote efficiency. Accordingly, production systems were designed to accommodate long runs (high-volume batches) of standardized products with provisions for large inventories to buffer against market uncertainties. Such manufacturing facilities are very limited in scope and performance and have, certainly, failed the international test on product functionality, cost, quality, and market delivery. It is a fact that the United States is presently operating with the most obsolete equipment among all major industrialized countries and is modernizing its facilities at a slower pace than most of them.[Sawhney, 1991] Jerald D. Stokes, partner at Arkansas Technologies, Inc., wrote in his testimony before the Senate Small Business Committee on Innovation, Technology, and Productivity:

"Japan and Germany have, after rising from the ashes, poured enormous amounts of money into modern fixed assets, with substantial focus on generating state-of-the-art manufacturing facilities, properly equipped to be cost-efficient producers, and thus have developed certain industries to be more than cost-competitive with aging and unrejuvenated U.S. bastions of manufacturing capability."[Walsh, 1988]

It is a fact that more than 34% of U.S. machine tools are twenty or more years old, the highest proportion of any major industrialized nation.[Bylinsky, 1983] The corresponding figures for England and Japan are 24% and 18%, respectively.

Introduction
Furthermore, in the United States only 31% are less than ten years old, while in Japan an astounding 61% are less than ten years old [Meredith and Hill, 1987] (also see Figure 1.2 below).

On the other hand, an inherited reactive attitude towards the product abandonment option, among several other managerial misconceptions about when and how to modernize the existing manufacturing systems, has certainly been a major obstacle to this modernization process. The problem has only been made worse by the lack of strategically sound capital-expenditure models which explicitly recognize and realistically account for various costs and benefits of abandoning antiquated technologies and/or acquiring new AMT’s. Dr James L. Pappas has ascertained that:

“The abandonment option is an exceedingly important factor in capital asset management. Failure to properly incorporate this possibility into decision analysis will likely lead to suboptimal actions.” [Pappas, 1977]

1.2.3 Problem statement

Considerable efforts have been lately deployed to change this state of affairs. However, the resulting solution approaches and policy recommendations have, typically, been marked by an apparent lack of integrative character with respect to the entire PLC, and their implementation has been on a piece-meal basis, at best.[Hall, 1987] Thus, the need arises for a solid strategic planning and control tool which enables U.S. manufacturers to reap the benefits of integrating various state-of-the-art managerial concepts and planning tools such as “continuous improvement”, “waste elimination”, “strategy-driven evaluation”, “total quality management”, “activity-based costing”, and “total performance measurement” among others (terms between quotes are defined in Appendix A).
Figure 1.2 Average Age of Industrial Equipment: U.S. vs. Japan

Source: [The National Coalition for Advanced Manufacturing, 1990]
In this research, the problem under investigation is (1) how to carefully prescribe a new managerial mind-set which proactively approaches the product abandonment problem as a strategically competing alternative? and (2) how to design an implementation tool which ensures the needed integration process mentioned above and at the same time incorporates the product abandonment option into the capital-expenditure decision-making process. Once these two problems are adequately solved, U.S. manufacturers will be able to acquire enough managerial flexibility to meet the challenges of the ever-changing business environment. And therefore, they will be able to maintain a leadership position in the international marketplace.

1.3 RESEARCH OBJECTIVES

In response to the problem stated above, this research is intended to provide decision-makers with a reliable model of corporate capital expenditure analysis (also to be referred to as the Global Decision Model, or GDM) which treats the product abandonment decision as an integral part of the overall PLC planning process. In particular, the following issues were addressed by the research:

(1) formulating the product abandonment problem from a new perspective which is consistent with various concepts and assumptions underlying the development of the GDM;
(2) developing a sophisticated, yet practical, abandonment algorithm which can accommodate a fairly wide range (i.e., with respect to cash flow patterns, capital rationing constraints, exit barriers’ profiles, etc.) of real-life industry situations. In particular, a powerful decision rule is to be developed which tells the decision-maker whether and when
in the product, process, or project life cycle it is strategically optimal to abandon the ongoing concern, and

(3) Incorporating the product abandonment option into the overall corporate planning and control system and extending its application from single project accept-reject (or keep-abandon) decisions to the case where the decision-maker has to select among competing mutually-exclusive investment portfolios.

1.4 RESEARCH SCOPE AND BASIC ASSUMPTIONS

Because of the diversity of concepts and operational tools needed to perform a complete implementation of the proposed solution methodology and to limit the scope of the research, the following major structural assumptions were made:

1- The market is perfectly competitive;
2- The company's corporate strategy must be well defined and translated into quantifiable performance measures with specified weights and improvement targets;
3- Strategic exit barriers must be identified and their maximum tolerable heights must be determined;
4- The behavior of management under conditions of uncertainty must be closely described with an experimentally determined corporate utility function;
5- A reliable forecasting model must be accessible to the company so that future events and outcomes are estimated as accurately as possible;
6- A production simulation software package should be available so that the performance of the existing system and any proposed improvement portfolio can be readily evaluated;
7- An "Activity-Based Costing" implementation package must be accessible to the company so that accurate cost profiles can be determined for each product within the studied system, and

8- The suitability of a Markov model to describe the cross-temporal inter-dependencies among future cash flows must be verified first.

1.5 RESEARCH ACTIVITIES AND ORGANIZATION

To achieve the aforementioned objectives, the research work has been divided into the following four major parts:

(1) An extensive bibliographical search was conducted to assess the current state of knowledge about the topic of "Abandonment Analysis" as treated in the literature of engineering economy, financial management, management accounting, marketing, and corporate organizational and behavioral sciences. Also, the frequency and ways of making abandonment decisions in actual industry practices were investigated. The results from this research phase are presented in chapter 2 whose main thrusts are to:

(a) outline the taxonomy of the product abandonment analysis topic;

(b) analyze the theoretical foundations (i.e., economic and strategic validity) of major product abandonment models developed to date, and

(c) highlight major conceptual and operational difficulties that have kept companies from successfully implementing such models;
(2) The second phase constitutes the heart of the research. It first seeks to describe the new managerial philosophy that decision-makers should acquire in order for them to feel:

(a) more comfortable dealing with abandonment analysis as a “routine” exercise, and

(b) more confident applying a decision tool that provides for more realistic abandonment decisions within an activity-based environment.

Then, it describes the proposed solution approach and its implementation methodology. The major thrust of this research phase is a software package which integrates various state-of-the-art concepts in a single strategic product abandonment model. The results from this phase are presented in chapters 3 and 4;

(3) An illustrative case-study is developed which tests the operational validity of the proposed model. Results from this research phase are summarized in chapter 5, and

(4) Pertinent conclusions and recommendations are then to be drawn based on the results obtained from the case-study as well as on potential applications of the model. These will make the body of chapter 6.
1.6 RESEARCH CONTRIBUTIONS AND SCIENTIFIC SIGNIFICANCE

This research offers a powerful implementation tool encompassing state-of-the-art approaches to world-class decision-making. It recognizes and seeks to master complexity and uncertainty in real-life situations. Major thrusts of this research work include:

1- A realistic global decision model which incorporates the product abandonment option into the company’s overall strategic capital-expenditure system;

2- A comprehensive taxonomy of the product abandonment analysis topic as treated in the literature of engineering economy, financial management, marketing, strategic management, and corporate organizational and behavioral sciences;

3- A powerful, yet practical, software package which uses dynamic programming to analyze the product abandonment option as a possible improvement opportunity inherent to the company’s strategic planning and control system;

4- An illustrative, implementation case-study which can be used for both documentation and educational purposes in academia as well as in industry, and

5- A case-application of dynamic programming as an operations research tool in situations of multi-attribute decisions.

Besides these tangible contributions to the body of scientific knowledge, this research work has addressed several operational and strategic issues of critical relevance to the success of any effort geared towards attaining manufacturing excellence in the international marketplace. These issues include the following:
(1) Challenging U.S. manufacturers to think of the product abandonment option as a possible improvement opportunity which must be inherent to the company’s strategic planning and control system;

(2) Expanding the organizational scope of conventional abandonment algorithms by incorporating strategic considerations into the model;

(3) Expanding the operational scope of conventional abandonment algorithms by considering a system-wide approach rather than a single-operation or compartment-based approach to evaluate the overall impact of a given course of action;

(4) Using an activity-based environment which provides for better measurement and allocation of costs to specific products;

(5) Evaluating only those alternatives relevant to the company’s corporate strategy as indicated by the activity-based reports on the existing system;

(6) Allowance for the use of up-dated forecasts for the various dynamic inputs to the model;

(7) Better monitoring of project riskiness by considering managerial attitudes toward risk and analyzing projects in terms of improvement portfolios rather than on a single-project basis;

(8) Considering after-tax effects on cash flows and abandonment values in the calculation of a given product’s financial merit;

(9) Extending abandonment analysis from the single-project keep-abandon decision to choosing among competing, mutually exclusive alternatives, and
(10) Expanding the application of dynamic programming as a mathematical decision-support tool to deal with multi-attribute decision situations.

Adopting the findings of this work will promote scientific and technological knowledge. That is, by adopting a proactive way of thinking and making decisions, efforts and time of scientists and technology innovators will be focused only upon areas of demand for improvement. Technology should emanate from the need for it and not the contrary. This is also a very precious educational lesson which goes beyond the limits of capital expenditure decision-making.

A more straightforward benefit is the fact that those manufacturers who are struggling for their own survival (mainly small businesses and single-product firms) will overcome, with enough confidence, traditional fears of investing in new AMT’s and/or abandoning ongoing concerns. Thus, U.S. manufacturers can regain a competitive advantage in the international market, and good domestic standards of living can be ensured. Besides these social benefits, by stressing the integrated systems approach, the proposed methodology calls for more inter-disciplinary involvement in the decision-making process. Accordingly, the infrastructure of science and engineering will be redistributed in a manner which provides for more understanding and improvement of the nation’s scientific and engineering research, education, and manpower base.
CHAPTER 2

A TAXONOMY OF THE PRODUCT ABANDONMENT TOPIC

This chapter presents the findings of an extensive taxonomic analysis of the product abandonment topic. Published literature in the fields of marketing, strategic management, financial management, management accounting, organizational management, and corporate behavioral sciences was extensively investigated to assess the questions of whether and how the product abandonment decision has been analyzed in academia and made in industry. Several models have been identified across the above fields. However, only three broad categories, or schools of thought, were identified which encompass practically all published product abandonment models. These are the “engineering economy, financial management, and management accounting” school, the marketing school, and the “strategic management and corporate organizational and behavioral sciences” school. Each school groups research fields having the same general solution approach to the product abandonment decision. Moreover, all the researched models were classified into two groups: normative models and empirical models. Major empirical studies regarding the product abandonment problem were investigated and are presented in this chapter under the “Empirical Models” section.

Major relative advantages of, and theoretical shortcomings and operational difficulties associated with, traditional abandonment models are discussed in lights of the requirements of the new manufacturing environment.

Finally, pertinent conclusions and implications from this taxonomic analysis are drawn to guide decision-makers during the design or implementation of their product abandonment decision models.
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2.1 NORMATIVE MODELS

2.1.1 Engineering Economy, Financial Management, and Management

Accounting Literature

Although the product abandonment problem was recognized for the first time in the financial management literature by Shillinglaw [Shillinglaw, (1959a, 1959b)] as early as 1959, this topic was not treated on a systematic basis until about a decade later.

2.1.1.1 Introduction of the Product Abandonment Option

Late in 1967, professors Robicheck and Van Horne, of the Graduate School of Business at Stanford University, published their first article regarding the product abandonment option and its role in the capital budgeting decision [Robicheck and VanHorne, 1967]. By 1969, professors Dyl and Long wrote their first abandonment-related article, in which they criticized the Robicheck-Van Horne algorithm and proposed their own algorithm [Dyl and Long, 1969]. Robicheck and Van Horne soon wrote a second article, in which they replied to the comments by Dyl and Long, criticized the Dyl-Long algorithm, and presented a revised version of their original model [Robicheck and Van Horne, 1969].

These pioneering articles have certainly marked the birth phase of the product abandonment option as a critical dimension of the firm's capital budgeting function. Dr. Anthony F. Herbst wrote:

"The R-VH (Robicheck-Van Horne) article called attention to what has been a neglected dimension in capital budgeting---abandonment value. ... Their article was an important step in bringing to academic attention a problem in capital budgeting that has
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always been of practical importance, but for which little explicit theoretical guidance has been offered.” [Herbst, 1976]

Subsequent works, although very few, have typically been directed towards improving the findings of their antecedents either by including one or more new aspects of the product abandonment option and its impact on the firm’s financial profitability or simply by trying to develop a more generic abandonment algorithm.

Major works published, to date, in the engineering economy, financial management, and management accounting literature are cited below by chronological order along with a brief presentation of how each work related to previous ones.

2.1.1.1.1 The Robichek-Van Horne Algorithm (R-VH)

In their 1967-article, professors Robichek and Van Horne stressed the importance of including the abandonment option in the capital budgeting decision. They have noted that:

“In the appraisal of investment proposals, insufficient attention in the literature is paid to the possibility of future abandonment. Customarily, projects are analyzed as though the firm were committed to the project over its entire estimated life. However, many projects have significant abandonment value over their economic lives; and this factor must be considered in the capital budgeting process if capital is to be allocated optimally.” [Robichek and VanHorne, 1967]

In constructing their abandonment decision rule, they advocated that a project should be abandoned at that point in time when its abandonment value first exceeds the net present value of the expected future cash flows associated with continued operations, discounted at the cost of capital rate. They also suggested the use of “internal rate of return” as an alternative decision rule. In order for these two rules to lead to the same optimal
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abandonment decision, the authors based their model on the following assumptions:[Robichek and VanHorne, 1967]

(1) A meaningful cost of capital rate does exist in the sense that the firm has access to capital at this cost;

(2) There is no capital rationing. If a project meets the acceptance criterion, capital is available at the cost of capital rate to finance the project;

(3) All projects, existing as well as proposed, have the same degree of risk, so that the acceptance or rejection of any project does not affect the cost of capital, and

(4) A meaningful, unique internal rate of return exists.

The R-VH model defines cash flows as all cash revenues that would be lost by abandonment less all cash expenses avoided. It also defines abandonment value as the net disposal value of the project to the company, in either cash or cash savings.

Using this decision rule, the proposed algorithm showed how consideration of abandonment may enhance the accept-decision by increasing the overall net present value (NPV) of the project if abandoned at that calculated point in time rather than at the end of its physical life. Moreover, the study has showed how the abandonment option can affect the riskiness (global variability and skewness) of a project. The Monte Carlo simulation technique was suggested when the decision problem is complex with respect to the number of possible future outcomes.

In the particular case of uniform abandonment values with respect to different cash flow sequences (probabilistic state outcomes), a constant positive abandonment value yields a higher expected project NPV, a lower variability, and a shift of the skewness of the obtained NPV distribution to the right. Thus, a risk-avoider investor is more likely to accept such project than in the case where the abandonment option is not taken into account. However, although the model assumed certain abandonment values, it discounted
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them back to the present by using the risk-adjusted cost of capital. Theoretically, this is valid only when the abandonment values are mean values of distributions having characteristics similar to the cash flows associated with continued holding of the project [Pappas, 1977].

2.1.1.2 The Dyl-Long Algorithm (D-L)

In their 1969-article, professors Dyl and Long argued that the R-VH algorithm does not necessarily lead to an optimal abandonment timing since it ignores the potential profitability of a deferred abandonment decision [Dyl and Long, 1969]. Instead, they have proposed a decision rule according to which the project’s NPV is calculated under the assumption of abandonment in every future period. The largest such calculated NPV, say found for period $t^*$, is then compared to the current abandonment value of the project. If it exceeds this value, the project should be held and abandoned at the end of period $t^*$. Otherwise, it should be abandoned at the current time.

The framework of the D-L algorithm is as follows:

**Step 1:** calculate the present value, $PV_{τ,a}$, at the current time, $τ$, of the stream of expected cash flows generated by keeping the project for $(a-τ)$ more periods and abandoning it at the end of period $a$ as:

$$PV_{τ,a} = \sum_{t=τ+1}^{a} \frac{EC_t \cdot τ}{(1 + k)^{i-τ}} + \frac{AV_a}{(1 + k)^{a-τ}}$$

(2.1)

for all future abandonment time possibilities: $τ+1 ≤ a ≤ n$
where: $EC_{t, \tau}$ is the expected cash flow in period $t$ as of time $\tau$

$AV_a$ is the abandonment value at time $a$.

$k$ is the cost of capital to the firm

$n$ is the estimated project life

**Step 2:** determine the largest present value among those calculated in step 1 and compare it to the project abandonment value at the current time, $\tau$. Then, the decision rule is such that:

$$\text{if } \max_{\tau+1 \leq a \leq n} (PV_{\tau,a}) < AV_\tau, \text{ then abandon the project.} \quad (2.2)$$

Otherwise, keep the project for the time being and abandon at time $a$ corresponding to $\max PV_{\tau,a}$.

Thus, the D-L model has shown that even when the first instance occurs that the abandonment value of a project exceeds the present value of continued operations, the firm may wish to hold the project and abandon later at a still more profitable time.

2.1.1.3 The Revised R-VH algorithm

In their reply to Dyl and Long, Robicheck and Van Horne accepted the main point that the abandonment analysis should consider the possibility that deferred abandonment may be more desirable than present abandonment [Robicheck and Van Horne, 1969]. However, they have criticized the D-L algorithm with respect to the following dimensions:
(1) It is cumbersome since it requires a complete enumeration of project NPV's over all future periods.

(2) It is relevant only when future operating cash flows and abandonment values are known with certainty. That is, contrary to the decision to abandon at time \( a \), reached under the D-L model when \( \max_{\tau+1 \leq a \leq n} (PV_{\tau,a}) \geq AV_{\tau} \), time \( a \) might become only suboptimal for abandonment if states of nature change causing the above relationship not to hold. In fact, this relationship is obtained using expectations of future cash flows and abandonment values as of time \( \tau \) and, therefore, there is a big chance that these expectations must be adjusted based on their corresponding, actual, future outcomes.

Accordingly, Robicheck and Van Horne have proposed the following modified algorithm: (Revised R-VH)

**Step 1:** Compute \( PV_{\tau,a} \) for \( a = n \), where

\[
PV_{\tau,a} = \sum_{t=\tau+1}^{a} \frac{EC_{t,\tau}}{(1+k)^{t-\tau}} + \frac{AV_{a}}{(1+k)^{a-\tau}} \quad (2.3)
\]

**Step 2:** If \( PV_{\tau,n} > AV_{\tau} \), continue to hold the project and evaluate it again at time \( \tau+1 \) based upon expectations at that time.

**Step 3:** If \( PV_{\tau,n} \leq AV_{\tau} \), compute \( PV_{\tau,a} \) for \( a = n-1 \)

**Step 4:** Compare \( PV_{\tau,n-1} \) with \( AV_{\tau} \) as in steps 2 and 3 above. Continue procedure until either the decision to hold is reached or \( a = \tau+1 \)
Step 5: If $PV_{\tau_a} \leq AV_{\tau}$ for all $\tau + 1 \leq a \leq n$, then abandon at time $\tau$.

This algorithm provides for optimal timing of the abandonment decision. In addition, it is less costly and time consuming than the D-L algorithm. A good illustration of the Revised R-VH algorithm is provided in Clarck’s [Clarck et al., 1977].

2.1.1.1.4 The Schwab-Lusztig Algorithm

In a 1970 article, professors Schwab and Lusztig have showed that the abandonment of an investment may be beneficial even if the project abandonment value does not exceed the NPV of its subsequent expected future cash flows [Schwab and Lusztig, 1970]. That is, the economic desirability of an investment project is not only determined by uncertainties in future cash flows which may lead to premature abandonment (as pointed out in the R-VH articles), but it also depends on the future availability of new and better investment alternatives which may lead to premature abandonment even when NPV’s are greater than abandonment values over all relevant time periods. Accordingly, they have proposed an abandonment decision rule which accounts for the stream of cash flows generated by reinvestment of the funds released upon abandonment.

2.1.1.1.5 The Jarrett Algorithm

Professor J. E. Jarrett published an article in 1970, in which he adopted the Revised R-VH model but assumed capital rationing and explicitly recognized variabilities of and auto-correlations among future abandonment values, cash flows, and costs [Jarrett, 1973]. He defined the abandonment value as the liquidation value of the project collected
by the company in either cash or cash savings upon liquidation of the investment. Future cash flows comprise all cash collections lost by disposing of the asset, and costs are cash outflows to the company if the project is held. This model implicitly recognizes the Schwab-Lusztig argument about the need to include the opportunity cost in the project abandonment value since it states that AV emanates from several sources including: (1) knowledge of the salvage value or price paid to the firm upon liquidation of the investment, and (2) the correlation between future revenue collections and the salvage value (i.e., future net cash flows attributable to the asset which is replacing the abandoned one.).

The Jarrett's decision rule states that:

"First, a project should be abandoned now if the rate of return on all future cash flows by abandoning the project now is greater than the rate of return on all future cash flows from holding on to the project. Second, the project should be held only until that moment when the rate of return on cash flows from abandoning the project at that moment is greater than the rate of return on cash flows from holding to the project. Last, the project should be held for its entire useful life as long as the rate of return from holding on to the asset is greater than the rate of return from abandoning the asset at any time in the future."(Jarrett, 1973)

Moreover, to account for uncertainty in the abandonment decision process, the model requires solving simultaneously for the expected rates of return and optimal abandonment time.

The rate of return on future cash flows from holding on to the project until the optimal abandonment time, K, was defined as:

\[
K = \frac{\sum_{i=T+1}^{T+a} X_i - \sum_{i=T+1}^{T+a} C_i + Y_{T+a}}{\sum_{i=T+1}^{T+a} X_i + Y_{T+a}}
\]  
(2.4)
where:

- \( T \) is the current time period;
- \( T+a \) is the optimal abandonment period;
- \( X_i \) and \( C_i \) are period \( i \) cash inflows and outflows, respectively, discounted back to period \( T \) at the appropriate interest factor, and
- \( Y_{T+a} \) is the abandonment value of the asset at the end of period \( T+a \), discounted back to the present at an appropriate rate.

The rate of return on future cash flows from current abandonment, \( A \), was defined as:

\[
A = \frac{Y_T}{\sum_{i=T+1}^{T+a} X_i + Y_T} \tag{2.5}
\]

where \( Y_T \) is the abandonment value in the current period.

The expectations for the two ratios above are then incorporated into the Revised R-VH algorithm to decide on whether to abandon now or not. In case of complete certainty, Jarrett’s decision rule is that the project should be held if \( K > A \). This rule does not necessarily lead to optimal abandonment timing. In fact, \( A \) is less than unity for any project incurring cash inflows if held, irrespective of how large \( Y_T \) may be. At the same time, \( K \) cannot fall below unity unless the project incurs cash outflows. Thus, for projects with no cash outflows, Jarrett’s rule instructs the decision-maker not to abandon the project even if the NPV of future cash flows associated with holding the asset is negligible by comparison to the project’s current abandonment value. This, indeed, acts against rational economic wisdom. Pappas has observed that the difficulty in Jarrett’s model stems from an incorrect
perception of the relevant opportunity cost of continuing to hold the project [Pappas, 1977].

2.1.1.6 Joy's Model

In his 1976 article, professor O. M. Joy debated the question of appropriate abandonment algorithm construction [Joy, 1976]. He has argued that a satisficing search algorithm such as the Revised R-VH is more suitable for accept-reject and keep-abandon decisions. An exhaustive search algorithm such as the D-L, on the other hand, is more suitable for mutually exclusive choices and capital rationing decisions. Joy's argument was that the accept-reject decision associated with a proposed investment project does not necessarily require determination of the project's a priori optimal abandonment time nor the associated maximum net present value. Since having the option to abandon never decreases project value, the typical consequences of ignoring such an option would be to underestimate the value of the project. Thus, all the analyst need do to reach an accept decision is find one instance where net present value is positive. This implies there will be no need for an exhaustive search abandonment algorithm such as D-L's.

On the other hand, the mutually exclusive choice does require the identification of the a priori optimal abandonment time because the existence of a positive net present value for a particular project is no longer a sufficient condition for investment in that project. Instead, it is necessary to present each competing project under its anticipated optimal perspective. Thus, an exhaustive search abandonment algorithm such as D-L's is required [Joy, 1976].
2.1.1.1.6 The Bonini Algorithm

A generalized dynamic model for assessing project value and riskiness with the option to abandon was developed in 1977 by Bonini [Bonini, 1977]. The proposed algorithm builds on the Hillier’s analytical model [Hillier, 1963]. It assumes a Markov-type auto-correlation among future cash flow streams and extends it to include the project abandonment option. The abandonment decision rule used in this algorithm is the same as that used in the Revised R-VH model. The optimal abandonment strategy is found by using the following dynamic programming recursion: [Bonini, 1977]

**Step 1:** Compute \( f^*_n(S_i) = AV_n(S_i) \) for all states \( S_i \)

**Step 2:** Compute \( f^*_i(S_i) = \max\{AV_i(S_i), \alpha \sum_{j=1}^{d} P_{i,j}(CF_{i+1}(S_j) + f^*_i(S_j))\} \) \hspace{1cm} (2.6)

backwards for \( 1 \leq t \leq n-1 \), and \( 1 \leq i \leq d \).

**Step 3:** Compute \( f^*_0 = \alpha \sum_{j=1}^{d} P_{0,j}(CF_1(S_j) + f^*_1(S_j)) - CF_0 \) \hspace{1cm} (2.7)

where:

- \( f^*_i(S_i) \) is the optimal expected present value of future cash flows at time \( t \) associated with being in state \( S_i \) at time \( t \), and making optimal decisions from period \( t \) on;
- \( f^*_0 \) is the expected net present value, at period \( t=0 \), associated with the investment;
- \( CF_0 \) is the initial investment cost;
- \( d \) is the number of possible states, assumed to be the same for all periods;
- \( CF_1(S_j) \) is the cash flow in period \( t \) associated with being in state \( S_j \) in that period;
- \( P_{i,j} \) is the transition probability from state \( S_i \) to state \( S_j \).
$P_{0,j}$ is the initial probability for cash flow state $S_j$ in period $t=1$;

$P_{0,j}$ is the abandonment value at the end of period $t$, given cash flow state during period $t$, and

$\alpha = 1/(1+k)$ is the discount factor, where $k$ is the cost of capital rate.

**Step 4**: If $f_0^*$ is positive, then the decision is to hold the project until the next period when the whole process is repeated from the beginning.

Bonini’s model has captured the essence of most of the findings of previous works on abandonment analysis and put it in a mathematical framework which lends itself easily to computer programming. However, in his illustration of the model, Bonini erroneously borrowed an example from Robicheck and Van Horn [Robicheck and Van Horn, 1976], which they had used to validate their simulation-based solution approach. In fact, Bonini failed to modify the R-VH illustrative example so that it fits his model’s assumption of first-order-Markovian-behavior regarding the stream of future cash flows.

### 2.1.1.2 Product Abandonment Analysis in the 1980’s

By the end of the 1970’s, the product abandonment topic had succeeded in catching the attention of a growing number of engineering economists, management accountants, and financial management authors in the United states as well as in Europe.

In a 1979-article, Dr. Nandan Choudhury, a British accounting professor, wrote:

“Accounting literature on capital budgeting has been deficient in only considering half of the investment decision process. Ample coverage has not been afforded the disinvestment decision. This decision is equally important to the overall profitability of the firm. Project analyses commonly contain an estimate of the salvage value of assets at the end of the project’s economic life, but fail to consider abandonment values for intermediate stages in the life of the asset. Such values may be substantial enough to justify
disinvestment, assuming more favorable investment alternatives are available for a reinvestment of the funds.” [Choudhury, 1979]

The result was the publication of several articles representing various attempts to extend the findings of previous work from the 1970’s, to compare the product abandonment decision with other conventional product decisions, or even to suggest new solution approaches. Another major event that has characterized this decade is the birth of the modern “Cost Management School”, an outgrowth of the CAM-i industrial consortium in 1984 [CAM-i/CMS’s Conceptual Design Document, 1987]. Pertinent findings are briefly summarized below:

2.1.1.2.1 Abandonment versus Other Product Decisions

Early in the 1980’s, a couple of authors tried to compare the product abandonment decision to other product decisions familiar to management.

In a 1980 article, Gaumnitz and Emery compared the abandonment decision to the like-for-like replacement decision and noted that the correct model for a particular case depends on the suitability of the assumptions [Gaumnitz, 1980]. Howe and McCabe, too, have extensively covered the topic of product abandonment as it compares to that of product replacement. In their 1983 article, they considered three cases to analyze the optimal life of an asset in an abandonment or replacement situation [Howe and McCabe, 1983]. Namely, they distinguished the following cases: (1) pure abandonment - a single, one-shot project that is not expected to be replaced, (2) infinite replacement chain model - the asset is replicated over an infinite number of cycles with market conditions remaining unchanged, and (3) finite-cycle replacement - the asset is expected to be replaced over a finite number of cycles. The three models were then examined in more depth to ascertain
the appropriate context for their use. Results have indicated that whether an abandonment model or a replacement model is appropriate depends less on whether the asset is expected to be purchased again at some point in the future and more on the context of the asset's use.

Kee and Feltus have advocated in a 1982 article that after an asset has been acquired, project abandonment is actually a reinvestment decision [Kee and Feltus, 1982]. They viewed the firm as continuously making decisions to leave funds in an asset (reinvestment) or to withdraw the funds (abandonment) and reinvest them somewhere else. Their proposed analytical framework explicitly considers abandonment values in the asset selection and subsequent reinvestment decisions.

In 1983, Cox and Martin wrote an article where they tried to solve the "capital deepening" problem (optimal economic life) under conditions of uncertainty with respect to project cash flows, terminal value of the asset, and the opportunity cost of the funds [Cox and Martin, 1983]. They also studied the impact of risk-averse behavior on the solution to the problem. Two major implications were drawn: (1) properly defined, the asset acquisition and abandonment decisions are almost identical. Finding a solution to both problems entails determining the optimal term to hold an asset or solving the "capital deepening" problem, and (2) giving explicit consideration to the stochastic nature of the capital-deepening problem does not change the basic character of its solution for the risk-neutral investor. Risk aversion, however, has the effect of shortening the optimal holding period for an asset.

In a 1983 Sloan School of Management internal working paper, Myers and Majd considered the option to abandon a project as formally equivalent to an American put option on a dividend-paying stock [Myers and Majd, 1983]. The exercise price of the put is the salvage value of the project; the cash flows from the project are equivalent to the dividend payments on the stock. Also, the project can be abandoned at any time during its life. Each
of these factors affect the abandonment value of the project, and to solve for the abandonment value, each was explicitly modeled by applying the contingent claim valuation techniques. An earlier attempt to model the product abandonment decision as a put option had been completed by Kensinger [Kensinger, 1980]. However, Kensinger assumed in his analysis that the option is of the European type with non-stochastic exercise prices. This is equivalent to assuming that the project can only be abandoned at one time, and that the salvage value is known with certainty.

2.1.1.2.2 Mathematical Programming Models

A few authors have tried to adopt the roll-back technique suggested in the Revised R-VH model [Robicheck and VanHorne, 1969], and first implemented by Bonini [Bonini, 1977], to come up with more powerful abandonment algorithms. Major works to be cited are those of De, Acharya, and Sahu, from the Netherlands, who suggested in a 1983 article the use of a multi-period capital asset pricing model as the basis for developing a dynamic programming approach to project evaluation [De et al., 1983]. Accordingly, the expected value of a project is determined on the basis of the variance in the net present value of the required capital investment, taking into consideration options for abandoning the project in the future. The analysis is extended to the case of project life uncertainty, incorporating both independent and correlated cash flows. Analytically, this model did not add much to Bonini’s model other than extending it to the random project life situation.

Srinivasan, Kim, and Thompson wrote an article in 1986 where they claimed that previous research on abandonment in capital budgeting has used enumeration to determine optimal choices, and that such methods have proved cumbersome in terms of finding solutions, and they have explicitly failed to consider the problem of project interactions.
[Srinivasan et al., 1986]. Instead, they suggested integer programming to resolve the project interaction problem when including abandonment value in capital budgeting. This model clearly identified the advantages of accounting for project interactions. However, it left much room for improvement in the way it modeled these interactions. Moreover, the authors have erroneously blamed enumeration techniques for not solving for project interactions while the blame ought to be rather on the problem formulation and solution approach themselves.

In a 1988-article, Sibley developed a general integer programming formulation of the investment-abandonment problem [Sibley, 1988]. This model assumes that the company has insufficient funds to undertake all favorable investments and must, therefore, use capital rationing. To illustrate the model, he used the example of a firm faced with eight investment alternatives with several constraints on project contingencies and abandonment possibilities. The main conclusion of the paper was that abandonment and investment decisions are interdependent if investment is limited by a constraint on external financing. The major shortcoming of this model is its narrow range of applicability because it is tailored to the specific problem described above.

2.1.1.2.3 Abandonment Analysis in the Modern Cost Management School:

When the new cost management concepts were first introduced in the mid-1980's, “activity-based costing” (ABC) systems, the major pillar of the modern cost management philosophy, were believed to be of minimal impact, if any, on product abandonment analysis. In CAM-i’s Conceptual Design Document, it was ascertained that:

“Abandonment analysis is an extension of normal DCF (Discounted Cash Flow) investment appraisal techniques, which allows the management accountant to assess whether it is more profitable to continue or to abandon a project. It does not involve
developing or applying new accounting theory.”[CAM-i’s Conceptual Design Document, 1987]

Assertions from leading authors in modern management accounting theory were made soon after the publication of CAM-i’s Conceptual Design Document strongly supporting the idea that ABC is a highly promising tool for assisting with strategic managerial decisions including the product abandonment decision. Kaplan has noted that:

“ Seriously distorted product costs can lead managers to choose a losing competitive strategy by de-emphasizing and overpricing products that are highly profitable and by expanding commitments to complex unprofitable lines. The company persists in the losing strategy because executives have no alternative sources of information to signal when product costs are distorted. Only after many years of declining market share and reduced profitability will managers learn how erroneous product costs led to poor product mix and pricing decisions.”[Kaplan, 1988]

Johnson, too, has argued that:

“Businesses need information about activities, not accounting costs, to manage competitive operations and to identify profitable products.” [Johnson, 1989]

Cooper and Kaplan have explicitly recognized the critical role of ABC systems in strategic product planning. They wrote:

“Indeed, activity-based costing is as much a tool of corporate strategy as it is a formal accounting system. Decisions about pricing, marketing, product design, and mix are among the most important ones managers make. None of them can be made effectively without accurate knowledge of product costs. … Once executives are armed with more reliable cost information they can ponder a range of strategic options. Dropping unprofitable products is one.”[Cooper and Kaplan, 1988]

Although CAM-i is largely responsible for the formulation and implementation of the new cost management philosophy, their assertion about the irrelevance of the new accounting theory to product abandonment analysis seems to be induced by the lack, at that
time, of a clear vision on how ABC can operationally interface with abandonment analysis. On the other hand, the quotations from Kaplan, Johnson, and Cooper and Kaplan reflect the new viewpoint of the “modern cost management school” regarding product abandonment and demonstrate the urgent need for applying sophisticated decision support tools such as ABC to product abandonment analysis. In fact, identification of “complex, unprofitable lines “ or “prevention and improvement of poor product mix” which Kaplan has referred to, “identification of profitable products” as Johnson said, and “decisions about ... product mix” or “Dropping unprofitable products” as Cooper and Kaplan have mentioned are simply different facets of the overall concern about product abandonment analysis.

The advent of ABC systems was applauded by decision-makers responsible for product abandonment. However, what was, and still is, lacking is a unified abandonment algorithm which incorporates these modern cost management concepts into the company’s global strategic decision model.

### 2.1.1.2.4 Other models

In a 1983-article, Chen and Moore argued that the traditional method of applying the expected net present value rule to the abandonment decision casts the problem in a classical statistical framework [Chen and Moore, 1983]. Instead, they suggested a Bayesian approach which formally accounts for the additional variation due to parameter uncertainty. They supported their model with an illustrative example which demonstrated how the Bayesian approach provided analytical and numerical evidence leading to abandonment decisions much different from those reached by classical approaches. Chen and Moore’s model has the advantages of an exhaustive search approach but also has its
disadvantages with respect to cost, time, and computational burden if the system is complex.

In a 1989 article, professors Aggrawal and Soenen used an abandonment decision rule similar to that in the D-L model. [Aggrawal, 1989] However, instead of using the conventional NPV criterion to evaluate the merit of the project, they defined a new one, the exit net present value (ENPV), based on the project abandonment concept as discussed by Kee and Feltus [Kee and Feltus, 1982].

The project ENPV is calculated as follows:

\[ \text{ENPV}_{t,a} = \sum_{n=t}^{a} \frac{\text{CF}_n}{(1 + r)^{n-t}} + \frac{\text{LV}_n}{(1 + r)^{a+1-t}} - \text{LV}_t \quad (2.8) \]

with \( 1 \leq y \leq N \)

where:
- \( t \) is the beginning year of the project;
- \( a \) is the year in which the project is abandoned;
- \( \text{CF}_n \) is the net after-tax operating cash flow in year \( n \);
- \( \text{LV}_n \) is the after-tax liquidation value in year \( n \);
- \( r \) is the risk-adjusted discount rate, and
- \( N \) is the estimated useful life of the project.

The proposed method provides a graph of the ENPV economic profile or life-cycle of the project. Each point on the curve represents the present value of the equivalent loss or profit if the project has to be terminated at that time. The ENPV accounts not only for a project's operating cash flows but also for changes in its economic or liquidation value. Although this graphical method might prove practical if the studied system is not very complex, it has apparently failed to add new intellectual substance to the theory of product abandonment analysis.
2.1.2 Marketing Literature

The product abandonment problem was first introduced to the marketing literature by Smith in his 1962 article, where he qualitatively showed how a company can improve the profitability of its operations by moving away from full-line-marketing strategies and pruning weak products from its portfolio [Smith, 1962]. However, no conceptual framework was constructed to incorporate the abandonment decision into the company’s overall strategic marketing process until 1963. Major works published to date are briefly presented and discussed below by chronological order.

2.1.2.1 Berenson’s Model

In a 1963 article, Berenson noted that:

“The whole subject of product elimination has been neglected by marketing managers and economists. The literature on product abandonment is extremely sparse and vaguely defined.” [Berenson, 1963]

In response, he came up with a conceptual framework which uses five criteria to evaluate the product abandonment decision as shown in Figure 2.1. While the financial security and financial opportunity criteria were quantitative measures, the final three criteria reflected qualitative factors influencing the product abandonment decision. More specifically, financial security was used to evaluate the basic profit motive of the firm. The
Figure 2.1 Berenson's Model for Product Abandonment Decisions

Source: [Berenson, 1963]
model suggests that additional weight be allocated to more financially profitable products. Financial opportunity was used to provide a measure of the product in terms of opportunity costs. Marketing strategy included non-financial measures such as market leadership, reliability of supply, users' buying habits, corporate objectives, correlation with other accounts, and emotional involvement that may justify holding a product even if it is financially unprofitable. Social responsibility reflects the company's obligations towards its stakeholders. Finally, organized intervention refers to possible reactions from the government, labor unions, or consumer groups to the abandonment decision. Once the performance of the product is determined with respect to these five classes of factors, the resulting scores are summed to determine the overall rating of the product. The final sum is then compared to a company-predetermined yardstick so that a decision can be made on whether to abandon or hold on to the product.

The major operational drawback of this model is the fact that the quantification scheme for the non-financial factors is very vaguely defined. Also, the author did not explain how the reference yardsticks would be determined. Neither did he allow for a systematic weighting scheme among the five classes of factors.

2.1.2.2 Alexander's Model

In 1964, Alexander suggested the following four-step procedure to help managers make the product abandonment decision: [Alexander, 1964]

**Step 1:** Select products which are candidates for deletion. To identify such products, the model recommends considering the following six factors:

- **Sales Trend:** If the of a product's sales is downward over time, it deserves examination;
• Price Trend: When the price of a product whose competitive pattern has been stable over time shows a downward trend over a significant period, that product should receive attention;
• Profit Trend: A decline in profit as measured in either dollars or percent of sales should raise questions about a product's continued existence;
• Substitute Products: When a new product enters the market, especially if it is an improvement over the old product, management must face the possibility of discarding the old product;
• Product Effectiveness: If the product loses some of its effectiveness over time, it should be examined for possible deletion, and
• Executive Time: Weak products usually demand an inordinate amount of executive time as compared to normal products, and therefore must be considered for deletion.

Step 2: Gather information about the selected products and analyze it. Alexander cautioned that the deletion decision should not turn on the sole issue of profitability. Instead, profitability, financial structure, employee relations, and marketing factors should all be considered to evaluate a given product. Moreover, the analysis should reflect both short-run and long-run objectives of the firm, and the weights assigned to each factor should be based on the specifics of the situation.

Step 3: Make decisions about elimination, and

Step 4: Remove the products selected for abandonment from the line. Once the decision to eliminate has been made, the product should be abandoned in such a manner that no adverse problems develop between the firm and its customers and/or suppliers. In particular, Alexander noticed how the abandonment timing is critical to the success of the abandonment process. However, he never elaborated on how to determine such optimal timing.

Generally speaking, one can say that this model has provided a basic, systematic approach for periodically searching for and selecting products for abandonment. However,
it has failed to quantify or explain how to combine the proposed factors. It has also failed to address the potential problems associated with the quality or availability of profit reports by product. In particular, it did not deal with the problem of assigning joint or overhead costs to specific products.

2.1.2.3 Kotler’s Model

In a 1965 article, Kotler suggested that a corporate team made up of representatives from different functional areas within the company be established to conduct the process of identifying, evaluating, and abandoning weak products [Kotler, 1965]. The proposed methodology involves the following six operational steps:

**Step 1:** Data sheets must be prepared for each product by the controller’s office.

**Step 2:** A computer program scans these data sheets to search for symptoms of product weakness. The program is governed by the following decision rules:

- Has the product’s share of total company sales declined for K1 periods?
- Have recent sales, after adjustment for cyclical factors, shown a consecutive decline for K2 or more periods?
- Has market share shown a consecutive decline for K3 or more periods?
- Has the gross margin on this product declined for K4 or more periods?
- Does the product’s coverage of its overhead amount to less than K5 percent?

The K’s are chosen by management, and a product has to earn a negative answer to all the questions asked above to avoid further investigation.

**Step 3:** The suspected products are then evaluated using the following criteria:

- What is the future market potential for this product?
• How much could be gained by product modification?
• How much could be gained by marketing strategy modification?
• How much useful executive time could be released by abandoning this product?
• How good are the firm’s other opportunities?
• How much is the product contributing beyond its direct costs?
• How much is the product contributing to the sales of the other products?

Step 4: The desirability of a given product is then evaluated by combining the rating results obtained in the previous step into a single measure called “product retention index.”

Step 5: In view of the results obtained for different products management should decide upon which products to abandon and which ones to keep.

Step 6: Management should formulate the specific phase-out strategy for those products selected for deletion.

This model has the advantage of involving decision-makers from various functional areas of the company to systematically evaluate and decide whether a given product should be abandoned. Another advantage of this model is its accounting for the contribution of each product beyond its direct costs. However, the model did not address the potential problems of availability and reliability of the desired accounting data. Furthermore, a product’s merit measure, or retention index, was based on the weighted average of subjective ratings.

2.1.2.4 Worthing’s Model

In a 1971 article, Worthing recommended the following two-step annual product evaluation procedure: [Worthing, 1971]
**Step 1:** The purpose of this step is to identify those products having a lower performance for the present year than for the previous year with respect to the following criteria:

- Return on investment: product profit as a percentage of its production and marketing costs;
- Profitability: product profit as a percentage of its dollar sales, and
- Sales: product sales as a percentage of total sales.

**Step 2:** Decision-makers should evaluate the past, present, and future performance of those products identified in step 1 with respect to fifteen indicators classified into three major categories: financial, marketing, and managerial, as indicated below.

1. **Financial Indicators:**
   - Contribution margin trend (past three years);
   - Profitability trend (past three years);
   - Sales volume trend (past three years);
   - Price level trend (past three years), and
   - Present versus potential use of funds.

2. **Marketing Indicators:**
   - Projected market growth (next three years);
   - Market share trend (past three years);
   - Product line complemental factor;
   - Competitive distinctiveness, and
   - Customer loyalty.

3. **Managerial Indicators:**
   - Marketing/Sales personnel response;
   - Distributor/Dealer reaction;
   - Machinery/Facilities Utilization;
   - Production personnel response, and
   - present versus potential use of manpower.

Scores ranging from 1 (poor) to 5 (excellent) are calculated for each product with respect to each indicator and then weighted to give an overall score. By rank-ordering scores, management can decide on whether to abandon or hold on to a given product.

The major drawback of this model is the fact that it did not address the data measurement problem at all.
2.1.2.5 Eckles’s Model

In 1971, Eckles proposed a product abandonment decision system made up of four stages: [Eckles, 1971]

Stage 1: To identify weak products, the entire product line is reviewed monthly based on inventory requirements, past sales volume, future sales volume, profit margin, competitive activity, and total generic demand trend.

Stage 2: Once sick products are identified, they are tested against the objectives of the corporation. If a product meets these objectives, corrective actions are taken to rejuvenate it. Otherwise, the product progresses to stage 3.

Stage 3: The product is analyzed in detail based on the following factors: past costs, future costs, past profitability, future profitability, scope of line, company new product research, consumer satisfaction, usage of production and warehouse facilities, production problems, and marketing problems. Once this intensive evaluation is completed, management either decides to retain the product, in which case it should be returned to stage 2, or decides to abandon it, in which case it progresses to stage 4.

Stage 4: The optimal timing for product abandonment should be determined based on the following four variables: stock on hand, holdover demand, timing’s effect on profit, and status of replacement parts.
Although this model has provided a more comprehensive and systematic framework to periodically review products status, it has failed to discuss how individual factors can be determined and, in general, it did not offer a clear implementation scheme.

2.1.2.6 The Hamelman-Mazze Model

In 1972, Hamelman and Mazze proposed a product abandonment model based on the analysis of specific cost/revenue accounting data [Hamelman, 1972]. The model periodically reviews all the firm’s products to identify those that were no longer earning revenue in proportion to the efforts and resources required. The authors called their model PRESS (Product Review and Evaluation Subsystem) and described it as follows:

"PRESS is a flexible and adaptable system designed as a tool to assist management in identifying those products which are candidates for deletion. It is different from most product-abandonment models in that it is capable of coping with a company’s total line rather than a segment of products thought to be weak. Inputs to the system are standard cost accounting and marketing data, and outputs are ratios and other information relevant to the value of each product to the firm." [Hamelman, 1972]

Operationally, the model is made up of the following four integrated modules:

- PRESS1: contains the primary model. It uses a variable cost accounting approach which includes the standard cost, unit price, and volume for the latest period. Fixed cost and other allocated expenses were excluded from the analysis. A given product i is evaluated by its "selection index number", SIN_i, defined as:

\[
\text{SIN}_i = \frac{(CM_i/\sum CM_i)^2}{FC_i/\sum FC_i} \tag{2.9}
\]
where, \( CM_i = \) contribution margin for product \( i \), and 
\( FC_i = \) Facility Cost for product \( i \)

- PRESS2: management should estimate sales sensitivity to small variability in price for each product in order to determine if the product relative contribution can be improved.

- PRESS3: Next year’s sales are forecasted for each product using an exponentially weighted moving average. Thus, expected cost changes can be incorporated in the analysis.

- PRESS4: For each product, the original SIN value is adjusted upward for tie-in sales due to the product, or downward for any replacement sales which would result if the product were deleted. To this end, the model calculates a new factor, RESIN, for each product. Then, products are deleted one at a time, starting with that having the lowest RESIN, until a specified target reduction of a particular resource cost was obtained.

Although this model had the advantage of accounting for the impacts of future cost changes and of the decision to delete the studied product on the remaining ones, it only included the price component of the marketing mix in the analysis. It also failed to address the potential implementation and cost measurement problems. Armstrong argued that the SIN index distorted the relative value of a particular product by favoring products with high contribution margins regardless of their disproportionate resource usage [Armstrong, 1973]. Moreover, by squaring the numerator in the SIN expression, the model failed to adequately account for negative contribution margins.
2.1.2.7 The Gordon-Miller-Mintzberg Normative Model

In 1975, Gordon, Miller, and Mintzberg developed the product abandonment model shown in Figure 2.2 below, as the thrust of one of the nine tasks reports of the “Business Decision Models Project” commissioned by the National Association of Accounts and the Society of Management Accountants of Canada [Gordon et al., 1975]. The model basically delineates the general framework that managers should follow in making their product abandonment decisions. It does not offer, however, any operational guidance to help them calculate the real numbers associated with or the implementational steps needed for such decision.

2.1.2.8 Browne and Kemp's Model

In their evaluation of pre-1976 product review procedures, Browne and Kemp noted that:

“They (the procedures) were limited in their applicability because they were rigid and had been predicated on enumerated needs.” [Browne and Kempe, 1976]

To overcome this limitation, the authors proposed the following three-phase process for product review:

**Phase 1:** All products in the product line are evaluated using only quantifiable data such as: sales volume, profitability, return on investment, costs and availability of raw materials, average order size, rate of market penetration, response to promotional activities, and the number of sales calls per sale. The overall performance of each product is to be compared
to forecasted or budgeted figures. Those products failing the test are then subjected to further analysis.

**Phase 2:** Management should identify the causes of the poor performance of these products using only historical and quantifiable data. If no corrective action is justifiable and the viability of the product is seriously threatened, this product should be passed to the third phase.

**Phase 3:** This is the product deletion phase. Management’s attention should now shift to evaluate the impact of the abandonment decision on the performance of the remaining products. In this phase, qualitative factors such as employee moral and the image of the company are considered in the analysis. If abandonment is the final decision, the authors stressed the importance of designing a well-thought out abandonment strategy which particularly accounts for such considerations as redirecting consumer demand and disposing of all unneeded parts, raw materials, and finished inventories.

The major operational drawback of this model is certainly the fact that it failed to address potential measurement and implementation problems.
1. Examine Objectives Of The Firm.


3. Determine Criteria For Selecting Candidates For Deletion From Product Line.


5. Screen Candidates For Deletion.

6. Can Candidates Be Found? (Decision Point)
   - No: Proceed to Abandonment.
   - Yes: Proceed to next step.

7. Solicit Detailed Data On The Costs And Benefits Of These Products And The Reciprocals Of Deleting Them.

8. Should We Continue To Consider Abandonment? (Decision Point)
   - No: Proceed to Abandonment.
   - Yes: Proceed to next step.

9. Search For Tactics Which May Serve As An Alternative To Product Abandonment.

10. Should We Delete Or Consider Another Solution? (Decision Point)
    - Consider Alternative Solution: Proceed to next step.
    - Delete Product: Proceed to next step.

11. Design Plan For Phasing Out Product.


13. Is Alternative Successful? (Decision Point)
    - No: Proceed to next step.
    - Yes: Proceed to next step.
    - Terminate.

Source: [Gordon et al., 1975]

Figure 2.2 The Gordon-Miller-Mintzberg Normative Product Abandonment Model
2.1.3 Strategic Management and Corporate Behavioral and Organizational Sciences Literature

Historically, researchers in business strategy and corporate portfolio management have emphasized expansion and acquisition decisions. As corporate portfolio management in practice has shifted from the acquisition trend of the late 1960's to more frequent divestment in the mid-1970's, research emphasis has begun to follow [Duhaime and Grant 1984, Wasson 1974, Marvin 1972, Brettauer 1967, Hayes 1972, and Kotler 1965]. Dr. Rocki-Lee Dewitt, professor of management and corporate organization at the Pennsylvania State University, has noted that:

“For many years, researchers in business strategy and industrial economics have focused on optimal methods for managers to allocate resources among growing or stable markets. Little attention has been given to the issues of phasing out aging products and withdrawing requisite resources from such products. Only recently, as more sectors experience the downside of demand due to import competition and industry decline, have researchers begun to examine strategic issues concerning the management of shrinking or disappearing markets.” [Dewitt, 1990]

However, a closer investigation of the problem of coping with declining demand as treated in the literature of strategic management and corporate behavioral and organizational sciences shows that researchers have typically focused only on macro-issues such as: strategies for declining businesses including retrenchment, reorientation, harvesting, and divestment, threats and opportunities in a declining market environment, factors influencing the divestment decision, factors to be considered in designing a divestment strategy, barriers to exit, pluses and minuses of downsizing strategies, and economic and social impacts of the divestment decision. In contrast with the financial management and marketing approaches to the product abandonment decision, this one has basically limited its scope to the acquisition or divestment decision-making process of whole business units.
or divisions of firms rather than on the decision to acquire or abandon a single asset or product line. Following is a brief discussion of the major corners of the literature on this topic.

2.1.3.1 Strategies for Declining Businesses

The PLC literature has customarily assumed a generalized scheme for product decline. According to this scheme, profit margins will disappear during the decline phase because competitors will use price reductions as a basis for competition. Advertising expenditures will be cut back. Research and development research will be eliminated. The market shrinks as buyer loyalties disappear and the cross-elasticity of demand grows higher. The degree of product differentiation is reduced. Pressures to reduce costs become increasingly strong. If prices cannot be reduced because of rising labor or raw material costs, then the firms gross margins will decrease significantly [Talley 1964, Rasseveiler 1961, Staudt et al. 1976, Kotler 1972, Wasson 1974, Levitt 1965, Patton 1959, Smallwood 1973, Day 1981, and Rink 1979]. Because the resale market for a business’s assets usually shrinks as industry demand declines, the most frequent strategy recommendation for this problem in the PLC literature has been a harvesting procedure of reducing investment levels to generate higher cash flows from the business, followed by ultimate divestiture [Conley 1976, BCG 1968, Kotler 1978, and Hayden 1977].

2.1.3.1.1 The Harvesting Strategy

In a 1978-article, Kotler advocated harvesting as a strategic management decision to reduce the investment in a business entity in the hopes of cutting cost and/or improving
cash flow [Kotler, 1978]. The following seven indicators were recommended for identifying candidates for harvesting:

• The business entity is in a stable or declining market;
• The entity has a small market share, and increasing it would be too costly: or it has a respectable market share that would be too costly to defend or maintain;
• The entity is not producing satisfactory profits;
• Sales would not decline too rapidly as a result of reduced investment;
• The company has better uses for the resources and capital used by the entity;
• The entity is not a major component of the firm’s portfolio, and
• The business entity does not contribute other desired features to the business portfolio such as sales stability or prestige.

Kotler suggested three methods of implementing the harvesting plan:

(1) Management can gradually reduce the budget without acknowledging that harvesting was taking place;
(2) A new manager, experienced in harvesting, can be appointed to implement the decision, and
(3) Top management can inform the business unit manager of the harvesting decision, and unless he/she can present evidence of the unit’s future potential, harvesting would begin. In any case, neither the competitors nor the customers should learn about the harvesting decision till implementation is entirely completed.

Kotler’s model has, however, ignored market considerations (i.e., how significant would demand likely continue to be for the harvested product) and strategic consideration (i.e., inter-relatedness of the harvested product with other products in the firm’s portfolio).

Talley [Tally, 1965], and Wasson [Wasson, 1974], advocated harvesting strategies, but they did not define the environmental conditions were such strategies for decline would be most successful. In general, the advocates of the harvesting strategy have
not distinguished between low-growth and declining businesses. The few treatments which have tried to make this distinction, have basically recognized that the likelihood of success for a particular strategy will be a function of the firm's position and strengths prior to the execution of the harvesting strategy [Clifford 1971, Schoeffler et al. 1974, and Catry et al. 1974]. Moreover, this distinction has usually been reduced to measures of market share. For instance, in 1973, Fox has identified some of the relevant structural determinants of end-game strategy formulation in his summary article about product management and the life cycle, but he only enumerated these factors instead of matching them to the proposed strategies [Fox, 1973].

2.1.3.1.2 The Divestiture Strategy

The divestment literature has suggested various reasons behind management's decision to divest. These reasons have ranged from reactive problem-solving ones, such as eliminating a unit with poor performance and little potential for future improvement, to more proactive opportunity-grabbing ones, such as funding potential stars in the corporate portfolio or gathering cash to introduce a new product [Duhaime 1983, Bing 1978, Lovejoy 1971, and Vignola 1974]. Schendel and Patton have noted that unexpected poor performance is needed to spur the firm to action and that turn-around of firms in decline usually requires substantial changes in the business [Schendel and Patton, 1976]. Divestment of a division or business unit is one such substantial change. In particular, divestiture-strategy advocates have argued that products whose primary demand has been replaced by technological substitutes are obsolete and should be divested soon [Wasson 1974, Luck 1977, Brettauer 1967, Hayes 1972, and Kotler 1965]. Either competition or management's choice will force the least efficient rivals to exit relatively early [Alexander
1964, and Johnson 1976]. Since excessive managerial time may be devoted to hopelessly declining businesses, divestiture has been a frequently recommended strategy in order to minimize unremunerative uses of managerial resources [Luck 1977, Vignola 1974, and Udell 1972]. Duhaime [1983], Gilmour [1973], Patton and Duhaime [1980], Duhaime and Grant [1984], Duhaime and Baird [1987], Harrigan [(1980, 1981)], Bing [1978], Lovejoy [1971], Vignola [1974], Porter [1976], and Harrigan and Porter [1983] have extensively covered the structure and influencing factors of the divestment decision, as will be briefly discussed in a following section.

2.1.3.1.3 Other Models From the PLC Literature

Several discussions of the PLC have recommended revitalization, or recycling, strategies to respond to declining demand trends [Dhill and Yuspeh 1976, Levitt 1965, and Talley 1964]. However, most of these studies were at the product-brand level rather than at the product-form level. Therefore, individual managers can often do little to halt the industry-wide decline for an entire product form [Enis et al., 1977].

In a 1971 article, Michael argued that eliminating products once they have passed through the decline stage of the PLC is not always the solution [Michael, 1971]. He stated that products exhibiting the following characteristics were candidates for what he called the petrification stage of the PLC: (1) consumers continue to seek the product through regular channels, (2) letters to the producer regarding the product's unavailability increase, and (3) competing or substitute items in the product line enjoy otherwise unexplained sales boost. Thus, by adopting a harvesting strategy, possible marginal returns from the petrification stage can be achieved due to a rate of decline in sales that is not increasing. In addition,
high brand loyalty on the part of the remaining customers may result in a demand curve that is price inelastic.

A major shortcoming in the available divestment literature is the vague formulation of the problem. Another one is the absence of a structured framework to identify which declining businesses are indeed hopeless and to guide managers, in a systematic manner, through the implementation phase of the divestiture decision. Moreover, where there have been discussion of the problem of declining demand, the shortcoming of these treatments has been the lack of matching appropriate strategies with specific decline environments [Harrigan and Porter, 1983].

2.1.3.1.4 Harrigan’s Model

Harrigan believes that the PLC literature has offered very few strategic alternatives for managers to deal with declining demand. She has noted that:

"The literature discussing harvesting strategies has suggested largely the same strategy for all declining industries and for most firms within them. These generalized treatments of the strategic problem of decline have ignored the differences between firms’ corporate-wide strategic requirements and their internal corporate attributes. These treatments have also assumed that firms will respond to decline in the same ways.” [Harrigan, 1980]

In response, she proposed a model whereby the strategy recommended for a particular firm in an “endgame” situation varies along a continuum according to: (1) the relative market share the firm seeks to retain and (2) the relative degree of asset commitment (or reinvestment) needed to maintain a particular strategic position. If the firm expects to recover profits from the endgame, it will stay invested; otherwise, it will choose to exit. In formulating a strategy for such an endgame environment, the author suggests that the firm
use the economic abandonment value calculations to plan the optimal timing of its exit.

Moreover, because the market for undepreciated endgame business assets is dynamic and could deteriorate rapidly, the firm may seek to retain maximum strategic flexibility in order to dispose of its endgame investment easily when the realizable market valuation of its assets approaches its optimum. However, holding these assets is not riskless. That is, despite the fact that the firm reinvests with the explicit expectation of being able to retrieve the value of the investment later through: (1) sale of its assets, (2) cash flows generated from the investment, and (3) benefits conferred upon other products in the firm’s strategic portfolio, there is no guarantee that this value can be recovered in a highly volatile endgame environment. To account for this precarious asset disposal problem, the author proposed the five endgame strategies briefly discussed below:[Harrigan, 1980]

(1) Increase the Investment:

This strategy requires the firm to reinvest in the endgame industry to attain market dominance. Accordingly, the firm must reposition itself to take advantage of remaining demand pockets and competitors’ reluctance to reinvest in the same industry. This means that the firm is ready to bear eventual short-term losses before achieving its market leadership position.

(2) Hold Investment Level:

This is a strategy of defensive reinvestment. That is, the firm has made a commitment to the industry to maintain the earnings power of its original investment rather
than to seek market dominance. This strategy might be recommended when: (1) the firm is serving a market of loyal customers whose demand is unlikely to deteriorate, (2) the firm possesses competitive strengths, (3) the declining business is relatively important to the firm, or (4) there is evidence that one of the firm’s major competitors intends to dominate the endgame industry. A firm may also choose to hold investment level in hope that few critical market uncertainties might be resolved soon. Hambrick, too, has argued how by holding an ongoing, but non-growing, business, a firm might be able to provide necessary cash to subsidize other operations [Hambrick, 1979].

(3) Shrink Selectively:

Because some niches of industry demand will continue to be profitable in a decline environment, a firm might choose to reposition itself by retrieving its resources from unprofitable segments of the market and reinvesting in profitable ones. Therefore, loyalties among the customers in these enduring pockets of demand can be created and maintained. To this end, the firm must monitor downstream industries which are least likely to convert to newer technologies or products and reposition itself to exploit the expected demand for the endgame products of these customers. Henderson [1974], Skinner [1974], Goldhar and Jelinek [(1983, 1986)], and Porter [1985] are but a few among a number of authors who have advocated the niche strategy as a promising strategic alternative in endgame environments whenever the firm still preserves some internal competitive advantage to serve the niche demand.
(4) Milk the Investment:

If an acceptable return on assets cannot be earned by remaining invested in the endgame business, the firm may wish to exit. However, if the market for its relatively undepreciated endgame assets is depressed, the firm may be forced to continue to compete until it has recovered more of the value of its investment through operations. According to this strategy, the firm is then continuously trying to retrieve the value of its earlier investments. It is similar to the harvest strategy. That is, although participation in the industry still yields attractive cash flows, the firm has made a commitment to depart from the industry as soon as: (1) the salvage value of its assets equals the expected value of cash flows generated, or (2) some other corporate criterion has been fulfilled.

(5) Divest Now:

When the above strategies are inappropriate, the firm has no other choice but to exit. However, timing is a major concern in this strategy. Dr. Harrigan has noted that:

“The objective of this strategy is one of prudent timing. As the earning power of the endgame business is shrinking, sell it before the asset values shrink too much. Divest could be a sale of business assets to competitors, if necessary, or simply junking them in order to avoid sustaining chronic losses and to release committed cash (working capital) to other uses.” [Harrigan, 1980]

The author stressed the fact that maintaining a flexible asset position is the firm’s critical consideration here because the skill with which a divestiture strategy is executed amid a rapidly deteriorating resale market can ultimately determine the profitability of a firm’s endgame venture.
Harrigan's model has certainly offered a more comprehensive treatment of the declining demand problem than previous models. However, in implementing the proposed strategies, the author stressed the critical role of the execution timing without giving any solid guidance on how to determine such optimal timing.

2.1.3.1.5 Downsizing Literature

Downsizing is a more disguised endgame strategy whereby management responds to declining demand and the resulting excess capacity and shrinking profit margins by reducing the firm's work-force through layoffs. It has been believed that such strategy would improve the firm's competitive position by directly reducing labor costs [Appelbaum 1987, Grennhalg 1983, Tomasko 1987, Kannan 1982, Perry 1986, Price and D'Aunno 1983, Neilson 1990, Smith 1982, Brockinton 1985, and Lauenstein 1984]. What Langdon C. Brockinton, of Olin Chemicals Company, said in the announcement below of the company's 1985-decision to downsize reflects a typical managerial mentality which has prevailed in the period from 1975 through 1985:

"John W. Johnstone, Jr., Olin's newly elected president, is leading a major restructuring program to position the company for the future. Olin (Stamford, Connecticut) plans to sell or liquidate non-strategic businesses that have been a drain on earnings and have tied up substantial capital; it also will shut down certain chemical facilities and continue eliminating 700 salaried positions. The restructuring, which should be completed by the end of 1986, is part of Olin's plan to redirect assets. ... Olin is emphasizing higher return businesses that are less cyclical and less capital-intensive. The restructuring program will lower the firm's book value and make it a less attractive takeover candidate."

[Brockinton, 1985]

However, many authors have argued that a downsizing decision is more of a human resources management decision than is a pure financial one [Heenan 1990, Bullock

"Several factors in the business environment are prompting many companies to assess and reduce their work-force requirements. A staff reduction is one of the most sensitive and complex projects that confronts management. Financial costs are only one issue in reduction; feelings and attitudes of remaining staff are also important considerations since a drop in production and morale almost always follow."[Bullock, 1985]

The impact of plant closings on the community as a whole, too, has captured the attention of many authors.[Fulmer 1985, Lawrence 1981, Starbuck 1976, Taber 1979, and Zammuto 1985] For instance, Fulmer has written:

"It is necessary to involve others in the closing process; the whole community is affected. Ripple effects may be felt by other businesses, the school system, property values, and city budgets." [Fulmer, 1985]

Moreover, downsizing has typically been viewed as a firm’s reactive response to decreases in its ongoing viability measured simply by the firm’s financial performance [Cameron and Zammuto, 1983]. Very few authors have acknowledged that downsizing can be undertaken in anticipation of the firm’s decreased viability [Tushman 1985, and Whetten 1987].

A variety of implementation alternatives have, therefore, been suggested in the downsizing literature [Appelbaum 1987, Bailey and Sherman 1988, Greenhalgh 1983, and Tomasko 1987]. For instance, in 1988, Esty proposed the following three-stage model for implementing the downsizing strategy: [Esty, 1988]

**Stage 1:** When downsizing is imminent, management bears the responsibility of providing straightforward information, squelching rumors, and fostering employee confidence.
Stage 2: When employees are laid off, plants are closed, and businesses are divested, management should: (1) acknowledge the changes and the stress involved, (2) reassure their top people, (3) arrange for regular sessions in which employees can vent their frustrations, and (4) work to help assure the best placement for those leaving.

Stage 3: When the new configuration is functioning, all staff should be involved in the restructuring work and the planning for the future. Management should take advantage of the atmosphere of change to introduce needed innovations. They also should keep communication flowing and emphasize the positive aspects of reorganization.

In his 1990 article, Heenan argued that downsizing do not necessarily provide the company with more control capabilities and better information flow. Specifically, he has noted that:

“The antidote to the era of command and control was the mini-headquarters. With the advent of downsizing, the traditional dominance of the center was deemphasized. ... The benefits of downsizing purportedly included lower overhead, less bureaucracy, faster decision-making, and greater entrepreneurship. Many firms now report major misgivings about the principles of downsizing. For example, scaled-down firms are often those least likely to make major investments in training and management development, so strategic planning suffers.” [Heenan, 1990]

Another major shortcoming in, apparently, most of the downsizing published literature is the failure to jointly solve for the capital asset and working labor problems. Price and D’Aunno [1983], Kuznits and Sussman [1979], , and Dewitt [1990] have argued that downsizing research has typically focused on restructuring firms through labor cost reductions and practically overlooked product-market and capital equipment cost reduction opportunities. Taber noted, as early as in 1979, that downsizing strategies must include both dimensions for human resource reduction and capital equipment reduction [Taber,
1979]. In fact, since scrapped or sold capital equipment no longer needs employee to operate it, resource reduction strategies are usually not accomplished without an associated laying off of employees. However, a more profound treatment of the subject did not occur until recently when Dewitt, in a 1990-working paper, investigated the downsizing literature and noticed the aforementioned shortcoming. She stated the problem as follows:

"Research to date has proven inadequate for guiding managers through the downsizing process. The conceptualization of downsizing has tended to limit management’s perspective concerning what downsizing truly means. Typically, downsizing is viewed as an operational move which improves the firm’s competitive position by reducing labor costs through layoffs. Downsizing is presumed to have occurred when a reduction in the number of the firm’s employees occurs. Earlier research has said nothing about trashing physical assets or the long-term strategic posture of the firm when it downsizes. This perspective of downsizing is wrong because it is (1) uni-dimensional, (2) unduly restrictive, and (3) inaccurate."[Dewitt, 1990]

In response, DeWitt generalized the formulation of the downsizing strategy to include both human and capital equipment resources. Thus, downsizing was defined as the process through which managers reduce their firms’ productive capacities to bring them in line with respective market demand. She, then, based her proposed downsizing model on the assumption that a firm’s need to downsize grows proportionally with the excess of its productive capacity. Resources and transformation processes being the two basic components of a firm’s productive capacity, the model suggests to design the downsizing strategy based on which component is showing an excessive capacity. Resources are excessive when the costs of ownership or contract cannot be recouped through production. Transformation processes are excessive when their cost exceeds the return they provide [Dewitt, 1990].

To control excess capacity, two general categories of downsizing strategies were proposed: retrenchment and reorientation. Retrenchment refers to changing the cost structures of the firm without changing its competitive posture (i.e., by release of few
resources which are easy to replace if needed in the future). Reorientation, on the other hand, involves major changes in the firm's structure which are intended to reposition its competitive posture (typically, both resources and transformation processes are substantially altered). While the nature of the competitive environment change causing excess capacity determines downsizing targets (i.e., resources and/or transformation processes), the appropriate timing to implement the downsizing strategy is determined by the ability of the firm to realign itself with the competitive environment. The model distinguishes reactive (after-crisis type management) from proactive downsizing (when management reads the future early and takes action prior to demand decline).

Although this model has offered a more realistic assessment of the internal and external antecedents to a firm's decision to downsize, the author did not adopt a system's approach by not accounting for the common correlations among production resources and transformation processes. Moreover, the importance of choosing an optimal timing for strategy implementation was emphasized without providing any framework to calculate such timing.

2.1.3.2 Factors Influencing the Divestment Decision:

emphasized the importance of business unit profitability as a primary factor affecting the
decision to divest [Vignola 1974, and Bing 1978]. Lovejoy has observed that the overall
corporate financial position is also a major factor in determining the attractiveness of the
divestment decision [Lovejoy, 1971]. Dundas and Richardson have noted that the degree of
relatedness among different business units within the company is likely to affect
management’s decision to divest a given unit [Dundas, 1982]. However, empirical research
on corporate divestment practices has suggested that various factors such as behavioral,
structural, economic, and environmental considerations also have an influence upon the
such findings are recapitulated below:

2.1.3.2.1 Harrigan’s Model

Harrigan has identified twenty factors, classified under four broad categories,
which influence a company’s endgame strategy formulation [Harrigan, 1980]. These
factors are listed below.

(a) Market (Demand) Characteristics:
   - Reasons for declining demand
   - Rate at which demand is declining
   - Presence of pockets of petrified demand
   - Firm’s expectations concerning demand

(b) Industry Structural Traits:
   - Product characteristics
   - Buyer characteristics
   - Supplier characteristics
   - Economic exit barrier characteristics
   - Factors influencing the volatility of competition
(c) Needs of the Firm Exogenous to the End-game Industry:

- External strategic influences
- Image maintenance goals
- The "single-business" firm
- Short-term reporting goals
- Vertical integration constraints
- Other strategic exit barriers

(d) The Firm's Internal Strengths Relative to Rivals in the Industry:

- Financial advantages
- Marketing and selling skills
- Product design and engineering skills
- Production advantages
- Firm's perceptions of the reality of declining demand

2.1.3.2 Duhaime's Model

While Harrigan has treated the general problem of endgame strategy formulation, Duhaime has focused mainly on the corporate divestment strategy. More specifically, she has extensively investigated the problem of what factors are the determinants in the divestment decision. The following six factors were originally identified to be primary in making such decisions:[Duhaime 1983, and Duhaime and Grant 1984]

- Financial strength of the firm;
- Competitive and economic strength of the unit;
- General economic environment in which the firm and the unit are operating;
- Distance of relation (extent of attachment) between the unit and the divestment decision-maker;
- Type of strategic relatedness sought by firms, and
- Extent of interdependency between the unit and the firm's other businesses.

Later on, Duhaime and Baird wrote an article in which they supported by empirical proof the role of business unit size in divestment decision-making [Duhaime and Baird, 1987].
2.1.3.2.3 Exit Barriers

Because of their direct impact on management's decision to divest, exit barriers need to be emphasized here. Exit barriers are various and can range from economic barriers (i.e. the lack of a resale market for the plant and undepreciated assets) to behavioral ones (i.e., the decision-maker's personal attachment to the project or business unit). They are important because they might deter the firm's timely exit from an unprofitable business. Benefiting from published research on exit barriers [Porter 1976, Caves and Porter 1976, Harrigan 1980, and Harrigan and Porter 1983], one can discern the following four broad categories:

(1) Economic Exit Barriers:

These are cost-of-exit related barriers. They might be due to a highly specialized nature of the equipment used by the firm, or simply to huge inventories and large fixed costs. In both cases, the chances of finding a potential buyer will be reduced. Harrigan has strongly urged strategy planners not to overlook the "asset flexibility" issue [Harrigan, 1980]. Other costs which can elevate the height of exit barriers have to do with various actions typically associated with leaving a business, such as labor settlements [Fruhan, 1985], contingent liabilities for land use, costs of breaking long-term contracts, past customers and employees support, and costs of dismantling facilities [Harrigan and Porter, 1983].
(2) **Strategic Exit Barriers:**

In addition to economic exit barriers, a decision-maker can face numerous strategic obstacles which force the firm to remain in business. Some of these barriers are presented below:

- **Corporate image:** A firm might choose to remain in a declining business and bear temporary losses with the objective of preserving its corporate image. Inadvertently pulling out of an established market, or even showing the intention or possibility of doing so, might deteriorate employee and customer loyalty to the company and, therefore, jeopardize the continuity of the whole corporation. Also, the firm may be a historical pioneer or the central unit of the whole company, and therefore the company will lose its identity by divesting this specific unit.

- **Unit inter-relatedness:** The studied unit might be a part of an overall strategy whereby different units support each other and share the same resources. Thus divesting such unit will affect the performance of the remaining ones.

- **Vertical integration:** Besides the horizontal inter-relatedness among units within the same business, a firm will face more exit barriers if it is a part of a vertically integrated business chain. It might have to remain in an unprofitable business simply to supply a healthier downstream link in the chain.
• The “single-product firm” case: If a firm has only one product in its portfolio, divestment means total dissolution of the company. Managers are more likely to be reluctant in undertaking such radical decision.

• Access to financial markets: The financial credibility of the firm can be reduced after the announcement of its decision to divest. So does its attractiveness to potential acquisition or buy-out candidates. By rising the cost of capital to the firm, its financial status and image will be even worse.

• Information gaps: It is more difficult for management to get reliable information about the actual performance of a given business unit when it is highly inter-related with other units. The poor performance of a given unit can easily be masked by the good performance of the remaining ones.

• Competition and the perception of future demand: If competitors do not foresee any future relief in the demand decline trend, there will be no reason for them to buy the divesting firm’s assets unless for some alternative use [McCabe and Saderson, 1984].

• Asset disposition and short-term reporting goals: If a publicly-traded firm which manages its balance sheets for acquisition purposes, claims all the right-off losses on disposal of its assets, potential acquisition candidates will lose confidence in the company and question its economic profitability [Harrigan, 1980]. On the other hand, by partially ignoring these write-offs, competitors are more likely to acquire the firm which strengthens their position and provides them with a better market control [Harrigan and Porter, 1983]. In both cases, management might think twice the decision to divest immediately.
(3) Behavioral Exit Barriers:

Harrigan and Porter have noted that:

"The difficulties of leaving a business extend well beyond the purely economic. Managers' emotional attachments and commitments to a business—coupled with pride in their accomplishments and fears about their own futures—create emotional exit barriers." [Harrigan and Porter, 1983]

These behavioral phenomena have been studied by several industrial psychologists, and various explanations were given ranging from simple resistance to change up to complex escalating commitment behavior [Duhaime and Schwenk 1985, Janis 1977, Kanodia et al. 1989, Langer 1975, Larwood 1977, Schwenk 1986, Staw 1981, and Taylor 1988].

Often, managers are afraid of communicating a less-than-expected image of themselves before their superiors through a divestment proposal [Nees, 1981]. In part, this is caused by a customary practice in the United States whereby managers are evaluated on the performance of their individual units. Thus, admitting the failure of an investment project might jeopardize a manager's own job. It has been documented in industry practices that divestment decisions are generally not made until management is changed [Gilmour 1973, and Duhaime and Schwenk 1985].

Managers might also be over-confident in themselves, mainly if they had prior successful experiences, which causes them to underestimate the situation and to think they are impervious to ruin. Langer and Roth have extensively studied this managerial behavior, which they have called "illusion of control" [Langer 1975, and Langer and Roth 1975].

Staw [1981], Duhaime and Schwenck [1985] and Kanodia et al [1989] have referred to another managerial behavior called "escalating commitment." According to this
behavior, individuals tend to allocate more funds to an investment project, to which they have already committed a significant amount of money, when they receive feedback that the project is failing than when it is doing well. This persistence to make the project succeed seems to be induced by a strong feeling of personal responsibility which might mask the evidence of project failure.

(4) Social and Legal Exit Barriers:

Because divesting a business is often accompanied by plant closings, employee layoffs, and consumers’ dissatisfaction, the decision to exit might be halted by regulatory bodies such as the government, labor unions, or consumer-right groups. Fulmer, for example, has strongly criticized management’s focus on financial effects of the divestment decision and their negligence of its impacts on the community. In his 1985-article, he wrote:

“For too long, the focus has been on income security programs; it is time for labor and management to focus on employment securities instead.”[Fulmer, 1985]

While it is very important to support morally and financially leaving employees as well as remaining ones, such pressures, as Fruhan has noted, significantly elevate exit barriers in front of the decision-maker, and therefore, reduce the set of his/her strategic alternatives [Fruhan, 1985].

Boddewyn has observed that social and legal exit barriers are usually higher when it comes to divest a foreign subsidiary [Boddewyn, 1983]. Such decision may mean crippling a local economy. A good example of that would be the case of the depressed
Canadian pulp industry when after closing down mills, whole towns had to be closed [Mehta, 1978].

2.2 EMPIRICAL STUDIES

Very few empirical studies of the product abandonment problem have been conducted so far. The findings of the six major studies published to date are briefly summarized below:

2.2.1 Rothe’s Study

In the Autumn of 1970, Rothe published the results of a survey he conducted on 500 manufacturers of consumer products to determine how the product abandonment decision was actually being made in industry [Rothe, 1970]. The response rate of the survey was approximately 30%, and the following main observations were reported by the author:

(1) Product abandonment activities were only one-third as important as new product activities. This ratio went down to one-fifth in the drug manufacturing industry;
(2) While most of the responding firms in the appliance industry had a more or less formal policy for product abandonment, respondents from the food and drug industry were much less formal in their product abandonment decisions;
(3) 75% of the responding firms reported that marketing executives were the most important participants in the product abandonment decision. Similar figures for corporate managers and financial/accounting executives were 16 and 2%, respectively;

(4) The most frequently used criteria to identify weak products were, by decreasing order of importance, minimum sales volume, minimum product volume, and market share;

(5) Product profitability was the most commonly used criterion to further analyze the identified weak products, and

(6) The most preferred strategy to implement the product abandonment decision was the “drop immediately” strategy followed by the “milk or slow phase-out” one.

2.2.2 Hise and McGinnis’s Study

In 1975, Hise and McGinnis investigated the marketing vice-presidents of the “Fortune-500” manufacturing firms concerning their practices of the product abandonment decision [Hise and McGinnis, 1975]. At a 19% response rate, the survey reported the following main observations:

(1) While all the respondents indicated that they had a more or less structured product abandonment program, only 31% had a written formal policy;

(2) Product elimination review sessions were conducted on a yearly basis by 44% of the responding firms, and no more than 22% reviewed their products at the end of every six months or more often;

(3) 35% of the respondents referred to the product manager as the person being most often responsible for product abandonment decisions. Non-marketing staff were second with a 17% figure;
(4) 68% of the respondents cited "poor future sales volume" as the most frequently used reason for abandoning a product. "Return on investment below a minimum acceptable level" was the second most frequently used criterion with a response level of 56%, and

(5) Asked about whether any alternative strategies to product abandonment were considered by management, respondents viewed product deletion as inevitable; however, they referred to using alternative strategies such as "make modifications in the product line", "increase the price of the product", "increase the level of efforts by the sales force", "increase promotional expenditures", and "decrease the price of the product" with response levels of 61, 49, 44, 35, and 30% respectively.

2.2.3 Harrigan's Study

In 1980, Harrigan published the results of her survey of fifty-two firms within seven different industries to explore their success and failure experiences in dealing with declining business environments [Harrigan, 1980]. Although major emphasis in the research was put on the evidence of persistent patterns of relationships among structural environmental traits, competitive performances, and endgame strategy decisions, her results have shown how the product abandonment decision must be viewed from a corporate strategy standpoint depending on the prevailing business-environment conditions. While few companies, such as GE and Raytheon, have viewed decline as a potential opportunity to reposition themselves and dominate the market, others, such as U.S. oil refineries, have viewed it as a problem and therefore failed to take advantage of it. Based on the results of this research, the author tried to pool major factors, internal as well as external to the firm, which are most likely to shape its strategic decisions for dealing with decline by opting to reinforce the affected product or to abandon it.
2.2.4 Avlonitis’s Study

In 1983, Avlonitis presented the results of his empirical study of product elimination decision-making behavior in engineering companies [Avlonitis, 1983]. Major research questions included: the magnitude of importance ascribed to the elimination decision by management, management’s approach to the decision, the shortcomings of the approaches utilized, and the problems encountered by management in the product elimination decision process. The author observed that many of the problems stemmed from the nature of buyer-supplier relationships in industrial markets and a poor internal decision-making. Recommendations for improvement included: (1) more attention by management to the product abandonment problem, (2) management support for and participation in the decision-making process, (3) ongoing review of the product range in view of the overall company’s policy, and (4) assignment of responsibilities for the product elimination process.

2.2.5 Duhaime-and-Grant’s Study

In 1984, Duhaime and Grant published the results of a field research in which they interviewed corporate executives of forty large diversified firms about which factors actually influence their corporate divestment decisions [Duhaime and Grant, 1984]. The obtained answers have especially emphasized the important role of business unit’s strength, its relationship to other units within the firm, and its parent company’s financial position relative to its competitors in such decisions. In particular, the study showed how firms are likely to divest units with low strength and low interdependence with other units.
2.2.6 Lambert's Study

In 1985, Lambert published the results of an extensive empirical study commissioned by the National Association of Accountants and the Society of Management Accounts of Canada to explore the decision process used by managers when making the product abandonment decision [Lambert 1985, and Lambert and Sterling 1985]. An in-depth survey of 12 companies was first conducted with the objective of designing a detailed, right-on-the-track questionnaire. The developed questionnaire contained two major parts: a financial section and a marketing one, which were then mailed to 1338 U.S. and Canadian companies in order to refine and generalize the results of the in-depth survey. A total of 126 firms completed both financial and marketing questionnaires, and major observations from the study are recapitulated below:

(1) Product abandonment is considered relatively unimportant as compared to other product decisions. 28% of the responding firms were reported to have a formal product abandonment policy, and only 20% had a written one;
(2) The product deletion review period, if any, was annual, quarterly, monthly, or semi-annual at a response level of 31.6, 12.5, 10.3, and 9.5%, respectively;
(3) 48% of the respondents referred to top management as the ones who would probably be involved the most in product abandonment decisions. Marketing and Product/brand management people were second;
(4) Sales volume and profitability were the most frequently used criteria to identify weak products. Gross margin comes after. Market share, on the other hand was not a very popular criterion;
(5) “Poor future sales volume” and “poor future profit” were the most frequently used criteria to decide on whether to abandon a weak product or not;

(6) The most widely considered alternative strategies to product abandonment were by decreasing order of importance: reviewing competitive position, reducing manufacturing costs, modifying product, increasing price, trimming product line, increasing sales force efforts, competing in selected market niches, and replacing with totally new product among others;

(7) Contrary to the results obtained in Rothe’s study, 96% of the respondents reported “profitability by product” as the most available and useful form of data for making product abandonment decisions. “Contribution margin by product” and “growth potential by product” come next with a response level of 93 and 75%, respectively, and

(8) Ninety five percent of the respondents used product profitability and contribution reports to evaluate a product. 51% of the respondents reported including overhead and general and administrative costs in such profitability reports.

Thus, all the presented empirical studies agreed that most firms have failed to accord to the product abandonment decision the needed strategic importance by not developing a well structured abandonment policy. Lambert has especially focused on the problem of data availability and accuracy. In particular, he observed that:

“Managers were using profitability as the major criterion in the identification and evaluation of products for abandonment. However, for 84% of the firms in this research, the costs included in profitability reports and the methods of cost allocation made the reports of questionable value.” [Lambert, 1985]

He then charged management accountants with the responsibility of providing reliable cost information to help the decision-maker assess the real cost contribution of a given product and decide on whether it is more profitable to abandon it or not.
2.3 DISCUSSION SUMMARY

A cross-sectional investigation of the product abandonment taxonomy discussed above highlights several observations which can serve as a starting point for any research effort geared towards helping U.S. manufacturers better understand and successfully execute the product abandonment decision-making process.

(1) A general observation, common to the three abandonment schools introduced above, is that relatively little attention has been given by both academicians and practitioners to the subject of product abandonment. This chapter has included more than 95% of all the product-abandonment-related material that has been published since 1959. Most of the work, however, has been done by marketing people. This fact, by itself, reflects a major shortcoming in the traditional perception of who is really responsible for the product abandonment decision;

(2) Another striking observation is the apparent lack of communication among the three abandonment schools working in parallel. Except the few common abandonment decision dimensions treated by both marketing and strategic and behavioral sciences people, no integrative effort has ever been reported which could put together, in a single model, the concepts developed separately in the three schools. In particular, only the “engineering economy, financial management, and management accounting” school has gotten into the detailed, quantitative calculation of the financial repercussions on the firm of the abandonment decision and of its optimal timing;
(3) A third major observation has to do with the availability and reliability of financial data used by researchers and practitioners from the three schools to evaluate product profitability and identify abandonment candidates. Profitability reports used for such evaluation customarily included many arbitrarily allocated costs and did not include many other overhead and general indirect costs which could have been better traced to specific products. Also, the impact of the decision to delete a given product on the financial profitability of other products in the firm's portfolio has not been well documented. Although the new concepts from the modern cost management school have revolutionized product costing and managerial accounting theory and practices with the advent of activity-based costing (ABC) systems [Brimson 1989, and Kaplan 1989], not a single abandonment model has emanated, so far, which incorporates these concepts;

(4) Research in the "engineering economy, financial management, and management accounting" school has basically focused on solving the abandonment optimal timing problem. The product abandonment option was perceived as a strategic alternative in the capital budgeting problem. However, different authors have generally emphasized different dimensions of this option; and operationally, no one has offered a model which incorporates a company's overall strategic considerations into the analysis. Instead, they were using, at best, empirical models based on product profit/cost/volume data as key decision criteria. Project NPV was the decision criterion used by the majority of the companies to evaluate the product and the alternatives. The resulting profitability and cost reports were therefore distorted due to the shortcomings of traditional accounting practices [Kaplan, 1988].

Furthermore, basing the abandonment decision on a specific product volume-related data usually results in a traditionally-believed optimal abandonment time right after the time
of maximum market penetration, or at the beginning of the product sales decline phase, as indicated by point $T_A^*$ in Figure 2.3. In fact, $T_A^*$ often corresponds to the maximum NPV generated by operating the product line over $T$ periods, $T_A^{**}$ being its estimated physical life. However, this decision process do not account for the possibility of newly available, better investment opportunities. For instance, an earlier abandonment of product A, at $T_B < T_A^*$ (see Figure 2.3), makes extra funds available to start producing product B. Investing in B at time $T_B$ will ensure more sales volume and favor a technology leadership position in front of competitors. Moreover, the decision process does not account for the impact of terminating product A or continuing its operation on other operations in the system. It also fails to evaluate the merit of product A in terms of investment portfolios (i.e., various feasible combinations of A, B, and C). Thus, failing to account for non-financial factors, coupled with an apparent lack of and distortion in the already available financial accounting data, made it very difficult for practitioners to justify their abandonment decisions by simply using such models;

(5) Researchers from the marketing school have typically viewed the abandonment option as an undesirable, but inevitable, decision that the firm has to make sooner or later. Accordingly, their proposed solutions have generally been in the form of a reactive response to market decline rather than a proactive, planned capital reallocation strategy which takes advantage of the potential opportunities that a dynamic business environment may present. While such models have generally included non-financial criteria of relevance to the firm's competitive position in the final product abandonment decision, identification of weak products has often been based on product sales volume and/or profitability reports. The accuracy of such reports is obviously questionable because of the inadequacy of traditional accounting practices.
Figure 2.3 Product Sales Profile
Moreover, once a firm makes its decision to abandon a given product, there is not enough guidance offered by these models with respect to the abandonment strategy implementation issue. In particular, these models have at best referred to the importance of choosing an optimal timing for abandonment, and sometimes to the factors to be considered in making such choice, but never went further to calculate this optimal timing or its financial impact on the firm’s future profitability;

(6) Most of the observations made about the marketing school are also true for the "strategic management and corporate organizational and behavioral sciences" school. Although this third school has offered a broader strategic perspective of the product abandonment option, it has failed to develop a ready-to-use, step-by-step methodology which guides managers through the whole product review process from identification of weak products through implementation of the deletion decision. In particular, it has emphasized the importance of such social and behavioral factors as employee security and morale, decision-makers' personal attachment to the project, and impact of the abandonment decision on the community as a whole; but it did not offer any tool to realistically measure and account for these factors. Moreover, this school has limited its research to the problem of abandoning whole business units or divisions and assumed that single-asset abandonment is rather a short-term, tactical capital budgeting problem, and

(7) The results from the empirical studies made it clear how practitioners, whenever they had a formal product abandonment policy, they had recourse primarily to much of their own intuitive judgement, heuristic approaches, and other empirical models they believed were suited to their specific situation. Although a few concepts and/or techniques might have eventually been borrowed from one of the three major abandonment schools, no one
company has been reported to having fully adopted one particular normative model among those presented above.

2.4 IMPLICATIONS AND CONCLUSIONS

In view of all the observations made above, the need for developing a sophisticated, easy-to-implement, strategic decision model which incorporates the product abandonment option seems to be critical in order for U.S. manufacturers to successfully modernize their production systems and their ways of doing business. To this end, they must first acquire a new managerial mind-set consistent with the requirements of the new international business environment. In particular, they must rid themselves of antiquated business assumptions and their resulting physical manufacturing systems, as well as of various flawed product evaluation and decision analysis techniques. Finally, the new product abandonment model should integrate the positive features of and concepts from the three conventional abandonment schools.

More specifically, various strategic factors, financial and non-financial, of relevance to the company's corporate goals should be incorporated into the product abandonment decision rule. Perceiving the product abandonment option as an opportunity rather than a constraint, the model should allow for accurate forecasting of future states of the market and proactive control of the company's decisions to meet the challenges of an ever-changing business environment. In particular, a reliable and accurate cost accounting system can play a primary role in evaluating the merits of a given product or course of action. Finally, the decision-maker should always keep in mind that no one normative model is good for all situations. Therefore, he/she must know the specifics of the particular
problem under consideration and try to fit the solution methodology to it rather than to blindly force such a methodology on any problem in hand.

In the following chapters, the solution approach developed in this research is presented as an attempt to overcome most of the limitations of traditional product abandonment analysis techniques. In addition, an overview of the solution approach's underlying philosophy, a summary of the theoretical foundations of various decision support tools needed by the developed solution methodology, a description of its implementation requirements, and an illustrative case study are presented.
CHAPTER 3
THE SOLUTION APPROACH: CONCEPTUAL DESIGN

The purpose of this chapter is threefold. First, major managerial concepts and principles underlying the conceptual design of the solution approach are introduced and discussed with respect to their impact on strategic capital expenditure analysis, in general, and on the product abandonment decision, in particular. Second, major operational decision support tools used to generate the needed data for the model, to analyze them, and/or to make inferences about them are briefly introduced and discussed. And third, the general frameworks of both the proposed global decision model (GDM) and its product abandonment algorithm are described.

3.1 UNDERLYING PHILOSOPHY

The factory of today is significantly different, both physically and functionally, from that of the past. This difference will become even more acute as factories continue to automate, thereby transforming the floor shop from labor-intensive to technology-intensive. Technical characteristics and managerial requirements of this new factory have dictated the need for more sophisticated approaches to understand the cause-to-effect relationship between the capital expenditure function and global business profitability.

This understanding should be articulated around the obvious fact that resources (capital, equipment, labor, and managerial effort and time) are consumed by activities performed during the business exercise of adding value. These activities themselves are
consumed by products to be delivered as services or goods to the consumer. The volume and quality of these activities will, therefore, determine product cost to the manufacturer (i.e., by requiring specific resources and incurring operating costs) and product value to the customer (i.e., by satisfying his/her requirements on functionality, quality, and timely delivery). In this respect, an activity-based environment constitutes a very appropriate one in which capital expenditure analyses can be carried out. Dr. H. T. Johnson has ascertained that:

"Businesses need information about activities, not accounting costs, to manage competitive operations and to identify profitable products" [Johnson, 1989]

Accordingly, U.S. manufacturers should strive to structure their activities in such a way so that available resources are effectively and efficiently applied to the manufacture of products which are competitive with regard to cost, quality, functionality, and market timing. To this end, the capital expenditure analysis should be as detailed as to the extent where all critical cost and performance drivers affecting various aspects of the company’s activities, tasks, and functions are explicitly identified. Waste elimination and performance improvement actions can, therefore, be achieved by manipulating a more manageable number of corresponding drivers. System complexity can be surmounted by breaking the system down to the level of its basic constituent activities. Thus, activity-based analysis holds the promise of providing a more accurate appraisal of product profitability. The need for such a system was expressed as early as in 1975 by Worthing who stated that:

"The managerial challenges posed by a complexity of products or product lines, positioned in different life cycle stages and progressing through these stages at different rates, make meaningful product appraisals difficult because data are seldom available in the amount and form which reflect the many ways which products-individually and collectively-contribute to a firm’s operational effectiveness, profitability, and growth."[Worthing, 1975]
To sustain a world-class manufacturing competitive edge, U.S. decision-makers must rid themselves of traditional, shortsighted cost-reduction practices. Instead, they have to adopt a philosophy under which management is committed to continual improvement and elimination of waste (i.e., non-value-added activities). Long-term business objectives should be clearly defined so as to sustain the company's competitive advantage. Strategic issues, financial and non-financial, should be addressed in terms of quantifiable performance measures so that selection among alternative courses of action, when exercising different phases of the continual improvement and control program, is feasible and realistic.

The management planning and control system should be dynamic in nature to reflect the impact of previous decisions on subsequent ones. It should also accommodate the impact of the ever-changing technological and economic environments on initial information forecasts. This system should recognize the impact of design on product cost, capacity management, make/buy decisions in capital intensive concerns, asset retention and abandonment analyses, and monitoring of strategic operations. In particular, the wealth maximization rationale dictates that scarce funds should be allocated to the most attractive course of action at any given point in time.

In this respect, business option value analysis may show the decision to abandon an ongoing concern, at some point in its life cycle, as a course of action which favors some new investment opportunity over continuing all or a segment of current operations. In fact, the decision to abandon may be more rewarding by producing positive cash flows as tax savings from depreciation write-offs, sale of equipment, return of working capital, the use of space and funds for more profitable projects [Bonini 1977, Aggrawal 1989], or at the limit, reduction of eventual adverse developments of the ongoing concern (waste elimination).
The product abandonment option should, therefore, be integrated into the overall planning and control model as a normal improvement opportunity wherever suggested by the ABC analysis. Strategic business objectives, financial and non-financial, should be clearly defined so as to sustain the company's competitive advantage and addressed in terms of quantifiable performance measures so that selection among alternative courses of action (including the abandonment option), when exercising different phases of the continual improvement and control program, is feasible and realistic.

Finally, the strategic planning and control system should be dynamic in nature to reflect the impact of previous decisions on subsequent ones. It should also accommodate the impact of the ever-changing technological and economic environments on initial information forecasts. Accordingly, the abandonment decision rule must reflect some trade-off among cost, performance, and riskiness of each improvement alternative instead of simply using the NPW criterion.

3.2 GUIDING PRINCIPLES

Several principles were proposed to guide the decision-maker select and/or design a strategic decision model which uses various managerial concepts and philosophies introduced in the previous section [CAM-i, 1988]. These principles include the following:

(1) Sound investment management decisions must be tied to long-term strategic objectives of the company as well as to its short-term operational goals;
(2) Investments should be evaluated based on quantitative, financial as well as non-financial, criteria of strategic relevance to the company;

(3) Investments should be evaluated in terms of portfolios of inter-related improvement opportunities rather than on a single-project basis;

(4) The investment decision model should account for all cross-sectional inter-dependencies among various activities and operations within the system as well as for cross-temporal inter-dependencies among consecutive decisions and states of the system;

(5) The investment decision model must identify, measure, and account for various aspects of risk and uncertainty associated with alternative courses of action;

(6) The investment decision model should be supported by a reliable system for collecting relevant, accurate, and timely input data, and

(7) A consensus-based evaluation process should be used whenever subjective judgement is needed.

3.3 REQUIRED DECISION SUPPORT TOOLS

To successfully apply the developed solution approach, the decision-maker is required to call on a number of operational decision support tools that allow him or her to implement the above guiding principles. This section attempts to help the decision-maker understand the nature of, and benefits from, applying such tools by briefly describing their theoretical backgrounds.
3.3.1 Activity-Based Costing

Most conventional accounting systems were designed for internal reporting and inventory valuation purposes and not for cost control or managerial decision-making purposes. These systems have usually used direct labor as the basis for allocating costs to various products within the company's portfolio. A significant portion of these costs has customarily been buried in the overhead term and then linearly distributed among different products based on their direct labor content.

Nowadays, because of factory automation, direct labor often represents no more than 15% of a product's total manufacturing cost. This figure can be as low as 2% in high-technology industries such as PC-boards manufacturing [Brimson, 1989]. At the same time, expenses associated with factory support operations and other overhead functions have increased significantly [Kaplan, 1988]. In particular, the preponderance of fixed costs and the diminished direct labor have placed a greater emphasis on fixed cost assignments to products via measures of activities other than direct labor [King, 1990].

In particular, many costs traditionally thought of as fixed actually vary according to the diversity and complexity of products. Much manufacturing overhead, for example, comes from transactions associated with the start or finish of production. To reflect these costs, the accounting system must include not only volume-related measures for tracing costs to products such as labor and machine hours or material quantities, but also measures that count setups, tooling, work-in-process, inspections, receipts, parts, vendors, and engineering change orders, among others. Thus, allocating costs to products in proportion to their direct labor content will obviously lead to distorted product costing reports. In today's manufacturing, data are much easier to collect and process in order to be used in
improving the traceability of costs. To control these costs, a bill of activities should be established for each product and primary cost drivers should be identified and monitored.

In response, activity-based costing (ABC), the backbone of the “total cost management” philosophy, was introduced in the late 1980’s as much a formal cost accounting system as it is a tool of strategic decision-making [CAM-i 1988, Cooper and Kaplan 1988]. The philosophy behind this approach relies on the premise that products consume activities and activities consume resources, and that each “activity” incurs certain costs to achieve a quantifiable output. The use of an ABC system requires first the identification of various activities performed by each support and operating department and then computing the unit costs of performing these activities. Once all of these are determined, support and indirect costs are assigned to products based on the number of activities performed for each individual product [Kaplan,1989]. Thus, according to this approach, the costs of an organization’s activities are assigned more accurately to the specific products which consume these activities.

Although ABC is not designed to trigger automatic decisions, its benefits relative to abandonment analysis are apparent. In particular, by providing more accurate information about production and various support activities, a better appraisal of product performance can be achieved (i.e., calculation of cost profiles by product). Moreover, management can focus its attention on the products and processes with the most leverage for increasing overall profitability (i.e., identification of relevant improvement opportunities). Improved visibility of demand for value-added activities and presence of non-value added activities in the system facilitates a great deal management’s task of designing and implementing continuous improvement and waste elimination programs and making competitive product abandonment decisions.
However, the focus in this research is put on utilizing the information generated with ABC systems rather than on generating this information. Therefore, it will be assumed that the company has access to an ABC implementation package, and that all the needed information about product and/or system cost profiles can be readily available.

3.3.2 Forecasting

Because of the uncertainty in future states of nature, the decision-making process is usually fraught with “risk.” Successful beforehand anticipation of “most likely” future trends in the global market for factors of production, international currency-exchange rates, international political and economic climates, competitors’ actions, and consumers’ behavior among other factors can, therefore, provide businesses with an invaluable competitive advantage with respect to technology leadership and timely responsiveness to market changes.

To this end, forecasting techniques are needed by business managers to predict as accurately as possible future states of nature and make decisions based upon expected outcomes from these states. The choice of an appropriate forecasting model is decidedly a matter of judgement and involves assumptions concerning the relevant variables and their interrelationships. One note of caution, though, is the fact that statistical models are not perfect predictors, and the variance from actual outcomes will in part be attributable to the particular assumptions of the model. In particular, good decision-making calls for the use of a forecasting model which dynamically readjusts its defining parameters based on the most updated information. Moving-average and exponential-smoothing forecasting techniques [Montgomery 1976, Makridakis 1983, Jarrett 1987], for instance, can satisfy
such requirement and are, therefore, recommended for use by decision-makers to predict future cash flows associated with various capital expenditure alternatives.

In this research, it will be assumed that an appropriate forecasting model has already been chosen by the company, and that expected future cash flows and abandonment values are readily available for use in the GDM and the abandonment algorithm. In particular, the model assumes that the inter-temporal correlation among cash flows is described by a first-order Markov chain [Howard 1960, Hillier 1969]. However, the forecasted values, at a given decision point in time, of cash flow states and their governing probability transition matrix should be readjusted during the next decision point in time based on most recent forecasts.

3.3.3 Statistical Decision Theory

The complexity of a given decision problem can be characterized by its relative position in the three-dimensional space defined by Figure 3.1 below.

The “physical scale” dimension refers to the actual number of decision variables in the problem. For example, points O and C represent single-variable decision problems, whereas points A, B, and D represent multi-variable decision problems. The higher the number of decision variables in a given problem, the further its position will be from O.

Similarly, the “dynamic nature” dimension refers to whether the decision problem involves time-dependent variables or not. A decision problem represented by point O or A is then a static problem. The terminologies “stationary versus transient” and “static versus dynamic” are sometimes used inter-changeably to describe the time-dependence of a system.
Figure 3.1 Dimensionality of a Physical Decision Problem
Finally, the “stochastic nature” dimension refers to whether uncertainty in state variables of the system are included in the decision problem or not. Points O, A, and B, for example, represent deterministic decision problems, where all state variables are known for certain; whereas points C and D represent stochastic decision problems, where little information is available about possible state variables.

Although a real-life problem will most likely be multi-variable, dynamic, and stochastic, such as the one represented by point D, decision-makers have customarily relaxed one or more of these dimensions to simplify the decision problem by reducing system complexity. Nowadays, information gathering and processing capabilities are made much easier and faster thanks to advances in computer technology. Decision-makers cannot, therefore, justify ignoring such important dimensions of their decision problems if realistic optimal solutions are to be reached.

In response, “statistical decision theory” (SDT) offers a good platform for solving such complex decision problems. It requires the decision-maker to explicitly describe his or her judgements regarding uncertain events, and to consistently account for his or her preferences under conditions of uncertainty. It also instills the concepts of rational behavior in the decision-making process. Two primary components of SDT are “probability theory” and “utility theory”. A brief description of and comments regarding these two theories are presented here.

3.3.3.1 Probability Theory

Probability theory deals with the problems of assessment and measurement of the likelihood of occurrence of a given event in the future. Although in a few structured
contexts the probability of an event can be objectively determined using an appropriate experimental setting, many real-life situations are not structured enough to be modeled mathematically, and therefore, human subjectivity, intuition, and heuristic approaches are required to calculate such probability [Howard 1968, Spetzler and Holstein 1975].

In assessing the probability of a future event, all prior experience and information about the event and/or similar events should be used so that the deviation between its expected and actual values can be reduced. A major problem, though, is how to encode, in a usable form, a knowledge which may range from a strong belief that results from many years of experience to a vague feeling that arises from a few haphazard observations. This task can become inextricable if the system is complex and events are correlated among each other.

Although advances in the computer technology have contributed significantly to alleviating the computational burden of joint probability profiles and making statistical inferences, decision-makers have usually resorted to simplifying assumptions to develop analytical stochastic models. The other alternative is to use simulation techniques whenever the system is very complex and inter-relationships among its components cannot be modeled easily. In particular, Monte Carlo simulation techniques have proven very useful in assessing such complex joint probability profiles [Hertz 1964, Sullivan and Orr 1984]. In fact, the decision-maker needs only to specify probability distributions of individual stochastic terms in the investment portfolio’s measure of merit, and the Monte Carlo simulation algorithm generates as many random replicates of the measure’s outcome as the decision-maker thinks appropriate in order for him to determine the expected value and variability of this measure.
3.3.3.2 Utility Theory

The formulation of "Cardinal Utility theory" was proposed by John Von Neumann and Oskar Morgenstern in their monumental Theory of Games and Economic Behavior [Neumann and Morgenstern, 1947]. This theory is based on the probability theory and some other axioms relating to the tenets of entrepreneurial behavior [Neumann 1947, Keeney and Raiffa 1976]. It advocates that it is possible to measure the attitudes of an individual or a group of individuals towards risk. Such quantification process usually requires subjective human judgement ranging from a very conservative attitude (i.e., a risk-averse, or risk-avoider type) to a more optimistic (i.e., a risk-seeker, or risk-taker type).

The aggregate attitude towards risk is evaluated by considering a broad set of preferences under conditions of uncertainty using standard techniques of assigning certainty equivalents to a series of lottery-type situations [Grant and Ireson 1960, Sharpe 1970]. If decision-makers are consistent with respect to their preferences under conditions of uncertainty, the relationship between monetary gain or loss and the utility, or relative desirability, of that gain or loss can be represented in the form of a corporate utility curve.

One cannot specify, from theory, a single mathematical function which represents the utility function for an individual or a group of individuals. In fact, being based upon much subjective judgement, this function depends greatly on the decision-maker's degree of risk aversion or risk preference, which is in itself, a function of the firm's wealth position and own reading of the future. Nevertheless, much work has been devoted to constructing empirical utility functions in real-life cases [Grant and Ireson 1960, Green 1963, Sharpe 1970]. The most commonly obtained results can be classified under three principal categories.
3.3.3.2.1 Quadratic Utility Functions (the E-V, or Expectancy-Variance, model)

Many decision-makers express a constant risk-aversion over their wealth-planning horizons. Thus, their monetary utility functions are concave downward, which implies diminishing marginal utility. The degree of concavity is determined by the level of risk-aversion of the decision-maker. Markowitz [Markowitz, 1959] has shown that, for these smooth, concave functions, a quadratic polynomial can provide a surprisingly close approximation. Accordingly, the utility of a given project's return $R$ can be expressed as:

$$U(R) = R - A*R^2$$ (3.1)

where $A$ is a positive constant called "coefficient of risk-aversion."

The first derivative of the utility function represents the marginal utility of the project for the investor and should, therefore, be positive in order for the incremental amount of invested capital to be economically justified. Similarly, its second derivative represents the marginal utility rate and should, therefore, be negative according to the principle of diminishing marginal utility, commonly observed in entrepreneurial behavior [Ouederni and Sullivan].

If the return $R$ has a preassumed normal distribution of mean $\mu$ and standard deviation $\sigma$, the expected utility of the project is given by:

$$E[U(R)] = \mu - A*(\mu^2 + \sigma^2)$$ (3.2)
The expected utility equation is commonly used in the "preference ordering" literature as a basis for making inferences about the risk attitudes of the decision-maker who possesses a quadratic utility function.

Despite the common acceptance of quadratic utility functions in industry, many authors have not explicitly recognized the potential of this model to represent entrepreneurial money utility. This criticism is mostly brought by the following facts:

1- Being a quadratic polynomial in return, this function exhibits an extremum at a value of the return R equal to 1/2A. Therefore, for all returns greater than 1/2A, the marginal utility becomes negative, which is not acceptable according to rational entrepreneurial behavior, and the quadratic function is, therefore, no longer valid to describe the true behavior of the decision-maker [Borch 1967, Ouederni and Sullivan 1991].

2- The greater the coefficient of risk-aversion, the smaller the range of validity of the quadratic utility function. To widen this range, A should be infinitesimally small. At the limit, A goes to zero, and the utility function becomes linear (U(R)=R) rather than quadratic. Hence, we end up with a situation where the decision-maker is insensitive to risk. Maximization of expected utility becomes simply that of expected monetary value [Ouederni and Sullivan, 1991].

3.3.3.2.2 Linear utility functions (the EMV, or Expected Monetary Value, model)

A decision-maker whose utility function is linear is neutral toward risk, and as a consequence, he/she simply seeks to maximize expected monetary value (EMV) instead of expected utility. Thus, there is no conceptual contradiction between this risk-ignoring attitude and the "Bernouilli principle" of maximizing expected utility [Bussey, 1978]. In
this case, the risk-aversion coefficient is simply zero, and the utility function expression is
given by:

\[ U(R) = R \] (3.3)

The expected utility is then:

\[ E[U(R)] = E[R], \text{ or } E[U(R)] = EMV \] (3.4)

which is the equation of a straight line passing through the origin (\( R=0, E[U(R)] = 0 \)).

Despite its mathematical simplicity, this method virtually overlooks the severe
consequences of possible widely-varying outcomes by merely taking a weighted average of
all outcomes [Canada and Sullivan, 1989].

3.3.2.2.3 Hybrid utility functions (the E-S, or Expectancy- Semi-variance, model).

Variance measures the risk of an investment by the scatter of its distribution around
the mean. However, the value of \( \mu \) might be of no critical relevance to the decision-maker
who may desire to minimize under-attainment of an objective in terms of a different target
figure, \( h \). It is, therefore, more adequate for this decision-maker to focus on the distribution
scatter around this critical value rather than around the mean. More specifically, the
decision-maker may be concerned only about negative deviations about that fixed point,
expressing his/her downside risk-aversion and neutrality toward positive deviations. In
fact, it is a common behavior that all risky dollars are not viewed by investors as having the
same value. For instance, a big loss (i.e., \( R<h \)) is clearly worse than an equivalent one at a
higher “profit margin.” The increment of pleasure to be gained through success is of lesser value than the increment of pain suffered if one loses. To describe such behavior, semi-variance (Sh) is an appropriate measure of risk that offers the aforementioned flexibility [Mao, 1970].

While traditional statistical variance is defined as:

$$V[R]=E[(R-\mu)^2]=\sigma^2$$  \hspace{1cm} (3.5)$$

semi-variance is defined as:

$$Sh[R]=E[((R-h)^-)^2]=s^2$$  \hspace{1cm} (3.6)$$

where the amount \((R-h)^-\) stands for the smaller of \((R-h)\) and 0.

Thus, semi-variance measures the expected value of the squared negative deviations of the outcome \(R\) from the critical value \(h\). To describe the decision-maker’s aversion to downside risk and neutrality to positive deviations, the utility function expression can be constructed as follows:

$$U(R)=U(h)+U'(h)(R-h)+0.5U''(h)(R-h)^2, \quad \text{if } R<h$$  \hspace{1cm} (3.7)$$

and,  \quad U(R)=U(h)+U'(h)(R-h), \quad \text{if } R>h$$  \hspace{1cm} (3.8)$$

So came the name “hybrid utility function”, for it is quadratic for values of \(R\) less than \(h\) and linear for those greater than \(h\).
If the return $R$ has a normal distribution of mean $\mu$ and standard deviation $\sigma$, the expected utility of the project is given by:

$$E[U(R)] = U(h) - h \cdot U'(h) + U'(h) \cdot \mu + 0.5U''(h) \cdot s^2$$  \hspace{1cm} (3.9)

For values of $R$ greater than $h$, the resulting indifference curves are monotonic, increasing, and concave downward [Ouederni and Sullivan 1991]. However, their shapes and curvatures are different from those obtained with the E-V model. In the region $R > h$, $Sh(R)$ is equal to zero, and therefore the defined expected utility is simply proportional to the EMV of the project. The corresponding indifference curves are, then, vertical straight lines passing through the point $(\mu, 0)$ for all values of $\mu$ greater than $h$ (see Figure 3.2). Thus, to achieve a given expected utility, any apparent risk should be counterbalanced by an expected value of return determined according to these indifference curves. The selection philosophy is then similar to that in the E-V model. However, the results are different most of the time, mainly when we deal with markedly skewed probability distributions.

One of the main advantages of this commonly manifested type of hybrid utility function is the fact that it has an infinite range of economic significance as compared with the E-V model type of quadratic utility function.

In view of what has been developed about the utilitarian approach, one can say that it is a realistic portrayal of the rational entrepreneurial behavior and it provides us with some useful insights into the matter of incorporating risk in capital investment analysis. However, the selection of the optimal portfolio of investment projects is greatly dependent on the selection criterion used in assessing risk profiles and in portraying the investor's attitude towards risk as well as on his degree of risk aversion or preference.
Figure 3.2 Indifference Curves (E-Sh Model)
Therefore, these characteristics have to be well defined and suited to the particular situation before any decision can be made.

Nevertheless, some authors have questioned the reliability of expected utility maximization as a selection tool. In fact, in discounting future cash flows to present time, the model uses a global figure of the cost of capital that contains an implicit allowance for risk in addition to the base interest rate (the time-value of money). Therefore, the risk allowance part of the cost of capital is also compounded. Such an operation may seriously distort the interpretation of the actual riskiness of future cash flows. "Certainty Equivalence" (CE) is proposed in this work as a substituting technique which retains much of the realism of the previous one while offering several operational advantages.

The CE method calls for reducing each project's worth to its certainty equivalent by considering both the expectancy and measure of risk of the project's worth outcomes [Bussey, 1978]. The alternative with the highest CE is, then, the one to be chosen. The proposed CE method enables us to avoid the problem of "double-counting" risk. Its computational tractability is based on indifference curves which can be obtained from either one of E-V and E-Sh models, depending on the true behavior of the investor in risky situations [Ouederni and Sullivan, 1991]. Other criticism about the utilitarian approach included the following arguments:

1. The use of an assumedly known and constant utility function for the firm does not bear any strong evidence in real-world life. That is, the attitudes of the firm's board of executives towards risk can vary widely with time, the states of nature, and the relative wealth position of the firm [Thompson and Thuesen, 1987].
2. In the portfolio case, there is a possibility that an individual risky project, or even a project of certain negative PW, can be accepted in a portfolio if it is negatively correlated to
some other efficient projects in the set. Therefore, the firm's average level of risk changes, and the first marginal cost of capital must be changed accordingly. Therefore, there must be a simultaneous determination of the cost of capital and the optimal portfolio (Lintner, 1964).

The proposed product abandonment model accounts for uncertainties in future cash flows and applies various utility theory concepts introduced above to make trade-offs between the value and riskiness of the existing system as well as all proposed improvement portfolios. To avoid "double counting" of risk, "certainty equivalence" has been used as a final measure of project's financial worth.

3.3.4 Multi-Attribute Decision Theory

With the advent of the strategic planning movement, decision-makers have realized the limitation of financial performance alone as a measure of the true value of a given project. They have also realized the importance of accounting for strategic corporate objectives, such as product quality, process flexibility, resource usage, time-to-market, and customer satisfaction among others, in their continuous improvement programs. To this end, these objectives must be translated into quantifiable performance measures and included in the evaluation criterion used by their capital expenditure decision models.

While there is quite a unanimous agreement on the need to consider both quantitative and qualitative factors in evaluating alternative investment options, different authors and/or companies have generally used different methods with respect to: (1) how to quantify intangible qualitative factors, and (2) how to incorporate both financial and non-financial measures into a single model, the multi-attribute decision model (MADM).
Kaplan, for instance, believes that pure financial analysis is sufficient as a first pass to compare alternatives [Kaplan, 1986]. Then, if a given alternative cannot be justified based on net present value (NPV) calculations, management should assess whether or not anticipated non-quantified benefits associated with this alternative outweigh the shortfall in its NPV. Sloggy [1984], Sullivan and LeClair [1985], Canada [1986], Falkner [1986], Canada and Sullivan [1989], Falkner and Benhajla [1990], and Sawhney [1991], on the other hand, all have suggested models using some weighted scheme of various performance measures derived from the company’s corporate strategy. These weights are typically determined by consensus (i.e., by using the Analytic Hierarchy Process techniques [Saaty 1980, Varney and Sullivan 1985]) to reflect the relative importance of each attribute to the corporate strategy.

Ideally, the reliability of a MADM should be measured in view of the following criteria: [DeGarmo et al., 1992]

1. Theoretical soundness: The MADM must be internally and logically consistent with the decision-makers value system in the given choice situation;
2. Credibility: The user must have confidence in the model’s accuracy and recommendations;
3. Verifiability: Lack of internal bias, explicitness and ease of implementation, and consistency of results are primary keys to the replicability and verifiability of the model;
4. Comprehensiveness: The model must be able to include and handle all relevant aspects of the choice situation;
5. Reasonable data requirements: The model must allow for economical and timely collection of all needed input data. The cost of additional information must be justified by the potential improvement in the quality of the model’s recommendations;
6. Explicitness of assumptions: All underlying assumptions of the model must be known and understood by the user in order for him or her to apply it only where it is appropriate;

7. Treatment of risk and uncertainty: The sensitivity of model's recommendations to changes in input variables must be investigated and quantified;

8. Dynamic behavior: Sequential decisions over time are common to continuous improvement programs. Therefore, time-dependence of model's parameters ought to be adequately included in the model;

9. Suitability to a group process: Complex decision problems span many functional areas of the organization and generally require a great deal of subjective judgement. The MADM must, therefore, accommodate consensus-driven decision-making, and

10. Ease of communication: The usefulness of the model is contingent upon how easily the user can understand it and apply it.

In this research, the proposed model calculates the actual performance change brought by the improvement portfolio under study to the base performance of the existing system with respect to each performance measure and compare it to predefined improvement targets. Thus, a final score can be determined for each competing alternative which represents its overall weighted performance.

3.3.5 Dynamic Systems Simulation

Simulation has been widely recognized as a standard systems analysis tool. Its applications span such diverse areas as weapon system planning, hospital design, production scheduling, traffic-light design, and election forecasting [Shannon 1975, Vester and Muller 1987, Reeve and Sullivan 1988].
Normally, we analyze a system so that we can explain, predict, and ultimately control its behavior. However, because of shortages in resources and/or knowledge, the decision-maker may opt to analyze the system through a simplified model which approximates its real behavior. While a shortage in resources refers to situations where experimentation with the actual system is not technically or economically feasible (i.e., destructive strength tests) or simply not desirable (i.e., tests with a bad impact on the environment), a shortage in knowledge has to do with the inability of the decision-maker to formulate a mathematical model which approximates closely the true behavior of the system over time and solves for various inter-relationships among its components in analytical terms. The tendency has been to turn to digital simulation as an operational tool to study the behavior of such complex dynamic systems [Kheir 1987, Pritsker 1989].

Other reasons for using simulation which may be independent of system’s size and complexity include requirements for experimental control (i.e., controlling parameter changes in different geographical locations or keeping ambient environmental conditions constant throughout a test) and the presence of statistical variation (i.e., structurally simple analytical models whose statistical properties do not admit simple analytical solutions) [Kiviat, 1967]. For instance, the technique of Monte Carlo simulation referred to earlier has proven to be very efficient in dealing with the presence of complex statistical variation in a given system [Hertz 1964, Sullivan and Orr 1982].

Thus, dynamic systems simulation is a very useful operational tool which permits the decision-maker to assess the dynamic behavior of the studied system with respect to various strategic and operational performance measures. However, simulation is only a “satisficing” search method and, as such, it leads to a satisfactory, but not necessarily optimal, solution of the decision problem [Law, 1982].
The proposed solution methodology requires the use of simulation techniques to evaluate the operational performance of the existing system and each proposed improvement portfolio. The obtained results will first be used by the activity-based analysis to assess activity consumption levels for each product within the system and then as inputs to the MADM.

3.3.6 Dynamic Programming

3.3.6.1 General Concepts

Many real-life decision problems can be structured as serial multi-stage systems. These systems can be described by models which are either an approximate representation of an actual physical system (i.e., balancing an assembly line where each workstation represents a stage) or simply an abstraction of a given decision problem (i.e., sequential decision-tree analysis where each decision point in time, or each time period, represents a stage). Their solutions can, therefore, be approached by conditional optimization techniques [Beightler, 1979]. In particular, the dynamic programming (DP) approach [Bellman and Dreyfus, 1962] seems to be very effective in solving multi-stage problems. In this respect, Beightler wrote:

"Problems involving decisions to be made at specified time intervals usually exhibit a serial structure and are therefore amenable to the type of analysis associated with dynamic programming...

The dynamic programming solution method is quite well adapted for solving problems in which the return and transition functions all consist of separable functions; in other words each term in these expressions is a function of only one variable. The individual terms may be highly non-linear, making the problem difficult to solve through most optimization techniques, yet dynamic programming handles these problems quite well. Multistage decision problems of this form occur in practice more often than one might imagine, especially those in which the decision variables are restricted to integer values." [Beighler, 1979]
The cornerstone of DP is the “principle of optimality” founded by Bellman. It states that,

"An optimal policy had the property that whatever the initial state and initial decisions are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision.” [Bellman and Dreyfus, 1962]

The mathematical transliteration of this principle yields a new class of functional equations in the form of a recursive relationship between the reward, or penalty, from an n stage system and those from its n-th stage and the remaining (n-1) stage sub-system [Kao, 1979]. Such a recursive functional equation, or objective function, can generally be expressed as [Bellman and Dreyfus, 1962]:

$$f_n(x_{n+1}) = \max_{\theta_n} [g_n(x_{n+1}, \theta_n) + f_{n-1}(x_n)]$$  \hspace{1cm} (3.10)

where

- $f_n$ is the maximized reward function from the n-stage system;
- $x_n$ is a state vector which represents a set of state variables from stage n;
- $\theta_n$ is a decision vector which represents a set of decision (or control) variables at stage n, and
- $g_n(x_{n+1}, \theta_n)$ is the individual reward from stage n being initially at state $x_{n+1}$ and subjected to decision $\theta_n$.

Figure 3.3, below, gives a graphical representation of a typical multi-stage system. Physically, this system can represent, for example, a series of continuous flow stirred tank reactors (CSTR) as commonly encountered in the process industry. Thus, state variables may be concentrations of the various reacting species and/or products. Decision variables
Figure 3.3 Structure of a Typical Multi-Stage System
may be the temperature and/or pressure of the reaction mixture or the residence time of each stage.

Note that the stages have been numbered backwards. A forward numbering scheme can also be used whenever it accommodates better the physical process and its specified boundary conditions. The notion of a stage can be either real or abstract. However, the function of each stage is invariably to transform the state variables from the input state to the output state. This transformation can generally be expressed as:

\[ x_n = T(x_{n+1}, \theta_n) \]  \hspace{1cm} (3.11)

If there are \( s \) state variables and one decision variable, equation (3.11) can be written as:

\[ x_{i,n} = T_{i,n}(x_{i,n+1}, x_{2,n+1}, \ldots, x_{s,n+1}, \theta_n) \]  \hspace{1cm} (3.12)

for \( 1 \leq i \leq s \) and \( N \geq n \geq 1 \).

The main advantage of using dynamic programming to solve this class of problems is the fact that it offers tremendous savings in the required computational time. In fact, (1) DP transforms a single \( N \)-stage optimization problem into \( N \) single-stage problems. That is equivalent to reducing the number of computations from an exponential figure of \( N \) as required by exhaustive search techniques (i.e., for \( N \) stages with \( s \) states each, the total number of possible paths is \( N^s N \)), to a figure proportional to \( N \) (only \( (2N-1)^s s^2 \) paths need be searched for the same system), and (2) problem constraints make the dynamic programming enumeration process even more efficient since non-feasible options are
automatically eliminated. Other advantages of dynamic programming are listed in [Cooper and Cooper, 1981].

3.3.6.2 Markov Programming

"Markov programming" is a relatively modern branch of DP which is attracting the attention of a growing number of researchers in the field of applied mathematical programming [Macqueen 1966, Howard 1971, Denardo 1982, El-Maghrabi 1991]. It is essentially concerned with the efficient application of classical DP techniques to optimize stochastic sequential decision processes whose underlying probability structure is that of a Markov process. Any "stochastic process" \( \{x_n, n=0,1,\ldots,N\} \) with a finite state space, and whose future development is dependent on its current state and not on how it got there, can be defined as a Markov process. Depending on the "transition mechanism" by which the system transfers from one state to another, one can distinguish two broad classes of Markov processes: discrete Markov processes and continuous Markov processes. Then, within each class, several different categories can be discerned based on the dynamic nature of the "transition probabilities matrix" governing the Markov process.

Markov programming owes much of its development and success to (1) the abundance of real-life processes exhibiting a Markovian behavior, or at least whose behavior can be closely approximated by a Markovian one, and (2) the relatively straightforward analytical and numerical tractability of the stochastic behavior of such models.

The rigorous optimization of a real-life "stochastic process" with general probability spaces may require tremendous analytical capabilities and advanced mathematical machinery. The decision problem under consideration can, however, be reduced to a
manageable size and an understandable degree of analytical complexity without loss of much realism through the use of carefully chosen simplifying assumptions. For instance, many authors have limited their analyses to the case of first-order Markov chains [Robichek and Van Horne 1967, Hillier 1969, Bonini 1977]. A Markov process is said to be a Markov chain if it possesses stationary transition probabilities; that is, if the probability of going from state i to state j in one transition is independent of the stage at which this transition takes place.

In this research, too, inter-temporal auto-correlations among future cash flows will be modeled as a first-order Markov chain. This assumption bears much realism with respect to a large number of real-life decision problems. At the same time, it simplifies significantly the analytical and computational burdens during the evaluation of a given system's financial worth and risk profiles. The validity of such an assumption was extensively discussed by Hillier [Hillier 1963 and 1969].

3.4 CONCEPTUAL FRAMEWORK OF THE SOLUTION APPROACH

The philosophy underlying the proposed solution approach calls for the treatment of the abandonment option as an ordinary segment of the product life-cycle analysis. The solution methodology must, therefore, incorporate this option into the company's strategic planning and control system. To this end, the general framework shown in Figure 3.4, below, was developed as an operational platform for implementing the proposed model. The model is governed by a dynamic programming algorithm which interactively exchanges information with a global decision model (GDM). The GDM uses a

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Figure 3.4 Conceptual Framework of the GDM
multi-attribute evaluative module which is supported by a reliable data base generated through the use of production simulation techniques within an activity-based environment.

The solution methodology is initiated by defining the company's corporate strategy and relative strategic objectives in terms of quantifiable performance measures. Then, the existing system is analyzed using ABC and dynamic simulation techniques to pinpoint demands for activity and locate waste origins (i.e., non-value added activities, declining performance drivers,...). Accordingly, strategically relevant improvement portfolios are identified and then evaluated in terms of improvement portfolios rather than on a single-project basis. Cross-sectional inter-dependencies among various activities within the system are captured by using an integrated-systems approach.

The abandonment option is investigated at each decision point in time to determine if it is strategically more profitable to abandon the concern under investigation or to continue its operations for one more period. In fact, this option is evaluated based on both its financial performance and other non-financial measures (i.e., whether the product represents a core competence to the company or not, social and legal exit barriers, etc.). The Abandonment Algorithm uses a recursive search method to ensure that the recommended decision is reached with all posterior decisions assumed to be optimal.

The decision rule used by the GDM makes use of a multi-attribute decision module (MADM) to select the best course of action among a given set of mutually exclusive improvement portfolios by trading off their cost, performance, and risk measures. The performance of the implemented improvement portfolio should then be continuously tracked and controlled according to corporate strategy imperatives.

Using the Abandonment Algorithm at the existing system level has three main objectives: (1) it tells the user about the potentialities of such a system. In fact, it calculates
the maximum realizeable financial return from the existing system based on financial and non-financial factors, and tells the user how to realize such a return (i.e., by abandoning now or by holding to the system for one more decision period), (2) by combining such results with other operational performance measures as indicated by the simulation and the ABC analysis, a more informed generation of improvement portfolios can be achieved, and (3) by calculating the optimal financial merit associated with the existing system along with its risk profile, a certainty equivalent amount can be calculated which will serve as the value of the “base-performance” in the MADM analysis.

3.5 FRAMEWORK OF THE ABANDONMENT ALGORITHM

A dynamic programming recursive algorithm has been developed which evaluates, at each decision point in the product life cycle, its financial merit assuming all posterior decisions are optimal. Optimality here refers to decisions being based on the recommendations of a multi-attribute decision model rather than solely on cost information as is the case with practically all conventional abandonment algorithms. The algorithm assumes that time-dependency of future cash flow streams can be described by a first-order Markov chain. At each stage (or decision point in time), state variables are the Markov-chain probabilistic cash flow states, and decision variables are either to abandon the project at that point in time or to keep it for one more period. The framework of the abandonment algorithm is described below.

For each candidate alternative:

1) Calculate
\[ \text{IPFW}_{t}^{*}(S_{i}) = \text{AV}_{n}(S_{i}) \]

for all states \( S_{i} \), \( i=1 \) through \( d \).

2) For states \( i=1 \) through \( d \), and periods \( t=1 \) through \( n-1 \), solve backwards starting with period \( t=n-1 \) and using the most pertinent forecasts:

(i) Call the GDM to compare the two alternatives of continued operations of the ongoing concern during period \( t \) and abandoning it at the beginning of this period based on trade-offs among financial return, risk, and strategic exit barriers associated with the studied alternative.

(ii) Calculate \( \text{IPFW}_{t}^{*}(S_{i}) \) as:

\[ \text{IPFW}_{t}^{*}(S_{i}) = \text{AV}_{t}(S_{i}) \]

if the decision is to abandon at the beginning of period \( t \), or

\[ \text{IPFW}_{t}^{*}(S_{i}) = \frac{1}{1+k} \sum_{j=1}^{d} P_{ij} \left( CF_{t+1}(S_{j}) + \text{IPFW}_{t+1}^{*}(S_{j}) \right) \]

if the decision is to continue for one more period.

3) For period 0 (the current time), calculate:

\[ \text{IPFW}_{0}^{*} = \frac{1}{1+k} \sum_{j=1}^{d} P_{0j} \left( CF_{1}(S_{j}) + \text{IPFW}_{1}^{*}(S_{j}) \right) - CF_{0} \]

4) \( \text{IPFW}_{0}^{*} \) represents the financial worth of the studied alternative, as of the current time projections, if it is to be exploited optimally in the future. This value should be fed back to the GDM for each alternative as one input to the multi-attribute selection process.

where

- \( S_{i} \) is probabilistic cash flow state \( i \). We assume that there are \( d \) possible states for each period \( t \).
- \( P_{ij} \) is the transition probability from state \( i \) to state \( j \). We assume that cross temporal correlations among cash flows are described by a first order Markov chain.
- \( P_{0j} \) is the probability for the initial cash flow state in period \( t=1 \).
IPFW\(^*_t(S_i)\) is the optimal expected present value, or improvement portfolio financial
worth of future cash flows at time t associated with being in state S\(_i\) at
time t, and making optimal decisions from period t on.

IPFW\(_0\) is the expected net present value of the improvement portfolio.

CF\(_t(S_j)\) is the cash flow in period t associated with being in state S\(_j\) in that period.

AV\(_t(S_i)\) is the abandonment value at the end of period t, given cash flow state S\(_i\)
during period t.

CF\(_0\) is the initial capital investment.

k is the cost of capital rate from period t to t+1.

Figure 3.5, below, gives a sketch of stage (n-t) of the recursive dynamic
programming model. It corresponds to operating the system during period (t+1); that is,
from time t, or the end of operating period t, through time (t+1).

3.6 CONCLUSION

In this chapter, state-of-the-art managerial concepts such as continuous
improvement, waste elimination, strategy-driven evaluation, total cost management, and
risk management were introduced as integral components of the managerial philosophy
underlying the design of the proposed solution approach. Also, major operational tools
required to generate, process, and/or analyze the needed information were discussed with
respect to their theoretical foundations and as they relate to the solution approach. Finally,
conceptual frameworks of both the global decision model (GDM) and the Abandonment
Algorithm were briefly described.
Figure 3.5 Sample decision path at time $t$
CHAPTER 4
DEVELOPMENT OF THE SOLUTION METHODOLOGY

In this chapter, the conceptual solution approach presented in chapter 4 is operationalized through an easy-to-implement methodology. Various assumptions and computational steps required for the execution of this methodology are also described in this chapter.

4.1 MODEL ASSUMPTIONS

To limit the scope of this research, several “structural assumptions” were made during the conceptual design of the solution approach. Furthermore, to reduce its complexity to an analytically manageable level, several “simplifying assumptions” were made during the development and the implementation phases of the solution methodology.

4.1.1 Structural Assumptions

This class includes all assumptions having to do with: (1) the conditions of applicability of the solution approach from a theoretical viewpoint and (2) the physical constraints delimiting the applicability of the solution methodology as an implementation tool. Major such assumptions include:

1- The market is assumed to be perfect so that both the net present value criterion and rational entrepreneurial preference-ordering axiomatics can be applied. This is also needed
during the analysis of market competition forces when designing the appropriate corporate objectives of the company;

2- The company’s corporate strategy must be well defined and explicitly translated into quantifiable performance measures with specified weights and improvement targets;

3- Strategic exit barriers must be identified and their maximum tolerable heights must be determined;

4- The behavior of management under conditions of uncertainty must be described as accurately as possible with an experimentally determined corporate utility function;

5- A reliable forecasting model must be accessible to the company so that future events and outcomes (i.e., cash flows, abandonment values, etc.) are estimated as accurately as possible;

6- A production simulation software package should be available so that the performance of the existing system and any proposed improvement portfolio can be readily evaluated;

7- An “Activity-Based Costing” implementation package must be accessible to the company so that accurate cost profiles can be determined for each product within the studied system, and

8- A regular Markov chain behavior is assumed in describing the cross-temporal interdependencies among future cash flows. The need for this assumption stems from the analytical intractability of real-life problems. Fortunately, a wide range of these problems can be approximated fairly well by a Markov model. El-Maghrabi wrote:

“Without doubt, regular Markov chains are predominant in actual applications, if for no other reason than the sheer magnitude of the effort required in securing accurate and precise values of the various statistical parameters in more complex models.” [El-Maghrabi, 1991]

These structural assumptions constitute the starting point of the proposed solution methodology.
4.1.2 Simplifying Assumptions

While most structural assumptions were defined during the conceptual design phase because of their relatedness to the "big picture" of the solution approach, simplifying assumptions generally reveal more of an operational nature and are, therefore, defined during the methodology development and implementation phases. Simplifying assumptions related to the solution methodology development are defined below, whereas those related to methodology implementation are likely to be case-related and are, therefore, defined separately for each particular case study such as the one presented in chapter 6.

The list of simplifying assumptions made during the development phase of this methodology included:

(1) The defined strategic performance measures and exit barriers are assumed to be mutually independent. This assumption will serve as the basis for using an additive multi-attribute model in phase 5 of the solution methodology;

(2) Strategic performance measures and exit barriers are assumed to be applicable to all alternatives and independent of time except for actual exit barrier heights which are likely to vary with the age of the system. For example, with respect to social exit barriers, it is usually more difficult to justify the decision to close a product line which has been providing secure jobs for the last ten years as opposed to closing another line in its first year of operation. This scheme may be reversed with respect to legal barriers since most of the contracts associated with the operation of a given product line are more likely to be unfulfilled early in its life;

(3) Strategic performance measures and exit barriers are also assumed to be independent of the cash flow state of the system at a given time;
(4) Individual exit barriers, if any, need to be defined for each particular improvement portfolio at each period t whenever asked for by the GDM;

(5) The assumed Markov probability space has a constant dimension (i.e., number of cash flow states) over time;

(6) The Markov chain is also assumed to be discrete. A continuous process can be simulated to generate discrete points (this will be needed any way for model implementation on the computer). However, to solve the problem either the first-order Markov chain assumption or the “principle of optimality” has to be sacrificed. While the first option may lead to an analytically complex problem, the second one defeats the purpose of using dynamic programming;

(7) The transition probabilities matrix defined for the user-provided before-tax cash flows are assumed to be equivalently valid for describing the correlation among after-tax cash flows;

(8) Although abandonment values are likely to be affected by future uncertainties, to simplify the mathematical nature of the problem, the solution methodology assumes that these values are dependent on time t but not on the cash flow state at that time. Nevertheless, to alleviate any distortion from reality that this assumption may cause, abandonment values must be entered to the GDM as certainty equivalent amounts. This will also be useful because the abandonment decision rule compares the certainty equivalent of future cash flows associated with continuing the project to its abandonment value at that time;

(9) At the end of the “useful life“ of the system, abandonment is assumed to be the optimal decision;

(10) “Physical lives” of various proposed improvement portfolios as well that of the existing system are assumed to be the same. Otherwise, cash flow repeatability has to be
assumed and the annual worth method is then used to evaluate the financial worth of each portfolio;

(11) The determined corporate utility function is assumed to be valid over the entire study period. A dynamic utility function (which varies with time) could be defined and used, but this will be at the expense of the mathematical simplicity of the model, and

(12) The purpose of using certainty equivalence rather than expected utility as a preference-ordering decision criterion is that the latter “double-counts” risk as explained in section 3.3.3.2 of chapter 3. Therefore, a risk-free figure of the cost of capital to the company should be used to account for the time value of money.

4.2 SOLUTION METHODOLOGY DESCRIPTION

To facilitate understanding the mechanics of the solution methodology, one can use a description scheme that reflects, to some extent, the pattern of information flow across various phases of the methodology (i.e., data acquisition, processing, analysis, and interpretation, decision drawing, and actual performance control).

The methodology is initiated by forming a Strategic Planning and Control Committee (SPCC) whose task is to identify the company’s strategic parameters, analyze the existing system accordingly, identify and evaluate potential improvement programs, and select and implement an optimal, or “near-optimal,” program. Then, the solution methodology is governed by two major modules, the Global Decision Model (GDM) and the Abandonment Algorithm. The mechanisms of these two modules and any interaction between them or among their various components are described below.
4.2.1 The Global Decision Model (GDM)

The sequential composition of the GDM is shown in Figure 3.4, where each block represents one major phase of the solution methodology. The objectives of and operational mechanism used by each phase are described below.

4.2.1.1 Phase 1: Strategic Issues

The SPCC initiates its task by assessing all the information relevant to the company’s corporate strategy. To complete this phase, the SPCC must explicitly, and as accurately as possible, identify all corporate information regarding the company’s “strategic performance measures,” its “strategic exit barriers,” and management’s “risk attitude.”

4.2.1.1.1 Strategic Performance Measures

Once the “business mission” of the company and its corporate strategy are clearly formulated, the SPCC must define a set of strategic performance measures, or “critical success factors,” which translate the company’s “corporate objectives” into controllable terms [Baron et al., 1988]. This task can sometimes be relatively difficult due to the following reasons:

(1) Being strategic in nature, these measures are likely to include non financial attributes, such as product quality, process flexibility, customer satisfaction, impact on the environment, and image of the company among a lengthy list of factors which are of critical importance to the company’s “competitive advantage” [CAM-i/CMS 1987, Fernandes
1987, Kaufman 1988, Keegan et al. 1989]. Moreover, these factors are in general auto-correlated and the synergistic effect of their sum is different from the sum of their individual effects. It is then quite difficult for the decision-maker to rigorously disaggregate their combined impact on corporate strategy and allocate it to specific factors. This is why heuristic approaches and experience have customarily been used the most to complete such a task [Brimson 1991, Kaplan 1990].

(2) To achieve the desired control objectives, these factors must be expressed in quantifiable terms. Traditionally, investment justification models used to ignore any qualitative factors which cannot be assigned an equivalent dollar amount. Doing so will severely hurt a company's "competitive posture" [Baron et al., 1988]. At the same time, the literature on strategic performance measurement has failed the test of offering a scientifically sound, systematic procedure for quantifying intangibles and qualitative performance indicators [Kaufman 1988, Lessner 1989].

To answer the above problem, the developed GDM suggests the use of different units for different performance measures whenever it is necessary (i.e., dollars for a financial measure, per cent defectives for a quality measure, minutes for lead time, etc.). Any appropriate "ordinal", "interval", or "ratio" scale can be used, either directly or after being transformed into a useable form, for this purpose. A couple of empirical models have also been suggested in academia and/or used in industry for dealing with such a problem [Hutchinson and Sinha 1986, IBM 1989, Globerson and Riggs 1989, Brill and Mandelbaum 1989, azzone and Bertele 1989, and Aggrawal 1990].

(3) A third dimension of this task has to do with the problem of assigning a weight to each performance measure which reflects its relative importance to the overall corporate strategy.
To this end, much subjective judgment is needed. The analytic hierarchy process (AHP) or the Delphi method are two examples out of several heuristic group-consensus techniques that can be used for this purpose [Falkner and Benthajla 1990, Saaty 1980].

(4) In addition, the MADM uses a ratio scale, as will be discussed in section 4.2.1.5 later in this chapter, to establish a common unit for all performance measures. To this end, strategic targets must be defined with respect to each performance measure. These targets should be determined based on market-driven considerations such as competitor's behavior and best available practices [Brimson, (1989, 1991)].

4.2.1.1.2 Strategic Exit Barriers

Strategic exit barriers must be identified by the SPCC which may reverse a financially more attractive abandonment decision. Such barriers can be social (i.e., impact on the community), legal (i.e., union pressures, volume of unfulfilled contracts, level of employee ownership, decision authority, ...), ecological (i.e., impact on the environment, ...), behavioral (i.e., employee morale, management's personal attachment to specific projects, ...), or political in nature depending on the company's corporate strategy, the nature of the products it manufactures, its work-force composition, and the community it operates in among other considerations (see section 2.1.3.2 of chapter 2).

In addition, the GDM requires the assessment of a maximum tolerable height, or “eliminatory height”, for each strategic exit barrier. The eliminatory height represents a threshold level beyond which abandonment is not acceptable. The determination of such a level requires (1) a quantification scheme similar to the one needed in the case of strategic performance measures, and (2) much subjective judgement regarding what is an acceptable level for a given exit barrier and what is not.
The eliminatory height of a given barrier is determined based on prevailing laws and regulations regarding this barrier. For example, the maximum allowable concentration of emission gases from a nuclear plant, or of an industrial sewage released in a running river, can be used to calculate the eliminatory height for an environmental exit barrier. Similarly, the total number of jobs lost because of the abandonment decision, or the volume of contracts unfulfilled, can be used to determine the height of a social or a legal exit barrier, respectively.

If such quantitative measures do not apply, or are not available, eliminatory heights should be determined subjectively using, for example, a scale of zero to one hundred, where an eliminatory height of zero means abandonment is out of question, and a height of one hundred means no eliminatory height exists, or in other words, there is no need at all to account for such a barrier in the analysis. Accordingly, an exit barrier with a lower eliminatory height is more likely to cause the rejection of a financially accepted abandonment decision. In fact, it is more likely that a given improvement portfolio scores at an actual height greater than this eliminatory height.

Actual heights of a given alternative with respect to each one of the identified exit barriers are determined using the same units as those used for the corresponding eliminatory height. Whenever eliminatory heights are subjectively determined, actual heights can be determined using a zero to one hundred scale, where an actual height of zero means that such barrier is no obstacle to an eventual product abandonment decision, whereas an actual height of one hundred means that the product cannot be abandoned regardless of the barrier’s eliminatory height.
4.2.1.3 Management's Attitude Toward Risk

To account for risk, the solution methodology requires the explicit specification of management's behavior towards risk. If such information is lacking, the SPCC must conduct the necessary experiments to assess the true preferences of corporate management [Green 1963, Keeney and Raiffa 1976, and Bussey 1978]. The resulting utility function must then be modeled as linear, quadratic, or hybrid depending on which model offers the best approximation of its true shape. Then, different characteristics of the chosen model, such as the risk-aversion coefficient for a quadratic model, or the value of the threshold h, the utility of h, its marginal utility, and its marginal utility rate for a hybrid model, must be calculated to allow for its analytical application by the GDM.

Since the solution methodology assumes that all strategic information is already in place for use by the GDM, there is no need for getting into the details of how to generate this information. Nevertheless, the user is briefly presented with a sample calculation of such data throughout the illustrative case study covered in chapter 5.

4.2.1.2 Phase 2: Existing System Analysis

This phase focuses on careful consideration of whether a firm is getting the best performance possible out of its existing facilities prior to engaging into a process of identification and evaluation of prospective improvement portfolios. It assumes that the SPCC has access to a reliable forecasting system, a dynamic systems simulation package, and an ABC implementation software so that the needed cost and performance information can be timely generated whenever asked for by the GDM. This phase includes the following operational steps:
4.2.1.2.1 Raw Data Collection

This step initiates phase 2 by requiring the user to retrieve the results from analyzing the existing system with the three operational decision support tools mentioned above and to put them into a format which can be readily used by the GDM. Namely, this step should provide the SPCC with:

* A detailed “bill of activities” for each product within the system from the ABC analysis. Then, the SPCC must use this information along with other information from simulation runs to calculate the overall system’s cost and performance profiles;

* A highlight of non-value-added activities (i.e., work-in-process inventories, waiting time, inspection time,...) so that waste can be eliminated through monitoring the corresponding drivers, and

* A highlight of activities efficiently contributing to sustaining the company’s competitive advantage so that continual improvement can be ensured.

4.2.1.2.2 Before-Tax Data

In this step, the user is asked to specify the system’s estimated useful life, various before-tax future cash flows and abandonment values, and transition probabilities from one cash flow state to another within the probability space defined by the assumed regular Markov chain. Obviously, all operational decision support tools mentioned above are required to complete this task.
4.2.1.2.3 After-Tax Data

In this step, the GDM takes all before-tax cash flows and abandonment values and transforms them into their after-tax equivalents using a user-specified effective tax-rate. The Modified Accelerated Cost Recovery System (MACRS) with "half-year convention" method created by the Tax Reform Act of 1986 is used by the GDM to calculate "asset depreciation" deductions for "income taxes" purposes [Degarmo et al., 1989]. If the system involves assets to which special rules for calculating the MACRS class life must be applied, then the user is asked to specify the appropriate class life.

4.2.1.2.4 Financial Merit Assessment

Once all after-tax quantities are calculated, the GDM calls the Abandonment Algorithm (to be described in section 4.2.2) to determine recursively for each and every decision point in the system's life cycle the financial merits of both the option to continue its operations for one more period and the option to abandon it at that point in time. Thus, the current optimal financial worth of the system and a measure of its "riskiness" can be calculated assuming all future decisions are optimal.

4.2.1.2.5 Non-Financial Data

In this step, the GDM asks the user to specify the actual system's performance with respect to all the selected non-financial performance measures as indicated by production simulation results. The entered data are then saved along with the existing system's current optimal financial worth as base-performance entries for later use by the MADM.
4.2.1.3 Phase 3: Generation of Candidate Improvement Portfolios

Based on results from the first step of the previous phase, wherever demand for activities is observed, investment opportunities (either available in the market or which can be readily designed and implemented in a still competitive time) should be identified. Similarly, wherever waste is detected or predicted, potential divestment opportunities should be identified.

At this level, some additional managerial expertise might be needed to reduce the set of feasible improvement alternatives to a manageable number of most promising ones. Mutually exclusive improvement portfolios are then formed out of these selected alternatives based on the nature of their contingencies and capital rationing constraints. Only these resulting portfolios will be evaluated and selected from by the GDM. Thus, a proposed improvement portfolio may contain simultaneously investment (i.e., product acquisition, augmentation, and/or replacement) and divestment (i.e., product abandonment and/or retrenchment) projects. Depending on the magnitude of the gap detected between the existing system performance and the specified strategic targets, the improvement program can be designed either on an incremental or on an integral basis.

4.2.1.4 Phase 4: Evaluation of Alternative Improvement Portfolios

During this phase, cost, performance, and risk profiles are calculated for each improvement portfolio using the same steps as those described in phase 2 regarding the existing system. Forecasts and computations should encompass all aspects of costs and benefits incurred by the continued operations of the studied course of action as well as those incurred by its premature termination or partial alteration at any decision point during
the portfolio's life cycle. Resulting cost and performance profiles are then saved by the GDM as actual performance entries for each improvement portfolio for later use by the MADM.

This phase constitutes the core of the solution methodology. It interfaces the Abandonment Algorithm with the GDM in a highly interactive mode. The information exchange pattern between the user, various operational decision support tools, the Abandonment Algorithm, and different modules of the GDM is depicted in Figure 4.1 below. In this figure, the user is shown as the centerpiece of the solution methodology. This is so because the solution approach relies in part on subjective judgement to calculate various strategic inputs to the GDM and a diversity of decision support tools, exogenous to the model, to calculate operational ones.

### 4.2.1.5 Phase 5: Selection of the Best Improvement Portfolio

This phase uses a MADM to select the best course of action among competing improvement portfolios based on their overall contribution towards achieving the targeted improvement of the existing system. The computational mechanism of this phase is described through the following steps:

**Step 1**

The MADM retrieves all the information regarding various strategic performance measures defined during phase 1.

**Step 2**

The MADM retrieves all base-performance information regarding each performance
Figure 4.1 Interactive Information Exchange Between the User and Various Componentss and Supporting Tools of the GDM
measure from the output of phase 2. the financial performance measure is entered to the MADM as a certainty equivalent amount to account for the risk associated with such an expected value.

**Step 3**

The MADM retrieves all actual-performance information regarding each performance measure from the output of phase 4. If the analysis involves improvement portfolios with different useful lives, the financial performance measure is first transformed into its annual worth equivalent as required by the cash flow repeatability assumption.

**Step 4**

For each proposed improvement portfolio, the MADM calculates the relative percent change realized with respect to each strategic performance measure as the ratio of the actual performance change (actual-performance minus base-performance) to the targeted one (target-performance minus base-performance). While a positive ratio reflects an improvement of the existing system’s performance, a negative one reflects a degradation of this performance.

Using such a ratio scale offers an invaluable analytical advantage by allowing the decision-maker to combine the outcomes of different performance measures with different measurement units into a single factor which indicates the overall performance of the improvement portfolio and can, therefore, be used to rank-order competing alternatives.
Step 5

For each improvement portfolio, relative percentage changes are weighted and summed over all strategic performance measures to calculate an overall score of the improvement portfolio.

Step 6

The improvement portfolio that scores the highest is then selected for implementation.

4.2.1.6 Phase 6: Continuous Tracking and Control

At each decision point in time, the status of the implemented portfolio should be revised. Any gap between current performance and targeted figures represents an improvement opportunity. The causes of this gap should be assessed and monitored using the most recent information available and updated forecasts.

4.2.2 The Abandonment Algorithm

This module is called by the GDM every time the existing system or a given improvement portfolio is to be evaluated as indicated in phases 2 and 4 respectively.

The Abandonment Algorithm makes use of a dynamic programming recursive search method which evaluates, at each decision point in the system’s life cycle, its financial merit’s expected value and measure of risk assuming all posterior decisions are optimal. An appropriate measure of risk should be selected based on the decision-maker’s utility model identified in phase 1. Namely, statistical variance is used to measure risk in
the case of a quadratic utility model, statistical semi-variance is used in the case of a hybrid
utility model, and no risk is explicitly considered in the case of a linear utility model.

The computational mechanism used by this algorithm involves the following three
major steps:

4.2.2.1 Optimal Decision at the End of the System’s Useful Life

After asking the user for the value of the company’s risk-free cost of capital, the
Abandonment Algorithm calculates the system’s optimal financial worth (IPFW_OPT(n,i))
for all cash flow states (i=1 through d) at the end of the system’s estimated useful life (t=n)
as their corresponding estimated abandonment values (ATAV(n,i)). It also calculates their
corresponding measures of risk (VAR(n,i) or SEMI_VAR(n,i) depending on the utility
model). All the quantities are evaluated on an after-tax basis.

However, since the model assumes that abandonment values are known for certain
and are dependent on the time t but not on the cash flow states at that time
(ATAV(t,i)=ATAV(t) for t=1 through n), one can write for i=1 through d:

\[
\text{IPFW\_OPT}(n, i) = \text{ATAV}(n) \tag{4.1}
\]

and

\[
\text{VAR}(n,i) = \text{SEMI\_VAR}(n,i) = 0 \tag{4.2} \text{ and } (4.3)
\]
4.2.2.2 Optimal Decision Policy for Intermediate Stages

For each decision period $t$, $t=n-1$ down to $t=1$, the Abandonment Algorithm calculates backwards, starting at $t=n-1$, the following quantities:

1. the expected value of the after-tax cash flow at period $t+1$ (the previous stage) given cash flow state $i$ at period $t$, for all states $i=1$ through $d$, as:

\[
\text{EXP\_ATCF}(t+1,i) = \sum_{j=1}^{d} P_{ij} \times \text{ATCF}(t+1,j)
\]  

(4.4)

2. the expected value of the improvement portfolio’s optimal financial worth at period $t+1$ given cash flow state $i$ at period $t$, for all states $i=1$ through $d$, as:

\[
\text{EXP\_IPFW\_OPT}(t+1,i) = \sum_{j=1}^{d} P_{ij} \times \text{IPFW\_OPT}(t+1,j)
\]  

(4.5)

3. the financial worth of the improvement portfolio if its operations are to be continued at period $t$ given cash flow state $i$, for all states $i=1$ through $d$, as:

\[
\text{IPFW}(t,i) = \frac{1}{1+k} \times \sum_{j=1}^{d} P_{ij} \times (\text{ATCF}(t+1,j) + \text{IPFW\_OPT}(t+1,j))
\]  

(4.6)

4. the variance of IPFW$(t,i)$, if management’s utility function is quadratic, for all states $i=1$ through $d$, as:
\[ \text{VAR}(t,i) = \frac{1}{(1+k)^2} \times \sum_{j=1}^{d} P_{ij} \times \left( \text{ATCF}(t+1,j) - \text{EXP}_\text{ATCF}(t+1,j) \right)^2 + \left( \text{IPFW}_\text{OPT}(t+1,j) - \text{EXP}_\text{IPFW}_\text{OPT}(t+1,j) \right)^2 \\
+ \left( \text{ATCF}(t+1,j) - \text{EXP}_\text{ATCF}(t+1,j) \right) \times \left( \text{IPFW}_\text{OPT}(t+1,j) - \text{EXP}_\text{IPFW}_\text{OPT}(t+1,j) \right) + \text{VAR}(t+1,j) \]  
(4.7)

The first term in equation (4.7) represents the variance of the cash flow at period t+1. The second term represents the variance of expected future cash flows from period t+1 on assuming all posterior decisions are optimal. The third term represents the covariance between the two first factors. Finally, the fourth term represents the variances of the improvement portfolio’s future financial worth from period t+1 on.

The summation in the variance expression is performed only over j, the cash flow states at period t+1, because the whole term is conditional on being in state i at period t. A complete mathematical derivation of equation (4.7) is given in [Hillier, 1963].

5) the semi-variance of IPFW(t,i), if management’s utility function is hybrid, for all states i=1 through d, as:

\[ \text{SEMI}_\text{VAR}(t,i) = \frac{1}{(1+k)^2} \times \sum_{j=1}^{d} P_{ij} \times \left( \text{ATCF}(t+1,j) - h^- \right)^2 \\
+ \left( \text{IPFW}_\text{OPT}(t+1,j) - h^- \right)^2 \\
+ \left( \text{ATCF}(t+1,j) - h^- \right) \times \left( \text{IPFW}_\text{OPT}(t+1,j) - h^- \right) + \text{VAR}(t+1,j) \]  
(4.8)
where \((\text{ATCF}(t+1,j)-h)^-\) is the smaller of \text{ATCF}(t+1,j) minus \(h\) and zero. Similarly, \((\text{IPFW\_OPT}(t+1,j)-h)^-\) is the smaller of \text{IPFW\_OPT}(t+1,j) minus \(h\) and 0. This is so because semi-variance accounts only for down-side risk relative to \(h\). Different terms in the right hand side of equation (4.8) are equivalent to their homologues in equation (4.7) except that semi-variance is used as a measure of risk instead of variance. Thus, four possible cases can be distinguished at each state \(j\) depending on the positions of \text{ATCF}(t+1,j) and \text{IPFW\_OPT}(t+1,j), \(j=1\) through \(d\), relative to the utility threshold \(h\).

(6) the expected utility of \text{IPFW}(t,i), if the utility function is quadratic, for all cash flow states \(i=1\) through \(d\), as:

\[
\text{EXP\_UTIL}(t,i) = \text{EXP\_IPFW}(t,i) - A \times ((\text{EXP\_IPFW}(t,i))^2 + \text{VAR}(t,i)) \tag{4.9}
\]

where

\[
\text{EXP\_IPFW}(t,i) = \sum_{j=1}^{d} P_{ij} \times \text{IPFW}(t,j) \tag{4.10}
\]

is the expected value of the improvement portfolio’s financial worth if its operations are to be continued at time \(t\) given cash flow state \(i\) at that time, and \(A\) is the risk aversion coefficient characterizing the quadratic utility function. \(A\) is provided by the user in step 3 of phase 1.

(7) the expected utility of \text{IPFW}(t,i), if the utility function is hybrid, for all cash flow states \(i=1\) through \(d\), as:

\[
\text{EXP\_UTIL}(t,i) = U(h) + U'(h) \times (\text{EXP\_IPFW}(t,i) - h)) + 0.5 \times U''(h) \times \text{SEMI\_VAR}(t,i) \tag{4.11}
\]
where EXP_IPFW(t,i) is the same as in the previous case, and the threshold h, its utility U(h), its marginal utility $U'(h)$, and its marginal utility rate $U''(h)$ are all defined by the user in step 3 of phase 1.

(8) the certainty equivalent of IPFW(t,i), if the utility function is linear, for all cash flow states $i=1$ through $d$, as:

$$\text{CERT}_{-}\text{EQUIV}(t,i) = \text{IPFW}(t,i) \quad (4.12)$$

(9) the certainty equivalent of IPFW(t,i), if the utility function is quadratic, for all cash flow states $i=1$ through $d$, as:

$$\text{CERT}_{-}\text{EQUIV}(t,i) = (1 - (1 - 4 \times A \times \text{EXP}_\text{UTIL}(t,i))^{0.5}) / (2 \times A) \quad (4.13)$$

(10) the certainty equivalent of IPFW(t,i), if the utility function is hybrid, for all cash flow states $i=1$ through $d$, as:

$$\text{CERT}_{-}\text{EQUIV}(t,i) = h + (\text{EXP}_\text{UTIL}(t,i) - U(h)) / U'(h) \quad (4.14)$$

(11) the optimal value of the improvement portfolio’s financial worth at period $t$, given cash flow state $i$, for all states $i=1$ through $d$, as:

$$\text{IPFW}_\text{OPT}(t,i) = \text{IPFW}(t,i) \quad (4.15)$$
if CERT_EQUIV(t,i) is greater than its after-tax abandonment value at period t 
(ATAV(t,i)). This means that the decision at period t should be to hold on to the portfolio 
for one more period.

(12) However, if CE(t,i) is less than ATAV(t,i), the solution methodology does not accept 
the abandonment decision automatically. Instead, the GDM asks the user to specify the 
actual exit heights associated with abandoning the studied portfolio at period t for all 
strategic exit barriers defined in phase 1.

If at least one barrier has an actual height that is greater than or equal to its 
corresponding eliminatory height, the abandonment option is automatically rejected and 
IPFW_OPT(t,i) is set equal to IPFW(t,i).

Otherwise, the GDM asks the user to identify all strategic exit barriers, if any, 
which are specific to the improvement portfolio under study at period t. Then, the actual 
exit barrier heights associated with these individual exit barriers are compared to their 
corresponding eliminatory heights. If at least one individual barrier has an actual height 
that is greater than or equal to its corresponding eliminatory height, the abandonment option 
is automatically rejected and IPFW_OPT(t,i) is set equal to IPFW(t,i). Otherwise, the 
decision to abandon the portfolio at period t given state i is accepted. The quantities 
IPFW_OPT(t,i) and VAR(t,i) (or SEMI_VAR(t,i) depending on the utility model) are then 
set equal to ATAV(t) and zero, respectively.

4.2.2.3 Optimal Decision at the Current Time

This step involves practically all the calculations presented in the previous step. 
However, due to the fact that at the current time (t=0) there is only one cash flow state
(CF0) which is known for certain, all the variables expressed as "VARIABLE(t,i)" are now expressed as "VARIABLE0" since both i and t are equal to zero here.

Thus, the calculated value of the improvement portfolio's optimal financial measure (IPFW\_OPT) represents the current present value of the portfolio if all decisions are optimal from now on. If the final decision was to abandon the portfolio now, IPFW0\_OPT is equal to CF0, and its measure of risk is equal to zero. If the final decision was to hold on to the portfolio for one more period, IPFW0\_OPT is equal to IPFW0, and its measure of risk is equal to either VAR0 or SEMI\_VAR0 depending on the utility model.

The quantity (CERT\_EQUIV0 - CF0) is then saved by the GDM to be fed into the MADM as the entry for the financial measure attribute relative to this improvement portfolio.

### 4.3 SUMMARY AND CONCLUSIONS

In chapter 4, a reliable methodology has been developed which puts state-of-the-art concepts presented in chapter 3 during the conceptual design of the solution approach into operational terms. Accordingly, the strategic merit of any ongoing concern and/or proposed improvement portfolio can be evaluated allowing for the abandonment option at any decision point in the system's life cycle and assuming that all future decisions are strategically optimal. Strategic optimality here refers to the fact that the abandonment decision includes other strategic factors (i.e., exit barriers, ...) in addition to the financial merit criterion. To select among competing improvement portfolios, the developed solution methodology uses a multi-attribute decision module which calculates an overall score of
each improvement portfolio as a weighted sum of its contributions to the improvement of the existing system's performance with respect to various prespecified strategic measures.

If the solution methodology is applied effectively and consistently, the SPCC should be able to arrive at a "near-optimal" recommendation about how to sustain their company's competitive advantage.
CHAPTER 5
IMPLEMENTATION OF THE SOLUTION METHODOLOGY

In this chapter, the software and hardware required to carry out various computations needed during the execution of different phases of the solution methodology are briefly described. In particular, a computer program was developed in this research to implement the solution methodology. The flow diagrams of this program and its various components and supporting utilities are presented in this chapter. The complete listing of the program's source code and associated documents are to be made available upon request from the Department of Industrial and Systems Engineering at VPI&SU.

5.1 SOFTWARE REQUIREMENTS

5.1.1 SPADA: A New Package to Assist With Strategic Product Abandonment Decisions

To implement the solution methodology described above, a software package has been developed using a Turbo C++ Boreland compiler. The software was called SPADA, for Strategic Product Abandonment Decisions Assistant.

The global logical structure of SPADA is shown in Figure 5.1 below. The computer program is governed by six main modules plus several support utilities, which required more than 2000 lines of source code. The interaction and information exchange pattern among various modules of SPADA and the user are shown in Figure 4.1. A brief
description of the main function of each module and how it relates to various phases and steps of the solution methodology described in chapter 4 are briefly presented below.

5.1.1.1 Module 1: Strategic Issues

This module asks the user to specify all strategic inputs to the GDM. Namely, all information about strategic performance measures, strategic exit barriers, and management’s risk attitude must be entered in this module. This corresponds to phase 1 of the solution methodology. The flow diagram of this module and those of its three major components mentioned above are provided in Figures 5.2, 5.2a, 5.2b, and 5.2c, respectively.

5.1.1.2 Module 2: Before- and After-Tax Data

This module first asks the user to specify all before-tax cash flows and abandonment values as well as the transition probability matrix. This corresponds to step 2 in either phase 2 (when analyzing the existing system) or phase 4 (when analyzing any proposed improvement portfolio). Then the module transforms all before-tax entries into their after-tax equivalents to complete the objectives of step 3 from phase 2. The flow diagrams of this module and its two major components are provided in Figures 5.3, 5.3a, and 5.3b, respectively.
Figure 5.1 Overall Flow Diagram of SPADA
Figure 5.2 Flow Diagram of module1()
Figure 5.2a Flow Diagram of performance_measures()
Figure 5.2b Flow Diagram of exit_barriers()
Figure 5.2c Flow Diagram of risk_attitude()
Figure 5.3 Flow Diagram of module2()
Figure 5.3a Flow Diagram of before_tax_data()
Figure 5.3b Flow Diagram of after_tax_data()
5.1.1.3 Module 3: The Abandonment Algorithm

This module calculates recursively for each alternative its optimal present financial worth allowing for the option to abandon at any decision point in the future and assuming that all future decisions are optimal. This module is called by the GDM during step 4 of phases 2 and 4. It includes all the computational steps required by the Abandonment Algorithm. The flow diagrams of this module and those of various functions it calls are provided in Figures 5.4, 5.4a, 5.4b, 5.4c, and 5.4d.

5.1.1.4 Module 4: Base-Performance Data

This module checks whether the alternative just being analyzed was the existing system or one of the proposed improvement portfolios. In the former case, SPADA will first ask the user to save cost and performance profiles of the system as base-performance entries for later use by the MADM. This corresponds to step 5 in phase 2. Then, the user is asked to identify mutually exclusive, candidate improvement portfolios as required by phase 3 of the solution methodology. In the latter one, SPADA will proceed to module 5. The flow diagram of this module is provided in Figure 5.5.

5.1.1.5 Module 5: Evaluation of Proposed Improvement Portfolios

This module evaluates various proposed improvement portfolios the same way the existing system was evaluated. Then SPADA will call the MADM to calculate an overall score for each improvement portfolio relative to the performance of the existing system.
Set decision at \( t = N \) equal to "abandon now" for all states \( i, 1 \leq i \leq d \)

Set \( t \) equal to \( N-1 \)

Calculate the means of after-tax cash flow and of the optimal financial worth at period \( t \) given state \( i \) over all states \( j, 1 \leq j \leq d \), for all states \( i, 1 \leq i \leq d \)

Calculate the value of the financial worth at period \( t \) given state \( i \) for all states \( i, 1 \leq i \leq d \)

Calculate \( \text{var}(t,i) \) or \( \text{semi-var}(t,i) \) and certainty equivalent \( t(i) \) depending on type of utility function

Call actual_exit_heights \( (t) \)

Call indiv_exit_barriers \( (t) \)

Is certainty equiv \( (t,i) > \) after_tax \( A(t,i) \) ?

Call indiv_exit_barriers_test \( (t,i) \)

Is exit_barriers_test passed? Yes

No

Figure 5.4 Flow Diagram of module3()
call indiv_exit_barr_test()

is indiv_exit_barr_test passed?

set IPFW_OPT (t,i) = ATAV (t,i)
VAR (t,i) = SEMI_VAR (t,i) = 0,
and decision = "abandon now"

set IPFW_OPT (t,i) = financial worth (t,i). Also, save value of VAR (t,i) or SEMI_VAR (t,i) depending on utility function type. set decision = "hold on to the portfolio for one more period"

are values of IPFW_OPT (t,i) and VAR (t,i) or SEMI_VAR (t,i) calculated for all states i, 1 ≤ i ≤ d

set t = t-1

is t < 0?

Print out final decision and save values of IPFW0, IPFW0_OPT, VAR0 or SEMI_VAR0, and CERTAINTY_EQUIV0

(continue)

Figure 5.4 Flow Diagram of module3( ) (contd)
Figure 5.4a Flow Diagram of actual_exit_heights()
Figure 5.4b Flow Diagram of indiv_exit_barriers()
Figure 5.4c Flow Diagram of exit_barriers_test( )
Figure 5.4d Flow Diagram of indiv_exit_barr_test( )
Figure 5.5 Flow Diagram of module4( )
This corresponds to steps 1 through 4 in phase 5. The flow diagram of this module and that of the MADM are provided in Figures 5.6 and 5.7, respectively.

5.1.1.6 Module 6: selection of the Best Improvement Portfolio

This module uses the results from the MADM analysis, as indicated by step 5 of phase 5, and selects the improvement portfolio that scores the highest among all competing portfolios as the “optimal” course of action to implement. The flow diagram of this module is provided in Figure 5.8.

The computer program is optimized as much as possible to avoid redundancy and save on computational time. For example, statistical calculations are performed at each decision point in time only for the specified utility function type. Also, whenever the abandonment decision is rejected because of a given exit barrier, SPADA exits the exit_barriers_test loop and does not check for the remaining exit barriers.

Furthermore, the package was made very user-friendly by including the following three major features:

(a) A simplified dialogue frame is established between the user and SPADA according to which all input data required from the user are asked for by SPADA using visual prompts on the screen of the monitor. If a non-allowed entry is typed in, a sound prompt (a beep) is initiated by SPADA, and the user is allowed to reenter a new, logically acceptable value.

(b) Every time a logically acceptable input value is typed in, SPADA takes it and then gives a chance to the user to change it, if he or she wishes to, without having to reenter all the input data from the beginning, and
Figure 5.6 Flow Diagram of module5( )
calculate relative performance change as:
\[
\frac{\text{actual} - \text{base}}{\text{target} - \text{base}} \times 100\% \text{ change}
\]

is such \% change calculated for all measures?

YES

calculate overall score for the improvement portfolio as:
\[
\text{score} = \sum \text{weight} \times \% \text{ change}
\]

(continue)

Figure 5.7 Flow Diagram of madm()

select best alt. using results from madm()

print out final recommendation

(continue)

Figure 5.8 Flow Diagram of module6()
(c) Two utility computer codes were developed in this research to support the SPADA package. The source codes for these two programs are attached to that of SPADA in the manual mentioned at the beginning of this chapter. Accordingly, whenever an output is generated, summary reports are prepared by SPADA and sent to a “display file” which activates a screen window displaying all such summary reports. All reports generated throughout the SPADA session are appended to each other so that at the end of the session the user can consult, review, and/or make comparisons among these reports. A “command and control menu” is provided at the top of the “display window” which allows the user to scroll up and down across the whole content of the “display file” and print any part or all of it. To exit the display window and proceed with the remaining phases of the SPADA session, all what the user has to do is to hit the [ESC] button of the keyboard.

5.1.2 Other Decision Support Implementation Packages

In addition to the developed software, the complete implementation of the solution methodology requires the user to have access to reliable implementation packages for use during the needed forecasting sessions, ABC analyses, and digital simulation runs.

In this respect, several packages are commercially available at a generally acceptable price. Namely, statistical analysis software packages such as SAS, MINITAB, STATGRAPHICS, or STATPRO can be used for forecasting [Jarrett, 1987]. Similarly, packages such as GPSS, QGERT, SLAMII, SIMAN/CINEMA, SIMSCRIPT, or SIMFACTORY can be used for dynamic systems simulation [Law, 1989]. In addition, many packages are available which are customized to specific problems. The user should therefore conduct some pre-study to identify those packages which are most appropriate for
the particular problem under consideration. Finally, the ABC analysis can be performed using any of the following few implementation packages available in the market:

* CMS-PC, from ICMS Software, Inc. [Brimson and Prior, 1990];
* REVEAL, from KPMG-Peat Marwick [KPMG, 1990];
* Easy-ABC, from ABC Technologies, Inc. [Turney, 1990];
* ACTIVA, from Price Water House [Prior and Brimson, 1991], and
* PRISM, from Makeem of Boston [Prior and Brimson, 1991].

Because of the young age of the ABC theory, most of these packages have not been fully tested yet in industry in order for the public to hear about their stories of success. However, those who are familiar with them are generally very enthusiastic about their effectiveness. In particular, the CMS-PC software offers reliable information, with a fair level of accuracy, about specific products’ cost profiles without requiring the user to breakdown the system into a non-manageable set of activities.

5.2 HARDWARE REQUIREMENT

It is expected that a personal computer with some memory expansion will be able to handle the whole analysis involved by SPADA. However, if the studied system is complex, a mini-frame will most probably be needed to handle all the computations associated with the required forecasting sessions, production simulation runs, ABC analyses, and the execution of SPADA. Being written in C, SPADA is easily portable
across most computer hardware using DOS or OS/2, such as IBM and IBM-compatibles, UNIX, such as NeXT, and Apple/OS, such as APPLE-MACINTOSH.

5.3 CONCLUSION

In this chapter, an implementation software package, SPADA, was developed and briefly described which represents a concrete tool for strategic product abandonment decision-making. SPADA offers the flexibility of reviewing products and/or portfolios of projects from a status quo viewpoint as well as of selecting an "optimal" alternative among competing improvement portfolios. It also offers the flexibility of accommodating a wide range of user specified parameters and subjective judgements. Another operational advantage of SPADA is its easy portability across a wide spectrum of commonly used hardware facilities.

The ease of implementation of the developed solution methodology on the computer was successfully verified to complete the objectives of this chapter. In particular, SPADA was written in a modular form which allows for much independence among various components of its code. This feature also offered the advantage of easy program debugging and reduced code compilation time. The reproducibility and reasonableness of SPADA results were also verified through several runs of manually solved problems.
CHAPTER 6
ILLUSTRATIVE CASE STUDY

In this chapter, the solution methodology developed in chapter 4 is applied to a typical real-life situation. Data collection for and results from the SPADA analysis are presented and discussed to reflect (1) how the methodology can be applied in real-life situations, and (2) how its application may lead to a more informed decision-making.

6.1 PROBLEM DESCRIPTION

XYZ, Inc. is a division of a typical multi-product manufacturing company in the ceramics production industry. In the early seventies, corporate management adopted a strategy of product diversification which has enabled their business to successfully expand into new market segments. Namely, three main products were manufactured by XYZ: (1) catalytic converter substrates, mainly for automakers, (2) porcelain kitchenware items, and (3) decorative ceramic tiles. Unfortunately, adverse performance trends began to show up by the end of the same decade. Not only did the company start losing market share in a number of its business segments to more aggressive competitors, but it also started finding it more and more difficult to manufacture products at a competitive cost by simply relying on the existing production system. The general manager of XYZ realized that his company was heading for trouble when he opened a letter from headquarters (HQ) harshly complaining about the declining profitability trend exhibited during the last three years by the kitchenware items and decorative tile product lines. However, because of his strong
attachment to these specific product lines, the general manager decided to try harder to make them profitable again rather than to consider the option to abandon them and to focus only on product line A which offers some competitive advantage to the company.

Later on, the company’s annual report referred to a continued declining profitability trend for products B and C and a decision by HQ to assign a new general manager to the XYZ division. The new manager felt no personal attachment to these “sick” products and made a commitment to reposition XYZ as a more focused company. To carry out this new strategy, she formed a Strategic Planning and Control Committee (SPCC) whose task was to analyze the existing system, identify potential improvement alternatives, and select and implement an optimal course of action. The solution methodology developed in this research was, therefore, recommended as an appropriate framework to perform the required task. Different phases of the SPADA analysis are presented below.

6.2 PROBLEM ANALYSIS

6.2.1 Phase 1: Strategic Issues

The SPCC initiated its analysis by collecting all relevant strategic inputs from HQ and translated them into quantifiable measures.

6.2.1.1 Strategic Performance Measures

The SPCC identified the company’s corporate strategy as management’s determination to reposition the company into a focused segment of the market to achieve the
following corporate objectives: (1) improve the value of the company to its "stakeholders" (including shareholders, management, employees, customers and suppliers, and the community impacted by company’s operations), (2) achieve market leadership through technological product differentiation, and (3) ensure customer satisfaction through timely product delivery.

To translate these objectives into quantifiable, operational measures which can be used to evaluate the performance of a given improvement proposal and/or to control that of an ongoing concern, the SPCC members reached by consensus a formula according to which the above corporate objectives can be reasonably translated as follows:

(1) To improve the value of the company to its shareholders, more financial return should be realized. This will also reflect a higher reinvestment rate which can lead to a better production environment, safer work conditions, higher employee compensation, better support of ecological issues, stronger competitive position, and more return. Thus, "financial return", or "worth", is a good translation of the first corporate objective of the company;

(2) Product differentiation as a competitive advantage requires company’s commitment to superior product and process innovation, design, and quality. In particular, product “quality” is highly correlated with the first two factors and can, therefore, be used to translate the company’s second corporate objective into operational terms, and

(3) Satisfying customers through timely product delivery requires the reduction of time delays from the moment the order for the product is received. Better management of such lead time calls for the collaboration of the supplier, the producer, and the customer. However, the producer is likely to have full control only on the throughput time of the
product across the company’s boundaries. Thus, “throughput time” can be used roughly to translate the third corporate objective of the company.

Then, the SPCC agreed on convenient units to measure the output of the three quantities above. They also assigned a weight for each strategic performance measure which reflects its relative importance to corporate strategy. Finally, they defined strategic targets for each measure. Table 6.1 below summarizes all such information.

6.2.1.2 Strategic Exit Barriers

To account for strategic factors associated with the product abandonment option, the SPCC identified three exit barriers which would eliminate such an option whenever the studied alternative’s score with respect to at least one of these barriers is higher than its corresponding prespecified “eliminatory height.” These barriers and their corresponding eliminatory heights are summarized in Table 6.2 below.

The “core competence” barrier refers to the importance of a particular product, or portfolio of products, to the overall image of the company. For instance, a company might lose its identity if it abandons a major product which has shaped its image and field of competence throughout history. The legal and social barriers, on the other hand, represent two classes of strategic exit barriers having to do with legal and social consequences associated with the product abandonment decision, respectively. Namely, the legal barrier was measured by the volume of unfulfilled contracts that the company has to clear out before proceeding with any decision to abandon the system under study. The social barrier, on the other hand, is measured by the number of jobs lost if the abandonment decision is undertaken.
Table 6.1 Strategic Performance Measures

<table>
<thead>
<tr>
<th>Name</th>
<th>Weight</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial worth (M$)(*)</td>
<td>0.4</td>
<td>700.00</td>
</tr>
<tr>
<td>Product quality (% non-defective)</td>
<td>0.3</td>
<td>99</td>
</tr>
<tr>
<td>Throughput time (min)</td>
<td>0.3</td>
<td>1.5(**)</td>
</tr>
</tbody>
</table>

(*) M$=Millions of $
(**) This value is assumed to be valid for the three products.

Table 6.2 Strategic Exit Barriers

<table>
<thead>
<tr>
<th>Name</th>
<th>Eliminatory Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>core competence (0 to 100 scale)</td>
<td>40</td>
</tr>
<tr>
<td>legal (M$)</td>
<td>70</td>
</tr>
<tr>
<td>social (jobs lost)</td>
<td>80</td>
</tr>
</tbody>
</table>
6.2.1.3 Management's Attitude Toward Risk

Standard lottery-type experiments were conducted by the SPCC to assess management's reaction to risky situations. It was found that the corporate utility function is best described by a hybrid utility model.

In particular, management specified that their utility has a value of zero at zero return and a value of unity at a return of M$700 based on the current wealth position of the company and projected performance improvements.

Management also manifested a neutral attitude toward risk for returns greater than M$400 (threshold h). They also expressed that they are indifferent between receiving this amount for certain and accepting a lottery according to which they receive either a sum of M$700 with a probability of p=0.6 or nothing with a probability of (1-p)=0.4. Thus, the utility of this M$400 amount to management can be calculated using the following expression:

\[ U(h) = (1-p)U(0) + pU(M$700) \]

(6.1)

Hence, \( U(M$400) = 0.6 \).

The values of the marginal utility and its rate at h can be calculated either by writing equation (3.7) for both values of return: \( R=M$0 \) and \( R=M$700 \), or graphically from the utility curve. The obtained results are \( U'(h) = 0.00133 \) and \( U''(h) = -8.33 \times 10^{-7} \), respectively.
6.2.2 Phase 2: Existing System Analysis

6.2.2.1 Before-Tax Input Data

The remaining useful life of the existing system and its residual cost were estimated to be 8 years and M$600, respectively.

Using forecasting techniques, five cash flow states were identified which are assumed to be descriptive of the uncertainty in actual future cash flows associated with continuing the operation of the existing system. Using results from dynamic simulation of the existing production system and from its ABC analysis, the aggregate cash flow states for the overall system are shown in Table 6.3.

Abandonment values were assumed to be independent of the cash flow state at each period and were estimated as shown in Table 6.4.

The transition probability matrix, $[P_{ij}]$, governing the assumed Markov-process was determined using subjective probability assessment techniques and is shown in Table 6.5.

6.2.2.2 After-Tax Data

Using an effective income tax-rate of 40%, SPADA used before-tax input data from the previous step and calculated their after-tax equivalents as shown in Tables 6.6 and 6.7 below.
Table 6.3 Before-Tax Cash Flows (existing system)

<table>
<thead>
<tr>
<th>State</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTCF</td>
<td>100</td>
<td>110</td>
<td>120</td>
<td>130</td>
<td>140</td>
</tr>
</tbody>
</table>

Table 6.4 Before-Tax Abandonment Values (existing system)

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTAV</td>
<td>400</td>
<td>300</td>
<td>200</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 6.5 Transition Probability Matrix (existing system)

<table>
<thead>
<tr>
<th>From State i (rows) to State j (columns)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>1</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.4</td>
</tr>
</tbody>
</table>
Table 6.6 After-Tax Cash Flows (existing system)

<table>
<thead>
<tr>
<th>Period(rows)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>State(columns)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>108.00</td>
<td>114.00</td>
<td>120.00</td>
<td>126.00</td>
<td>132.00</td>
</tr>
<tr>
<td>2</td>
<td>136.800</td>
<td>142.800</td>
<td>148.800</td>
<td>154.800</td>
<td>160.800</td>
</tr>
<tr>
<td>3</td>
<td>106.080</td>
<td>112.080</td>
<td>118.080</td>
<td>124.080</td>
<td>130.080</td>
</tr>
<tr>
<td>4</td>
<td>87.648</td>
<td>93.648</td>
<td>99.648</td>
<td>105.648</td>
<td>111.648</td>
</tr>
<tr>
<td>5</td>
<td>87.648</td>
<td>93.648</td>
<td>99.648</td>
<td>105.648</td>
<td>111.648</td>
</tr>
<tr>
<td>6</td>
<td>73.824</td>
<td>79.824</td>
<td>85.824</td>
<td>91.824</td>
<td>97.824</td>
</tr>
<tr>
<td>7</td>
<td>60.000</td>
<td>66.000</td>
<td>72.000</td>
<td>78.000</td>
<td>84.000</td>
</tr>
<tr>
<td>8</td>
<td>60.000</td>
<td>66.000</td>
<td>72.000</td>
<td>78.000</td>
<td>84.000</td>
</tr>
</tbody>
</table>

Table 6.7 After-Tax Abandonment Values (existing system)

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATAV</td>
<td>432.00</td>
<td>295.200</td>
<td>189.120</td>
<td>101.472</td>
<td>43.824</td>
<td>15.000</td>
<td>6.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
6.2.2.3 Existing System Analysis Results

By applying the dynamic programming abandonment algorithm (Module III of SPADA) to the existing system, the calculated optimal decision policy showed that the financial worth of the existing system cannot exceed a net of negative M$88.889 based on the data above if its operations are to be continued. The certainty equivalent of such an amount was calculated to be equal to negative M$109.950 as indicated by SPADA output.

The optimal decision policy calculated for the existing system, which generates the above maximum financial worth, indicted that abandonment should occur now based on the financial criterion alone. It was also shown that there was no instance in the existing system's life when the abandonment option was rejected because of one or more exit barrier constraints.

Simulation results indicated that the three products manufactured by XYZ are currently produced on the existing system at an 88% defect rate on the average. They also indicated that the average throughput time of the existing system is equal to 2.9 minutes per unit. This information is to be used by the MADM as "base-performance" data.

6.2.3 Phase 3: Generation of Candidate Improvement Portfolios

The information collected at HQ referred to a targeted business mission slightly different from what the company is currently operating with. In fact, the kitchenware product line is no longer a desirable item in the company's portfolio of products. Its historic attractiveness to the consumer has tremendously declined, and the company does not foresee any future contribution of this product to sustaining its competitive advantage.
In addition to these strategic reasons for considering the abandonment of the kitchenware product line, the ABC analysis has particularly pointed to this latter and the decorative tile product line as being responsible for most of the poor performance of the existing system. Not only did they account for most of the current non-value-added activities within the production system, but they were also diverting management’s attention from concentrating on the catalytic convertor substrate product line which is obviously much more profitable than the two other lines.

Thus, based on the results from the “existing system analysis” phase and other strategic and external market considerations, the SPCC has identified the following three major improvement opportunities:

• Delete the porcelain kitchenware product line;
• Delete the decorative ceramic tile product line, and
• Expand the investment in the catalytic convertor substrate product line.

Therefore, eight \(2^3\) possible mutually exclusive improvement portfolios were formed as shown in Table 6.8 below (where 1 means the improvement opportunity is included in the portfolio, and 0 means it is not included).

However, only portfolios 1, 2, 6, and 8 were feasible because of the following three constraints identified by the SPCC:

• The production of ceramic tiles is contingent on that of the kitchenware items since tiles are made out of the scrapped material from the kitchenware product line. This constraint eliminates portfolios 3 and 7;
<table>
<thead>
<tr>
<th>Portfolio Number</th>
<th>Delete Ceramic Tile Product Line</th>
<th>Delete Kitchenware Item Product Line</th>
<th>Expand Catalytic Converter Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
• Because of budget constraints, the catalytic converter substrate product line cannot be expanded without deleting at least one of the two other lines. This eliminates portfolio 4, and
• To satisfy union requirements on employee lay-offs, if the ceramic tile and kitchenware product lines are both deleted, the catalytic converter product line must be expanded to accommodate displaced employees. This constraint eliminates portfolio 5.

Thus, only feasible improvement portfolios were analyzed by SPADA in order to select an “optimal” course of action. These portfolios were first renamed as follows:

• Portfolio 1 -- Do nothing -- corresponds to the status quo, which is the existing system. This portfolio has already been analyzed during phase 2;
• Portfolio 2 -- Delete the ceramic tile product line and keep the two other lines as such - will be called “improvement portfolio 1;”
• Portfolio 6 -- Delete the ceramic tile product line only and expand the catalytic converter line -- will be called “improvement portfolio 2”, and
• Portfolio 8 -- Delete both the ceramic tile and the kitchenware product lines and expand the catalytic converter line -- will be called “improvement portfolio 3.”

6.2.4 Phase 4: Evaluation of Proposed Improvement Portfolios

Phases 2 and 3 were executed for each improvement portfolio the same way the existing system was analyzed. The results obtained for each improvement portfolio are presented below.
6.2.4.1 Improvement portfolio 1

6.2.4.1.1 Before-Tax Input Data

The useful life of improvement portfolio 1 and its initial cost were estimated to be 8 years and M$450, respectively.

Three cash flow states were identified for improvement portfolio 1. Using results from dynamic simulation of the production system associated with improvement portfolio 1 and from its ABC analysis, the aggregate cash flow states for the overall system are shown in Table 6.9.

Abandonment values were assumed to be independent of the cash flow state at each period and were estimated as shown in Table 6.10.

The transition probability matrix, \([P_{ij}]\), governing the assumed Markov-process was determined using subjective probability assessment techniques and is shown in Table 6.11 below.

6.2.4.1.2 After-Tax Data

Using a tax-rate of 40\%, SPADA used before-tax input data from the previous step and calculated their after-tax equivalents as shown in Tables 6.12 and 6.13 below.
### Table 6.9 Before-Tax Cash Flows (improvement portfolio 1)

<table>
<thead>
<tr>
<th>State</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATCF</td>
<td>180</td>
<td>190</td>
<td>200</td>
</tr>
</tbody>
</table>

### Table 6.10 Before-Tax Abandonment Values (improvement portfolio 1)

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTAV</td>
<td>300</td>
<td>200</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 6.11 Transition Probability Matrix (improvement portfolio 1)

<table>
<thead>
<tr>
<th>From State i (rows) to State j (columns)</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.3</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>1</td>
<td>0.4</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>
### Table 6.12 After-Tax Cash Flows (improvement portfolio 1)

<table>
<thead>
<tr>
<th>Period(rows)</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>State(columns)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>144.000</td>
<td>150.000</td>
<td>156.000</td>
</tr>
<tr>
<td>2</td>
<td>165.600</td>
<td>171.600</td>
<td>177.600</td>
</tr>
<tr>
<td>3</td>
<td>142.560</td>
<td>148.560</td>
<td>154.560</td>
</tr>
<tr>
<td>4</td>
<td>128.736</td>
<td>134.736</td>
<td>140.736</td>
</tr>
<tr>
<td>5</td>
<td>128.736</td>
<td>134.736</td>
<td>140.736</td>
</tr>
<tr>
<td>6</td>
<td>118.368</td>
<td>124.368</td>
<td>130.368</td>
</tr>
<tr>
<td>7</td>
<td>108.000</td>
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<td>120.000</td>
</tr>
<tr>
<td>8</td>
<td>108.000</td>
<td>114.000</td>
<td>120.000</td>
</tr>
</tbody>
</table>

### Table 6.13 After-Tax Abandonment Values (improvement portfolio 1)

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATAV</td>
<td>324.000</td>
<td>206.400</td>
<td>111.840</td>
<td>61.104</td>
<td>25.368</td>
<td>6.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
6.2.4.1.3 Improvement Portfolio 1 Analysis Results

By applying the developed dynamic programming abandonment algorithm (Module III of SPADA) to improvement portfolio 1, the calculated optimal decision policy showed that its financial worth cannot exceed a net of negative M$11.111 based on the data above if its operations are to be continued. The certainty equivalent of such an amount was calculated to be equal to negative M$39.650 as indicated by SPADA output.

The optimal decision policy, calculated for this portfolio, which generates the above maximum financial worth indicates to abandon it now based on the financial criterion alone. It was also shown that there was no instance in the existing system’s life at which the abandonment option was rejected because it violates one or more strategic exit barriers.

Moreover, simulation results indicated that the catalytic substrate and kitchenware items can be produced by the production system associated with improvement portfolio 1 at a 90% defect rate on the average. They also indicated that the average throughput time of such a system is equal to 2.5 minutes per unit. This information is to be used by the MADM as “actual-performance” data for improvement portfolio 1.

6.2.4.2 Improvement portfolio 2

6.2.4.2.1 Before-Tax Input Data

The useful life of improvement portfolio 2 and its initial cost were estimated to be 8 years and M$600, respectively.

Four cash flow states were identified for improvement portfolio 2. Using results from dynamic simulation of the production system associated with improvement portfolio 2
and from its ABC analysis, the aggregate cash flow states for the overall system are shown in Table 6.14.

Abandonment values were assumed to be independent of the cash flow state at each period and were estimated as shown in Table 6.15.

The transition probability matrix, \([P_{ij}]\), governing the assumed Markov-process was determined using subjective probability assessment techniques and is shown in Table 6.16.

### 6.2.4.2.2 After-Tax Data

Using a tax-rate of 40\%, SPADA used before-tax input data from the previous step and calculated their after-tax equivalents as shown in Tables 6.17 and 6.18 below.

### 6.2.4.2.3 Improvement Portfolio 2 Analysis Results

The output from SPADA analysis of improvement portfolio 2 showed that it can generate a maximum financial worth with a net expected value of M\$373.058 based on the data above if its operations are to be continued. However, the certainty equivalent of such an amount was calculated to be equal to only M\$230.269 because of management’s aversion to the risk associated with such an expected value of return.

The optimal decision policy, calculated for this portfolio, which generates the above maximum financial worth dictates to hold on to it for one more decision period based on the financial criterion alone. It was also shown that there was no instance in the portfolio’s life at which the abandonment option was rejected because it violates one or more strategic exit barriers. Although in period one, the legal exit barrier exhibited an actual height equal to its
Table 6.14 Before-Tax Cash Flows (improvement portfolio 2)

<table>
<thead>
<tr>
<th>State</th>
<th>1</th>
<th>2</th>
<th>3</th>
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</thead>
<tbody>
<tr>
<td>ATCF</td>
<td>210</td>
<td>220</td>
<td>230</td>
<td>240</td>
</tr>
</tbody>
</table>

Table 6.15 Before-Tax Abandonment Values (improvement portfolio 2)

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTAV</td>
<td>350</td>
<td>200</td>
<td>100</td>
<td>75</td>
<td>50</td>
<td>25</td>
<td>10</td>
<td>0</td>
</tr>
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</table>

Table 6.16 Transition Probabilities Matrix (improvement portfolio 2)

<table>
<thead>
<tr>
<th>From state i (rows)</th>
<th>to state j (columns)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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</thead>
<tbody>
<tr>
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<td>0.3</td>
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<td>0.2</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>
Table 6.17 After-Tax Cash Flows (improvement portfolio 2)

<table>
<thead>
<tr>
<th>Period (rows)</th>
<th>State (columns)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>174.000</td>
<td>180.000</td>
<td>186.000</td>
<td>192.000</td>
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<tr>
<td>2</td>
<td></td>
<td>202.800</td>
<td>208.800</td>
<td>214.800</td>
<td>220.800</td>
</tr>
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<td>3</td>
<td></td>
<td>172.080</td>
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<td>171.648</td>
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<td>6</td>
<td></td>
<td>139.824</td>
<td>145.824</td>
<td>151.824</td>
<td>157.824</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>126.000</td>
<td>132.000</td>
<td>138.000</td>
<td>144.000</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>126.000</td>
<td>132.000</td>
<td>138.000</td>
<td>144.000</td>
</tr>
</tbody>
</table>

Table 6.18 After-Tax Abandonment values (improvement portfolio 2)

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATAV</td>
<td>402.000</td>
<td>235.200</td>
<td>129.120</td>
<td>86.472</td>
<td>43.824</td>
<td>15.000</td>
<td>6.000</td>
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</tr>
</tbody>
</table>
eliminatory height due to signing new contracts regarding the expansion of product line A, this fact did not affect the decision at the end of period one because at that time the financial reward from continuing the operations of the portfolio was larger than its abandonment value.

Moreover, simulation results indicated that products the catalytic substrate and kitchenware items can be produced by the production system associated with improvement portfolio 2 at a 93% defect rate in average. They also indicated that the average throughput time of such a system is equal to 2.4 minutes per unit. This information is to be used by the MADM as "actual-performance" data for improvement portfolio 2.

6.2.4.3 Improvement portfolio 3

6.2.4.3.1 Before-Tax Input Data:

The useful life of improvement portfolio 3 and its initial cost were estimated to be 8 years and M$550, respectively.

Four cash flow states were identified for improvement portfolio 3. Using results from dynamic simulation of the production system associated with improvement portfolio 3 and from its ABC analysis, the aggregate cash flow states for the overall system are shown in Table 6.19.

Abandonment values were assumed to be independent of the cash flow state at each period and were estimated as shown in Table 6.20.

The transition probability matrix, [Pij], governing the assumed Markov-process was determined using subjective probability assessment techniques and is shown in Table 6.21.
Table 6.19 Before-Tax Cash Flows (improvement portfolio 3)

<table>
<thead>
<tr>
<th>State</th>
<th>1</th>
<th>2</th>
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<tbody>
<tr>
<td>ATCF</td>
<td>190</td>
<td>200</td>
<td>210</td>
<td>220</td>
</tr>
</tbody>
</table>

Table 6.20 Before-Tax Abandonment Values (improvement portfolio 3)

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTAV</td>
<td>300</td>
<td>200</td>
<td>100</td>
<td>75</td>
<td>50</td>
<td>25</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 6.21 Transition Probabilities Matrix (improvement portfolio 3)

<table>
<thead>
<tr>
<th>From state i (rows) to state j (columns)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
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<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
</tr>
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<td>1</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>3</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

6.2.4.3.2 After-Tax Data

Illustrative Case Study
Using a tax-rate of 40%, SPADA used before-tax input data from the previous step and calculated their after-tax equivalents as shown in Tables 6.22 and 6.23.

6.2.4.3.3 Improvement Portfolio 3 Analysis Results

The output from SPADA analysis of improvement portfolio 3 showed that it can generate a maximum financial worth with a net expected value of M$341.149 based on the data above if its operations are to be continued. The certainty equivalent of such an amount was calculated to be equal to only M$181.242.

The optimal decision policy, calculated for this portfolio, which generates the above maximum financial worth dictates to hold on to it for one more decision period based on the financial criterion alone. SPADA output also referred to the abandonment option as being more attractive financially for all cash flow states at period seven. However, portfolio 3 was not abandoned at that time because its actual exit height with respect to at least the core competence exit barrier was as high as the eliminatory height of this barrier. The legal and social exit barriers, too, exhibited actual heights greater than or equal to their corresponding elimatory heights at different instances as indicated by SPADA output. However, such information was not needed in the particular conditions of this analysis because at each instance either the financial reward from continuing the operations of the portfolio was larger than its abandonment value, or the abandonment option has already been eliminated due to the core competence exit barrier such as the case in period seven.

Moreover, simulation results indicated that the catalytic covertor substrate can be produced according to improvement portfolio 3 at a 96% defect rate on the average. They
### Table 6.22 After-Tax Cash Flows (improvement portfolio 3)

<table>
<thead>
<tr>
<th>Period(rows)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>State(columns)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>158.000</td>
<td>164.000</td>
<td>170.000</td>
<td>176.000</td>
</tr>
<tr>
<td>2</td>
<td>184.400</td>
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<td>196.400</td>
<td>202.400</td>
</tr>
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<td>3</td>
<td>156.240</td>
<td>162.240</td>
<td>168.240</td>
<td>174.240</td>
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<td>157.344</td>
</tr>
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<td>156.240</td>
<td>162.240</td>
<td>168.240</td>
<td>174.240</td>
</tr>
<tr>
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<td>126.672</td>
<td>132.672</td>
<td>138.672</td>
<td>144.672</td>
</tr>
<tr>
<td>7</td>
<td>114.000</td>
<td>120.000</td>
<td>126.000</td>
<td>132.000</td>
</tr>
<tr>
<td>8</td>
<td>114.000</td>
<td>120.000</td>
<td>126.000</td>
<td>132.000</td>
</tr>
</tbody>
</table>

### Table 6.23 After-Tax Abandonment Values (improvement portfolio 3)

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATAV</td>
<td>356.000</td>
<td>225.600</td>
<td>123.360</td>
<td>83.016</td>
<td>42.672</td>
<td>15.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
also indicated that the average throughput time associated with implementing improvement portfolio 3 is equal to 1.8 minutes per unit. This is due in part to management focus on the latter product alone as opposed to diverting their attention to the other two lines as is the case with the existing system and improvement portfolios 1 and 2.

6.2.5 Phase 5: Selection of the “optimal” improvement portfolio

Based on the financial criterion alone, improvement portfolio 2 is obviously the “optimal” choice since it maximizes the certainty equivalent of the company’s financial worth. However, to account for all corporate objectives of the company, SPADA included various strategic performance measures defined by the SPCC in phase 1 of the analysis. While SPADA calculates the financial performance of each improvement portfolio, actual performance outputs with respect to non financial measures are collected from simulation results and asked for by SPADA at the end of the analysis of each improvement portfolio. Table 6.24 summarizes such information.

Thus, the weighted overall improvement figures are equal to 17.50%, 41.15 and 59.77% for improvement portfolios 1, 2, and 3, respectively. Contrary to the decision reached based solely on financial criteria, the GDM recommends the implementation of improvement portfolio 3 since it has the highest weighted overall score.

6.3 ANALYSIS SUMMARY AND CONCLUSIONS

To best contribute to the achievement of the company’s continual improvement program as dictated by its strategic corporate objectives, SPADA recommends
improvement portfolio 3 for implementation (Delete both the ceramic tile and the porcelain kitchenware product lines and expand the catalytic convertor substrate line). This decision yields an overall improvement of the existing system’s performance equal to 59.77%. In particular, its financial worth will increase from a certainty equivalent amount of negative M$109,950 to one of M$181,242. That is a net improvement of 35.95%.

The selection of improvement portfolio 3 despite its lower financial worth than that of improvement portfolio 2 illustrates how accounting for strategic factors other than financial ones may reverse the final capital expenditure decision.

Moreover, the analysis of this case-study showed how accounting for the abandonment option at each decision point in the portfolio’s life cycle can lead to a better evaluation of a given portfolio’s potential financial merit. Appendix B also contains the results of a SPADA run for the same case-study but with no consideration of the abandonment option. According to these results, the financial worth of the existing system cannot exceed a maximum of negative M$311,111, or negative M$375,000 for certain, if its operations were to be continued. Thus, by ignoring the abandonment option, the company will forego a net amount of negative 109,950 minus negative M$375,000 for certain, based on current information. Although improvement portfolio 3 is again selected by SPADA, the final decision may be different when the abandonment option is ignored. This is true mainly when abandonment values are of comparable magnitude to that of their corresponding future cash flow streams.

In conclusion, this chapter provided an illustration of the benefits from accounting for the abandonment option as a strategic alternative in the company’s capital budgeting function. It also served as a tool to verify the applicability of the developed solution methodology and the ease of implementation of its computer code (the SPADA package).
Table 6.24 Actual Performance of Various Improvement Portfolios

<table>
<thead>
<tr>
<th>System</th>
<th>Financial Worth (millions of $)</th>
<th>Quality (% non-defective)</th>
<th>Throughput Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing System</td>
<td>-109.950</td>
<td>88</td>
<td>2.9</td>
</tr>
<tr>
<td>(base-alternative)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improvement Portfolio 1</td>
<td>-39.650</td>
<td>90</td>
<td>2.5</td>
</tr>
<tr>
<td>Improvement Portfolio 2</td>
<td>230.269</td>
<td>93</td>
<td>2.4</td>
</tr>
<tr>
<td>Improvement Portfolio 3</td>
<td>181.242</td>
<td>97</td>
<td>1.8</td>
</tr>
<tr>
<td>Target</td>
<td>700.000</td>
<td>99</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 6.25 Ratio of Actual versus Targeted Improvement Figures

<table>
<thead>
<tr>
<th>System</th>
<th>Financial Worth (%)</th>
<th>Quality (%)</th>
<th>Throughput Time (%)</th>
<th>Weighted Overall Score (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement Portfolio 1</td>
<td>8.68(*)</td>
<td>18.18</td>
<td>28.57</td>
<td>17.50(**)</td>
</tr>
<tr>
<td>Improvement Portfolio 2</td>
<td>42.00</td>
<td>45.45</td>
<td>35.71</td>
<td>41.15</td>
</tr>
<tr>
<td>Improvement Portfolio 3</td>
<td>35.95</td>
<td>72.73</td>
<td>78.57</td>
<td>59.77</td>
</tr>
</tbody>
</table>

(*) \[\frac{-39.650-(-109.950)}{(700.000-(-109.950))}=0.0868=8.68\%\]

(**) \[(0.4\times8.68)+(0.3\times18.18)+(0.3\times28.57)=17.50\%\]
CHAPTER 7
RESEARCH CONCLUSIONS AND RECOMMENDATIONS

7.1 SUMMARY OF RESEARCH FINDINGS

The main thrusts of this research work included (1) the reformulation of the product/process abandonment problem from a new perspective which is congruent with the requirements of the new global business environment, and (2) the development of a sophisticated, but practical, global decision model (GDM) incorporating the product abandonment option into the company's overall strategic planning and control system which seeks to help U.S. manufacturers make world-class capital expenditure decisions.

To this end, an extensive taxonomic analysis was first conducted to investigate the product abandonment analysis topic as treated in the literature of engineering economy, financial management, management accounting, marketing, strategic management, and corporate organizational and behavioral sciences. The product abandonment problem is then reformulated in view of both the strengths and shortcomings of older models and the requirements of the new business environment. Finally, the developed GDM is described and illustrated through an actual case-study.

7.1.1 Taxonomic Analysis Results

Three broad schools of thought were identified by the taxonomic analysis of the product abandonment topic. Namely, these are the "engineering economy, financial management, and management accounting" school, the marketing school, and the "strategic
management and corporate organizational and behavioral sciences” school. Although very little empirical research has been done, so far, with respect to the product abandonment problem, field evidence from the few completed attempts reveals the following major observations common to the three abandonment schools mentioned above:

(1) A general observation is that relatively little attention has been given by both academicians and practitioners to the subject of product abandonment.

(2) Another observation is the apparent disjoint efforts of the three abandonment schools working in parallel. Practically, no integrative efforts have been reported yet which could put together, in a single model, the concepts developed separately in the three schools. In particular, only the “engineering economy, financial management, and management accounting” school has gotten into the detailed, quantitative calculation of the financial repercussions on the firm of the abandonment decision and of its optimal timing.

(3) A third major observation has to do with the lack and reliability of relevant financial data customarily used by researchers and practitioners from the three schools to evaluate product profitability and identify abandonment candidates. Also, the impact of the abandonment decision on the financial profitability of other products in the firm’s portfolio has not been well documented.

### 7.1.2 Reformulation of the Product Abandonment Problem

The second phase of the research was intended to reformulate the product abandonment problem based on various characteristics of the new manufacturing
environment and on the new managerial concepts required to meet the challenges of such environment. More specifically, it was shown that in a global business environment marked by inflation, soaring energy costs, hardly predictable currency-exchange rate fluctuations, political instability in many regions of the globe, and high uncertainties about the dynamics of international factors of production, market growth is no longer "a given". Less-than-competitive managerial practices can, therefore, no longer be tolerated if business leadership is to be achieved.

To compete effectively, companies must strive to manufacture innovative products at a low cost while simultaneously maintaining high quality standards and providing outstanding customer service. At the same time, they must have the needed flexibility to meet the challenges of decreasing product life cycles and increasing time-based global competition. To this end, manufacturers must rid themselves of antiquated managerial philosophies which are based on traditional assumptions of economies of scale and short-sighted cost-reduction practices. In particular, they must quit viewing their decisions to invest in a given project as a commitment to such investment over its entire physical life. Because managing the capital budget is usually a rationing problem, a firm cannot tie up its funds in investments which are below acceptable standards. The wealth maximization rationale dictates that the most rewarding investment opportunity available at a given decision point in time is the one which must be adopted.

In this respect, premature abandonment of an ongoing concern may generate more return than if operations were to be continued. This return can be in the form of released funds for better investment alternatives or simply in the form of avoided losses from continuing the operation of unprofitable products. The product abandonment option must, therefore, be proactively integrated into the strategic capital expenditure decision model rather than being simply viewed as a reactive response to conditions of declining demand.
7.1.3 The Solution Methodology

In the third phase of this research work, the focus was put on designing a global decision model (GDM) which incorporates the product option into the company's overall planning and control system. The proposed GDM was based on various state-of-the-art managerial concepts and evaluation techniques. In particular, it requires that strategic performance measures, or critical success factors, be defined to translate the company's corporate objectives into quantifiable terms. Production simulation techniques and activity-based costing systems (ABC) can then be used to evaluate the performance of the existing system, highlight non-value added activities, and identify where the need for system improvement is. Accordingly, improvement alternatives are generated in terms of portfolios of combined acquisition, replacement, and abandonment projects. Then, each improvement portfolio is analyzed using again simulation techniques and ABC systems. The required forecasts and computations should encompass all aspects of costs and benefits incurred by the continued operations of the proposed system as well as those incurred by its premature abandonment or partial alteration at any decision point during the project life cycle.

The GDM is governed by an abandonment algorithm and a multi-attribute decision module (MADM) which are interfaced in a highly interactive mode. The developed abandonment algorithm uses dynamic programming recursive search methods to determine, at each decision point throughout the life cycle of the portfolio under study, the financial merits of both the option to continue the project for one more period and the option to abandon it at that time, assuming all posterior decisions are optimal. Optimality here refers to decisions being based on financial as well as non-financial criteria rather than solely on cost information as is the case with practically all conventional abandonment algorithms.
Once cost, and risk profiles are established for each candidate improvement portfolio, rational preference ordering principles should be used to make trade-offs among these measures. The multi-attribute decision module (MADM) of the GDM is then used to calculate the actual improvement brought by each alternative to the existing system as a percentage of the total targeted improvement for each performance measure. Then, a weighted overall improvement figure is calculated for each alternative. The improvement portfolio which scores the highest is the one to be selected for implementation. After implementation, the performance of the selected improvement portfolio should be continuously tracked and controlled in view the company’s objectives.

7.1.4 Methodology Implementation

A computer program was developed to put the solution methodology into concrete terms and verify its implementability on commercially available hardware. The package was called SPADA, for Strategic Product Abandonment Decisions Assistant. A Turbo C++ Boreland compiler was used to write the code of the computer program, which provides the package with an invaluable portability feature over a wide spectrum of commonly used computing hardware. The package was also made very user-friendly by using user/machine dialogue boxes and several menu-driven capabilities. Moreover, the program has a modular structure which confers much flexibility to the package for future improvements.

7.1.5 Methodology Illustration

The final research task was to illustrate the proposed model with a real-life-like case study. The results obtained from the analysis of this case study confirmed the economic
validity of the philosophy underlying the developed solution methodology as well as the ease of application of such a methodology to a wide range of real-life problems. They also demonstrated the benefits that a company can forgo by ignoring the abandonment option throughout the product life cycle.

7.2 SUMMARY OF RESEARCH CONTRIBUTIONS

The developed methodology represents a powerful implementation tool encompassing state-of-the-art approaches to decision-making. Major thrusts of this research work include:

(1) A comprehensive and practical strategic capital-expenditure decision model;

(2) A software package which implements the decision model using dynamic programming techniques to analyze the product abandonment option as a possible improvement opportunity;

(3) A comprehensive taxonomy of the product abandonment analysis topic as treated in the literature of engineering economy, financial management, marketing, strategic management, and corporate organizational and behavioral sciences;

(4) An illustrative, implementation case-study which can be used for both documentation and educational purposes in academia as well as in industry, and

(5) A case-application of dynamic programming as an operations research tool in situations of multi-attribute decisions.
Besides these tangible contributions to the body of scientific knowledge, this research work is unique in addressing an integrated treatment of several state-of-the-art operational and strategic issues critical to the success of any effort geared towards attaining manufacturing excellence in the international marketplace. These issues include:

(1) Enticing U.S. manufacturers to think of the product abandonment option as a possible improvement opportunity which must be inherent to the company’s strategic planning and control system;

(2) Upgrading the organizational scope of conventional abandonment algorithms by incorporating strategic considerations into the model;

(3) Upgrading the operational scope of conventional abandonment algorithms by considering a system-wide approach rather than a single-operation or compartment-based approach to evaluate the overall impact of a given course of action;

(4) Assessing whether the best possible is made out of the existing system prior to any engagement in searching for alternative systems;

(5) Evaluating only those alternatives relevant to the company’s corporate strategy as indicated by the activity-based reports on the existing system;

(6) Allowance for the use of up-dated forecasts for the various dynamic inputs to the model;

(7) Better treatment of project riskiness by assessing and incorporating managerial attitudes toward risk into the decision rule. In this respect, the preference-ordering theory is used for the first time in this research to assess the impact of future uncertainties on the product abandonment decision;
(8) Analyzing projects in terms of improvement portfolios rather than on a single-project basis;

(9) Considering after-tax effects on cash flows and abandonment values (i.e., capital gain issues) in the calculation of a given product's financial merit;

(10) Extending abandonment analysis from the single-project keep-abandon decision to choosing among competing, mutually exclusive alternatives, and

(11) Expanding the application of dynamic programming as a mathematical decision-support tool to deal with multi-attribute decision situations.

Thus, by adopting the findings of this research manufacturers who are struggling for survival (mainly small businesses and single-product firms) will overcome, with enough confidence, traditional fears of investing in new AMT’s and/or abandoning ongoing concerns. In particular, U.S. manufacturers can regain a competitive advantage in the international market, and good domestic standards of living can be ensured.

7.3 RECOMMENDATIONS FOR FUTURE WORK

Due to the diversity of both the concepts underlying the solution approach presented in chapter 3 and the operational tools required to execute the solution methodology developed in chapter 4, several structural and simplifying assumptions were made to limit the scope of this research. However, much flexibility was left for the user to apply the methodology without deviating from the big-picture of the solution approach.
As such, the methodology developed in the present research represents a good starting point for future work to extend its scope and refine a number of its dimensions where simplifying assumptions had to be made. In particular, the following points provide room for future improvement:

(1) While the GDM framework has a very generic nature, the range of applicability of the Abandonment Algorithm can be extended to encompass real-life situations where cash flow auto-correlations do not have to be described by a first-order Markov chain;

(2) The model can be extended to deal with cash flows having continuous probability distributions. In this respect, a good discretization procedure must be defined which allow the representation of continuous probability distribution functions by finite discrete distributions. While such a discretization is needed to numerically resolve the dynamic programming problem, caution must be taken in how to perform it so that neither the principle of optimality underlying the dynamic programming concept nor the assumption of regular Markovian behavior are violated. By failure to fulfill these two requirements, a more exhaustive search algorithm might be needed to evaluate all possible cash flow paths. Also, Monte Carlo simulation techniques might be needed to determine risk profiles associated with different improvement portfolios;

(3) Instead of working with expected abandonment values, the randomness in future abandonment values can be explicitly described with probability distributions. Adding this embellishment to the developed abandonment algorithm will also require the specification of auto-correlations among abandonment values and inter-correlations between cash flows
and abandonment values during the same time period as well as from one period to the other. Thus, the problem can become very complex analytically;

(4) More explicit consideration of tax effects on different assets within the same system but at different stages of their depreciation life can be included in the model;

(5) Since the methodology involves subjective judgement, there is room for improvement regarding the assessment and collection of such data. In particular, a more systematic procedure can be developed to identify and evaluate all strategic inputs such as non-financial performance measures and their relative weights, strategic exit barriers and their heights, and management’s attitude toward risk;

(6) The assumption of a constant corporate utility function over the entire study horizon can be relaxed;

(7) A multi-attribute utility function can be used to make simultaneous trade-offs among competing portfolios based on the perceived utility of their joint performance. In this respect risk profiles must be assessed for each performance measure, and more involving experiments must be performed to determine the corporate joint utility curve. This task can become very complex if all performance measures are not mutually independent. Also, the analytical modeling of such a utility function can become very difficult;

(8) More explicit procedures can be identified and described which allow the user to systematically identify relevant operational input data and establish a better interface between the outputs from the forecasting, simulation, and ABC analyses and SPADA, and
(9) Finally, a knowledge-base can be developed which makes use of all the expertise called upon by the solution methodology. The resulting expert system should be able to offer the required guidance for non-expert decision-makers to conduct their strategic capital expenditure analyses in a very user-friendly environment.
REFERENCES


Keegan, D.P., R.G. Eiler, and C.R. Jones, "Are Your Performance Measures Obsolete?" Management Accounting, June 1989, pp. 45-


Turney, P. B., "Introduction to EasyABC Software," in As Easy as ABC (a publication of ABC Technologies, Inc.), No.3, Portland, Oregon, fall 1990.


APPENDIX A
GLOSSARY

Abandonment Analysis: The process of determining if it is more profitable to continue or terminate the operations of a product, process, project, or portfolio of projects.

Abandonment Option: The option to terminate the operations of an ongoing concern.

Abandonment Value: The market value generated by selling the abandoned equipment.

ABC System: A management/accounting system according to which product costs measurement and allocation are performed based on the specific product’s bill of activities rather than on its production volume.

Acquisition Decision: The decision to acquire new equipment or augment the capacity of existing ones.

Activity-Based Environment: A managerial accounting environment in which an ABC system is used.

Activity: Any set of one or more repetitive tasks performed as various functions of the organization are performed. An activity consumes people, funds, technology, raw materials, methods, and the environment to produce goods and/or services.

Advanced Manufacturing Technology: Leading technological process and the physical resources it requires (usually used in connection with automation)

Asset Flexibility: The design and or acquisition of an asset with an account for its potential future usage and/or liquidation.

Base-Performance: The actual performance of the existing system to be used as a benchmark to evaluate various proposed improvement portfolios.

Bill of Activities: A list of the activities required to produce a product, their volume, and their unit costs.

Business Mission: A formulated statement of a company’s intention regarding which industry and which segment of the market they want to conduct their business in.

Capital Budgeting: The process of optimally allocating scarce resources (i.e. funds) to alternative capital expenditure options in order to increase the value of the company.

Capital Deepening Problem: (also referred to as Capital Decay problem) A situation where an asset loses its value because of technological obsolescence.

Capital Expenditure Analysis: Same as Capital Budgeting.

Cash Flow: Any liquid money transaction such as revenues or operating expenses.
Certainty Equivalent: a measure of the expected utility of a project which combines its expectancy and riskiness based on management's utility function.

Competitive Advantage: Main strategic advantage the company adopts to stay ahead of its competitors (i.e. technology leadership, price leadership).

Competitive Posture: A company's position relative to competition.

Continuous Improvement: A philosophy according to which the status-quo of the existing system is continuously challenged with respect to the company's strategic objectives.

Core Competence: An area of specialty which offers, or at least used to offer, a competitive advantage to the company.

Corporate Objectives: A list of a company’s long-term objectives established to efficiently perform various tasks of the business mission.

Corporate Strategy: The company's large scale future-oriented plan for inter-acting with the external environment to achieve its organizational objectives.

Cost Accounting: The process of collecting and allocating all costs incurred by the activities associated with a given product.

Cost Management: The process of monitoring the reports from cost accounting to control the performance and costs associated with a given product.

Cost of capital: A condensed term to account for the time value of money, the risk associated with its acquisition or investment, and the interest for its lender if any.

Critical Success Factors: (also Strategic Performance Measures) Metrics used to quantify the performance of the studied system. They are critical (or strategic) in the sense that they are defined in such a way that company’s corporate objectives (i.e. quality, cost, lead time, flexibility, etc) can be translated into quantifiable, operational measures.

Decision Rule/Criterion: A mathematical or heuristic rule used to compare the merit of the studied concern against some critical target figure.

Decision-Making Process: The process of selecting the best course of action among various possible options through the use of one or more decision rules.

Depreciation Write-Offs: The allowances subtracted from the total operating income for tax computation purposes. They correspond to the gradual wear-out of physical equipment as time goes by.

Divestment Decision: The decision to divest capital. It involves abandoning an entire concern or a part of it.
Dynamic Simulation Modeling: Representation of a real-life system through a mathematical model that approximates its behavior as a function of time.

Eliminatory Height: A subjectively determined maximum tolerable score that a project can have in order for it to be eligible for the abandonment option.

Endgame Industry/Environment: An industry or group of industries where market demand exhibits a persistent declining trend.

Equipment Obsolescence: A situation where an equipment loses entirely the capability of achieving a specified function as required. It might be caused by technological changes or shifting in customer preferences.

Escalating Commitment: A behavioral phenomenon according to which a manager commit even more funds to a project in which he or she had previously invested large amounts of capital when a negative performance feedback is received.

Expert System: A computer-based program that relies on knowledge, facts and deductive reasoning to perform a difficult task usually undertaken only by a human expert.

Externally Driven Target: A market-based benchmark against which system performance measures are to be evaluated.

Financial Worth: A measure of a portfolio’s financial merit. It can be calculated as a net present value (NPV) amount or as an annual amount.

Half-Year-Convention: Refers to the 1986 Tax Reform Act instituting the MACRS depreciation method with an allowance for deduction of only half of the depreciation amount at the last year of service of the asset.

Illusion of Control: A behavioral phenomenon exhibited by managers who, because of previous successful experiences or any other reason, become overconfident of their managerial skills and might erroneously believe that their business is either doing well or can be easily restored to do well.

Improvement Portfolio: A set of inter-related improvement opportunities which may include simultaneous investment, divestment, and replacement projects.

Industrial productivity: An indicator of a nation’s economic well-being. One commonly used measure of productivity, called labor productivity, is expressed in dollars of output (adjusted for inflation) per hour worked. A second measure, called multifactor productivity, is a composite measure of how efficiently an economy makes use of both labor and capital resources. It is expressed in terms of output per unit of combined labor and capital input.
Initial Capital Investment: The initial amount of money expended to install the project.

Integrated-Systems Approach: An approach which accounts for inter-dependencies among various activities within the integral system.

Integrated-Systems approach: A managerial approach according to which a given element of or activity within a system is designed and evaluated based on both its individual performance and its impact on and influence by the remaining components of the entire system.

Internal Rate of Return: A measure of financial return which calculates the value of capital interest at which a given pattern of cash flow incurs neither a profit nor a loss.

Interval Scale: A measurement scale in which one cannot legitimately speak of differences between scale points (e.g., temperature in °C)

Investment Decision: A decision to postpone current consumption of money and tie it in a given venture to reap future rewards.

Multi-Attribute Decision Model: An evaluative model which measures the overall merit of the studied concern according to a weighted combination of different strategic performance measures.

National Competitiveness: The degree to which a nation can, under free and fair market conditions, produce goods and services that meet the test of international markets while at the same time maintaining or expanding the real incomes of its citizens.

Net Present Worth: The difference between the capitalized value of the flow of net future expected benefits (inflows minus outflows) discounted at a rate which reflects their degree of uncertainty (cost of capital) and the amount of capital investment required to achieve these benefits (initial capital investment).

Nominal Scale: According to this scale, items are assigned descriptive labels rather than measurable amounts (e.g., names).

Non-value-Added Activity: An activity which does not contribute to the process of adding value to the product (i.e. set-up, material handling, waiting time, etc).

Normative Models: Models which prescribe to the user what must be done to achieve the objectives of the applied model.

Option Value Analysis: According to this method, a given investment alternative is evaluated not only on the basis of its intrinsic merits but also through the flexibility it generates for future return options.

Ordinal Scale: A scale of measurement which orders people, objects, or events along a continuum (e.g., ranks in the Navy).
**Output Measure:** Metrics used to describe the output of a given activity in terms of number of units of its physical product or some function of it.

**Performance Measure:** See Critical Success Factor.

**Physical Life of an Asset:** The number of time periods (usually years) after which the system becomes physically obsolete.

**Prescriptive Models:** Models which describe what the user has been doing to achieve the objectives of the model.

**Product Life Cycle:** The entire life span of a product from initial inception till final abandonment.

**Product Line:** The set of physical equipment and activities associated with manufacturing a given product.

**Product Quality:** Conformance and consistency of a product with market specification and process control requirements.

**Product Sales Profile:** The curve describing the sales volume of the product from its first introduction to the market to its complete retirement.

**Product:** Refers to the final output of the manufacturing function. Sometimes, it is used interchangeably with Product Line.

**Profit Margin:** The difference between a product's unit selling price and its unit production cost.

**Ratio Scale:** A measurement scale which has a true zero point. A value of zero will therefore represent the absence of the variable (e.g., length, volume).

**Recursive Search Method:** A search method according to which different stages in the decision tree are executed backwards to ensure optimality for all posterior decisions at any given decision point.

**Replacement Decision:** The decision to retire a given asset or concern an replace usually by a more efficient one.

**Risk Analysis:** The process which studies the effects of future uncertainties on present decisions. In the area of strategic capital budgeting several types of risk (i.e., financial, operational, political, etc.) can be identified and their relevance is situation dependent. In particular, operational risk measures the deviation of actual future outcomes from their expected values and is extensively used in the literature.

**Risk Attitude:** Management's behavior with respect to risk-value trade-offs under conditions of uncertainty.

**Sick Product:** (also Weak Product) A product exhibiting a declining performance trend.
Simplifying Assumption: An assumption intended to facilitate the analytical or operational implementability of the model without altering its scope of applicability.

Simultaneous Engineering: A new design and analysis philosophy according to which representatives from all functional areas of the company must sit together to reach decisions on product design, manufacturability, and marketability among other strategic decisions.

Stakeholders: All the parties affected by the operation of a business. This set includes shareholders, management, employees, customers, suppliers, and the community affected by the quality of operations of the business.

Standard of Living: A global indicator of how well an individual is living. It measures the spending capacity against the average remuneration figure.

Strategic Exit Barriers: Qualitative factors which may cause the decision-maker to reject the abandonment option regardless of its financial attractiveness.

Strategic Planning and Control System: The directives and tools used to operationalize the company’s corporate strategy and to control the effects of implementing these directives.

Strategic Planning: A planning process which identifies company’s corporate objectives and devises operational strategies to achieve them.


Structural Assumption: An assumption relating to the scope of applicability (i.e., theoretical limitations, ...) of a model.

System: A set of functional elements and activities all working together to achieve a common objective plus any inter-relationships among them.

Target Cost: A market-based cost determined based on a calculated unit selling price necessary to capture a prespecified market share.

Throughput Time: The total time that a product spends to cross the production system from receiving raw materials through delivering the finished product to the customer.

Useful Life of an Asset: The number of time periods the asset is needed to perform a specified function with a specified objective.

Waste Elimination: Actions aimed at mitigating non-value-added activities or reducing their negative effects on product costs. It can involve the elimination of a whole product line.
Wealth Maximization Rationale: It states that the course of action which generates more value (i.e., NPV) for the firm is preferred to one which generates less.

Work-in-Process Inventory: The excess inventory waiting for processing on the production line. To be distinguished from raw materials and finished products inventories.

Working Capital: The excess of current assets over current liabilities (i.e. liquid funds available to the company for day to day operational transactions).
APPENDIX B
CASE STUDY OUTPUT SUMMARY REPORTS

*********************************************************************************************
SPADA Analysis Run on Mon Mar 30 01:40:33 1992
*********************************************************************************************

Strategic input data:

3 strategic performance measures were declared:

Measure 1:  Name = financial worth
            Unit = millions of $
            Weight = 0.400
            Target = 700.000

Measure 2:  Name = product quality
            Unit = % non-defective
            Weight = 0.300
            Target = 99.000

Measure 3:  Name = throughput time
            Unit = min
            Weight = 0.300
            Target = 1.500

3 strategic exit barriers were declared:

Barrier 1  Name = core competence
            Eliminatory height = 40.00

Barrier 2  Name = legal
            Eliminatory height = 70.00

Barrier 3  Name = social
            Eliminatory height = 80.00

Management's attitude toward risk is best described by a Hybrid utility function type.

\[ U(R) = U(h) + U'(h)(R-h) + 0.5U''(h)[\min(R-h,0)]^{\gamma} \]

where

\[ h = 400.000 \]
\[ U(h) = 0.600 \]
\[ U'(h) = 0.001330 \]
\[ U''(h) = -0.000000833000 \]
Analysis of the existing system

Estimated remaining useful life of existing system: 8
Number of cash flow states: 5
Initial cost: 600.000 (in millions of $)

Before-Tax Cash Flows (in millions of $):
  State 1: 100.000
  State 2: 110.000
  State 3: 120.000
  State 4: 130.000
  State 5: 140.000

Before-Tax Abandonment Values (in millions of $):
  Period 1: 400.000
  Period 2: 300.000
  Period 3: 200.000
  Period 4: 100.000
  Period 5: 50.000
  Period 6: 25.000
  Period 7: 10.000
  Period 8: 0.000

Transition Probabilities Matrix
(from state i (i=0...5) to state j (j=1...5)):

prb[0,j=1...5]: 0.10 0.20 0.40 0.20 0.10
prb[1,j=1...5]: 0.30 0.30 0.20 0.10 0.10
prb[2,j=1...5]: 0.10 0.30 0.30 0.20 0.10
prb[3,j=1...5]: 0.10 0.10 0.30 0.30 0.20
prb[4,j=1...5]: 0.10 0.10 0.20 0.30 0.30
prb[5,j=1...5]: 0.10 0.10 0.20 0.20 0.40

Data summary for after-tax abandonment values at different periods:

<table>
<thead>
<tr>
<th>period</th>
<th>btav</th>
<th>deprec.</th>
<th>book value</th>
<th>atav</th>
</tr>
</thead>
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<tr>
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<td>120.000</td>
<td>480.000</td>
<td>432.000</td>
</tr>
<tr>
<td>2</td>
<td>300.000</td>
<td>192.000</td>
<td>288.000</td>
<td>295.200</td>
</tr>
<tr>
<td>3</td>
<td>200.000</td>
<td>115.200</td>
<td>172.800</td>
<td>189.120</td>
</tr>
<tr>
<td>4</td>
<td>100.000</td>
<td>69.120</td>
<td>103.680</td>
<td>101.472</td>
</tr>
<tr>
<td>5</td>
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<td>69.120</td>
<td>34.560</td>
<td>43.824</td>
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<tr>
<td>6</td>
<td>25.000</td>
<td>34.560</td>
<td>0.000</td>
<td>15.000</td>
</tr>
<tr>
<td>7</td>
<td>10.000</td>
<td>0.000</td>
<td>0.000</td>
<td>6.000</td>
</tr>
<tr>
<td>8</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>
Data summary for after-tax cash flows at different periods (rows) and different states (columns):

\[\text{atcf}[t=1,i]: \quad 108.000 \quad 114.000 \quad 120.000 \quad 126.000 \quad 132.000\]
\[\text{atcf}[t=2,i]: \quad 136.800 \quad 142.800 \quad 148.800 \quad 154.800 \quad 160.800\]
\[\text{atcf}[t=3,i]: \quad 106.080 \quad 112.080 \quad 118.080 \quad 124.080 \quad 130.080\]
\[\text{atcf}[t=4,i]: \quad 87.648 \quad 93.648 \quad 99.648 \quad 105.648 \quad 111.648\]
\[\text{atcf}[t=5,i]: \quad 87.648 \quad 93.648 \quad 99.648 \quad 105.648 \quad 111.648\]
\[\text{atcf}[t=6,i]: \quad 73.824 \quad 79.824 \quad 85.824 \quad 91.824 \quad 97.824\]
\[\text{atcf}[t=7,i]: \quad 60.000 \quad 66.000 \quad 72.000 \quad 78.000 \quad 84.000\]
\[\text{atcf}[t=8,i]: \quad 60.000 \quad 66.000 \quad 72.000 \quad 78.000 \quad 84.000\]

Cost of capital to the company = 8.00%

Data summary for actual heights of various strategic exit barriers at different periods:

At period 0:
  Barrier 1: Name = core competence
              Actual height = 20.00
  Barrier 2: Name = legal
              Actual height = 40.00
  Barrier 3: Name = social
              Actual height = 30.00

At period 1:
  Barrier 1: Name = core competence
              Actual height = 20.00
  Barrier 2: Name = legal
              Actual height = 40.00
  Barrier 3: Name = social
              Actual height = 30.00

At period 2:
  Barrier 1: Name = core competence
              Actual height = 20.00
  Barrier 2: Name = legal
              Actual height = 40.00
  Barrier 3: Name = social
              Actual height = 30.00

At period 3:
  Barrier 1: Name = core competence
              Actual height = 20.00
  Barrier 2: Name = legal
              Actual height = 35.00
  Barrier 3: Name = social
              Actual height = 40.00

At period 4:
  Barrier 1: Name = core competence
              Actual height = 20.00
  Barrier 2: Name = legal
              Actual height = 30.00
Barrier 3: Name = social
  Actual height = 40.00

At period 5:
  Barrier 1: Name = core competence
  Actual height = 20.00
  Barrier 2: Name = legal
  Actual height = 15.00
  Barrier 3: Name = social
  Actual height = 50.00

At period 6:
  Barrier 1: Name = core competence
  Actual height = 20.00
  Barrier 2: Name = legal
  Actual height = 10.00
  Barrier 3: Name = social
  Actual height = 60.00

At period 7:
  Barrier 1: Name = core competence
  Actual height = 20.00
  Barrier 2: Name = legal
  Actual height = 0.00
  Barrier 3: Name = social
  Actual height = 60.00

Data summary for individual exit barriers at different periods:

At period 0:
  No individual exit barriers were declared

At period 1:
  No individual exit barriers were declared

At period 2:
  No individual exit barriers were declared

At period 3:
  No individual exit barriers were declared

At period 4:
  No individual exit barriers were declared

At period 5:
  No individual exit barriers were declared

At period 6:
  No individual exit barriers were declared

At period 7:
  No individual exit barriers were declared
SPADA recommends to ABANDON this alternative NOW based on its financial performance alone since the NPV associated with its continued operations is equal to -88.889 (in millions of $). This is equivalent to a net amount of -109.950 (in millions of $) for certain. However, the MADM analysis later on may reverse this decision.

Actual performance of the existing system (base-performance):
  for the financial worth measure: -109.949524
  for the product quality measure: 88.000000
  for the throughput time measure: 2.900000

At this level of the analysis, you must have all feasible improvement portfolios identified, and their actual performance and cost profiles ready.
Analysis of improvement portfolio 1

Number of cash flow states : 3
Initial cost.............. : 450.000 (in millions of $)

Before-Tax Cash Flows (in millions of $):
  State 1: 180.000
  State 2: 190.000
  State 3: 200.000

Before-Tax Abandonment Values (in millions of $):
  Period 1: 300.000
  Period 2: 200.000
  Period 3: 100.000
  Period 4: 50.000
  Period 5: 25.000
  Period 6: 10.000
  Period 7: 0.000
  Period 8: 0.000

Transition Probabilities Matrix
(from state i (i=0...3) to state j (j=1...3)):

prb[0,j=1...3]:  0.30  0.40  0.30
prb[1,j=1...3]:  0.40  0.30  0.30
prb[2,j=1...3]:  0.30  0.40  0.30
prb[3,j=1...3]:  0.30  0.30  0.40

Data summary for after-tax abandonment values at different periods:

<table>
<thead>
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<td>1</td>
<td>300.000</td>
<td>90.000</td>
<td>360.000</td>
<td>324.000</td>
</tr>
<tr>
<td>2</td>
<td>200.000</td>
<td>144.000</td>
<td>216.000</td>
<td>206.400</td>
</tr>
<tr>
<td>3</td>
<td>100.000</td>
<td>86.400</td>
<td>129.600</td>
<td>111.840</td>
</tr>
<tr>
<td>4</td>
<td>50.000</td>
<td>51.840</td>
<td>77.760</td>
<td>61.104</td>
</tr>
<tr>
<td>5</td>
<td>25.000</td>
<td>51.840</td>
<td>25.920</td>
<td>25.368</td>
</tr>
<tr>
<td>6</td>
<td>10.000</td>
<td>25.920</td>
<td>0.000</td>
<td>6.000</td>
</tr>
<tr>
<td>7</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>8</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Data summary for after-tax cash flows at different periods (rows) and different states (columns):

atcf[t=1,i]:  144.000  150.000  156.000
atcf[t=2,i]:  165.600  171.600  177.600
atcf[t=3,i]:  142.560  148.560  154.560
atcf[t=4,i]:  128.736  134.736  140.736
atcf[t=5,i]:  128.736  134.736  140.736
atcf[t=6,i]:  118.368  124.368  130.368
atcf[t=7,i]:  108.000  114.000  120.000
atcf[t=8,i]:  108.000  114.000  120.000
Data summary for actual heights of various strategic exit barriers at different periods:

At period 0:

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Name</th>
<th>Actual height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>core competence</td>
<td>20.00</td>
</tr>
<tr>
<td>2</td>
<td>legal</td>
<td>40.00</td>
</tr>
<tr>
<td>3</td>
<td>social</td>
<td>30.00</td>
</tr>
</tbody>
</table>

At period 1:

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Name</th>
<th>Actual height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>core competence</td>
<td>20.00</td>
</tr>
<tr>
<td>2</td>
<td>legal</td>
<td>40.00</td>
</tr>
<tr>
<td>3</td>
<td>social</td>
<td>30.00</td>
</tr>
</tbody>
</table>

At period 2:

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Name</th>
<th>Actual height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>core competence</td>
<td>20.00</td>
</tr>
<tr>
<td>2</td>
<td>legal</td>
<td>40.00</td>
</tr>
<tr>
<td>3</td>
<td>social</td>
<td>30.00</td>
</tr>
</tbody>
</table>

At period 3:

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Name</th>
<th>Actual height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>core competence</td>
<td>20.00</td>
</tr>
<tr>
<td>2</td>
<td>legal</td>
<td>35.00</td>
</tr>
<tr>
<td>3</td>
<td>social</td>
<td>30.00</td>
</tr>
</tbody>
</table>

At period 4:

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Name</th>
<th>Actual height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>core competence</td>
<td>20.00</td>
</tr>
<tr>
<td>2</td>
<td>legal</td>
<td>30.00</td>
</tr>
<tr>
<td>3</td>
<td>social</td>
<td>40.00</td>
</tr>
</tbody>
</table>

At period 5:

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Name</th>
<th>Actual height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>core competence</td>
<td>20.00</td>
</tr>
<tr>
<td>2</td>
<td>legal</td>
<td>15.00</td>
</tr>
<tr>
<td>3</td>
<td>social</td>
<td>50.00</td>
</tr>
</tbody>
</table>

At period 6:

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Name</th>
<th>Actual height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>core competence</td>
<td>20.00</td>
</tr>
</tbody>
</table>
Barrier 2: Name = legal
    Actual height = 10.00
Barrier 3: Name = social
    Actual height = 60.00

At period 7:
    Barrier 1: Name = core competence
        Actual height = 20.00
    Barrier 2: Name = legal
        Actual height = 0.00
    Barrier 3: Name = social
        Actual height = 60.00

Data summary for individual exit barriers at different periods:

At period 0:
    No individual exit barriers were declared

At period 1:
    No individual exit barriers were declared

At period 2:
    No individual exit barriers were declared

At period 3:
    No individual exit barriers were declared

At period 4:
    No individual exit barriers were declared

At period 5:
    No individual exit barriers were declared

At period 6:
    No individual exit barriers were declared

At period 7:
    No individual exit barriers were declared

---------------------------------------------

SPADA recommends to ABANDON this alternative NOW based on its financial performance alone since the NPV associated with its continued operations is equal to -11,111 (in millions of $). This is equivalent to a net amount of -39,650 (in millions of $) for certain. However, the MADM analysis later on may reverse this decision.

---------------------------------------------
Actual performance of portfolio 1:
  for the financial worth measure: -39.650169
  for the product quality measure: 90.000000
  for the throughput time measure: 2.500000

performance improvement with respect to the financial worth measure: 8.68%

performance improvement with respect to the product quality measure: 18.18%

performance improvement with respect to the throughput time measure: 28.57%

+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

According to the MADM, the overall improvement that can be brought to the existing system by improvement portfolio 1 is 17.50% (in percent change relative to the total targeted improvement).

+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Analysis of improvement portfolio 2

Number of cash flow states : 4
Initial cost.............. : 600.000 (in millions of $)

Before-Tax Cash Flows (in millions of $):
State 1: 210.000
State 2: 220.000
State 3: 230.000
State 4: 240.000

Before-Tax Abandonment Values (in millions of $):
Period 1: 350.000
Period 2: 200.000
Period 3: 100.000
Period 4: 75.000
Period 5: 50.000
Period 6: 25.000
Period 7: 10.000
Period 8: 0.000

Transition Probabilities Matrix
(from state i (i=0...4) to state j (j=1...4)):

prb[0,j=1...4]: 0.20 0.30 0.30 0.20
prb[1,j=1...4]: 0.30 0.30 0.20 0.20
prb[2,j=1...4]: 0.20 0.30 0.30 0.20
prb[3,j=1...4]: 0.20 0.20 0.30 0.30
prb[4,j=1...4]: 0.20 0.20 0.20 0.40

Data summary for after-tax abandonment values at different periods:

<table>
<thead>
<tr>
<th>period</th>
<th>btav</th>
<th>deprec.</th>
<th>book value</th>
<th>atav</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>350.000</td>
<td>120.000</td>
<td>480.000</td>
<td>402.000</td>
</tr>
<tr>
<td>2</td>
<td>200.000</td>
<td>192.000</td>
<td>288.000</td>
<td>235.200</td>
</tr>
<tr>
<td>3</td>
<td>100.000</td>
<td>115.200</td>
<td>172.800</td>
<td>129.120</td>
</tr>
<tr>
<td>4</td>
<td>75.000</td>
<td>69.120</td>
<td>103.680</td>
<td>86.472</td>
</tr>
<tr>
<td>5</td>
<td>50.000</td>
<td>69.120</td>
<td>34.560</td>
<td>43.324</td>
</tr>
<tr>
<td>6</td>
<td>25.000</td>
<td>34.560</td>
<td>0.000</td>
<td>15.000</td>
</tr>
<tr>
<td>7</td>
<td>10.000</td>
<td>0.000</td>
<td>0.000</td>
<td>6.000</td>
</tr>
<tr>
<td>8</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Data summary for after-tax cash flows at different periods (rows) and different states (columns):

| atcf[t=1,i]: | 174.000 | 180.000 | 186.000 | 192.000 |
| atcf[t=2,i]: | 202.800 | 208.800 | 214.800 | 220.800 |
| atcf[t=3,i]: | 172.080 | 178.080 | 184.080 | 190.080 |
| atcf[t=4,i]: | 153.648 | 159.648 | 165.648 | 171.648 |
| atcf[t=5,i]: | 153.648 | 159.648 | 165.648 | 171.648 |
| atcf[t=6,i]: | 139.824 | 145.824 | 151.824 | 157.824 |
| atcf[t=7,i]: | 126.000 | 132.000 | 138.000 | 144.000 |
| atcf[t=8,i]: | 126.000 | 132.000 | 138.000 | 144.000 |
Data summary for actual heights of various strategic exit barriers at different periods:

At period 0:
   Barrier 1: Name = core competence
             Actual height = 20.00
   Barrier 2: Name = legal
             Actual height = 40.00
   Barrier 3: Name = social
             Actual height = 30.00

At period 1:
   Barrier 1: Name = core competence
             Actual height = 20.00
   Barrier 2: Name = legal
             Actual height = 70.00
   Barrier 3: Name = social
             Actual height = 30.00

At period 2:
   Barrier 1: Name = core competence
             Actual height = 20.00
   Barrier 2: Name = legal
             Actual height = 60.00
   Barrier 3: Name = social
             Actual height = 30.00

At period 3:
   Barrier 1: Name = core competence
             Actual height = 30.00
   Barrier 2: Name = legal
             Actual height = 50.00
   Barrier 3: Name = social
             Actual height = 40.00

At period 4:
   Barrier 1: Name = core competence
             Actual height = 30.00
   Barrier 2: Name = legal
             Actual height = 40.00
   Barrier 3: Name = social
             Actual height = 40.00

At period 5:
   Barrier 1: Name = core competence
             Actual height = 30.00
   Barrier 2: Name = legal
             Actual height = 30.00
   Barrier 3: Name = social
             Actual height = 50.00

At period 6:
   Barrier 1: Name = core competence
             Actual height = 30.00
Barrier 2: Name = legal
   Actual height = 20.00
Barrier 3: Name = social
   Actual height = 60.00

At period 7:
   Barrier 1: Name = core competence
   Actual height = 30.00
   Barrier 2: Name = legal
   Actual height = 10.00
   Barrier 3: Name = social
   Actual height = 60.00

Data summary for individual exit barriers at different periods:

At period 0:
   No individual exit barriers were declared

At period 1:
   No individual exit barriers were declared

At period 2:
   No individual exit barriers were declared

At period 3:
   No individual exit barriers were declared

At period 4:
   No individual exit barriers were declared

At period 5:
   No individual exit barriers were declared

At period 6:
   No individual exit barriers were declared

At period 7:
   Barrier 1: Name = behavioral
       Eliminatory height = 70.00
       Actual height = 50.00

------------------------------------------------------
If this alternative is selected by the MADM later on, SPADA recommends that you HOLD ON TO IT FOR ONE MORE PERIOD. This will generate a maximum financial worth whose expected net present value is 373.058 (in millions of $) and semi-std deviation (risk measure) is 675.252. This is equivalent to a net amount of 230.269 (in millions of $) for certain.
------------------------------------------------------

Appendix B 247
Actual performance of portfolio 2:
for the financial worth measure: 230.269440
for the product quality measure: 93.000000
for the throughput time measure: 2.400000

performance improvement with respect to the financial worth measure:
42.00%

performance improvement with respect to the product quality measure:
45.45%

performance improvement with respect to the throughput time measure:
35.71%

********************************************************************************
According to the MADM, the overall improvement
that can be brought to the existing system by
improvement portfolio 2 is 41.15%
(in percent change relative to the total targeted
improvement).
********************************************************************************
Analysis of improvement portfolio 3

Number of cash flow states : 4
Initial cost............ : 550.000 (in millions of $)

Before-Tax Cash Flows (in millions of $):
  State 1: 190.000
  State 2: 200.000
  State 3: 210.000
  State 4: 220.000

Before-Tax Abandonment Values (in millions of $):
  Period 1: 300.000
  Period 2: 200.000
  Period 3: 100.000
  Period 4: 75.000
  Period 5: 50.000
  Period 6: 25.000
  Period 7: 0.000
  Period 8: 0.000

Transition Probabilities Matrix
(from state i (i=0...4) to state j (j=1...4)):
prb[0,j=1...4]: 0.20 0.30 0.30 0.20
prb[1,j=1...4]: 0.40 0.30 0.20 0.10
prb[2,j=1...4]: 0.10 0.40 0.30 0.20
prb[3,j=1...4]: 0.10 0.20 0.40 0.30
prb[4,j=1...4]: 0.10 0.20 0.30 0.40

Data summary for after-tax abandonment values at different periods:

<table>
<thead>
<tr>
<th>period</th>
<th>btav</th>
<th>depreci.</th>
<th>book value</th>
<th>atav</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300.000</td>
<td>110.000</td>
<td>440.000</td>
<td>356.000</td>
</tr>
<tr>
<td>2</td>
<td>200.000</td>
<td>176.000</td>
<td>264.000</td>
<td>225.600</td>
</tr>
<tr>
<td>3</td>
<td>100.000</td>
<td>105.600</td>
<td>158.400</td>
<td>123.360</td>
</tr>
<tr>
<td>4</td>
<td>75.000</td>
<td>63.360</td>
<td>95.040</td>
<td>83.016</td>
</tr>
<tr>
<td>5</td>
<td>50.000</td>
<td>63.360</td>
<td>31.680</td>
<td>42.672</td>
</tr>
<tr>
<td>6</td>
<td>25.000</td>
<td>31.680</td>
<td>0.000</td>
<td>15.000</td>
</tr>
<tr>
<td>7</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>8</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Data summary for after-tax cash flows at different periods (rows) and different states (columns):

| atcf[t=1,i]: | 158.000 | 164.000 | 170.000 | 176.000 |
| atcf[t=2,i]: | 184.400 | 190.400 | 196.400 | 202.400 |
| atcf[t=3,i]: | 156.240 | 162.240 | 168.240 | 174.240 |
| atcf[t=4,i]: | 139.344 | 145.344 | 151.344 | 157.344 |
| atcf[t=5,i]: | 139.344 | 145.344 | 151.344 | 157.344 |
| atcf[t=6,i]: | 126.672 | 132.672 | 138.672 | 144.672 |
| atcf[t=7,i]: | 114.000 | 120.000 | 126.000 | 132.000 |
atcf[t=8,i]: 114.000 120.000 126.000 132.000

Although abandonment of this alternative at time 7 given cash flow state 1 is more rewarding financially, you cannot abandon it because the actual height of at least the core competence exit barrier is larger than its eliminatory height.

Although abandonment of this alternative at time 7 given cash flow state 2 is more rewarding financially, you cannot abandon it because the actual height of at least the core competence exit barrier is larger than its eliminatory height.

Although abandonment of this alternative at time 7 given cash flow state 3 is more rewarding financially, you cannot abandon it because the actual height of at least the core competence exit barrier is larger than its eliminatory height.

Although abandonment of this alternative at time 7 given cash flow state 4 is more rewarding financially, you cannot abandon it because the actual height of at least the core competence exit barrier is larger than its eliminatory height.

Data summary for actual heights of various strategic exit barriers at different periods:

At period 0:
  Barrier 1: Name = core competence
           Actual height = 20.00
  Barrier 2: Name = legal
           Actual height = 40.00
  Barrier 3: Name = social
           Actual height = 30.00

At period 1:
  Barrier 1: Name = core competence
           Actual height = 20.00
  Barrier 2: Name = legal
Barrier 3: Name = social
Actual height = 30.00

At period 2:
Barrier 1: Name = core competence
Actual height = 30.00
Barrier 2: Name = legal
Actual height = 70.00
Barrier 3: Name = social
Actual height = 30.00

At period 3:
Barrier 1: Name = core competence
Actual height = 30.00
Barrier 2: Name = legal
Actual height = 60.00
Barrier 3: Name = social
Actual height = 30.00

At period 4:
Barrier 1: Name = core competence
Actual height = 30.00
Barrier 2: Name = legal
Actual height = 40.00
Barrier 3: Name = social
Actual height = 40.00

At period 5:
Barrier 1: Name = core competence
Actual height = 30.00
Barrier 2: Name = legal
Actual height = 30.00
Barrier 3: Name = social
Actual height = 60.00

At period 6:
Barrier 1: Name = core competence
Actual height = 40.00
Barrier 2: Name = legal
Actual height = 20.00
Barrier 3: Name = social
Actual height = 80.00

At period 7:
Barrier 1: Name = core competence
Actual height = 40.00
Barrier 2: Name = legal
Actual height = 10.00
Barrier 3: Name = social
Actual height = 80.00

Data summary for individual exit barriers at different periods:
At period 0:
   No individual exit barriers were declared

At period 1:
   No individual exit barriers were declared

At period 2:
   No individual exit barriers were declared

At period 3:
   No individual exit barriers were declared

At period 4:
   Barrier 1: Name = behavioral
               Eliminatory height = 70.00
               Actual height = 20.00

At period 5:
   Barrier 1: Name = behavioral
               Eliminatory height = 70.00
               Actual height = 50.00

At period 6:
   Barrier 1: Name = behavioral
               Eliminatory height = 70.00
               Actual height = 70.00

At period 7:
   Barrier 1: Name = behavioral
               Eliminatory height = 70.00
               Actual height = 75.00

---------------------------------------------

If this alternative is selected by the MADM later on, SPADA recommends that you HOLD ON TO IT FOR ONE MORE PERIOD. This will generate a maximum financial worth whose expected net present value is 341.149 (in millions of $) and semi-std deviation (risk measure) is 714.581. This is equivalent to a net amount of 181.242 (in millions of $) for certain.

---------------------------------------------

Actual performance of portfolio 3:
   for the financial worth measure: 181.242188
   for the product quality measure: 96.000000
   for the throughput time measure: 1.800000

performance improvement with respect to the financial worth measure:
   35.95%
performance improvement with respect to the product quality measure: 72.73%

performance improvement with respect to the throughput time measure: 78.57%

************************************************************
According to the MADM, the overall improvement that can be brought to the existing system by improvement portfolio 3 is 59.77% (in percent change relative to the total targeted improvement).
************************************************************

************************************************************
*************** FINAL RECOMMENDATION **********************
*************** **********************
************************************************************

SPADA recommends IMPROVEMENT PORTFOLIO 3 for implementation according to the optimal decision policy indicated by its evaluation using MODULE III.
SPADA run for same case study without abandonment option

******************************************************************************
******************************************************************************
********** SPADA Analysis Run on Mon Mar 30 13:04:40 1992
******************************************************************************
******************************************************************************

Strategic input data
******************************************************************************

3 strategic performance measures were declared:

Measure 1: Name = financial worth
Unit = millions of $
Weight= 0.400
Target= 700.000

Measure 2: Name = product quality
Unit = % non-defective
Weight= 0.300
Target= 99.000

Measure 3: Name = throughput time
Unit = min
Weight= 0.300
Target= 1.500

0 strategic exit barriers were declared:

Management's attitude toward risk is best described by a Hybrid utility function type.

\[ U(R) = U(h) + U'(h)(R-h) + 0.5U''(h)\min(R-h,0) \]

where

\[ h = 400.000 \]
\[ U(h) = 0.600 \]
\[ U'(h) = 0.001330 \]
\[ U''(h) = -0.000000833000 \]
Analysis of the existing system

Estimated remaining useful life of existing system : 8
Number of cash flow states : 5
Initial cost ............. : 600.000 (in millions of $)

Before-Tax Cash Flows (in millions of $):
State 1: 100.000
State 2: 110.000
State 3: 120.000
State 4: 130.000
State 5: 140.000

Transition Probabilities Matrix
(from state i (i=0...5) to state j (j=1...5)):

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<td>0.20</td>
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<td>0.20</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
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<td>0.20</td>
<td>0.10</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>prb[2]</td>
<td>0.10</td>
<td>0.30</td>
<td>0.30</td>
<td>0.20</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>prb[3]</td>
<td>0.10</td>
<td>0.10</td>
<td>0.30</td>
<td>0.30</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>prb[4]</td>
<td>0.10</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>prb[5]</td>
<td>0.10</td>
<td>0.10</td>
<td>0.20</td>
<td>0.20</td>
<td>0.40</td>
<td></td>
</tr>
</tbody>
</table>

Data summary for after-tax cash flows at different periods (rows) and different states (columns):

<table>
<thead>
<tr>
<th></th>
<th>atcf[t=1,i]</th>
<th>atcf[t=2,i]</th>
<th>atcf[t=3,i]</th>
<th>atcf[t=4,i]</th>
<th>atcf[t=5,i]</th>
<th>atcf[t=6,i]</th>
<th>atcf[t=7,i]</th>
<th>atcf[t=8,i]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>108.000</td>
<td>114.000</td>
<td>120.000</td>
<td>126.000</td>
<td>132.000</td>
<td>136.800</td>
<td>142.800</td>
<td>148.800</td>
</tr>
<tr>
<td></td>
<td>106.080</td>
<td>112.080</td>
<td>118.080</td>
<td>124.080</td>
<td>130.080</td>
<td>128.000</td>
<td>134.000</td>
<td>140.000</td>
</tr>
<tr>
<td></td>
<td>87.648</td>
<td>93.648</td>
<td>99.648</td>
<td>105.648</td>
<td>111.648</td>
<td>80.000</td>
<td>86.000</td>
<td>92.000</td>
</tr>
<tr>
<td></td>
<td>87.648</td>
<td>93.648</td>
<td>99.648</td>
<td>105.648</td>
<td>111.648</td>
<td>73.824</td>
<td>79.824</td>
<td>85.824</td>
</tr>
<tr>
<td></td>
<td>60.000</td>
<td>66.000</td>
<td>72.000</td>
<td>78.000</td>
<td>84.000</td>
<td>60.000</td>
<td>66.000</td>
<td>72.000</td>
</tr>
</tbody>
</table>

Cost of capital to the company = 8.00%

SPADA recommends to ABANDON this alternative NOW based
on its financial performance alone since the NPV
associated with its continued operations is equal to
-311.111 (in millions of $). This is equivalent to
a net amount of -375.060 (in millions of $) for
certain. However, the MADM analysis later on
may reverse this decision.

Actual performance of the existing system (base-performance):
for the financial worth measure: -375.060181
for the product quality measure: 88.000000
for the throughput time measure: 2.900000

*****************************************************************************
At this level of the analysis, you must have all feasible improvement portfolios identified, and their actual performance and cost profiles ready.
*****************************************************************************
Analysis of improvement portfolio 1

Number of cash flow states : 3
Initial cost .............. : 450.000 (in millions of $)

Before-Tax Cash Flows (in millions of $):
State 1: 180.000
State 2: 190.000
State 3: 200.000

Transition Probabilities Matrix
(from state i (i=0...3) to state j (j=1...3)):

prb[0,j=1...3]: 0.30 0.40 0.30
prb[1,j=1...3]: 0.40 0.30 0.30
prb[2,j=1...3]: 0.30 0.40 0.30
prb[3,j=1...3]: 0.30 0.30 0.40

Data summary for after-tax cash flows at different periods (rows) and different states (columns):

atcf[t=1,i]: 144.000 150.000 156.000
atcf[t=2,i]: 165.600 171.600 177.600
atcf[t=3,i]: 142.560 148.560 154.560
atcf[t=4,i]: 128.736 134.736 140.736
atcf[t=5,i]: 128.736 134.736 140.736
atcf[t=6,i]: 118.368 124.368 130.368
atcf[t=7,i]: 108.000 114.000 120.000
atcf[t=8,i]: 108.000 114.000 120.000

-----------------------------------------------

SPADA recommends to ABANDON this alternative NOW based on its financial performance alone since the NPV associated with its continued operations is equal to -4.908 (in millions of $). This is equivalent to a net amount of -148.388 (in millions of $) for certain. However, the MADM analysis later on may reverse this decision.

-----------------------------------------------

Actual performance of portfolio 1:
for the financial worth measure: -148.388153
for the product quality measure: 90.000000
for the throughput time measure: 2.500000

performance improvement with respect to the financial worth measure: 21.08%

Appendix B
performance improvement with respect to the product quality measure: 18.18%

performance improvement with respect to the throughput time measure: 28.57%

*************************************************
According to the MADM, the overall improvement that can be brought to the existing system by improvement portfolio 1 is 22.46% (in percent change relative to the total targeted improvement).
*************************************************
Analysis of improvement portfolio 2

Number of cash flow states: 4
Initial cost: 600.000 (in millions of $)

Before-Tax Cash Flows (in millions of $):
  State 1: 210.000
  State 2: 220.000
  State 3: 230.000
  State 4: 240.000

Transition Probabilities Matrix
(from state i (i=0...4) to state j (j=1...4)):

\[
\begin{array}{cccc}
\text{prb}[0,j=1...4] & 0.20 & 0.30 & 0.30 & 0.20 \\
\text{prb}[1,j=1...4] & 0.30 & 0.30 & 0.20 & 0.20 \\
\text{prb}[2,j=1...4] & 0.20 & 0.30 & 0.30 & 0.20 \\
\text{prb}[3,j=1...4] & 0.20 & 0.20 & 0.30 & 0.30 \\
\text{prb}[4,j=1...4] & 0.20 & 0.20 & 0.20 & 0.40 \\
\end{array}
\]

Data summary for after-tax cash flows at different periods (rows) and different states (columns):

\[
\begin{array}{cccccccc}
\text{atcf}[t=1,i] & 174.000 & 180.000 & 186.000 & 192.000 \\
\text{atcf}[t=2,i] & 202.800 & 208.800 & 214.800 & 220.800 \\
\text{atcf}[t=3,i] & 172.080 & 178.080 & 184.080 & 190.080 \\
\text{atcf}[t=4,i] & 153.648 & 159.648 & 165.648 & 171.648 \\
\text{atcf}[t=5,i] & 153.648 & 159.648 & 165.648 & 171.648 \\
\text{atcf}[t=6,i] & 139.824 & 145.824 & 151.824 & 157.824 \\
\text{atcf}[t=7,i] & 126.000 & 132.000 & 138.000 & 144.000 \\
\text{atcf}[t=8,i] & 126.000 & 132.000 & 138.000 & 144.000 \\
\end{array}
\]

If this alternative is selected by the MADM later on, SPADA recommends that you HOLD ON TO IT FOR ONE MORE PERIOD. This will generate a maximum financial worth whose expected net present value is 373.058 (in millions of $) and semi-std deviation (risk measure) is 675.252. This is equivalent to a net amount of 230.269 (in millions of $) for certain.

Actual performance of portfolio 2:
  for the financial worth measure: 230.269440
  for the product quality measure: 93.000000
  for the throughput time measure: 2.400000

Appendix B
performance improvement with respect to the financial worth measure: 56.31%

performance improvement with respect to the product quality measure: 45.45%

performance improvement with respect to the throughput time measure: 35.71%

******************************************************************************
According to the MADM, the overall improvement that can be brought to the existing system by improvement portfolio 2 is 46.87% (in percent change relative to the total targeted improvement).
******************************************************************************
Analysis of improvement portfolio 3

Number of cash flow states : 4
Initial cost.............. : 550.000 (in millions of $)

Before-Tax Cash Flows (in millions of $):
  State 1: 190.000
  State 2: 200.000
  State 3: 210.000
  State 4: 220.000

Transition Probabilities Matrix
(from state i (i=0...4) to state j (j=1...4)):

prb[0,j=1...4]: 0.20 0.30 0.30 0.20
prb[1,j=1...4]: 0.40 0.30 0.20 0.10
prb[2,j=1...4]: 0.10 0.40 0.30 0.20
prb[3,j=1...4]: 0.10 0.20 0.40 0.30
prb[4,j=1...4]: 0.10 0.20 0.30 0.40

Data summary for after-tax cash flows at different periods (rows) and different states (columns):

atcf[t=1,i]: 158.000 164.000 170.000 176.000
atcf[t=2,i]: 184.400 190.400 186.400 202.400
atcf[t=3,i]: 156.240 162.240 168.240 174.240
atcf[t=4,i]: 139.344 145.344 151.344 157.344
atcf[t=5,i]: 139.344 145.344 151.344 157.344
atcf[t=6,i]: 126.672 132.672 138.672 144.672
atcf[t=7,i]: 114.000 120.000 126.000 132.000
atcf[t=8,i]: 114.000 120.000 126.000 132.000

SPADA recommends to ABANDON this alternative NOW based on its financial performance alone since the NPV associated with its continued operations is equal to 123.760 (in millions of $). This is equivalent to a net amount of -26.896 (in millions of $) for certain. However, the MADM analysis later on may reverse this decision.

Actual performance of portfolio 3:
  for the financial worth measure: -26.896332
  for the product quality measure: 96.000000
  for the throughput time measure: 1.800000

Appendix B 261
performance improvement with respect to the financial worth measure: 32.39%

performance improvement with respect to the product quality measure: 72.73%

performance improvement with respect to the throughput time measure: 78.57%

****************************************************************************************************

According to the MADM, the overall improvement that can be brought to the existing system by improvement portfolio 3 is 58.34% (in percent change relative to the total targeted improvement).

****************************************************************************************************

****************************************************************************************************

**************  FINAL RECOMMENDATION **************

**************  ****************

SPADA recommends IMPROVEMENT PORTFOLIO 3 for implementation according to the optimal decision policy indicated by its evaluation using MODULE III.
VITA

Bechir Nacer Ouederni was born in BenGardane, Tunisia, on February 19, 1962. He received a Diplôme d’Ingénieur Principal in Chemical Engineering from the Ecole Nationale d’Ingénieurs de Gabés, Tunisia, on June 1986. Throughout his six years of college, Mr. Ouederni was extensively involved in production as well as research and development functions in the chemical industry. He also had the chance to conduct research work in both academia and industry in Tunisia as well as in Europe.

In January of 1990, Mr. Ouederni joined the graduate program at Virginia Polytechnic Institute and State University, Blacksburg, Virginia, to complete the requirements for a Ph.D. degree in Industrial and Systems Engineering.

Mr. Ouederni’s research interests are in the areas of engineering economy, strategic decision analysis, and management of technology for advanced manufacturing environments.