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Optimization Models for Strategic Planning

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NORTH-HOLLAND

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FOREWORD

The problem of strategic planning is threefold: (1) Which businesses should the company be in? (2) What is the level of commitment (investment) to make in each business? (3) Which specific marketing, production, and financial strategies should be employed by each business?

Throughout the 1970s, corporations accumulated a wealth of experience in the use of corporate simulation models and analytical portfolio models as strategic planning tools. Corporate simulation models are essentially "What if?" models that enable firms to evaluate the consequences of alternative business strategies. Analytical portfolio models, such as those developed by The Boston Consulting Group, McKinsey, and others, are based on well-known concepts, such as strategic business units, the experience curve, and the growth-share matrix. Literally hundreds of corporations began successfully using these two types of tools throughout North America, Europe, and Latin America. In spite of the substantial experience with business simulation models and analytical portfolio models, relatively few firms used traditional optimization models, such as linear programming, as strategic planning tools.

Why have so few corporations experimented with optimization models as strategic planning tools? What has been the experience of those firms that have used optimization? Is it possible to introduce optimization models in companies that have nearly ten years of experience with "What if?" models? What does the future hold for the use of optimization as a strategic planning tool?

On October 28-29, 1982, a conference was held at Duke University on "The Future of Optimization Models for Strategic Planning." The objective of the conference was to provide answers to the aforementioned question. This volume contains a collection of the papers that were presented at that conference, which was sponsored by the Center for Corporate Economics and Strategy, the Fuqua School of Business, and the Department of Economics at Duke University.

Although a number of people assisted in the organization of the conference and the publication of this book, two deserve special acknowledgement. Dean Thomas F. Keller of the Fuqua School of Business at Duke University was instrumental in organizing not only the conference but the Center for Corporate Economics and Strategy as well. Yvonne Lamvik spent countless hours assisting in editing the manuscripts for this volume and supervising the production of the book.

Thomas H. Naylor
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OPTIMIZATION MODELS IN STRATEGIC PLANNING

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INTRODUCTION

Since Robert Dorfman (1951) first proposed the use of linear programming as an alternative model to represent the so-called economic theory of the firm, economists and management scientists have consistently advocated the use of optimization models as tools of corporate strategic planning. Although strategic planning (Naylor, 1980) gained widespread acceptance among corporations in the 1970s, experience with the use of optimization models for strategic planning has been minimal. Those companies which have used formal planning models to support their strategic planning have, almost without exception, used either corporate simulation models (Naylor, 1979) or simplistic, nonoptimization portfolio models of the type proposed by consulting firms such as The Boston Consulting Group, McKinsey, and Arthur D. Little (Abel, 1979).

In this book, we define the problem of corporate strategy and attempt to better understand those strategic planning problems which lend themselves to analysis through the use of optimization tools. We also examine some of the practical and methodological problems involved in the use of optimization models. In addition, the book contains a review of the computational experience with mathematical programming models, as well as some recent innovations in decision support systems which may enhance the use of optimization as a strategic planning tool.

The book also contains a paper describing a unique application of optimization, developed by Shell Oil Company, that overcomes some of the limitations of previous optimization models. This approach is known as the *strategy matrix*. Finally, we set forth our assessment of the future of optimization models as strategic planning tools.

THE PROBLEM OF CORPORATE STRATEGY

To assess the feasibility of using optimization models as strategic planning tools, it is appropriate that we be explicit in how we define the term *strategic planning*. The problem of corporate strategy is basically a threefold problem. Given a set of goals and objectives, and a set of assumptions about the company's external environment, the problem of strategic planning consists of (1) a *portfolio* problem, (2) an *investment* problem, and (3) a *business strategy* problem.

The *portfolio* problem is concerned with which businesses the company should be in and how they should be financed. The *investment* problem refers to the level of commitment to be made to each business in the portfolio by the corporation.

The problem of *business strategy* involves positioning the business in the marketplace and selecting the appropriate marketing, production, and organizational strategies to enable the firm to compete effectively.

The portfolio problem is a top-down decision problem in most companies, with acquisition and divestiture decisions being made by senior corporate management. The selection of specific business strategies, on the other hand, is usually a bottom-up decision problem, dealt with by the individual business units. The investment problem is characterized by the fact that its solution is usually negotiated between top management and the general managers of the operating units.

PORTFOLIO MODELS

Two classes of models have been proposed in the literature to deal with the portfolio problem of corporate strategy – deterministic models and risk analysis models. To illustrate some of the characteristics of deterministic portfolio models, we shall describe a strategy based model developed by a leading management consulting firm and a corporate financial model developed by Hamilton and Moses (1973). Most of the literature on portfolio optimization models under risk is based on the original work of Markowitz (1959). The capital asset pricing model (Naylor and Tapon, 1982) and the arbitrage pricing model (Ross, 1976) are among the best-known portfolio models under the assumptions of risk.

STRATEGY-BASED MODEL

One of the leading consulting firms in the field of strategic planning has proposed a model that is concerned with six major decisions:

1. Which businesses should be supported for growth?
2. Which businesses should be managed for greater cash generation?
3. What should the level of dividends to shareholders be?
4. How much debt should the company use to finance its growth?
5. Should the company divest specific businesses or divisions?
6. Should the company seek acquisitions, and if so, what should the nature of these acquisitions be?

The model is a linear programming model which helps management choose either a growth strategy or a cash strategy for each business in the company's portfolio, thus allocating the company's scarce resources as optimally as possible.

For each business, the model indicates which strategic option maximizes the company's growth or long-run earnings, subject to a set of financial constraints. The strategic option selected takes into consideration the necessary trade-offs between growth and return over a specific planning horizon, say, five years. Both the cash plan and the growth plan for each business are based on the following financial forecasts for each business: return on assets, growth in sales, growth in assets, and growth in earnings. In the process of formulating growth and cash plans for the specific businesses, the model maintains a balance between cash inflows and outflows.

There are two alternative versions of the model for resource allocation. In the first case, the objective is to select a portfolio of cash and/or growth plans to maximize growth, which is defined as assets at the end of the planning horizon. In the second case, the objective is to maximize earnings, which are defined as net income after interest at the beginning of the planning period. In both cases, the selection of strategic options is constrained by the following three cash constraints, assuming a five-year planning horizon.

1. Five yearly cash balances reflecting yearly minimum cash requirements and maximum cash availabilities (other than from operations and financial policies).
2. Four minimum yearly growth rates in earnings per share.

3. A five-year minimum cash balance requirement, averaging over the entire planning period the cash flows from operations and financial decisions.

Although this model represents a step in the right direction, it has several obvious limitations, which may explain why it is not widely used by corporate executives. First, the assumption that all strategic decisions can be reduced to the dichotomy of cash versus growth is an oversimplification of the planning problem. Second, the model unduly restricts the firm's investment options. And third, the methodology is incapable of handling interdependent businesses.

Malcolm Coate, in his paper in this book, discusses an approach to optimization that is not so restrictive in considering the investment strategies available to the firm. He proposes three distinct and all-inclusive strategies which, he maintains, will allow the firm to consider more appropriately its relevant choices.

Let us note here that a paper which is potentially of great interest to the planners considering certain innovative approaches to strategic planning such as are described in the Coate paper and elsewhere in this volume is that by Dennis Sweeney, who assesses the applicability of mixed integer programming as a strategic planning tool. He takes the Coate model as an example of mixed integer programming in planning and reports on practical considerations such as solution times for such a model.

OTHER PORTFOLIO MODELS

Perhaps the best-known portfolio optimization model was published by Hamilton and Moses in 1973. The model was designed specifically for strategic planning in a large diversified company. The model includes a full range of financial decisions, including internal capital budgeting, acquisitions, divestments, debt creation/repayment, stock issue/repurchase, and dividend payout. The model employs mixed integer programming to select optimal investment and financing strategies over a multiperiod planning horizon.

Like the strategy-based model above, this model also permits two types of strategy options: momentum strategies and development strategies. Momentum strategies represent a continuation of present activities in current lines of business. Development strategies reflect proposed changes in the nature or level of present activities.

The objective of the firm is to maximize earnings per share, subject to a set of goal constraints, corporate constraints, and group constraints. The three different types of financial constraints included in the model are outlined below.

I. Goal constraints
   - A. Stable growth in earnings per share
   - B. Return on assets
   - C. Return on equity

II. Corporate constraints
   - A. Funds flow
   - B. Interest coverage
   - C. Leverage ratio
   - D. Short-term debt
   - E. Additions to common stock
   - F. Minimum corporate income

III. Group constraints
   - A. Business mix
   - B. Strategy/source constraints
   - C. Divestment
   - D. Development/momentum strategies
   - E. Tied financing

F. Early debt repayment
G. Funds/source limits

There is little evidence to suggest that either the strategy-based model or the Hamilton and Moses model has been used extensively as a strategic planning tool. However, a portfolio model which has been used by a number of banks, including Bankers Trust and North Carolina National Bank, is described in the paper by Kalman J. Cohen and Frederick S. Hammer. This model has become somewhat of a prototype for bank planning.

CAPITAL ASSET PRICING MODEL

The modern literature on finance abounds with applications of the capital asset pricing model (CAPM), which was first developed by Sharpe (1963) and Lintner (1965) and is based on the earlier work of Markowitz (1959). Until recently, most of the applications of the CAPM were oriented toward the problem of an individual investor involved in the selection of a portfolio of securities under conditions of risk.

Markowitz showed that the variance of the return on a portfolio of financial securities depends not only on the riskiness of the individual securities in the portfolio but also on the relationship among these securities; i.e., on the covariances between the respective securities in the portfolio. He showed that the variance of a portfolio of securities may be less than the smallest variance of an individual security, if there are sufficient negative covariances among the securities. (A negative covariance between two securities can be interpreted to mean that, when the return from one security is above its average value, the return from the other is below its average value.) The optimum portfolio involves selecting that combination of securities which yields the best combination of expected return and risk, which, of course, depends on the investor's utility function.

It can be shown that there is an implied equilibrium relationship between risk and return for each security. In equilibrium, a security will be expected to yield a return commensurate with its unavoidable risk. This is simply the risk that cannot be avoided by diversification. The greater the unavoidable risk of a security, the greater the return that the investor will expect from the security. The relationship between expected return and unavoidable risk and the valuation of securities in this context constitutes the essence of the capital asset pricing model.

Among the numerous financial applications of the CAPM described in the literature are (1) valuation of a firm's common stock, (2) capital budgeting, (3) merger and acquisition analysis, and (4) valuation of warrants and convertible securities. Recently, two management consulting firms, Marakon Associates and Strategic Planning Associates, have proposed the possibility of employing the CAPM, not only as a decision-making tool for investors with a portfolio of financial assets, but also as a planning tool for corporations that manage a portfolio of businesses, divisions, or strategic business units. In the latter case, the portfolio consists of tangible assets, while in the former case it consists only of financial assets. The CAPM is based on the following assumptions.

1. All investors in securities are single-period (say, one year), expected-utility wealth maximizers, who choose securities on the basis of mean and variance of return.
2. Investors can borrow or lend funds at a risk-free interest rate.
3. Investors have identical subjective estimates of the means, variances and covariances of all securities.
4. The market for financial securities is perfectly competitive, and all investors are price takers.
5. The quantity of securities is fixed.

6. All securities are perfectly divisible and liquid; i.e., they are marketable without significant transaction costs.
7. There are no taxes.

The CAPM attempts to determine how an investor's financial assets are valued when the behavior of all investors in the stock market is taken into consideration. To extend the CAPM to the case of a corporation that owns a portfolio of businesses, we must assume that the businesses have the same properties as securities.[1] More recently, Ross (1976) and Roll and Ross (1980) have proposed an alternative formulation of risk-return problems called the "arbitrage pricing model."

INVESTMENT MODELS

Obviously, the decision as to which businesses a firm should be in is not unrelated to the level of investment required in each business. That is, portfolio decisions are not made in a vacuum. They are not independent of the level of investment required to support the businesses in the company's portfolio.

The following simple model, first proposed by Weingartner (1963), is illustrative of the investment problem. The firm is assumed to have a portfolio of different businesses available to it for investment purposes. The problem of the firm is to select that combination of businesses in which to invest its funds so as to maximize the net present value of the total portfolio over the planning horizon, $\underline{T}$, subject to a set of budget constraints. The model consists of the following variables:

X_i = fraction of business $\underline{i}$ to be undertaken

PV_i = net present value of business $\underline{i}$

I_{ti} = present value of investment required in business $\underline{i}$ in time year $\underline{t}$

B_t = present value of budget ceiling for year $\underline{t}$

UF_t = amount of unused funds in year $\underline{t}$

The objective is to maximize total net present value NPV.

$$NPV = \sum_{i=1}^{n} PV_i X_i, \tag{1}$$

subject to a set of budgeting constraints

$$\sum_{i=1}^{n} I_{1i} X_i + UF_1 = B_1 \tag{2}$$

$$\sum_{i=1}^{n} I_{ti} X_i - UF_{t-1} + UF_t = B_t \tag{3}$$

$$t = 2, \ldots, T$$

and,

$$0 \leqslant X_i \leqslant 1 \qquad i = 1, \ldots, n \tag{4}$$

$$UF_t \geqslant 0 \qquad t = 1, \ldots, T \tag{5}$$

[1] For a more complete treatment of the possible application of capital asset pricing models as a strategic planning tool, see Naylor and Tapon (1982).

Equation (2) states that the amount invested in all n businesses plus the amount of unused funds available in year 1 should be equal to the budget constraint of the first year. For all future years, equation (3) holds. It states that the amount invested in all businesses during year t minus the amount of unused funds carried over from the previous year plus the amount of unused funds in the current year must equal the budget for that year. Inequality (4) indicates that the commitment to a particular business can vary from 0 to 1. If X_i is equal to zero, then the business is, in effect, being dropped from the portfolio. If X_i is equal to 1, then investment is being carried out at its full potential for that business. Of course, it is possible to require X_i to be an integer, thus transforming the portfolio problem into an integer programming problem. Finally, equation (5) simply requires nonnegative cash balances. That is, no debt is permitted in this model.

This model has been extended by Weingartner and others to include debt, equity, and other forms of financing, as well as constraints similar to those included in the Hamilton and Moses (1973) model. This volume contains two papers dealing with optimization models for investment: "Strategic Planning and the Problem of Capital Budgeting in a Steel Firm: A Multi-Criteria Approach," by Kenneth D. Lawrence and John B. Guerard, Jr., and "Operations Planning and Investment Strategy in the Owner Financed Firm," by Richard M. Burton, William W. Damon, and Børge Obel.

BUSINESS STRATEGY MODELS

Most of the successful applications of optimization models for strategic planning have been developed at the specific business-unit level rather than at the overall corporate level. Professor Jeremy Shapiro reports in his paper in this volume on the successful application of optimization to business strategy problems in a paper company and a consumer products company.

In the case of the paper company, a mathematical programming model was used to evaluate contracts for the supply of chlorine and caustic soda to the company's paper mills throughout the United States. Using information from the solution to the mathematical programming problem about the relative value of current contractual arrangements, the paper company was able to renegotiate more favorable contract terms from some vendors. The strategy resulted in annual savings of more than $1 million, or more than two percent of the annual cost of the chemicals. Another optimization model was used to develop a new production/distribution system and expanded marketing strategy for two families of products — lumber and plywood.

Shapiro and his associates have also successfully implemented a mathematical programming model for a division of a consumer products company. This application involves the design and evaluation of manufacturing and distribution strategies, including the substitution of plastic bottles for glass bottles for one of the company's major products. Thus, while mathematical programming has rarely been used to deal with the portfolio problem of strategic planning, it has been used successfully by a limited number of companies as a strategic planning tool within specific businesses.

Two other applications of mathematical programming to problems of business strategy are described in this volume. The paper by Klingman, Ross and Schneider treats the application of optimization to facility location planning. The use of optimization for branch bank development is the subject of the paper by Chitariance and Reisman.

METHODOLOGICAL PROBLEMS

Although mathematical programming had achieved widespread utilization as an operational planning tool by the 1960s, its use as a strategic planning tool has been primarily restricted to a few selected business strategy problems in a limited number of businesses. In this section, we briefly summarize six methodological problems which have served as impediments to the use of optimization as a strategic planning tool.

1. Ill-defined problems
2. The economics of interdependence
3. Degree of resolution and aggregation
4. Inadequate theory of strategic planning
5. Computational problems
6. Inadequate decision support systems

ILL-DEFINED PROBLEMS

One of the major obstacles to the use of mathematical programming as a strategic planning tool is the difficulty in reducing the problem of strategic planning to the optimization of a single objective function. Although measures of profitability, such as return on investment and discounted cash flow, may be the most important measures used by corporate managers to judge the performance of a business, they are by no means the only measures of performance which are important. If the firm wants to survive, it must be concerned with liquidity, growth, market share, and relationship to its external environment. To evaluate strategic plans, management must observe a vector of output variables, not a single variable.

Forcing the problem of strategic planning into the mold of optimizing a single objective function is thus a very difficult practical and conceptual problem. Although some have suggested the use of goal programming or utility maximization as a way to circumvent the problem of multiple objectives, neither of these techniques has an impressive record of performance as a tool of strategic planning. The Coate paper noted earlier discusses the proper role of the objective function as a measurement of the overall value to the firm of a set of strategies, and suggests some approaches to defining such a function.

THE ECONOMICS OF INTERDEPENDENCE

We have noted previously that all of the portfolio models assume that strategic business units are characterized by independent production processes and product demand functions. However, in many industries, such as petroleum, chemicals, wood products, electric utilities, and pharmaceuticals, to mention only a few, individual businesses are, in fact, highly interdependent. Examples of interdependent businesses might include gasoline and petrochemicals, as well as plywood and pulpwood. Jerome Waldron demonstrates in his paper in this volume that firms which treat interdependent businesses as though they are independent can be expected to overprice their products and underproduce, thus resulting in lower profits than would have been the case if the interdependencies had been taken into consideration.

DEGREE OF RESOLUTION AND AGGREGATION

A number of oil companies use extremely large linear programming models for short-run, operational planning problems. One oil company has a worldwide optimization model consisting of 7,500 equations and 15,000 variables. Obviously, this model contains far too much detail to be useful as a strategic planning tool. The problem of model resolution and aggregation is concerned with the formulation of

models with a level of detail which is consistent with the information requirements of the specific strategic planning problem. Ron Dembo has come up with some innovative ways of extracting the appropriate information needed for strategic planning from more detailed models, and his work is presented in this volume. This is an extremely important problem — a problem whose solution could have enormous practical benefits to the petroleum industry in particular.

INADEQUATE THEORY OF STRATEGIC PLANNING

The absence of a well-defined theory of strategic planning further frustrates efforts to use optimization models as strategic planning tools. Although the microeconomic theory of the firm offers considerable promise as a conceptual framework for strategic planning, much additional work is required to adapt this model to strategic planning. The lack of a viable theory of strategic planning serves to confound the problem of problem definition, which was outlined above.

COMPUTATIONAL PROBLEMS

So long as a strategic planning problem can be formulated as a continuous linear programming problem, computational algorithms are available for efficiently solving very large problems involving literally thousands of equations and variables. Unfortunately, both the portfolio problem and the investment problem of strategic planning often involve mixed integer programming problems. Mixed integer problems are difficult to solve. Most of the generalized algorithms for solving such problems are restricted to very small or highly structured problems. Let us note here that the paper by David Hirshfeld, which appears in this book, provides an extremely useful overview of the use of mathematical programming models in strategic planning in general, and of practical computational issues in particular. In the Hirshfeld paper is found an extensive review of the capabilities of proven commercial mathematical programming software.

INADEQUATE DECISION SUPPORT SYSTEMS

During the 1970s, a number of software systems for computer-based models were developed (Naylor and Mann, 1982). Often referred to as "decision support systems" (DSS), these include such systems as CUFFS, EXPRESS, IFPS, SIMPLAN and XSIM. For the most part, these software systems were designed to deal exclusively with simulation models rather than with optimization models.

Kirk Jones, in his paper in this volume, takes us through the history of decision support systems. He discusses trends in computer hardware and software, and the broadening of the discipline of management science as evolutionary forces in the current state of decision support systems. If optimization is to become a viable tool of strategic planning, then optimization techniques must be integrated into these systems.

INDUSTRIAL ORGANIZATION AND CORPORATE STRATEGY

In that area of economic analysis known as industrial organization, links are drawn between the structure of an industry and member firms. The study of industrial organization has produced over time a set of observations relating structural characteristics, such as the number of buyers and sellers in an industry, the degree of product differentiation, the structure of costs, and barriers to entering the industry, among others, to behavioral variables, such as pricing, advertising, and research expenditures. It is obvious that those concepts in

microeconomics which constitute the theory of industrial organization have important implications for the strategic behavior of the firm.

In his recent book entitled *Competitive Strategy*, Michael Porter (1980) has taken an initial step towards identifying the relevant characteristics of markets and has indicated how they might be used by the firm. According to Porter, the essence of formulating a competitive strategy is considering the position of the firm with respect to: (1) threat of entry, (2) threat of substitution by the buyer, (3) bargaining power of buyers, (4) bargaining power of suppliers, and (5) rivalry among competitors.

Porter presents a method for designing three types of "generic" strategies including cost leadership, product differentiation, and market focus. At the heart of his framework for developing competitive strategies is what he calls a "competitive analysis" of one's rivals which includes the following elements: (1) future goals, (2) assumptions, (3) current strategy, (4) capabilities, and (5) response profile. Armed with this framework, Porter than applies his competitive strategy model to five types of industries, and, finally, he examines three types of strategic decisions, including vertical integration, capacity expansion, and entry.

The modern literature on industrial organization and corporate strategy appears to offer an abundance of possible applications of optimization models to problems of strategic planning. Both strategic planners and management scientists may find it useful to review such publications as Laitinen (1980) and Porter (1980).

THE STRATEGY MATRIX

What do Shell Oil, IBM, General Electric, Velsicol Chemical, and Federal Express have in common other than a high degree of financial success over the past few years? At least one attribute shared by these firms is an innovative approach to strategic planning known as the "strategy matrix," which overcomes many of the limitations of existing planning models used in divisional and functional organizations. Basically, the strategy matrix represents an attempt to meld the concepts underlying strategic management with those of matrix management.

Among the benefits of the strategy matrix approach are the following: (1) it provides increased flexibility to respond to an ever-changing external environment; (2) it provides a means of dealing with interdependent strategic business units that are characterized by shared resources; (3) it can facilitate the breakdown of barriers within traditional functional organizations; (4) it can diffuse some of the divisive, zero-sum attitudes that exist among functional managers; and (5) it provides an analytical framework in which optimization models can be applied to the firm's portfolio, investment, and business strategy problems. The concluding paper in this book describes the experiences of Shell Oil Company and Velsicol Chemical Corporation in the use of the strategy matrix.

THE FUTURE OF OPTIMIZATION MODELS IN STRATEGIC PLANNING

Although the historical record of the use of optimization models as strategic planning tools is at best somewhat spotty, there is reason to believe that a limited number of companies will begin to experiment with the use of optimization in strategic planning. In part this stems from the fact that many companies have almost a decade of experience with business simulation models of individual businesses or operating companies. Given this experience with modeling a specific business or strategic business unit, it is not such a giant step to formulate an optimization model of that same business. (Remember, we are talking about an optimization model of a particular business at this point, not a model of a portfolio of businesses.) Therefore, we believe that the initial thrust towards

increased utilization of optimization for strategic planning will take place at the business level, not the corporate level.

Another approach also seems to offer promise. If one is careful in the specification of a business simulation model to include the major investment options of the business, then it may be possible to superimpose an optimization umbrella over a collection of individual business models. This would enable management to evaluate portfolio and investment strategies across the portfolio of business models. Such a model could be run under the assumption that individual business plans are given (bottom-up planning) or calculated by the overall optimization model (top-down planning).

The experience of Shell Oil Company is particularly promising in that they have combined intuitive methods, optimization, and simulation in their treatment of the strategy matrix. They use intuitive methods for the portfolio problem, linear programming for the investment problem, and simulation for business unit planning.

In summary, there is reason to believe that much of the experience gained in the 1970s with problem formulation, simulation, and decision support systems will prove to be extremely useful in extending the state of the art of strategic planning one step further, namely, to include optimization as a viable tool of analysis.

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