CHALLENGES OF
STRATEGIC SUPPLY CHAIN PLANNING AND MODELING

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Abstract

The increasing number of applications of supply chain network optimization models to strategic planning has created new challenges for model practitioners and their clients. These challenges are discussed in the context of four categories of modeling and organizational imperatives.

Keywords

Supply chain network optimization, theory of industrial organization, real options

Introduction

Until recently, strategic planning exercises were based on qualitative, managerial judgments about future directions of the firm and the markets in which they compete. Supply chain options were often ignored. In the past few years, however, important supply chain decisions, such as those relating to acquisitions or new product introductions, have been incorporated in these exercises. Managerial interest has been stimulated in part by a growing commitment at all levels of planning to fact-based, supply chain management, which has served to emphasize its importance to the competitiveness of the firm.

Fact-based management requires the development and application of descriptive and prescriptive models for extracting knowledge from the firm's Enterprise Resource Planning and other transactional databases. Descriptive models include those used to forecast customer demands, compute manufacturing and distribution costs using activity-based costing methods, or project the future costs of key raw materials. Prescriptive models, which are constructed from descriptive models, are optimization models that assist supply chain managers in making better decisions. While a wide variety of descriptive models have been applied in understanding the form and functioning of the firm's supply chain, the most prevalent and effective prescriptive models are those based on linear and mixed integer programming, possibly combined with heuristic methods.

Recent attempts at fact-based strategic planning have created intriguing new challenges for modeling practitioners and the managers who are their clients. The purpose of this paper is to review these challenges and to suggest new areas of research aimed at harmonizing managerial judgment with quantitative analysis of strategic planning problems. Our discussion will be divided into four overlapping topics

- Enlarging the Scope of Strategic Supply Chain Planning Studies and Models
- Reflecting Theories of Strategy in Data-driven Optimization Models
- Formalizing Scenario Planning, Applying Stochastic Programming and Modeling Risk
- Expanding Business Processes to Exploit Fact-based Analysis of Strategic Plans

Because each of these topics is vast and our space is limited, we will discuss them at a high level and provide references for interested readers. The paper concludes with a brief summary.

Enlarging the Scope of Strategic Supply Chain Planning Studies and Models

An increasing number and range of manufacturing and distribution companies are performing strategic supply chain studies based on insights from supply chain network optimization models. The term “network” connotes the importance of holistic and integrated analysis of a firm’s geographically dispersed suppliers, plants, distribution centers, and markets. Despite managerial interest in expanding the scope of strategic analysis, current supply chain network optimization studies are still too timid and limited.

First, in too many companies, purchasing, manufacturing and distribution planning activities are not well integrated. This partitioning of decision-making in the firm is reflected in the goals of strategic supply chain studies and the optimization models developed to support them. For example, in a recently completed pilot study to locate a new plant for a health care firm that produces and distributes chemicals, the focus was exclusively on minimizing total transportation costs. The opportunity to analyze manufacturing decisions across several plants in the company’s supply chain network to achieve greater savings was not on the agenda of the pilot study.

Still, as the result of developing and applying a supply chain network optimization model to the limited agenda of the pilot study, the consciousness of senior management was expanded to the extent that a follow-on study was approved that will consider the broader product mix decisions. Indeed, we have found that an approach whereby models are introduced to the firm by pilot studies has considerable merit in educating skeptical senior managers about the potential of fact-based strategic planning.

Second, even when a holistic analysis of the firm’s supply chain is undertaken, the analysis is too often aimed at simply minimizing the total supply chain cost of meeting fixed and given demand over a future planning horizon rather than the more ambitious and appropriate objective of maximizing net revenues by letting sales vary. In other words, the firm does not seek to maximize net revenue by coordinating supply chain and demand management decisions. The demand management decisions to be captured in a model obviously depend on the nature of the company’s industry. For a company that manufactures and sells commodities such as forest products or petrochemicals, whose sales are price driven, the supply chain network optimization model could be extended to optimize product mix decisions based on revenue functions derived from product price elasticities. For a company that manufactures and sells consumer products, the analysis is more complicated and requires the integration of a supply chain network optimization model with a marketing science model that forecasts product sales as a function of advertising, promotions, pricing, and sales force efforts.

Lastly, strategic planning in the firm should include analysis of corporate financial decisions as well as those affecting supply chain and demand management. Moreover, linkages among the three classes of decisions should be evaluated. For example, each year’s projected earnings before interest and taxes, which are heavily dependent on supply chain and demand management decisions, are critical inputs to financial planning exercises. Conversely, corporate financial decisions regarding the acquisition of capital needed to expand, for example, the firm’s existing supply chain or to acquire companies with complementary product lines are critical to the projected competitiveness of the firm’s supply chain. Issues and modeling approaches for integrating the three classes of decisions are discussed in Shapiro (2001a), (2001b).

Despite these complaints about the limited scope of today’s strategic supply chain studies, we applaud the fact that data-driven optimization models are increasingly employed to assist management in fathoming the complex interactions and ripple effects underlying the firm’s future. (We treat the terms “fact-based” and “data-driven” as synonyms.) Indeed, the community of managers, analysts, modeling practitioners and consultants who develop and apply optimization models to strategic supply chain planning problems are leading the way to fact-based strategic planning at the enterprise level.

Reflecting Theories of Strategy in Data-driven Optimization Models

Theories of strategy are derived from human experience and intuition about how firms achieve and sustain competitive advantage in seeking profits. They are an important and appropriate point of departure for strategic supply chain studies, which, as we have argued in the previous section, should attempt to incorporate relevant demand management and corporate financial decisions. For example, these theories include: five forces affecting competition (Porter 1980); the resource-based view of the firm (Foss 1997); and the theory of industrial organization (Tirole 1988). Some theories of strategy (e.g., the five forces affecting competition) are purely qualitative, whereas others (e.g., the theory of industrial organization) involve mathematical models but no data. Such models are used to derive qualitative results characterizing competition among firms, but they have rarely been tested with empirical data or used to support managerial decision-making.

The disciplines are converging in that the theories of strategy are focusing more on the microeconomics of managing the firm, which includes supply chain management as a large and important component. Thus, we can expect greater cross-fertilization of concepts between these theories and data-driven models.

Modeling practitioners can benefit in at least two important ways by trying to incorporate concepts from theories of strategy in their data-driven models. First, academics and other scholars engaged in developing theories are not distracted by the details and complexities of empirical modeling. As a result, they are free to derive abstract insights into strategic issues facing the firm from broad perspectives. By examining these insights, modeling practitioners may identify important decisions, relationships, constraints and objectives for their models that might otherwise be overlooked.

Second, senior managers involved in strategic studies often have been exposed to and understand some of these theories. By contrast, their understanding of descriptive and prescriptive models may be far less, especially when sophisticated time-series forecasting or mixed integer programming models are required. Thus, by relating modeling constructs to recognized theories of strategy, the practitioner can better explain the purpose and even the details of the models and the results they produce. In short, in addition to suggesting new ideas for constructing models, theories of strategy provide a useful vocabulary for explaining the form of and output from data-driven models.

Given these benefits, modeling practitioners face several challenges. First, they must translate qualitative concepts about strategy into descriptive and prescriptive model structures supported by data. For example, one of Porter's five forces in an industry is the bargaining power of suppliers, which is characterized by a number of factors including differentiation of inputs, importance of volume to supplier, switching costs, and a host of other factors. In constructing a strategic supply chain model, such factors may be captured by incorporating decisions, costs and constraints relating to supplier volume discounts, supplier switching, input substitutions, and so on. Such constructions might well require the development and validation of new descriptive models. The effort made in constructing them depends on their perceived importance by decision-makers and the time and resources available to the strategic supply chain study.

A second challenge faced by modeling practitioners is to interpret results from data-driven models in terms of the theories of strategy. For example, the resource-based view of the firm states that the firm's competitive advantage depends heavily on heterogeneous resources possessed by the firm. These are resources, which are used to create rents (large profits), that may not be easily imitated by or transferred to other firms. Examples cited are Honda's knowledge about the design and manufacture of engines or Wal-mart's inventory management systems and processes.

Although some heterogeneous resources are qualitative, others may be quantitatively identifiable but implicitly dependent on a complex confluence of activities, which theorists call "causal ambiguity" leading to resource heterogeneity. Linear programming shadow prices derived from an optimal supply chain solution might help identify such resources. For example, a shadow price on a machine capacity constraint that is much higher than the marginal investment cost of acquiring additional capacity might indicate that the firm has at least a short-term competitive advantage in its ability to exploit that resource. Careful study of the optimal solution yielding that shadow price might provide the firm with insights into the current and hopefully sustainable nature of this competitive advantage. Such insights about a number of resources could assist the decision-makers in choosing capital investment options to be incorporated in a strategic planning model.

A third challenge in harmonizing theories of strategy with data-driven models for strategic supply chain planning arises when the models indicate flaws in a theory. For example, assumptions ensuring the existence of competitive supply and demand equilibria are central to the theory of industrial organization.

Data-driven supply chain models, which seek to maximize net revenues given market prices, are empirical realizations that may be used in computing such equilibria. However, these models will violate assumptions underlying the existence of an equilibrium when they incorporate fixed costs, economies of scale, and other non-convexities. Such empirical imperfections suggest the need for theoretical extensions and/or artistic, less rigorous, interpretations of the theory.

A data-driven application of equilibrium theory to commodities produced by a US-based forest products company is given in Shapiro (2001a). For selected product lines, a mixed integer programming model for maximizing net revenues was constructed for the company and each of its major competitors. Given prices for the products in each market, these models were optimized to determine the individual firm's and total supply to the markets. The prices were then adjusted to reflect imbalances between supply and market demand.

The models were used to determine an (approximate) equilibrium solution for each product line. The equilibrium was approximate because the supply models were not convex. In addition, a practical constraint for each market was added that limited the supply of any company to that market to 50%. These constraints reflected the empirical reality that many customers, especially large ones, would split their purchases among two, three, or even four firms.

The company used the equilibrium analysis to divide the markets into three categories. Category A consisted of markets where the company was the least cost provider. In these markets, the company would compete on price and even exercise local monopolistic control to raise prices if that would increase revenues. Category B consisted of markets where the company was not the least cost provider, but its cost was not significantly higher. In these markets, the company would seek arrangements to be the non-primary supplier to large customers. Category C consisted of markets where the company's delivered cost was significantly higher than that of the least cost supplier. In these markets, the company would make no marketing or sales effort and hope for opportunistic sales based on non-price factors.

Formalizing Scenario Planning, Applying Stochastic Programming and Modeling Risk

Strategic planning exercises should identify major uncertainties about the firm's future to assist senior management in developing effective contingency plans and hedging strategies for coping with them. In this section, we discuss three related methodologies to be considered when designing and carrying out exercises to address uncertainty: scenario planning, stochastic programming, and risk management.

Scenario planning is a methodology intended to assist senior managers in defining scenarios of the firm's future that are consistent plausible, and comprehensive. Following Schoemaker (1993) (see also Russo and Schoemaker (2002)), scenarios are defined as focused descriptions of fundamentally different futures presented in coherent narratives. Schoemaker (1993) proposes a ten-step methodology for defining scenarios that centers on learning and exploring interrelationships among strategic trends and key uncertainties. It aims at overcoming human and organizational barriers to consistent and realistic assessment of the long-term future. Scenario planning helps managers compensate for overconfidence and tunnel vision, which are frequent errors in strategic thinking. For example, many companies approach strategic planning by assuming only one scenario of the future and prepare only a single budget for the coming years.

Russo and Schoemaker (2002) cite an application at Royal Dutch/Shell where scenario planning has been used since the early 1970's. As a result, it has been consistently better in its oil forecasts than other major oil companies, and anticipated the overcapacity in its tanker business and European petrochemical production earlier than its competitors. The firm has taken scenario planning to a natural next step by developing data-driven models that predict oil prices, inflation, GNP growth, taxes, oil inventories, interest rates, and other factors, in plausible balances.

Formal or informal scenario planning is an important element of any supply chain strategic planning study in which data-driven models are implemented and optimized. More formal approaches, such as the methodology outlined above, become desirable and perhaps necessary when the scope of the study and the models is expanded in the directions we suggested in the previous sections. However, applying the formal scenario planning methodology may well require the development of new descriptive models to forecast consistent and plausible, as well as accurate, data describing various scenarios.

The challenge for the modeling practitioner when scenario planning emerges as a central theme in a study, whether formal methodologies are used or not, is to decide if and how to extend deterministic linear and mixed integer programming models traditionally used in such studies to their stochastic programming versions, which explicitly model the uncertainties associated with multiple scenarios. The distinction between deterministic and stochastic programming models is simple to explain. When performing scenario planning with a deterministic model, multiple scenarios with their associated data are optimized one at a time as if they will occur with certainty. By contrast, a stochastic model will consider the ensemble of all scenarios, each with an associated probability of occurrence, as a probabilistic description of the future.

Optimization of the stochastic model holistically identifies an optimal contingency plan for each scenario and a here-and-now plan that optimally hedges against these contingencies. Here-and-now refers to short-term decisions that must be made before the uncertainties occur. They will almost certainly be markedly different than the short-term decisions developed by deterministic models that examine each scenario separately. Similarly, the contingency plans will almost certainly be markedly different than those identified by the deterministic models.

Stochastic programming has the additional benefit that it allows decision-makers to impose constraints reflecting their judgment of the risks associated with the firm's performance under various scenarios. For example, constraints stating that losses by the firm in year three cannot exceed $50 Million under any scenario. Alternatively, these constraints may be expressed differently as a single probabilistic constraint requiring that the probability that losses by the firm in year three exceed $50 Million may not exceed 0.02. Of course, the decision-makers may view such targets as somewhat arbitrary implying the need to apply methods of multiple objective optimization to systematically explore the tradeoff of maximal net revenues against risk targets. Thus, using stochastic programming models, risk management is translated into systematic procedures for searching efficient frontiers describing the tradeoffs of return against explicit descriptions of risk exposure faced by the firm and/or the decision-makers.

Thus far, for reasons discussed below, few applications of stochastic programming to data-driven supply chain planning problems have been made. Fisher et al (1994) report on an informal stochastic programming analysis of demand planning for a firm that designs, manufactures and sells ski clothing with short life cycles. Their analysis demonstrated that revised demand forecasts based on initial sales data could be used to great advantage in adjusting planning production decisions midway through product life cycles. Specifically, the firm was able to reduce both lost sales for popular products and excess inventories for unpopular products.

Swaminathan and Tayur (1999) have developed stochastic programming models to help manage product variety in the manufacture of computers and other high technology equipment. These are planning problems involving finished products that are assembled from components with long lead times. Demands for the products are also highly volatile and correlated. Although the products share many common components, their final assembly involves some customization. Stochastic programming models were designed and implemented to assist planners identify effective dynamic inventory stocking policies for the components.

Stochastic programming models have also been recently been proposed as tools to assist corporations in identifying real options as alternatives to financial options for hedging prices, foreign exchange rates, demands and a host of other uncertainties. Cohen and Huchzermeier (1999) suggest that a multinational corporation can add to shareholder value by considering dynamic investment strategies that include options such as: to wait/to defer, to abandon/to exit, to expand, to contract, to switch, or to improve. Qualitative research indicates that the firm's downside risk can be reduced by operational responses to varying demand and price scenarios. For example, a multinational corporation might consider constructing and maintaining manufacturing facilities in countries with negative correlations in exchange rate movements as a hedge against exchange rate uncertainties. Some research even suggests that operational risk management strategies can be more effective than ones that rely solely on financial risk management.

Despite the attractiveness of real options as a new concept for mitigating risk, very few data-driven models incorporating them have been implemented. To date, academic research in real options has been similar in spirit to that of the theory of industrial organization; namely, mathematical models have been used to identify qualitative insights for reducing risk, but not to analyze specific strategic planning problems characterized by data. For example, Cohen and Huchzermeier (1999) extend a deterministic supply chain network optimization model for locating facilities worldwide to a model that admits stochastic exchange rates and demands. Using the structure of this optimization model and assumptions about normal distributions of the uncertainties, they derive a number of results such as

- a minimum threshold value for the exchange rate implying that a plant may be utilized in an optimal solution
- the probability that a plant will be open in an optimal solution that is determined by reference to an inverse normal distribution
- in an n-country model, incremental investments in capacity will always have diminishing returns

Meier, Christofides and Salkin (2001) report on the application of stochastic programming to a class of capital budgeting models arising in the financing of projects (e.g., construction, R&D) that develop stochastically over time. Zero-one (go/no-go) decisions regarding project selection are real options available to the firm at various states in the probability tree underlying the model. Depending on the scenario realized, some projects might be initiated while others might be postponed or cancelled.

Although extensions of deterministic mathematical programming models to the types of stochastic programming models just reviewed are very appealing for strategic planning, they represent a serious expansion of the state-of-the-art. Managers have only recently been exposed to deterministic supply chain network optimization models. Thus, it is still too early in the evolution of modeling applications for practitioners to suggest widespread use of stochastic programming models. Still, as we have noted, a few applications employing such models have already appeared, which suggests that the time is ripe to actively seek new applications for studies where they are most needed and can be accepted by management.

Still, the modeling practitioner faces two serious technical challenges when seeking to design and implement a stochastic programming model for strategic planning. First, he/she must estimate the probabilities of occurrence associated with each scenario. In general, such probabilities are computed using a combination of statistical forecasting methods and human judgment. Forecasting models might be employed to predict demand for the firm's products in the years to come, whereas a judgmental model might be employed to estimate the timing and likelihood that government regulation seriously affecting the firm will be put into law. A related difficulty when using statistical models is the need to map multivariate continuous distributions into a finite number of scenarios with associated characteristics and probabilities. In short, construction of the decision tree underlying a stochastic programming model may well involve the resolution of a host of technical, prescriptive modeling issues.

Second, because a stochastic programming model has a planning horizon with multiple periods and explicitly captures multiple scenarios over these horizons, it can easily attain a size that makes computation difficult or impossible. This difficulty is related to the first difficulty in that management may believe there are several major sources of uncertainty to be captured, which can easily lead to very large models because each source has a multiplicative effect on the number of scenarios and hence model size. The technical challenges just mentioned and others associated with stochastic programming are not insurmountable but may require the implementation of complex algorithms using, for example, decomposition or statistical sampling methods (see Bienstock and Shapiro (1988), Infanger (1994), Birge and Louveaux (1997)). Research into new methods for overcoming these difficulties should be focused on the structure and requirements of real-world applications.

Expanding Business Processes to Exploit Fact-based Analysis of Strategic Plans

Our discussion thus far has focused on concepts underlying the design, implementation and application of fact-based optimization models to support strategic planning of the firm's supply chain. We argued that such planning can and should incorporate demand management and corporate financial decision-making. The many successful efforts to date of optimization models applied to such planning problems confirm the assertion that technical requirements are not barriers to new and deeper applications. Instead, the barriers are due to human and organizational behavior that impedes the acceptance and effective use of data-driven models for all levels of planning. Our discussion in this section addresses these barriers as they relate to strategic planning.

A central issue is the extent to which the firm and its managers wish to base strategic planning on facts and rational decision-making. Over the past 40 years, scholars studying how individuals and organizations make decision became divided into two camps (March 1994). One camp includes economists and other social scientists who believe that individuals and organizations should and will be rational in their decision-making, at least within the limits set by their information gathering resources.

The second camp includes organizational behaviorists concerned with understanding how decisions in organizations are actually made, rather than how they should be made according to rational principles. Although organizations may attempt to make intelligent decisions leading to desirable outcomes, behaviorists have found that many managers are inconsistent in their decision-making, in large part because they cannot overcome problems due to ignorance, conflict and ambiguity.

The growing interest in fact-based decision-making indicates a preference among managers for rational decision-making, but it is too early in the information revolution to predict exactly how this shift in managerial thinking will be played out. Assuming fact-based strategic planning is increasingly desired and pursued by the firm, at least to a reasonable extent, many issues remain about how to do it. We discuss briefly two such issues.

The central issues to be resolved in seeking fact-based strategic supply chain planning and, in general, supply chain planning at all levels, are connected to the need for business process expansion (Shapiro (2001a). First, such expansion is needed to facilitate the creation and maintenance of supply chain decision databases from Enterprise Resource Planning systems and other corporate databases. These decision databases are constructed using descriptive models, aggregation methods, and other analytics. In addition to serving as inputs to optimization models, the databases provide managers with useful perspectives on the tangled forest of the firm's transactional databases. Employees with new job descriptions to support strategic planning processes, and new software and data collection procedures are needed for these purposes.

Second, the firm must develop new processes for systematically reviewing their strategic supply chain plans, including the development of consistent and comprehensive scenarios. New process are also needed to resolve conflicts that will arise when the firm seeks to implement integrated supply chain plans and use such plans to modify marketing and sales plans. Finally, new managerial incentive schemes must be devised and implemented that reflect holistic supply chain management at the strategic and tactical levels of planning. Although organizational change to exploit fact-based strategic planning may be difficult and painful, the potential benefits are enormous.

Conclusions

While recognizing that the number of successful modeling applications for strategic supply chain planning is increasing rapidly, we announced our intention at the start to examine approaches for extending their scope. Our motivation was that state-of-the-art models ignore decisions involving revenues, marketing campaigns, hedging against uncertainties, investment planning and other corporate financial decisions, and many other aspects of enterprise planning that interact with supply chain planning. The paper has been devoted to a review of the many challenges that modeling practitioners and their clients face when they set out to extend and apply strategic planning models that analyze wider and deeper decision problems. Finally, we provided a brief overview of the issues surrounding business process expansion to exploit fact-based strategic supply chain planning and its natural extensions to fact-based enterprise planning.

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